Grand Bay National Estuarine Research Reserve: An Ecological Characterization

Mark S. Peterson, Gretchen L. Waggy, and Mark S. Woodrey, editors

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PREFACE

The Grand Bay National Estuarine Research Reserve (NERR) Ecological Characterization (Site Profile) characterizes the environmental features, habitat types, species distribution and biological communities within the Grand Bay providing valuable insight into our current knowledge relating to this coastal gem in southeastern Mississippi.. The document is intended to highlight what is currently known about this NERR and draws on peer-reviewed and other 'grey-literature' sources of published information. To complete this project, the editors contacted and solicited specific chapters from colleagues recognized as experts in their respective fields who have experience working in and around the Grand Bay area. Each chapter reflects the expertise and experiences of individual authors and provides a detailed summary and overview of the current "state of knowledge" for respective topics. The thoughts, opinions, and recommendations are those of the authors and do not necessarily reflect those of the editors, Grand Bay NERR staff, Grand Bay NERR Management Board, or the Mississippi Department of Marine Resources. The document is organized and written to serve the many needs of valued stakeholders ranging from the scientific community to the public, and we provide complete citations pertinent to the Grand Bay NERR. Despite the relative lack of research and monitoring activities that have occurred historically within the confines of the Grand Bay NERR, we have accumulated a considerable amount of information to form this baseline and in a few cases have drawn from the wider geographic literature that we feel is appropriate and representative of the Grand Bay NERR environment. With the broad range of coastal habitats, biotic communities, environmental challenges, and human impacts within the Grand Bay NERR, this site can serve as a baseline and model for future studies on dynamic coastal ecosystems in an ever-changing landscape. The Site Profile will provide a starting point from which the Grand Bay NERR staff, resource managers and collaborators working at the site will develop research, stewardship and educational activities. With the designation of the Grand Bay NERR in 1999 as the 24th reserve within the National Estuarine Research Reserve System, our abilities and means to better understand this complex coastal ecosystem were greatly enhanced. Now, with this and other new tools and support the NERR will move its programming deep into the 21st century.

The Grand Bay National Research Reserve (NERR) is pleased to have developed the Grand Bay NERR Site Profile in collaboration with Dr. Mark S. Peterson of the Department of Coastal Sciences at The University of Southern Mississippi, Ocean Springs, MS. A special thank you is also extended to the other editors and many chapter authors for their valuable contributions.

David Ruple
Reserve Manager

ACKNOWLEDGEMENTS

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The editors thank the myriad of authors who gave of their time and energy selfishly to produce the numerous chapters in this volume. Without their help and expertise this document would not have been completed. We also specifically thank David Ruple, Manager, and Chris May, Stewardship Coordinator, of the Grand Bay NERR, for their editorial contributions and support of our efforts. Jennifer Buchanan, the Grand Bay NERR Education Coordinator, kindly provided assistance with the design and formatting of this document. We also extend our thanks to the library staff at the Gulf Coast Research Laboratory (GCRL) who obtained some hard to find references, and Dr. Ralf Reidel of GCRL who shared the historic data in the Nekton chapter from the Gulf of Mexico Estuarine Inventory (GMEI) database.

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CONTRIBUTORS

Joel A. Borden
Department of Biology
University of South Alabama
Mobile, Alabama 36688

Shelia A. Brown
J. L. Scott Marine Education Center
The University of Southern Mississippi
703 East Beach Drive
Ocean Springs, Mississippi 39564

Greg Carter
Gulf Coast Geospatial Center and
Department of Coastal Sciences
The University of Southern Mississippi
703 East Beach Drive
Ocean Springs, Mississippi 39564

Kevin S. Dillon
Department of Coastal Sciences
703 East Beach Drive
The University of Southern Mississippi
Ocean Springs, Mississippi 39564

Gabriel Langford
School of Biological Sciences
University of Nebraska-Lincoln
Lincoln, NE 68588

Sara LeCroy
Department of Coastal Sciences
703 East Beach Drive
The University of Southern Mississippi
Ocean Springs, Mississippi 39564

Julia S. Lytle
Department of Coastal Sciences
703 East Beach Drive
The University of Southern Mississippi
Ocean Springs, Mississippi 39564

Thomas F. Lytle
Department of Coastal Sciences
703 East Beach Drive
The University of Southern Mississippi
Ocean Springs, Mississippi 39564

C. Smoot Major
Department of Biology
University of South Alabama
Mobile, Alabama 36688

Chris A. May
Grand Bay National Estuarine Research Reserve
6005 Bayou Heron Road
Moss Point, Mississippi 39562

Jerry A. McLelland
Department of Coastal Sciences
703 East Beach Drive
The University of Southern Mississippi
Ocean Springs, Mississippi 39564

David H. Nelson
Department of Biology
University of South Alabama
Mobile, Alabama 36688

Mark S. Peterson
Department of Coastal Sciences
703 East Beach Drive
The University of Southern Mississippi
Ocean Springs, Mississippi 39564

Ervin Otvos
Department of Coastal Sciences
703 East Beach Drive
The University of Southern Mississippi
Ocean Springs, Mississippi 39564

Chet F. Rakocinski
Department of Coastal Sciences
703 East Beach Drive
The University of Southern Mississippi
Ocean Springs, Mississippi 39564

Bradley Randall
Mississippi Department of Marine Resources
1141 Bayview Ave.
Biloxi, Mississippi 39530

Gretchen L. Waggy
Grand Bay National Estuarine Research Reserve
6005 Bayou Heron Road
Moss Point, Mississippi 39562

S. Christine Walters
Grand Bay National Estuarine Research Reserve
6005 Bayou Heron Road
Moss Point, Mississippi 39562

Ronald G. Wieland
3025 Kyle Ave N
Golden Valley, Minnesota 55422

Mark S. Woodrey
Mississippi State University
Coastal Research and Extension Center
Grand Bay National Estuarine Research Reserve
6005 Bayou Heron Road
Moss Point, Mississippi 39562

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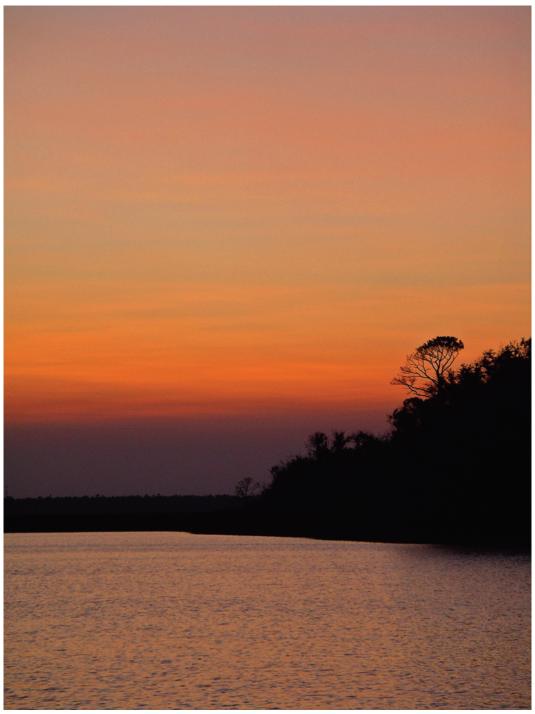
ECOLOGICAL/BIOLOGICAL SETTINGS

CHAPTER 1

INTRODUCTION

Mark S. Woodrey

1.1. OVERVIEW OF THE NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM



Sunset over Bayou Cumbest, Grand Bay NERR. Photo credit: Gretchen Waggy.

The National Estuarine Research Reserve System (NERRS) is a network of 27 sites scattered across the country (National Oceanic and Atmospheric Administration 2005; Figure 1.1). These reserves, established for long-term research, monitoring, education, and stewardship, provide excellent opportunities for the study of coastal ecosystems. Established by the Coastal Zone Management Act of 1972, these sites represent different biogeographic regions of the United States. The reserve system is a state-federal partnership between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states and territories. The National Oceanic and Atmospheric Administration provides funding, national guidance, and technical assistance whereas states provide matching funds, personnel, and management oversight Sites are operated on a daily basis by a lead state agency or university, with input from local partners. This system of reserves currently protects more than 1.3 million acres of coastal habitat including estuarine lands and water which serve as living laboratories for scientists, educators, and students (National Oceanic and Atmospheric Administration 2006a).

Two existing programs within the NERRS, the System-Wide Monitoring Program (SWMP) and the Graduate Research Fellowship (GRF) program, provide data critical to the our understanding of the ecology of each reserve as well as addressing the system as a whole (Owen and White 2005, National Oceanic and Atmospheric Administration 2006a). In addition, these programs are important sources of data which are used to develop management strategies for the conservation of critical coastal resources. Further, these programs provide baseline data and supplement research and monitoring efforts outside the local reserve and support efforts such as the compilation of information in site profiles to inform the public of the current state of knowledge for a particular reserve.

The NERRS System-Wide Monitoring Program was developed in 1995 to collect quantitative data to assess short-term variability and long-term change in estuarine conditions (Owen and White 2005, National Oceanic and Atmospheric Administration 2006a). A key element in the establishment of SWMP was the implementation of a set of consistent standard operating procedures that ensure the long-term collection of data that is comparable across time and space. The SWMP program utilizes a phased monitoring approach that focuses on three different ecosystem characteristics (National Oceanic and Atmospheric Administration 2002, 2006a, Owen and White 2005):

1. Phase 1 – Abiotic Parameters, including atmospheric conditions and water quality (nutrients, salinity, contaminants, etc.);
2. Phase 2 – Biological Monitoring, including biodiversity, habitat and population characteristics; and
3. Phase 3 – Watershed and Land Use Classifications, including changes in human uses and land cover types.

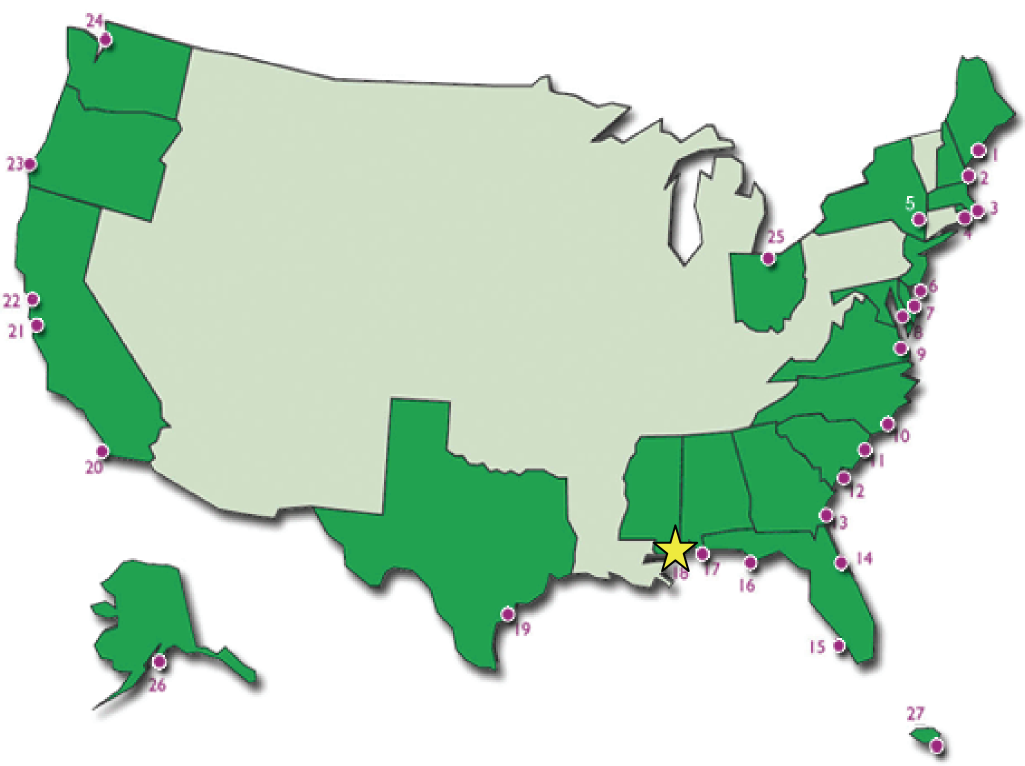


Figure 1.1. Map of NERR locations: 1. Wells Reserve, ME; 2. Great Bay Reserve, NH; 3. Waquoit Bay Reserve, MA; 4. Narragansett Bay Reserve, RI; 5. Hudson river Reserve, NY; 6. Jacques Cousteau Reserve, NJ; 7. Delaware Reserve; 8. Chesapeake Bay Reserve, MD; 9. Chesapeake Bay Reserve, VA; 10. North Carolina Reserve; 11. North Inlet-Winyah Bay Reserve, SC; 12. ACE Basin Reserve, SC; 13. Sapelo Island, GA; 14. Guana Tolomato Matanzas Reserve, FL; 15. Rookery Bay Reserve, FL; 16. Apalachicola Reserve, FL; 17. Weeks Bay Reserve, AL; 18. ☆ Grand Bay Reserve, MS; 19. Mission-Aransas, TX; 20. Tijuana River Reserve, CA; 21. Elkhorn Slough Reserve, CA; 22. San Francisco Bay, CA; 23. South Slough Reserve, OR; 24. Padilla Bay Reserve, WA; 25. Old Woman Creek, OH; 26. Kachemak Bay Reserve, AK; 27. Jobos Bay Reserve, Puerto Rico

Industrial area located on the western boundary of the Reserve. Photo credit: Bob Lord.

Currently, water quality data are being collected at 15 minute intervals via data loggers continuously deployed at a minimum of four water quality stations at each reserve. In addition, each reserve also collects monthly nutrient data from the water column at each of the four water quality sampling locations. At least one weather station per reserve records meteorological measurements at 15 minute intervals. Finally, reserve staff are working to integrate the phase-one SWMP data collection network into the backbone of the United States' Integrated Ocean Observing System (IOOS) with near-real-time telemetry for timely data dissemination (National Estuarine Research Reserve 2004, 2006a, Owen and White 2005). Phase 2, or Biological Monitoring, was initiated in 2004, with biomonitoring demonstration projects at 16 reserves focused on developing baseline data on submerged and emergent vegetation distribution for use in land change use research, tracking changes in the health and distribution of these communities with long-term changes in water quality and quantity, and quantifying changes in estuarine habitat types (Owen and White 2005, National Oceanic and Atmospheric Administration 2006a). As in Phase 1, rigorous protocols were established to ensure compatibility across the reserve system, while retaining local flexibility as appropriate for individual reserves (Moore and Bulthius 2003). The Watershed and Land Use Classifications (Phase 3 of SWMP) portion has also been initiated with a recent effort to development a common classification system to assist reserves in consistent, and this nationally comparable, habitat and watershed mapping and inventory efforts (Kutcher et al. 2005). Several reserves are now piloting this "NERRS Classification Scheme" to assess its applicability to the reserve system (Owen and White 2005).

A second NERRS program, the Graduate Research Fellowship program, provides master's students and PhD candidates with opportunities to conduct research of local and national significance to promote the conservation of coastal ecosystems. The five focus areas for the GRF program are (1) eutrophication, effects of non-point source pollution and/or nutrient dynamics; (2) habitat conservation and/or restoration; (3) biodiversity and/or the effects of invasive species; (4) mechanisms for sustaining resources within estuarine ecosystems; and (5) economic, sociological, and/or anthropological research applicable to estuarine ecosystem management Created in 1997, this program has funded more than 160 fellows from 56 universities across the country (National Oceanic and Atmospheric Administration 2006a). At Grand Bay, eight students have been funded through the GRF program since 2000 and their work has made substantial contributions to our understanding of the ecology of the NERR as well as to the content of this document (Table 1.1). Fellows conduct their research within a NERR and gain hands-on experience by participating in their host reserve's research and monitoring program (National Oceanic and Atmospheric Administration 2006b).

Table 1.1. List of Graduate Research Fellows at the Grand Bay NERR from 2000 through 2008.

Year(s)	Fellow Name	Affiliation	Title
2000-2001	Donna Drury	University of Southern Mississippi	Functional role of the grazing olive nerite snail, *Neritina reclivata*: An essential trophic link within estuarine *Vallisneria americana* habitat
2001-2002	Guillermo Sanchez	University of Southern Mississippi	Habitat mapping of oyster resources and submerged vegetation for the Grand Bay National Estuarine Research Reserve, Mississippi
2002	Donna Drury	University of Southern Mississippi	Effects of invertebrate grazer density manipulations on wigeongrass, *Ruppia maritima*, exposed to nutrient enrichment
2003	Virginia Shervette	Texas A&M University	Assessment of essential fish habitats in Grand Bay as nurseries for economically important fishes: tools for management and conservation
2004-2006	Megan Hughes	University of Southern Mississippi	Assessing the value of coastal hammocks as stopover habitat for passerine migrants: Habitat selection and resource acquisition on the Grand Bay NERR
2004-2005	Zhijun Liu	Mississippi State University	Guidelines for the development of a Grand Bay hydrology and water quality simulation model: Criteria and data assessments
2006-2007	Gabe Langford	University of Nebraska	Parasite biodiversity of amphibians and reptiles from the Grand Bay National Estuarine Research Reserve, Mississippi
2007-2008	Scott Rush	University of Georgia	Ecology of Mississippi's tidal marsh birds: Perspectives gained through the application of surveys, telemetry and ecological tracers

1.2. GENERAL OVERVIEW OF THE GRAND BAY NATIONAL ESTUARINE RESEARCH RESERVE

The Grand Bay NERR is a large, pristine, intact estuary which supports a highly diverse floral and faunal community. This site, located in southeastern Jackson County, encompasses about 7,446 ha and is one of the largest estuarine systems in Mississippi (Figure 1.2; Mississippi Department of Marine Resources 1998). Designated in 1999 as one of 27 NERR sites, the Grand Bay NERR is a state and federal partnership. The state partner is the Mississippi Department of Marine Resources (MS DMR) and the federal partner is the National Oceanic and Atmospheric

Administration (NOAA). In addition to MS DMR and NOAA, the Grand Bay NERR has several other primary partners, including the U.S. Fish and Wildlife Service, Mississippi Secretary of State, Mississippi State University, University of Southern Mississippi, and The Nature Conservancy of Mississippi. The administrative framework for the reserve includes a Reserve Management Board made up of representatives from each primary partner and the chairman of the Citizens Advisory Committee and reserve staff (Mississippi Department of Marine Resources 1998).

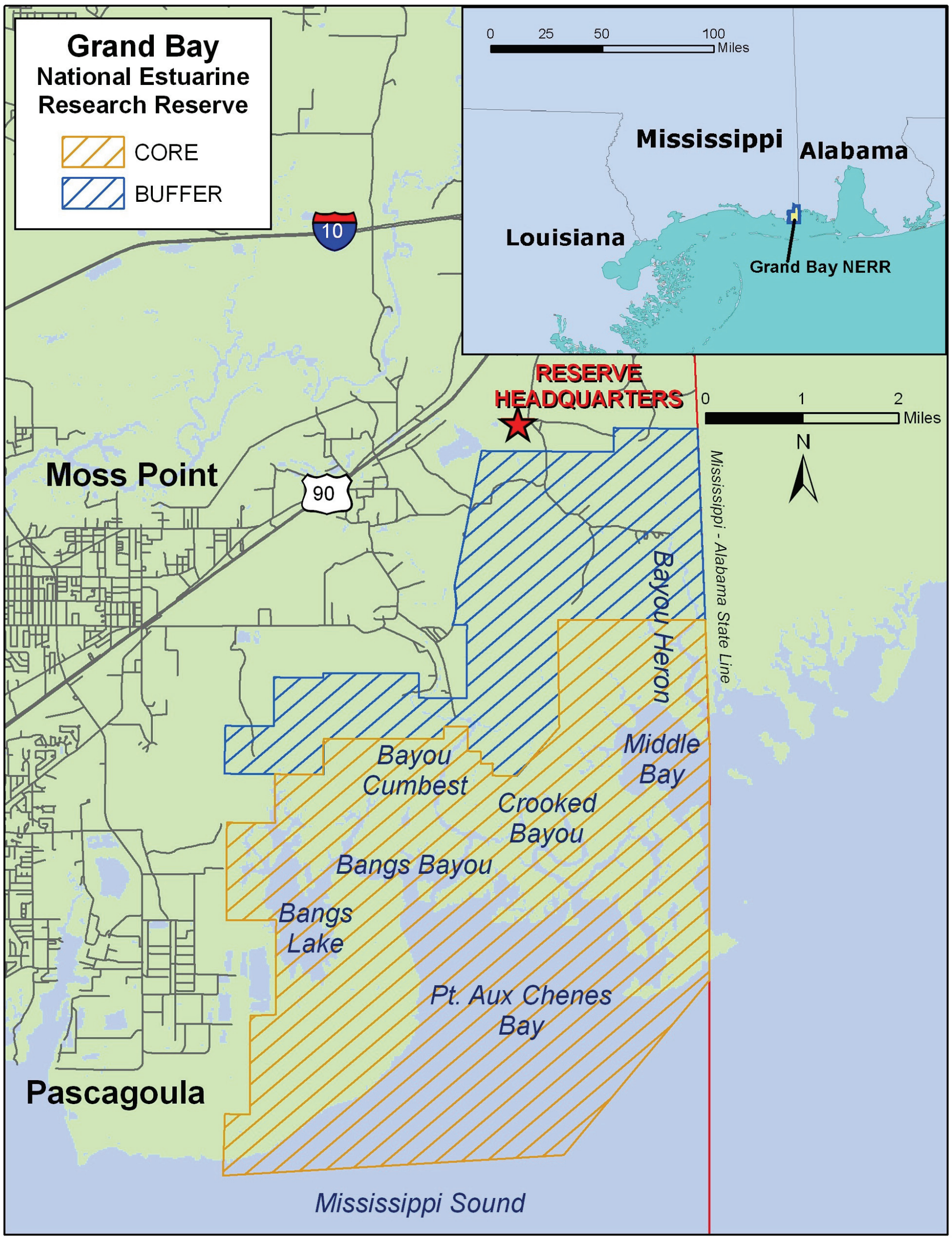


Figure 1.2. Map of the core and buffer areas of the Grand Bay NERR, 2007.

Kenny's Island American Indian shell midden. Photo credit: Gretchen Waggy

The Grand Bay NERR is representative of the Louisianian biogeographic region and is located in the Mississippi Deltaic subregion (Mississippi Department of Marine Resources 1998). Thus, the reserve research and stewardship staff are actively engaged in conducting monitoring, research, restoration, and management projects throughout the area. Other reserve staff, including the education and coastal training program currently provide educational and training opportunities for a variety of audiences throughout this biogeographic region as well (Grand Bay National Estuarine Research Reserve 2005). The Grand Bay area consists of a broad variety of estuarine and non-estuarine wetland habitats that together form a largely intact coastal watershed (Figure 1.3; Table 1.2). Geologic data suggest this area was historically part of a larger river delta although it is now characterized as a retrograding delta due to a change in the river's course. The open-water estuarine areas support large, productive patches of submerged aquatic vegetation, including widgeon grass (*Ruppia maritima*) with smaller patches of shoal grass (*Halodule wrightii*; Chris May Personal communication). The muddy intertidal areas support scattered, unconsolidated, or fringe oyster reefs. At slightly higher elevations, a wide variety of representative marsh types (low, mid-level and high elevation zones across a wide range of salinity) as well as some of the most extensive, unvegetated salt flats or pannes in Mississippi are found. The non-tidal areas include wet pine savanna, coastal bayhead and cypress swamps, freshwater marshes and maritime forests. Of the nearly 7,400 ha within the boundaries of the site, approximately 75 % (5,550 ha) are publicly owned.

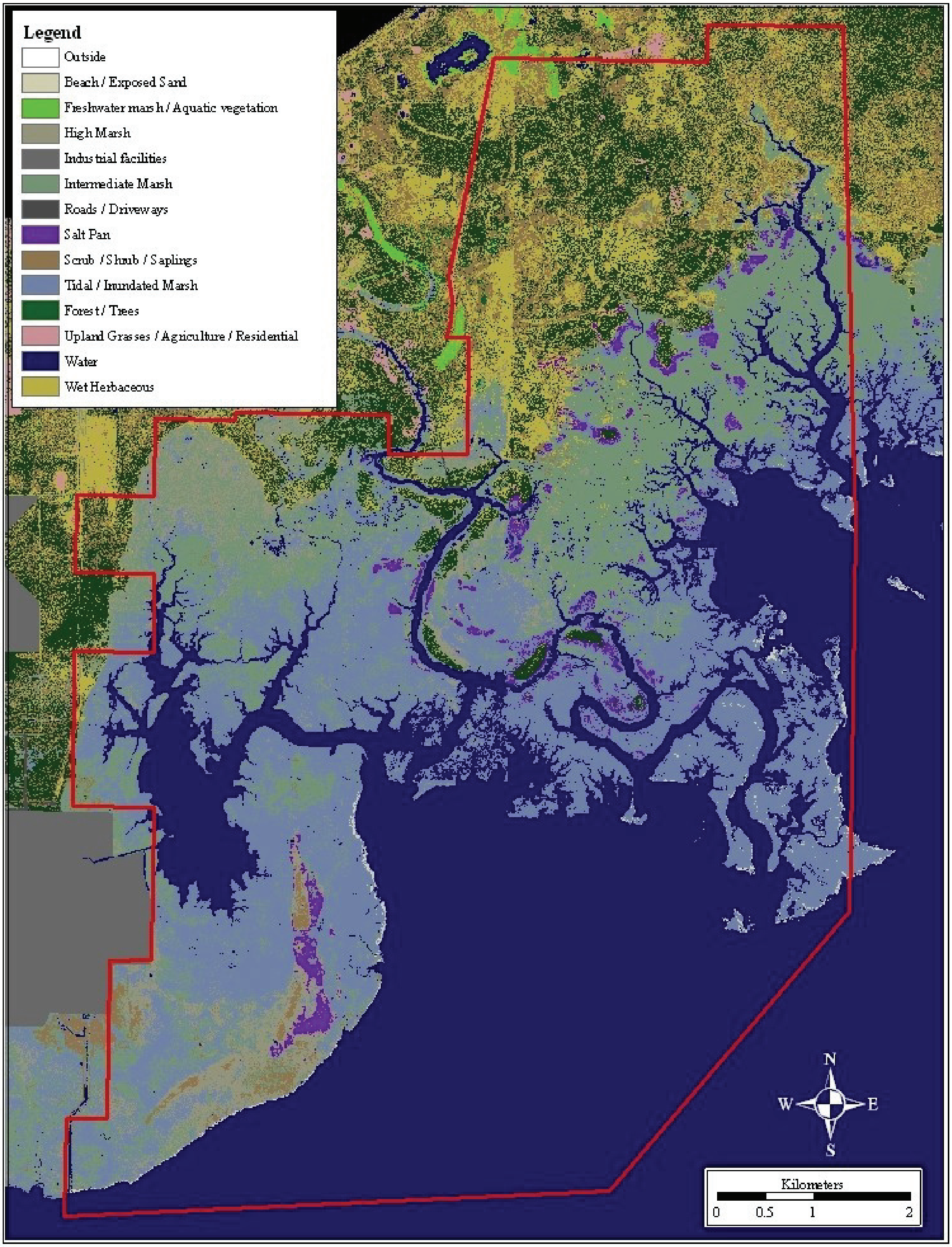


Figure 1.3. Habitat map of the Grand Bay NERR, 2007.

Table 1.2. Extent of habitat types at the Grand Bay NERR, 2007.

Habitat Type	Hectares	Acres
Roads/Driveways	3.2	7.8
Forest/Trees	476.3	1176.5
Wet Herbaceous	463.9	1145.7
Freshwater Marsh/Aquatic Vegetation	8.2	20.2
Industrial Facilities	4.0	9.9
Upland Grasses/Agriculture/Residential	7.9	19.4
Scrub/Shrub/Saplings	343.2	847.8
Beach/Exposed Sand	22.6	55.9
Intermediate Marsh	1129.2	2789.2
Tidal/Inundated Marsh	1611.0	3979.1
High Marsh	297.2	734.0
Water	2835.1	7002.7
Salt Panne	105.7	261.0
Total	7,307.5	18,049.2

1.3 GRAND BAY NERR STRATEGIC PLAN: 2003

In March 2003, the Grand Bay NERR convened a meeting of reserve staff, Management Board members, and other partners to develop a strategic plan to help guide the reserve's efforts over several years. The outcome of this successful exercise resulted in the completion of the three year strategic plan which outlines the activities of the reserve staff and its' partners (Grand Bay National Estuarine Research Reserve 2003). Sections of the strategic plan most relevant to this ecological characterization are noted in this section to provide an overview of the mission of the reserve and highlight the current goals and objectives of the Grand Bay NERR. The mission of the Grand Bay NERR is to "…*increase our understanding of coastal resources through long-term research and monitoring and to transfer this knowledge using education and interpretation programs to foster informed decision-making and resource management of our coastal landscape*."

To meet the mission of the Grand Bay NERR, several goals were established with each goal focused on the core programs of the Grand Bay NERR (i.e., research, education, coastal training, and stewardship). The goals as outlined in the strategic plan are as follows:

- Establish conditions for a successful research program including: monitoring program, site characterization, Research Advisory Committee, and research cooperatives.
- Establish a sense of place among targeted audiences by interpreting the relevance of research results and resource management through the development and implementation of experiential (hands-on) programs and exhibitry.
- Acquire all available lands within the NERR boundary; keep them open to public use and manage them with partners according to best management practices to address natural fire, hydrologic regime and native species, etc.

- Fully implement the research, education and resource management components of the Grand Bay NERR, through appropriate and effective staffing, funding, facilities and operational independence.

In addition to supporting the mission of the Grand Bay NERR, these goals support and are consistent with regional and national goals as outlined in the National Estuarine Research Reserve System 2005-2010 Strategic Plan and Research and Monitoring Plan (National Oceanic and Atmospheric Administration 2005, 2006a).

The 2003 Grand Bay NERR Strategic Plan directs the on-going activities at the reserve. In particular, the Vision of Success as noted in the strategic plan is especially relevant: "*By 2006, we envision the Grand Bay NERR as a focal site for extensive terrestrial and aquatic research designed to gain a better understanding of the ecology of the reserve. Educators will transfer technical information and research data to coastal decision-makers for them to make well informed choices. The NERR will be a center for coastal resource management, with adequate funding and staff to support a wide array of programs. Broad expanses of wet pine savanna, coastal marsh, grassland prairies and clean coastal waters will extend as far the eye can see, with natural processes functioning across the landscape including new oyster reefs open to harvest as a result of improved water quality*." There are currently many research and restoration projects being conducted at the Grand Bay NERR. There is an active community education program and coastal decision-makers are being informed through the reserve's Coastal Training Program. In addition, the reserve has a dynamic, well-trained, and highly motivated staff focused on providing the scientifically-based data to coastal resource managers so they can make informed, science-based management decisions to conserve the natural resources of coastal Mississippi.

1.4. OVERVIEW OF SITE PROFILE/ECOLOGICAL CHARACTERIZATION

This site profile, or ecological characterization, consists of 17 chapters highlighting the current state of ecological knowledge for the Grand Bay NERR. The content and organization of these chapters closely follows guidance provided by the NOAA Estuarine Reserve Division. With the exception of Chapters 1 (Introduction) and 17 (Monitoring and Research Needs for the Grand Bay NERR), the individual chapters are grouped according to two major headings, either Environmental or Ecological/Biological focused. Chapters 2 through 8 address the Environmental Setting at the Grand Bay NERR and highlight the geology, climate, historical land use, hydrology, water quality and pollution issues of the area. Chapters 9 through 16 address the Ecological/Biological Setting of the reserve and emphasize habitat types and ecological communities, vegetation, macroinvertebrates, oysters, nekton, reptiles and amphibians, birds, and mammals. To ensure the most comprehensive treatment of each topic, the editors selected experts, from the local area or the region, most familiar with their topic and the Grand Bay area of Mississippi and Alabama. Thus, these chapters provide the most up-to-date and comprehensive summary of our current knowledge of the ecology of the Grand Bay NERR.

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CHAPTER 2

GEOLOGICAL FRAMEWORK AND EVOLUTIONARY HISTORY

Ervin G. Otvos

2.1. LOCATION, LANDFORMS, AND GENERAL GEOLOGIC FRAMEWORK

The Grand Bay National Estuarine Research Reserve (NERR), the area in and surrounding Pt. aux Chenes Bay represents the western part of the Grand Bay-Pt. aux Chenes Bay complex (Figures 2.1A - C). Most of the Grand Bay NERR and adjacent area on the mainland are underlain by Holocene marsh and swampland at sea-level. Between sea-level and +2 m elevation, the ground is represented by the nearly level, Pleistocene-age Prairie Formation, mostly covered by pinewoods (Otvos 1991, 1997, 2000). A 1.5 - 2.0 km wide marshy-swampy wetland zone separates the Grand Bay shoreline from the Citronelle Uplands in the northeast. The Citronelle Uplands are underlain by the Pliocene-age alluvial sandy-muddy, occasionally gravelly Citronelle Formation that represents most of the land surface in southern Mississippi and Alabama (Table 2.1). The rim of the Citronelle Uplands surface is located at +23 m elevation. An east-west trending, steep fault-line scarp (Figure 2.1C) separates the rim from the 1.5 - 2.0 km wide swamp-marsh belt that flanks Grand Bay. Further north, near the town of Grand Bay, the Citronelle surface rises to +33 m mean sea level (MSL).

North of Pt. aux Chenes Bay, the terrain is dominated by the Escatawpa River, a major tributary of the Pascagoula River. After leaving its incised valley in the coastal interior and reaching the low, level Prairie terrain, the stream takes an abrupt right-angle turn west of the town of Orange Grove (Figure 2.1C) to join its trunk stream, the Pascagoula River. The large meanders (Figures 2.1A, B) representoccupy relict stream channels that formed in the late the Pleistocene. As sea-level fell, this meanderbelt was incised into the high, late Pleistocene alluvial Prairie upland surface by a long-defunct small distributary of the Pascagoula River prior to termination of the Pleistocene Epoch. This meandering distributary probably formed about 130,000-116,000 years ago during and following a late Pleistocene interglacial sea-level highstand, or shortly thereafter. Most of the coastal plain Prairie Formation alluvium was deposited at that time. The southeastward-trending distributary channel exited the Pascagoula River trunk channel at approximately 8 km NW of the present intersection between the relict meanderbelt and the modern Escatawpa River. Becoming the dominant tributary to the Pascagoula distributary channel, the flow of the ancestral Escatawpa entered this meander channel near present-day Orange Grove.

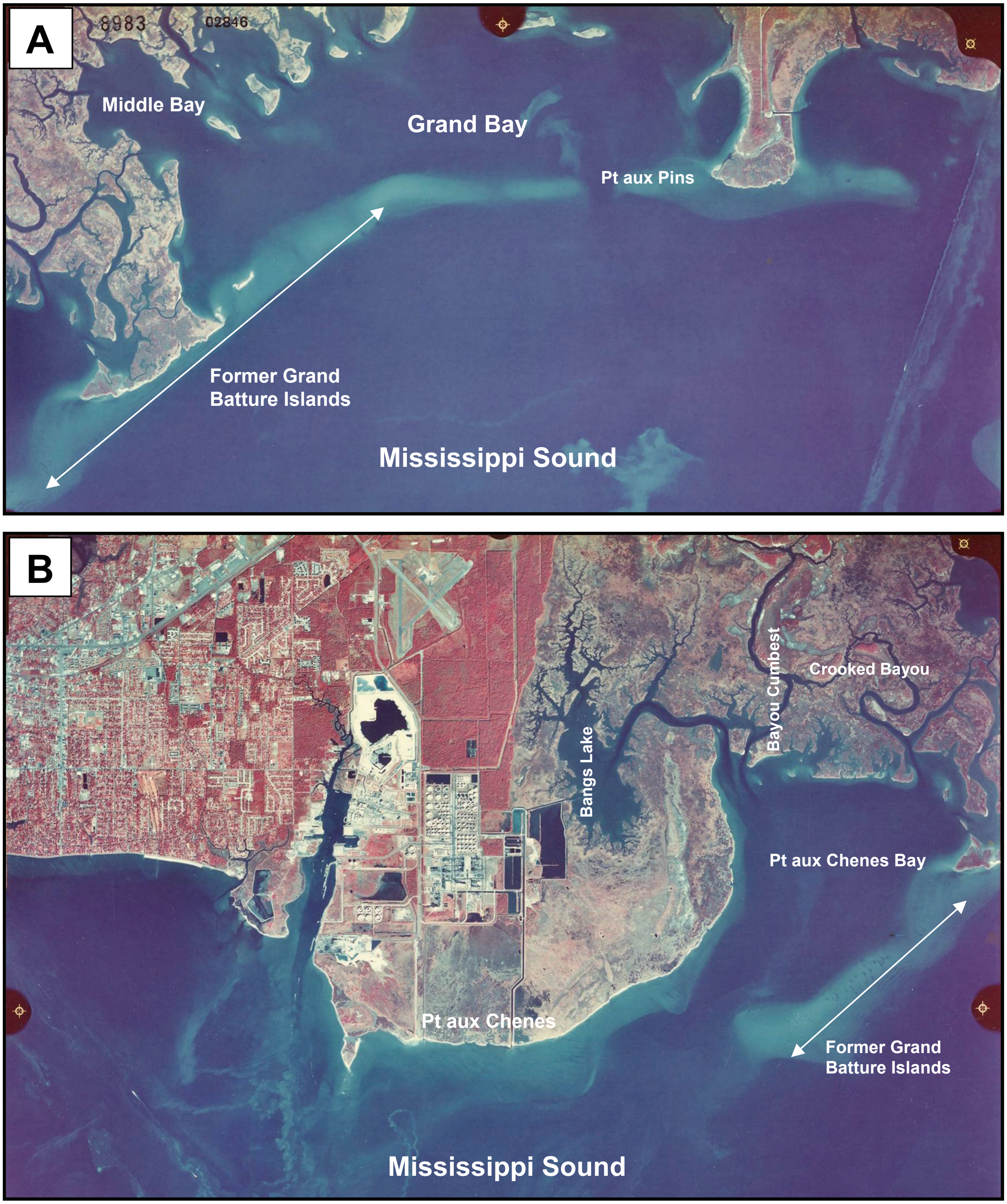

Figure 2.1. A) - Shoal zone (light color), site of extinct Grand Batture delta front island chain between relict delta headlands, Grand Bay, MS-AL. Note Crooked Bayou and other meander bends of tidal creeks; channels inherited from westward-diverted Escatawpa River. Pt. aux Pins headland (right) flanked by former site of abandoned, shorter island chain. NASA Photography (Roll 2846), November 1979. B) - Pt. aux Chenes cuspate, mostly late Pleistocene headland. Pt. aux Chenes Bay with shoals of former west Grand Batture Islands. Pleistocene Upland area: red color.

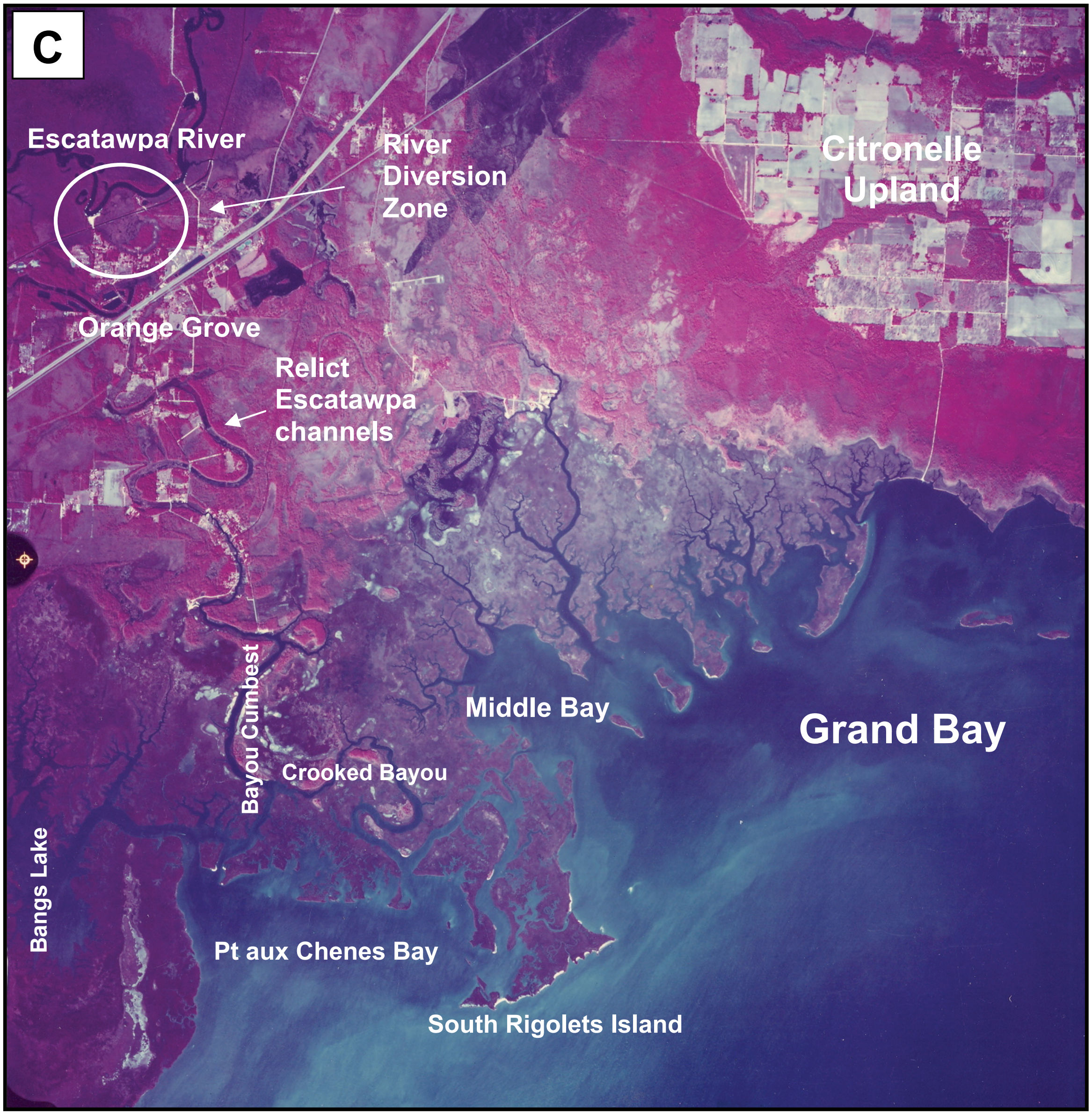

Figure 2.1. ***continued.*** C) - Abandoned Escatawpa delta channels and location of stream piracy at rectangular river bend at Orange Grove, MS, in the north. Pt. aux Chenes Bay (left), former South Rigolets delta headland with relict late Holocene Escatawpa channel network (middle) and the rest of central Grand Bay (right). No trace of the Batture island chain left, west and east of the delta headland (1989). Color false infrared image, NASA Photography (Roll #3841).

Table 2.1. Generalized stratigraphy of coastal Mississippi and Alabama, including Prairie Formation and Holocene units (Otvos 1997).

EPOCHS, AGES		GEOLOGICAL UNITS
HOLOCENE		Coastal wetlands, lagoonal, inlet, and delta deposits. Mainland and island strandplains, beach complexes, alluvium. Transgressive and regressive hemicycles preserved in certain estuaries.
PLEISTONCENE	**WISCONSIN GLACIAL**	Alabama and Florida: dunes over Gulfport Formation barrier sectors; Louisiana: Florida Parishes dune clusters. Valley fill alluvium. Prairie Formation (alluvial).
	SANGAMON INTERGLACIAL	Prairie Formation (alluvial); Gulfport Formation (barrier complex). Biloxi Formation (neritic-to-estuarine deposits). Undifferentiated early and pre-Sangamonian alluvial deposits.
	PRE-SANGAMON	Montgomery Terraces (e.g., Big Ridge Terrace, central Mississippi) Coast and southeast Mississippi.
PLIOCENE	**UPPER**	Citronelle Formation (in uplands only).
	MIDDLE	Perdido Key Formation (AL-FL border area); Undifferentiated alluvial and marine siliciclastics.
	LOWER	Pensacola Formation; Jackson Bluff Formation - Intracoastal Formation. Graham Ferry Member.
MIOCENE	**UPPER**	Pensacola Formation; Choctawhatchee Formation Stage. Pascagoula Member (=? Part of Intracoastal Formation).

The very thin nature of the Holocene fluvial sediment interval beneath the small late Holocene Grand Bay delta (Kramer 1990) indicates the lack of significant deltaic Pleistocene deposition. During the Pleistocene lowstand and immediately following it, the contemporary shoreline was located far offshore from its present position. The combined Pascagoula-Leaf River maintained its present wide, deeply incised, scarp-flanked valley probably throughout the entire Pleistocene Epoch. As the Pascagoula River was cutting down, occupying gradually lower levels during the post-Sangamon sea-level decline in the late Pleistocene, discharge from the now lower Pascagoula floodplain to the meandering distributary channel, still occupying higher elevation, has stopped. Seaward flow of the lower Escatawpa River through the meanderbelt past Orange Grove, however, continued uninterrupted until late Holocene times when the Gulf rose back to its present level. Consequently, the Escatawpa was the only sediment source of the Grand Bay Delta.

Grand Bay Delta was established only a relatively short time ago, at the end of the Holocene when the transgressing Gulf shoreline neared its current position. Soon after construction of the delta, the Escatawpa became a major tributary to the Pascagoula River when its flow was captured through “piracy” by a creek, small tributary of the Pascagoula. The process of gradual headward (eastward) extension eventually connected the creek to the then southward-flowing Escatawpa River. With the Escatawpa's entire flow shunted into the Pascagoula River, sediment discharge to Grand Bay Delta and its further growth was also terminated. In the first reference to the pre-modern history of the Escatawpa, Brown et al. (1944, p. 28) mistakenly credit the *Pascagoula River* as having been the source of the delta.

The meandering delta channels of the Escatawpa became exclusively tidal water courses after cessation of river flow. The longest of these, Bayou Cumbest extends 2 km inland from Pt. aux Chenes Bay to ca. 2 km south of Orange Grove. High point bars in the meander bends carry forest and shrub vegetation (Figure 2.1C, lower left corner). Crooked Bayou, a tributary of Bayou Cumbest and other presently tidal channels also appear to have been stream channels before abandonment. These include North and South Rigolets, Jose Bay, and L'Isle Chaude Bay which separate the deltaic marsh islands that include North and South Rigolets Islands, and L'Isle Chaude. Judging from the width of its shoal zone to the south, the South Rigolets marsh island has undergone at least 500 m of shore retreat since formation of the now-extinct Grand Batture island chain. South Rigolets was a delta headland that, with its now extinct western spit, separated Pt. aux Chenes Bay from Grand Bay. Marsh islands and marshy peninsulas (e.g., Long, Big, Barton, and Little Bay Islands) on the northwestern Grand Bay shore, mostly in Alabama, are also relicts of deltaic sedimentation.

The sediments that underlie these islands originated in deposits transmitted through the eastern distributary channels of the Escatawpa to the present Middle and Heron Bayous and local streams, including the predecessor of present Franklin Creek. A cuspate land area, with Pt. aux Chenes at its apex, forms the western shore of Pt. aux Chenes Bay. At shallow depths, this broad peninsula is also underlain by the Prairie Formation, covered by modern peaty tidal marshland and upland grasslands. Bangs Bayou links estuarine Bangs Lake, in its interior of the cuspate Prairie area (Figure 2.1B) to Pt. aux Chenes Bay. The lake probably formed in a topographic low, flooded by intruding estuarine waters during the late Holocene transgression.

The bays are shallow bodies, generally 0.5 - 1.8 m deep. Only the tidally scoured entrance to Pt. aux Chenes Bay, between the Pt. aux Chenes headland in the southwest and the shallow subtidal sandy island platform to the east (the site of the extinct Grand Batture island chain), reaches 3 m in water depth. The sandy shoal belt, composed of fine-grained, moderately sorted, yellowish gray sand of 97 - 98 % sand content, flanks the South Rigolets Island headland (Figure 2.1). This shoal belt represents the former western and eastern barrier spits, each about 4 km long and attached to either side of the headland.

2.2. GEOLOGICAL HISTORY

2.2.1. Pliocene and Pleistocene Epochs

Pliocene

The mostly alluvial, locally estuarine, Citronelle Formation in the vicinity of the Grand Bay NERR is about three million years old and includes muddy sands, sands, and gravelly sand intervals (Table 2.1). It forms the highest upland surface and represents the earliest geological unit exposed in the surface near Grand Bay (Otvos 1997, 2004). Slow uplift of the coastal plain raised this formation to gradually increasing elevations inland.

Pleistocene (1.75 million years to 11,500 years before the present)

Late Pleistocene geological units are present in the shallow subsurface and the surface in the general area. They were deposited following a period of low sea-level, succeeded by sea-level rise, transgression, and highstand during marine isotope stage (MIS) 5e, between ca. 135-115 thousand years ago. This warm interglacial period is represented by muddy, muddy-sandy, fossil-rich, brackish, and marine beds of the Biloxi Formation, deposited Gulf wide in open Gulf of Mexico (GOM) waters and reduced salinity estuarine environments (Otvos 1997). Alluvial deposits of the Prairie Formation cover the Biloxi and underlie most of the upland surface in and near the NERR. It was deposited in river floodplains during the MIS (marine isotope stage) 5e marine highstand and the following glacial Eowisconsin and Wisconsin substages at various times at different locations between 115 and 28 thousand years ago (Otvos and Giardino 2004). Oxidized yellowish-brown, pale yellow, and olive gray silty sands and sandy muds of the alluvial Prairie Formation are exposed in the higher ground. The Prairie, also encountered at shallow depths in numerous drillcores in and around Pt. aux Chenes Bay, underlies the thin Holocene sediment interval under the bays (Kramer 1990).

Prairie alluviation was interrupted by an abrupt, major drop in sea-level that culminated close to the end of the Wisconsin glacial stage, between 22 - 18 thousand years ago. As sea-level eventually fell about 125 m, the GOM shoreline advanced seaward. The meander channels incised into the Prairie surface in the Grand Bay NERR area had originated at this time. The river valleys that crossed the coastal plain to the new shoreline were deeply incised in the area of the present shelf that was subaerial during much of the lowstand. Judging from the shallow sub-sea depth of the Pleistocene surface in the Grand Bay area (Figure 2.2), the late Pleistocene Escatawpa River coincided with the present incised valley. Clearly, only a small part of the Pascagoula distributary channel system crossed into the present Grand Bay area in the late Pleistocene. Should a major eastward switch of the Pascagoula have taken place either in the late Pleistocene or Holocene, a deep and wide valley incision would have occurred and preserved. This shift would have been accompanied by widespread oversized meanders and other prominent surface manifestations of a broad Pleistocene valley, filled by thick Pleistocene or Holocene deltaic deposits. These are absent from the Grand Bay area and its subsurface.

Holocene Epoch (11,500 years before the present to the present day)

As sea-level started to rise again, the previously incised and entrenched stream valleys were partially filled with Holocene alluvium. The considerable 1 - 2 km width of the present tidal lowest course of the Escatawpa River between the towns of Escatawpa and Moss Point suggests that, as with the rest of the present Escatawpa river valley, this valley segment was already in existence during Wisconsin low sea-level stages. Through meandering channels, incised into the Prairie surface west and south of the town of Orange Grove (Figure 2.1C), waters of the Escatawpa may have been periodically rediverted several times in the past. This would have taken place during major flood events when a steeper valley slope gradient along an alternate course offered a new route in reaching the GOM. Westward flow toward the Pascagoula River thus may have alternated with southward flow toward the Escatawpa delta in western Grand Bay.

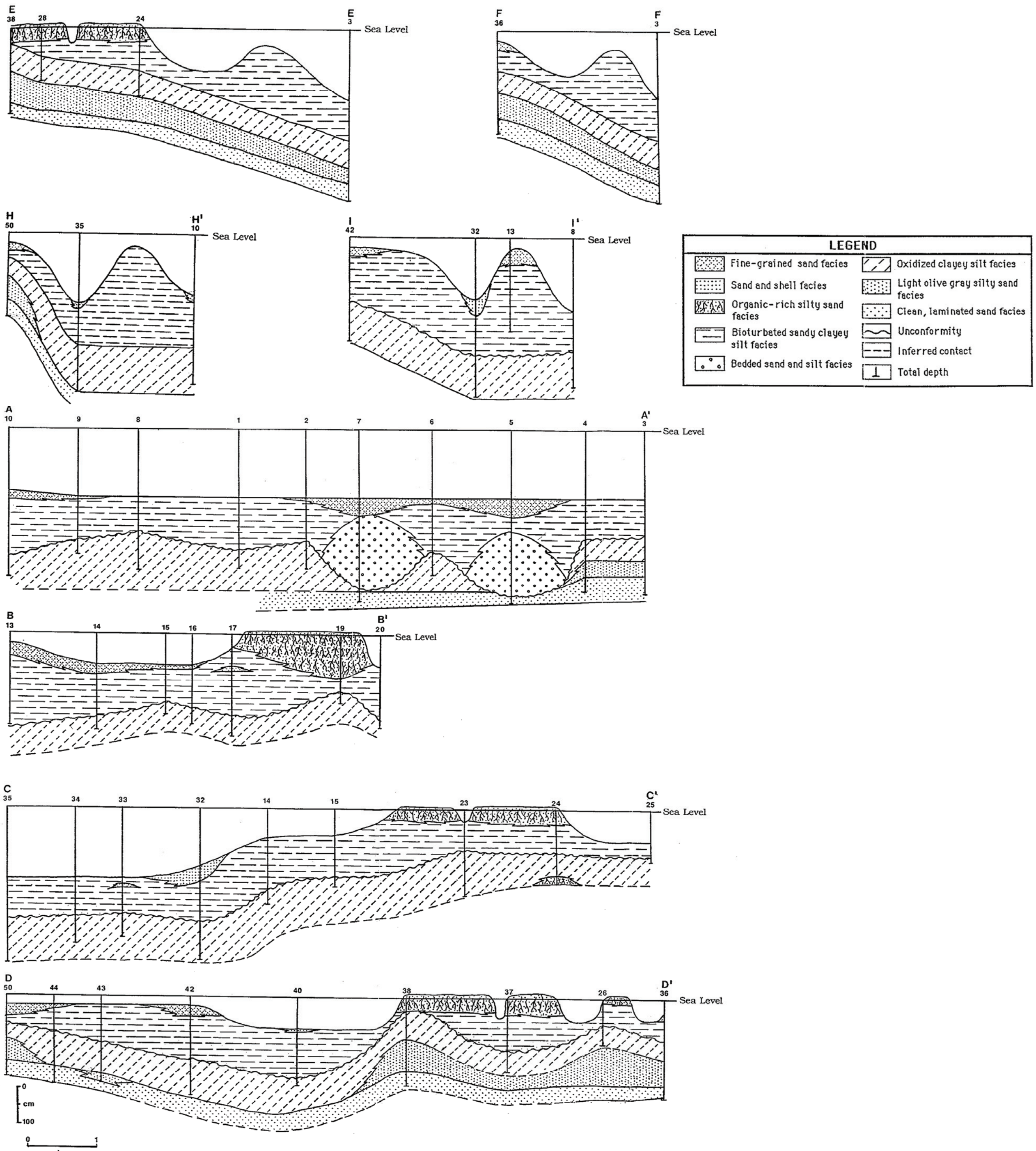

Figure 2.2. Geological cross section of Holocene sediments and Pleistocene-Holocene unconformity surface from Kramer (1990). The oxidized clay-silt facies in the cross sections represent the Pleistocene deposits.

Sediment accretion in the floodplain near the diversion site has determined the location where the capture and diversion of the Escatawpa took place near Orange Grove (Figure 2.1C). This piracy was performed by a preexisting short, westward-flowing tributary of the Pascagoula River (Figure 2.1C). Reviving its now moribund delta, another flow reversal sometime in the future may yet shunt the Escatawpa River back to its original direction.

The emergence of the Alabama-Louisiana barrier island chain and the associated Mississippi Sound lagoon in the final phase of Holocene transgression, about 5 - 4 thousand years ago (Otvos and Giardino 2004), took place before the present sea-level and mainland shoreline were established. The islands that faced Grand Bay across ca. 14 km of Mississippi Sound waters, 3 to 5 m deep, protected the mainland shore against the full brunt of tropical storms and minor hurricanes.

Aggradation of the Grand Bay delta started in the late Holocene as the steadily rising GOM closely approached its present level. Radiocarbon dating of the top and bottom portions of the tidal marsh peat beds that are 20-40 cm thick (Kramer 1990; Figure 2.2) may succeed in constraining the age range of the Grand Bay delta. The ages of Marksville (Site 13, JA-576) and Tchefuncte and younger cultural horizons (Site 10, JA-582; Table 2.2, Figure 2.3, and Appendix) associated with the oldest cultural intervals (Indian mounds) suggest that the delta already existed at the time of Christ, probably several centuries earlier (Otvos 2000, Mississippi Archives-Archeological Site Survey Files, Blitz and Mann 2000).

French and British charts compiled between 1713 and 1720 show Dauphin (Massacre) and Petit Bois Islands as a single entity that stretched westward to the vicinity of Horn Island. The permanent separation into two islands may date to the major breakup of Dauphin Island by the 1740 hurricane when allegedly half of the ca. 35 km long island was eroded. Charts indicate that Petit Bois Island, formerly the westernmost sector of Dauphin was isolated by 1765 - 1770 at the latest (Otvos 1979, p. 305-306). Rapid westward growth of narrow, western Dauphin Island and the fast erosional retreat of Petit Bois' eastern end translated into steady widening of the Petit Bois Pass that permanently separated the two islands. By the late 20th century, the pass was 9 km wide.

While no dependable charts exist prior to 1713, the documented history of the islands since then strongly suggests that barrier island passes that funneled storm waves into the Sound formed periodically throughout the late Holocene. Storm cuts first widened the semi-permanent inlets, and then created a wide inter-island pass, occupied by a narrow, deep tidal channel. By allowing erosive waves to reach the SW Alabama - SE Mississippi mainland shore, storm gaps between islands played a vital part in the intensive erosion of the marshy Grand Bay shore deposits and in the consequent rapid shoreline retreat.

Erosion of the Escatawpa deltaic headland by fair-weather, winter and summer-fall cyclonic storm waves approaching from the GOM eventually destroyed most of the relict delta. Redistribution of the eroded sediment first resulted in a pair of long sand spits from a central headland, the site of South Rigolets Island, backed by marshes. Enclosing Grand and Pt. aux Chenes Bays that flanked remains of the central delta plain, wave refraction, and resulting littoral drift extended the spits northeastward and southwestward respectively from the headland shores.

Continued erosion during the prefrontal stage of cold winter fronts and the impact of frequent tropical cyclonic activity in the summer and early fall season resulted in further delta degradation and elimination of the entire Batture marsh island chain by 1980 (Figure 2.4, Otvos 2005).

Table 2.2. Native American cultural chronology, eastern Mississippi Sound region (Blitz and Mann 2000).

	PERIOD	CERAMIC SERIES	PHASE
1830	Historic	Natchezan/ Choctawan	undefined
1775			La Pointe
1699	Protohistoric		Bear Point
1550	Mississippi	Pensacola	Singing River
1350		Moundville	Pinola
1200	Woodland	Coles Creek; Weeden Island	Tates Hammock
700		Troyville	Graveline
400		Issaquena	Godsey
A.D. B.C.		Marksville; Santa Rosa	Greenwood Island
100	Gulf Formational	Bayou La Batre and Alexander	Apple Street
800		Tchefuncte/ non-tempered; Wheeler	Claiborne
1200	Late Archaic	Preceramic	undefined
2000			

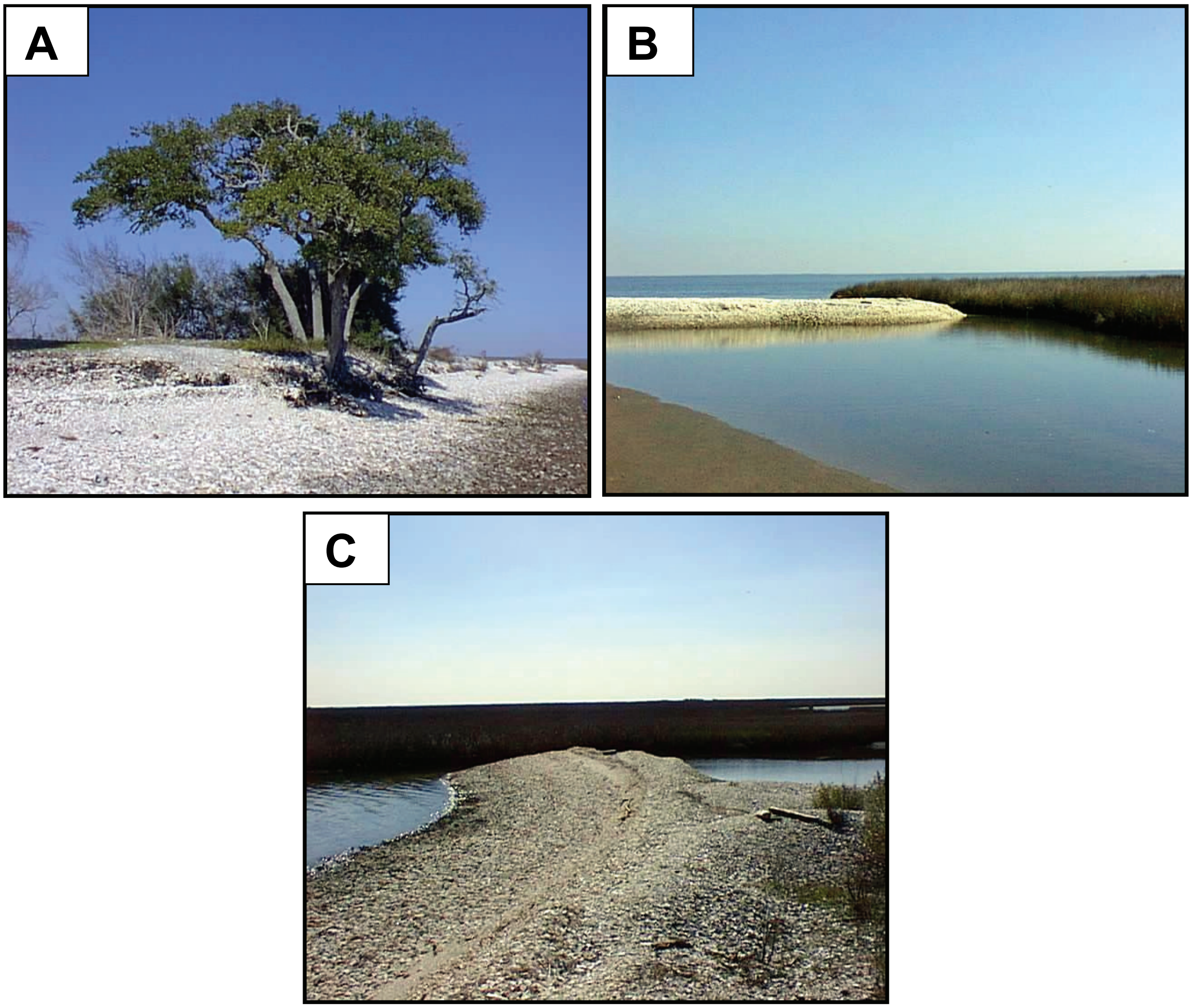

Figure 2.3. A) Eroding large Indian oyster midden, Site 13 on west shore (right) of Grand Bay. B) Wave-reworked shell from midden blocks Grand Bay entrance to South Rigolets Bayou south of Site 13. C) View toward Grand Bay with shell bank at mouth of South Rigolets Bayou. Photos by Alan Criss 1998; locations of sites can be found in Appendix.

Figure 2.4. A) Wave erosion on retreating marsh edge, with scarping (background) and horizontal benched marsh peat exposure. B) Marsh grass and peat remnant exposed along eroding marsh shore with narrow sand beach. Both A and B are located on the west shore of Pt. aux Chenes Bay, south of archaeological Site 15. Photographs by Alan Criss 1995; locations can be found in Appendix.

2.3. BOTTOM SEDIMENT DISTRIBUTION, PT. AUX CHENES AND MIDDLE BAYS

2.3.1. Pleistocene Unit.

Alluvial deposits that underlie the Holocene alluvial and bay sediments are characterized by oxidized or bleached sandy silts and fine silty sands. In coreholes, Kramer (1990) encountered oxidized olive-gray and yellowish-gray with oxidized stains clayey silt underlain by light olive-gray silty sand. These sediment types occurred from 0.25 - 2.5 m below sea level beneath the headland down to 2 - 3 m below sea-level offshore from the bay mouth. These deposits represent the late Pleistocene Prairie Formation. Laminated thin clean sands in the bottom interval of several of the Kramer cores represent stream channel and/or point bar sediments.

2.4. HOLOCENE AND MODERN DEPOSITS

2.4.1. Holocene Deposits

The Prairie unconformity is overlain by 0.5 - 1.5 m of bioturbated sandy, clayey silt that generally extends to the present-day bay floor. Lenses of fine grained sand and organic-rich silty sand overlie marsh-peaty deposits of the Escatawpa Delta that prograded into Grand Bay coving the sandy, clayey bay silts in the late Holocene, (Kramer 1990). Radiocarbon dates from these organic-rich, peaty deposits have provided the maximum and minimum dates of this fluvial phase. The crossbedded sand and silty facies in coreholes Soundward of the headland remnants represent fluvial channel fill.

In Pt. aux Chenes Bay, the thickness of the olive gray, mottled, Holocene sandy silty clay increases from zero at the shoreline to 1.0 - 1.5 m deep near the mouth of Pt. aux Chenes Bay. The sandy residue that occupies former Grand Batture Island locations was a maximum of 50 cm thick in the drillcores (Kramer 1990; Figure 2.2).

2.4.2. Modern Erosive Shore Processes

Shore erosion is generally caused by wave action during tropical cyclonic storms in the mid-summer to early-fall season and by the effects of Arctic and Pacific-maritime frontal events between the late fall and early spring (Otvos, Climate and Weather, this volume). Severe backshore and foreshore erosion results in the winter-early spring season. When heavy rain events occur, ground water outflows from the toe of the backshore scarps. This takes place by ground water sapping in miniature box canyons (Figure 2.5A, B) and in hundreds of newly formed small meandering channels that cross the beach backshores, especially during north wind-induced extreme low tides (Figure 2.5C, D; Otvos 1999).

2.4.3. Modern Bayfloor Environments

The clay mineral composition of recent Pt. aux Chenes Bay sediments (D. Darby, Old Dominion University, Norfolk, Virginia, per. comm. 1999) matches that of the adjacent Mississippi Sound. The Bay's dominant smectite (montmorillonite) content is 62 %, comparable with 70 % reported from the eastern Mississippi Sound and 79 % in the western Mississippi Sound. The illite content in the Sound increases from east to west, from 11 to 15 %; the kaolinite content decreases from 19 to 7 % along the same gradient (Isphording et al. 1985). Montmorillonite originates in Holocene Mississippi River deltas and is reworked by waves in the western part of the Sound, while kaolinite is derived from the eroding older coastal plain formations with Appalachian sediment sources. These were recycled from the Appalachian region and presently are found north and northeast of Mississippi Sound.

In Middle Bay (Figure 2.1A), bayou tributaries displayed the highest (20 - 37 %) clay content, whereas the lower portion of the Bay, had only intermediate (10 - 20 %) clay content. Except in landward pockets, the sand content was 30 - 62 %, with two separate, large sand-dominated areas of 50 - 62 %. These are located in the upper and lower reaches of the Bay (Figures 2.6 - 2.8). In Pt. aux Chenes Bay (Figure 2.1B), a belt of fine sands flanks the western shore, adjacent to the Pt. aux Chenes Pleistocene headland, and stretches SW-ward from the Rigolets Island headland into the Sound. Very fine sands, muds and silts characterize the northern shore margin and an offshore area in Mississippi Sound to the SW. The rest of the bay bottom is underlain by coarse silty and muddy very fine sands. Bottom areas of higher clay content stretch from the northern bay shore to the SW bay entrance. These areas are adjacent to the sand belt along the Pt. aux Chenes Headland shore. A clay-enriched area also occurs along the northeast bay shore adjacent to the delta remnant. The highest sand concentrations occur in a zone adjacent to the east shore of the Pt. aux Chenes Headland and in the sand platform belt at the site of the former western Grand Batture sand spit. This contiguous zone is 1.0 - 1.5 km wide and stretches SW-ward into Mississippi Sound (Figure 2.1A, B and Figures 2.9 - 2.11). *Juncus* and *Spartina* dominate the marshes that fringe the bays.

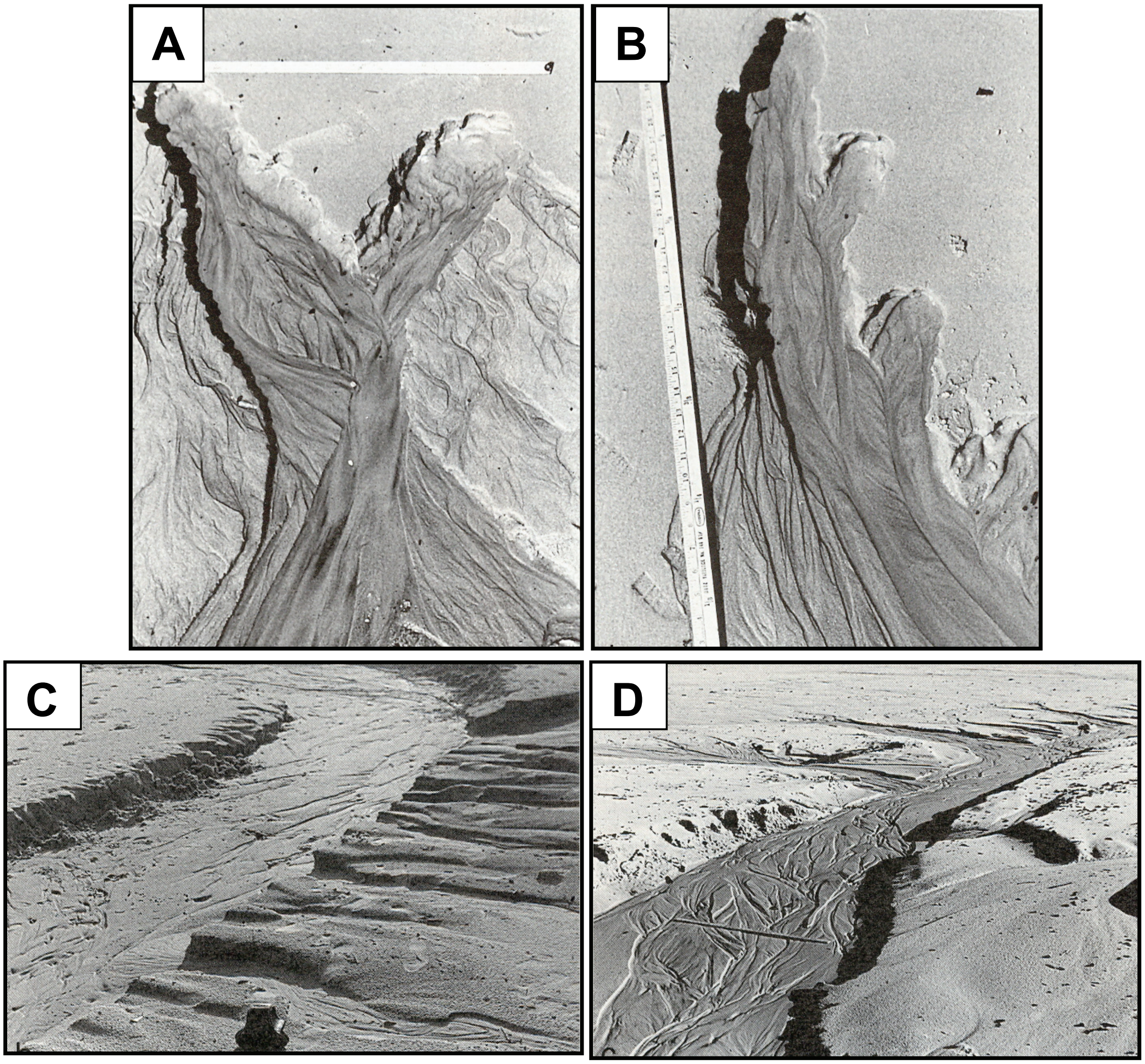

Figure 2.5. Rain-related erosion features on modern beaches. A, B) Sapping-excavated miniature box canyons, formed by escaping ground water. Belle Fontaine Beach, west Jackson County, Mississippi, January 9, 1990. C, D) Channel erosion on Harrison County Beach, Mississippi, March 19, 1990 (Otvos 1999).

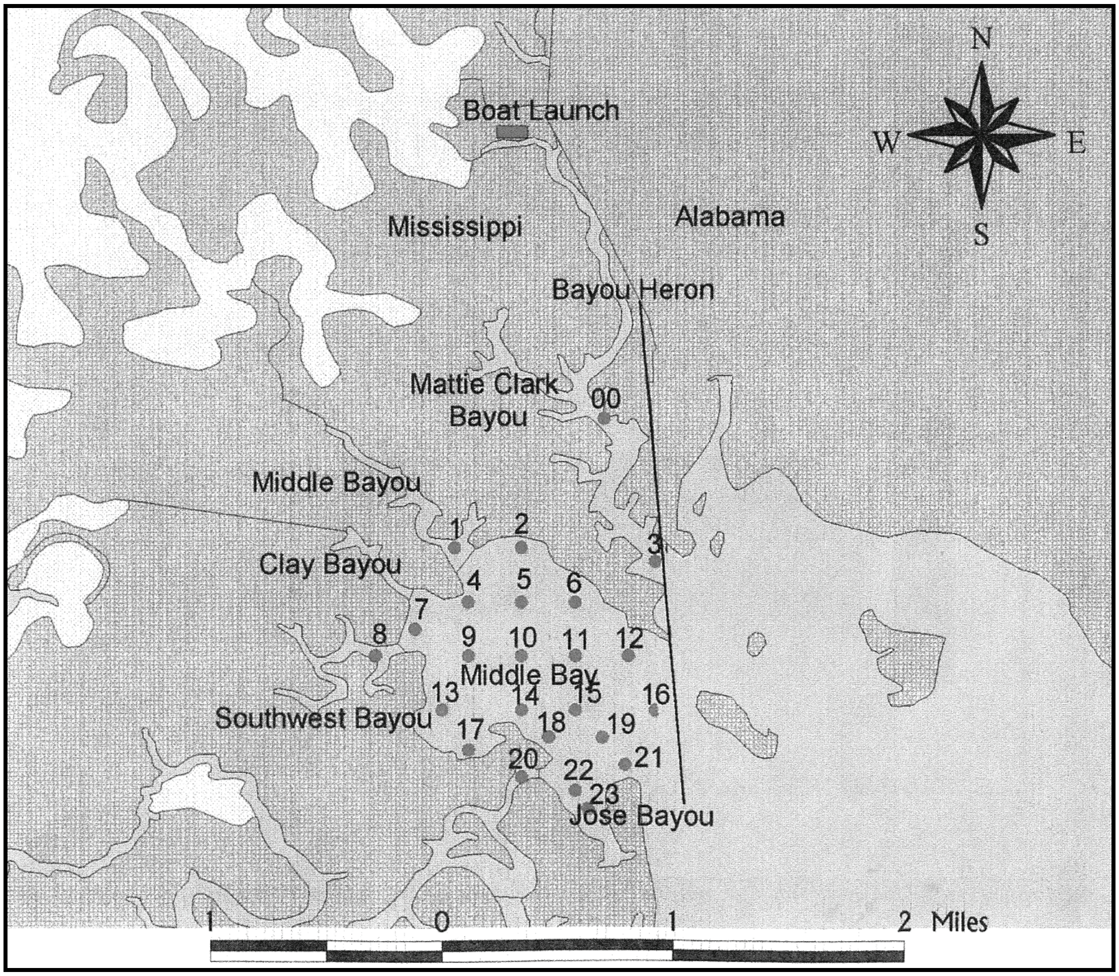

Figure 2.6. Sediment sample locations in Middle Bay in 1998 - 1999, western Grand Bay (Otvos 2000).

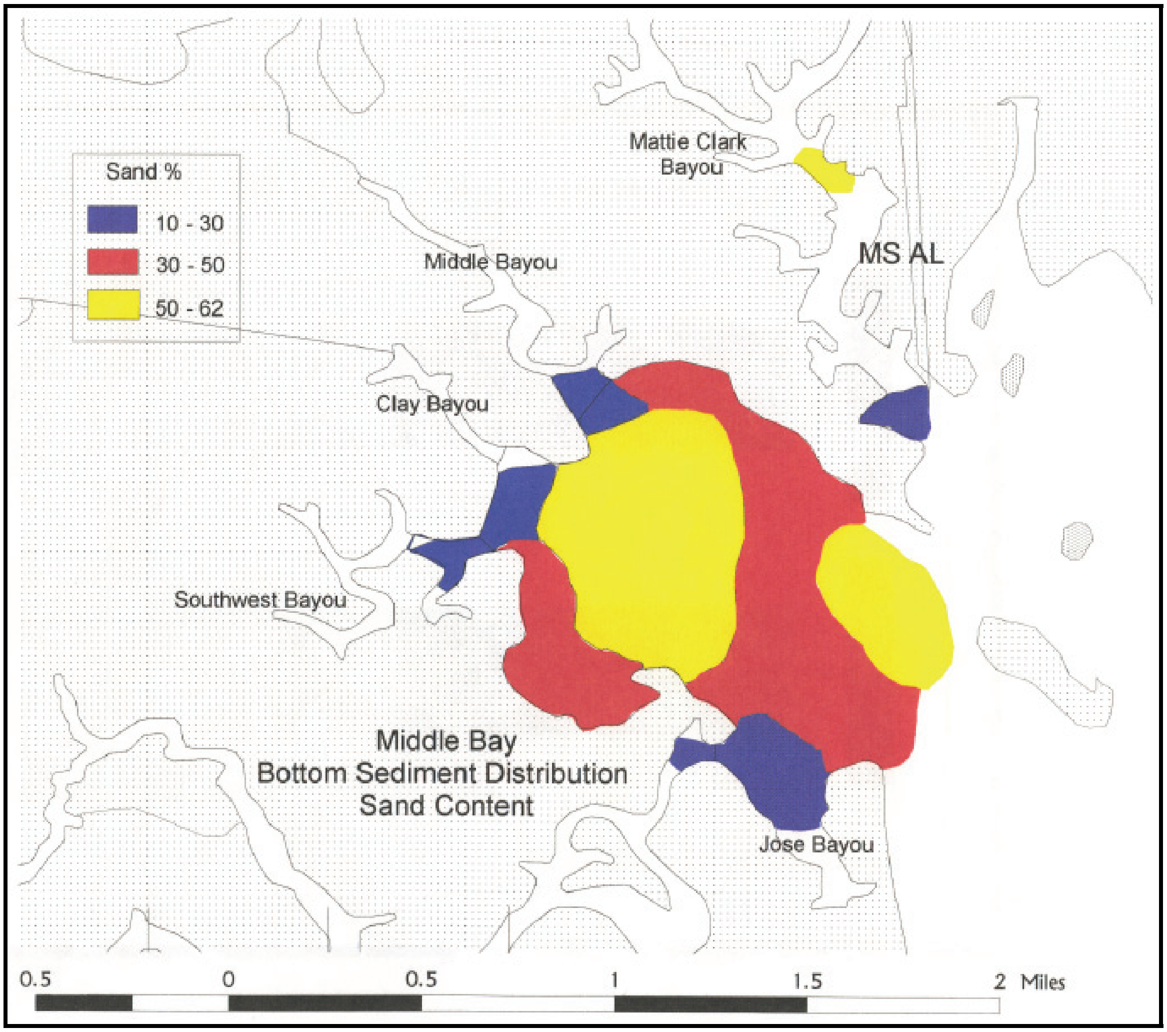

Figure 2.7. Middle Bay bottom sediment distribution in 1998 - 1999 with sand content in percentages.

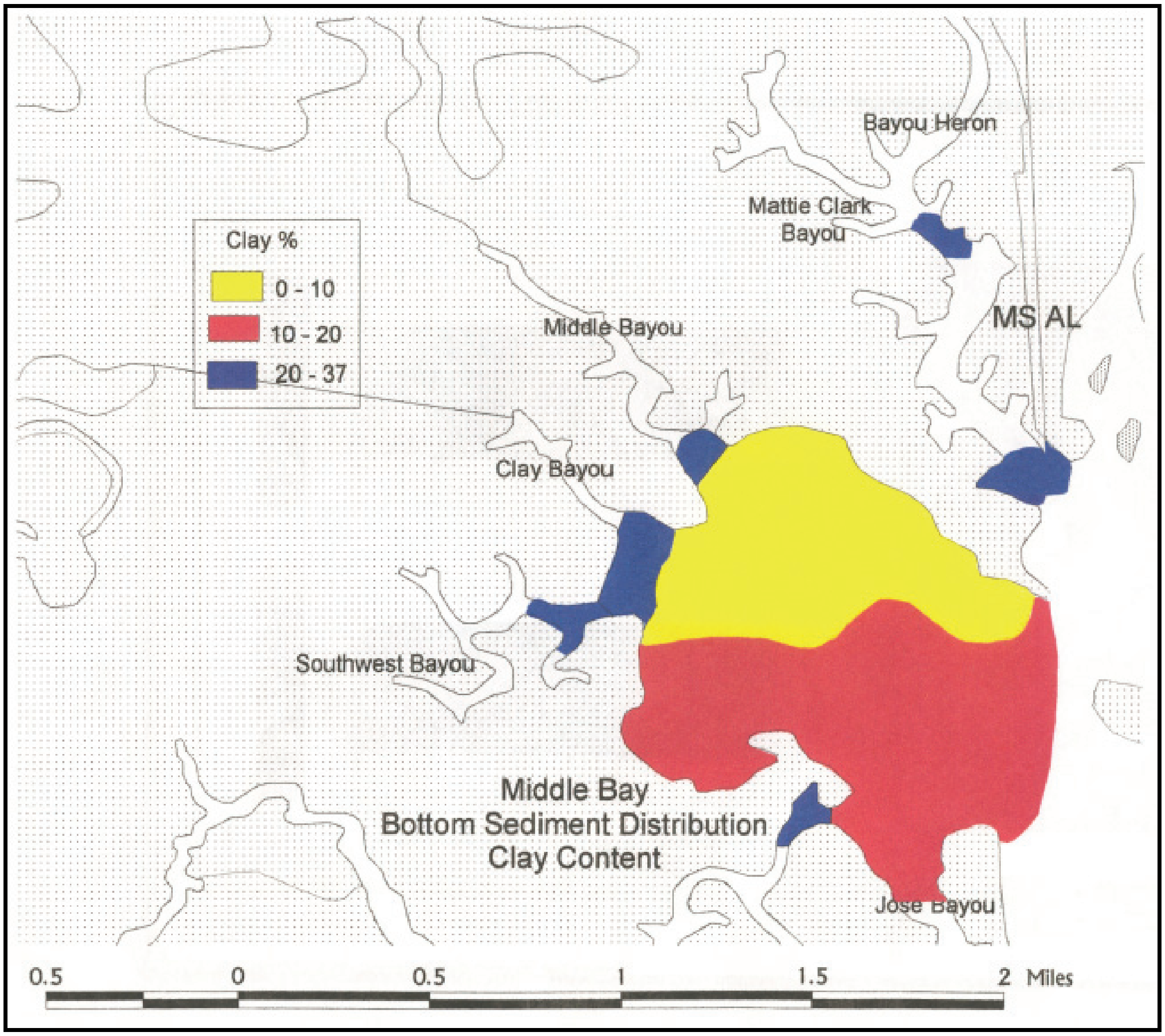

Figure 2.8. Middle Bay bottom sediment distribution in 1998 - 1999 with clay content in percentages.

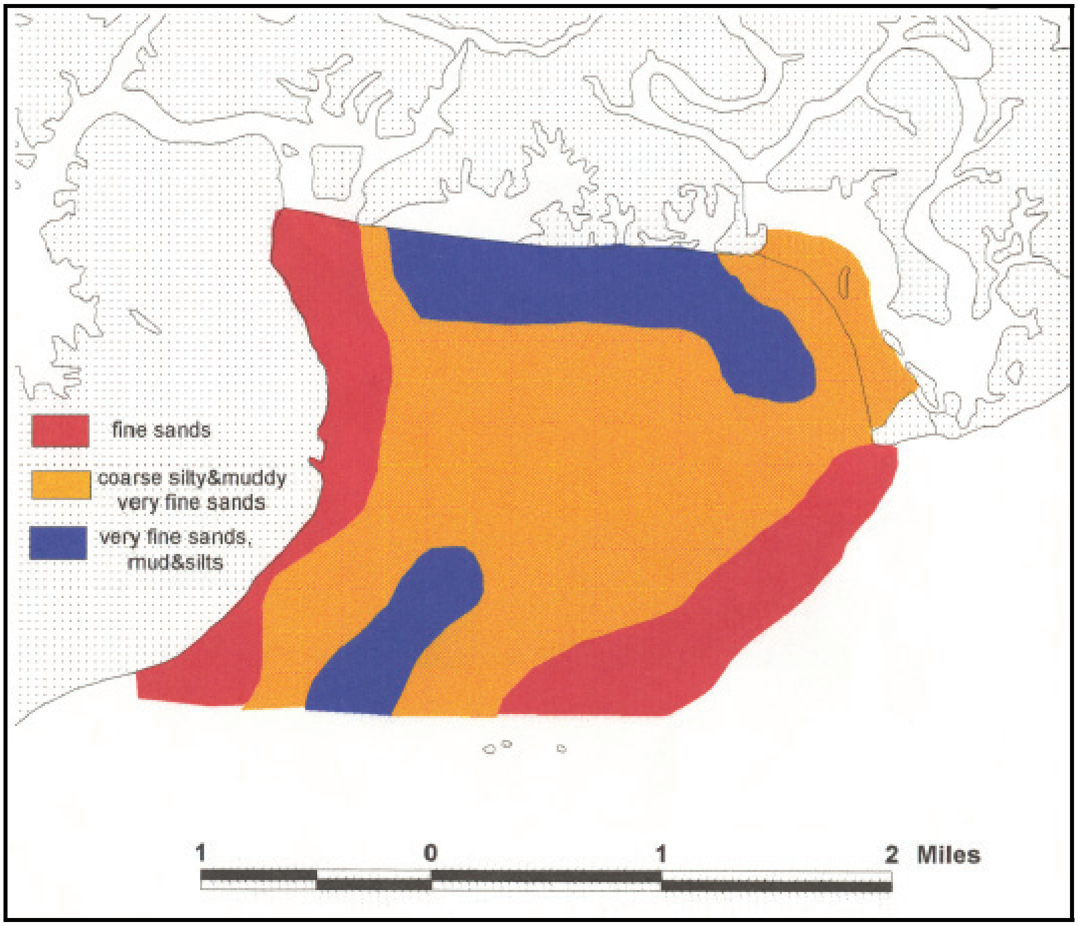

Figure 2.9. Bottom sediment types in 1998 - 1999, Pt. aux Chenes Bay (Otvos 2000).

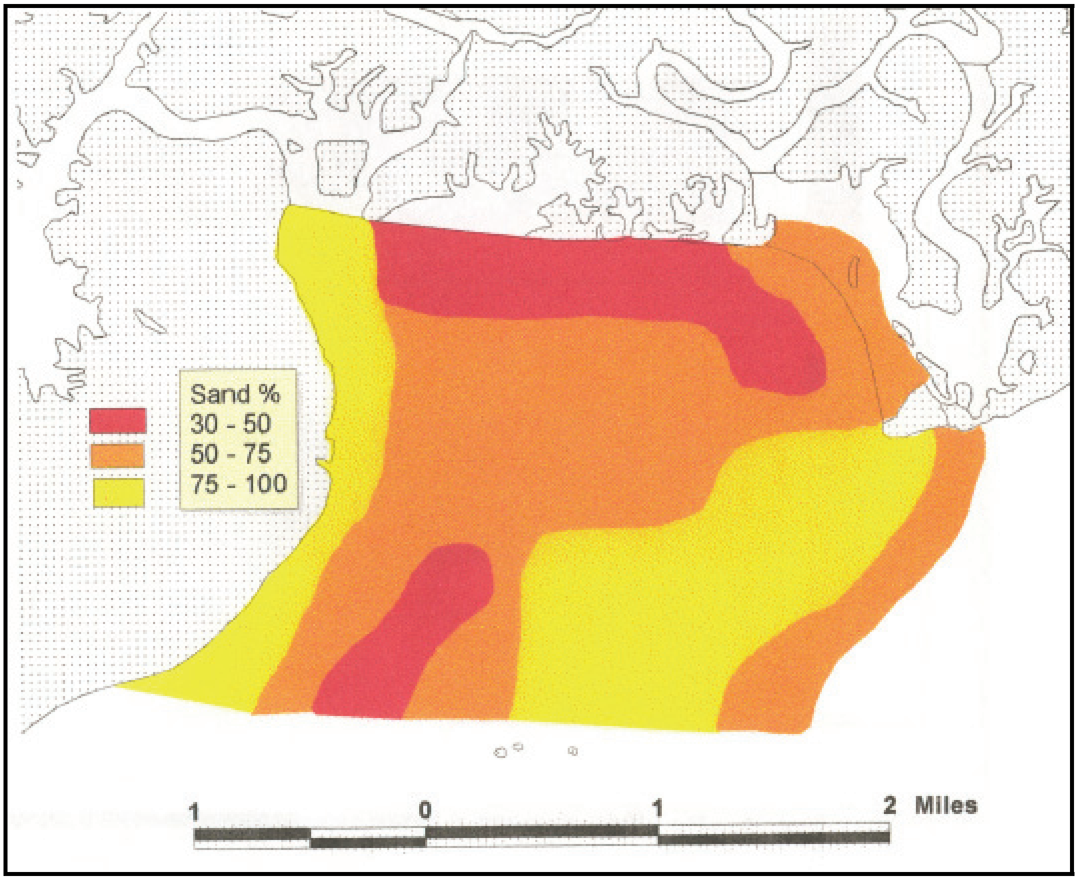

Figure 2.10. Bottom sediment distribution in 1998 - 1999, Pt. aux Chenes Bay with sand content in percentages.

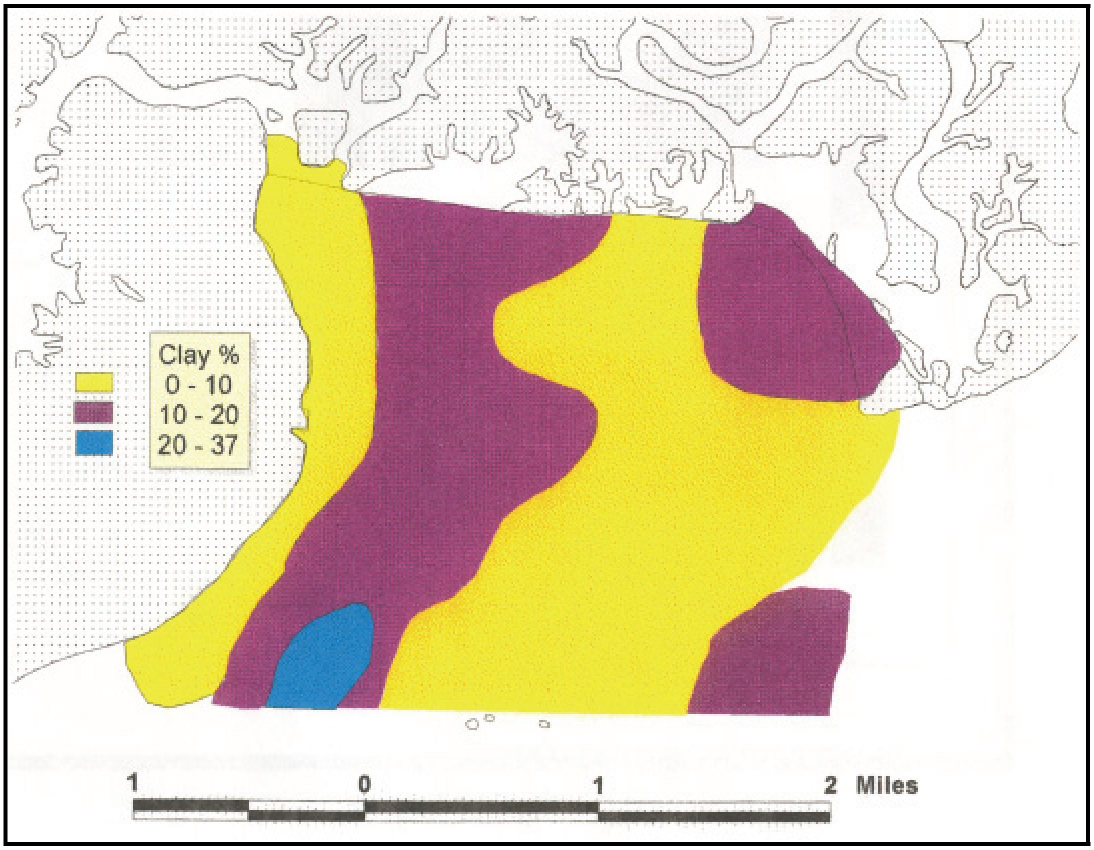

Figure 2.11. Bottom sediment distribution in 1998 - 1999, Pt. aux Chenes Bay with clay content in percentages.

2.4.4. Indian Mounds

The numerous Native mounds in the general Pt. aux Chenes Bay area (Otvos 2000) are composed of oyster and/or *Rangia* shells, major staple items of the Indian population that hunted, fished and gathered various estuarine food resources. They represent both the archaeological record of the area during at least the last two millennia (Mann 1996, Blitz and Mann 2000) and also man-made, sizable shell accumulations. Most have been disintegrating by storm erosion and regular wave activity. These shell mounds accumulated either along bay shores or on the banks of former distributary channels in the Holocene Grand Bay delta. Judging from the cultural ages of these archaeological sites, the delta may have existed and its outer channels carried brackish estuarine waters as early as 1000 B.C - 0 A.D. (2000 - 3000 years BP).

Cultural horizons at Site #1 (JA-633) on Bayou Cumbest belong to the Gulf Formational Period that dates from 1200 to 100 BC. One of the largest, oldest, heavily vegetated oyster mounds, Site #13 between Grand and Pt. aux Chenes Bays (Table 2.2; Figure 2.12, JA-576), rises more than one meter above sea-level. It contained artifacts of the Lower Woodland and Marksville Ceramic Cultural Phase (100 BC-0 AD; Table 2.2). The reworked molluscan shells from the mound formed a wide shell-spit that blocks the entrance to adjacent South Rigolets Bayou (Figure 2.3A

- C). Short stretches of shelly pocket beaches were constructed by waves reworking shell matter from nearby middens (See Figures 2.9 and 2.10 in Otvos 2000).

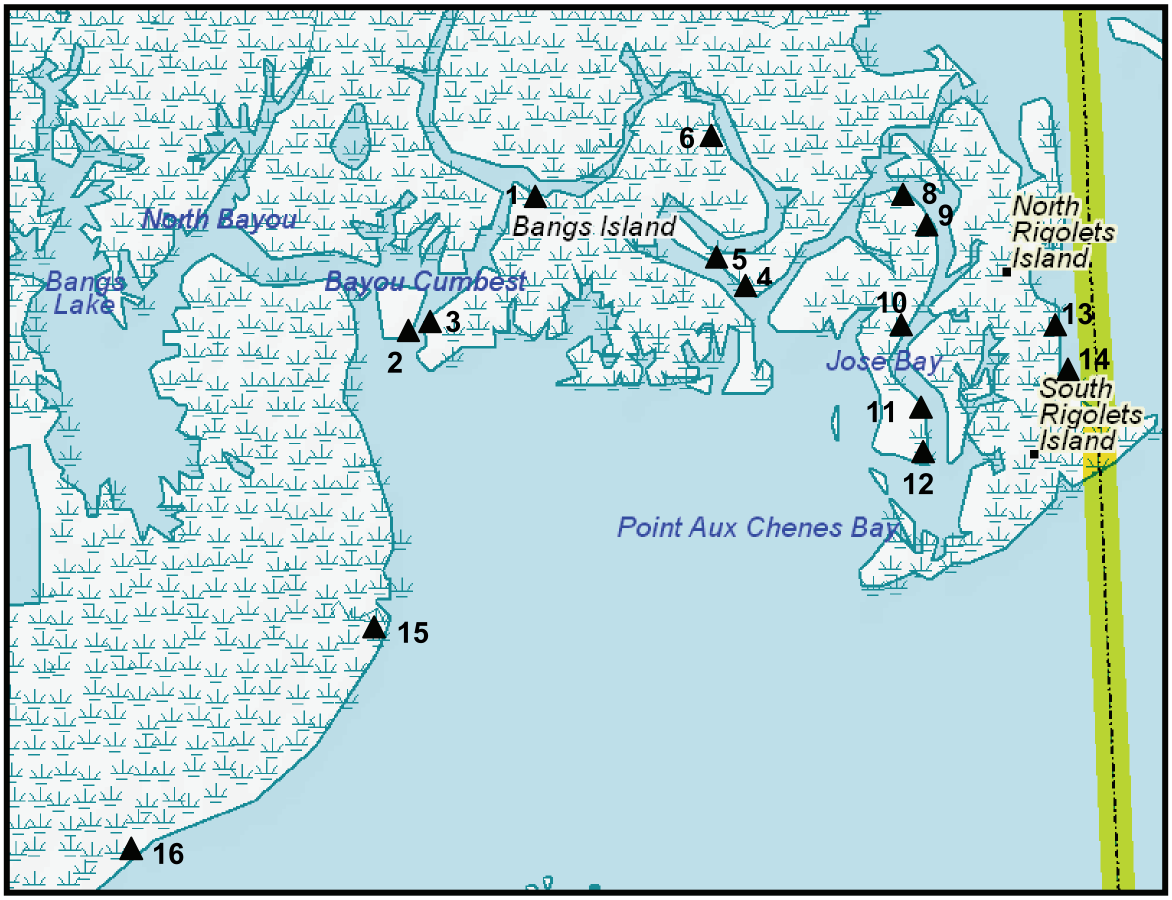

Figure 2.12. Major archaeological sites in western Grand Bay-Pt. aux Chenes Bay area (Blitz and Mann 2000, Otvos 2000).

2.4.5. Tropical Storm and Hurricane Events

Tropical storm erosion played and plays a vital role in the recession of soft marshy mainland shoreline, specifically that of the Grand Bay area. Sixteen tropical storms (maximum wind speed < 74 mph) and hurricanes (> 74 mph in center) impacted parts of south Mississippi between 1870 and 1895 and twelve between 1896 and 1921. Fifteen storms and hurricanes, most prominently Frederic in 1979, a high-Category 3 hurricane (111 - 130 mph) may have had at least a marginal impact in the Grand Bay area between 1921 - 1998. The land area that surrounds the Grand Bay - Pt. aux Chenes Bay complex and extends landward was inundated by storm tide for a distance of 5 km during Hurricane Frederic (U.S. Army, Corps of Engineers 1981, Plate 13).

The 1998 Hurricane Georges, considered a long-track "Cape Verde" type Category 1 (74 - 94 mph) to low Category 2 (96 - 110 mph), created significant aggradation from sand eroded in other intertidal beach, backfill and dune areas in certain Harrison and Jackson County beach sectors (Otvos 2004). Grand Bay's funneling effect created a record 4.2 m high storm run-up in the NW corner, east of the Chevron Oil Refinery (Blackwell and Calhoun 1999). Being in the NE quadrant from the hurricane's eye, this value was higher than measured at the Ocean Springs landfall location (Otvos 2004, 2005). The extraordinary catastrophic impact of Hurricane Katrina (August 29, 2005) along the entire Mississippi Coast is only briefly noted in Chapter 3 of he present volume.

2.4.6. Shore Erosion Rates

Changes in the eastern and western barrier spits that flanked the South Rigolets Island deltaic headland from before 1850 until the turn of the 20th century (Figure 2.13; Otvos 1991 Eleuterius and Criss 1991) indicate extensive erosional retreat and lateral sediment redistribution.

The wide sand shoal belt Soundward, in front of this island suggests that the earlier delta shoreline was located ca. 500 m Soundward from the present South Rigolets headland shoreline. Historic maps illustrate gradual segmentation of the two barrier spits that became the Grand Batture island chain between 1896 and 1921. Erosion gradually converted the steadily shrinking island fragments into the present sandy shallow subtidal platform belt. By 1980, all remnants of the former Grand Batture chain were gone (Figure 2.1 A - C and Figure 2.13).

Sporadic measurements of very short-term shore erosion rates at twenty periodically reoccupied stake locations give a good idea of shore recession. One-to-eight m of shore recession was recorded between 1995 and 1997. A value of 13 m (Station 8) was recorded for the 1990 - 1997 time interval, which was unaffected by hurricanes (O'Sullivan and Criss 1998, Figures 2.3 and 2.4). Based on Mississippi Office of Geology GPS surveys, Schmid (2000) indicated that the South Rigolets headland retreated as much as ca. 50 m between 1993 and 1999, a period that included Hurricane Georges in 1998. According to this report, 6 km of the 11.3 km long shore stretch surveyed underwent more than 2.5 m/yr shore retreat, with a total of 15 m shore recession and 80 acres of land loss between 1993 - 1999. A value of 217.8 m^2/yr, which probably underestimates the land loss rate, was provided for the bay shoreline as a whole. Schmid's rough estimates for the 1986 - 1999 period claimed 53.8 hectares of land loss along the entire bay shoreline. However, most of this shoreline was not actually surveyed, and a 3.8 km sector of the total 11.3 km shoreline surveyed for this time interval underwent >3 m/yr retreat.

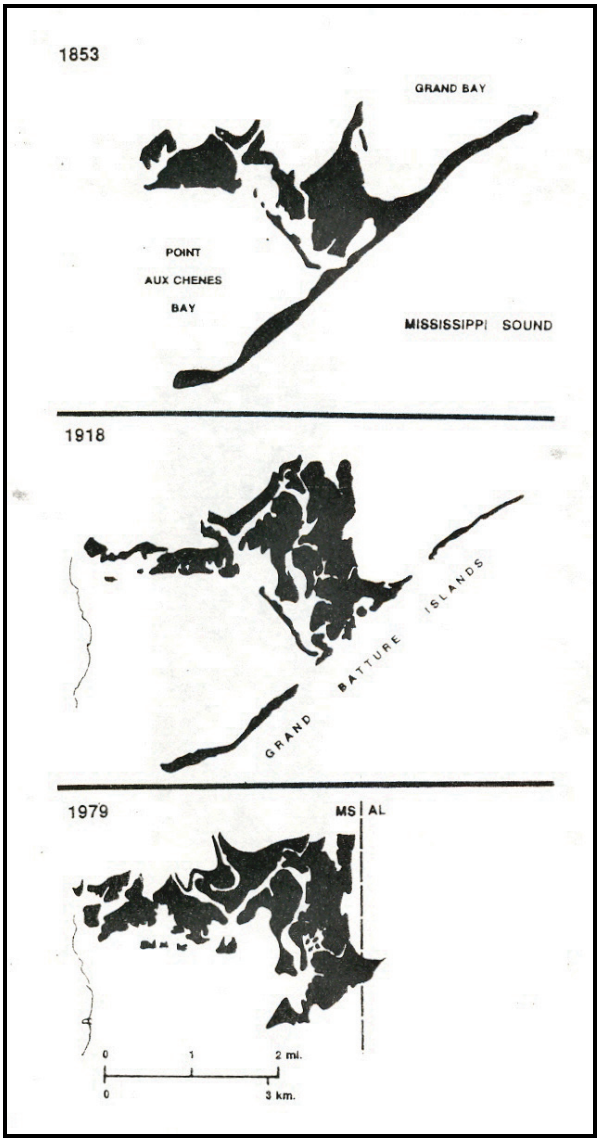

Figure 2.13. Gradual disintegration of relict Escatawpa delta plain and the Grand Batture marsh island chain (Otvos 1991).

2.5. GEOLOGICAL FUTURE OF THE GRAND BAY AREA

Barring another highly unlikely reversal of the Escatawpa flow in the future, recurring tropical cyclonic and winter front activity will combine to continue steady erosion of the relict, marshy Escatawpa delta plain and its still remaining Indian cultural sites. Continued sea-level rise, currently at the rate of about 15 - 18 cm/century in the Biloxi-Mobile area (Burdin 1991), in coming centuries will contribute to the disappearance of the last vestiges of the delta plain. Wave erosion will deepen and widen the entrance to the Bay. By opening it up, more saline influences of the Sound waters measurably change the Bay's low salinity ecosystem. With the eventual loss of its broad marginal tidal marsh framework, Prairie alluvial deposits fringed by a much narrower belt of marshland will directly form the Bay's shoreline.

APPENDIX

PT. AUX CHENES BAY AREA SIGNIFICANT ARCHEOLOGICAL (INDIAN MIDDEN) SITES (Provided as Site numbers and solid triangles in Figure 2.12; Cultural chronology: Table 2.2). Information based on Blitz and Mann 2000; Mississippi Department of Archives and History and Archeological Site Survey Files, Jackson, MS, and recent field observations.

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CHAPTER 3

CLIMATE AND WEATHER OF COASTAL MISSISSIPPI

Ervin G. Otvos

The Mississippi coast is located in the humid-temperate, nearly subtropical region where summers and early fall are hot (Figures 3.1 and 3.2A) and humid (> 80 %), with occasional tropical cyclonic activity. Winters, late fall, and early spring tend to be mild with brief interruptions by cold to very cold Arctic and maritime episodes, generated by the passage of frequent weather fronts (Figure 3.2B), followed by coastward expansion of the high pressure ridge. Yearly precipitation values on the Mississippi coast range widely between 94.0 and 246.4 cm but generally are above 127.0 cm (Figure 3.1). Annual rainfall averaged 184.4 cm between 1947 and 2003. Even during the six hurricane-impacted years between 1947 and 1998, rainfall averaged less than the over all annual mean of only 155.2 cm (Otvos 2005).

3.1. LATE SPRING TO EARLY FALL SEASON (Apr - early Oct)

During the spring and summer the Bermuda-Azores High Pressure Ridge intensifies and expands northward into the Gulf of Mexico (GOM). Winds shift, blowing northward from the GOM, and humid airmasses start to intrude over the continent. The Polar Front Jet Stream recedes and the Sub-Tropical Jet Stream begins to influence the GOM weather. Frontal systems typically stall 161 - 322 km north of the GOM coast as the result of the westward migration of the Bermuda High Ridge. The semi-permanent subtropical anticyclone dominates, with moist air influx from the GOM. Prevailing winds from March through August are from the SE, S, and SW.

Mean maximum summer air temperatures vary between 20 - 32° C (mean of 27.6° C). Frequent mid-day to early afternoon thunderstorms usually moderate the summer heat to “only” 32 - 33° C. The highest temperatures occur between July and September, with a July overall record of 40° C (Reuscher 1998). The greatest numbers of days with thunderstorm activity (81 out of 106) occurs between June and September. Onshore *sea breeze* dominates during the hot day hours when hot air lifts over the coast and saturated GOM air flows inland. This results in almost daily convective early afternoon rainfall. Between April and June, mean monthly precipitation ranges from 10.7 to 12.7 cm. Due to the interaction with the marine air layer that moves inland, hazy conditions are typical at higher levels in the summer. As the land area cools faster than the sea late in the day, offshore-directed *land breeze* often brings the Coast a respite of cooler air in the evening and night hours.

Tropical Atlantic-Gulf cyclonic wind episodes, often impacting the northern GOM, start in the early summer between mid-June and mid-July. July and August are the wettest, with a mean of 83.8 cm of precipitation. The lowest mean for these months is 20.3 cm (Reuscher 1998). By September, the Bermuda system weakens and retreats southeastward. Despite early frontal activity, precipitation rates decline.

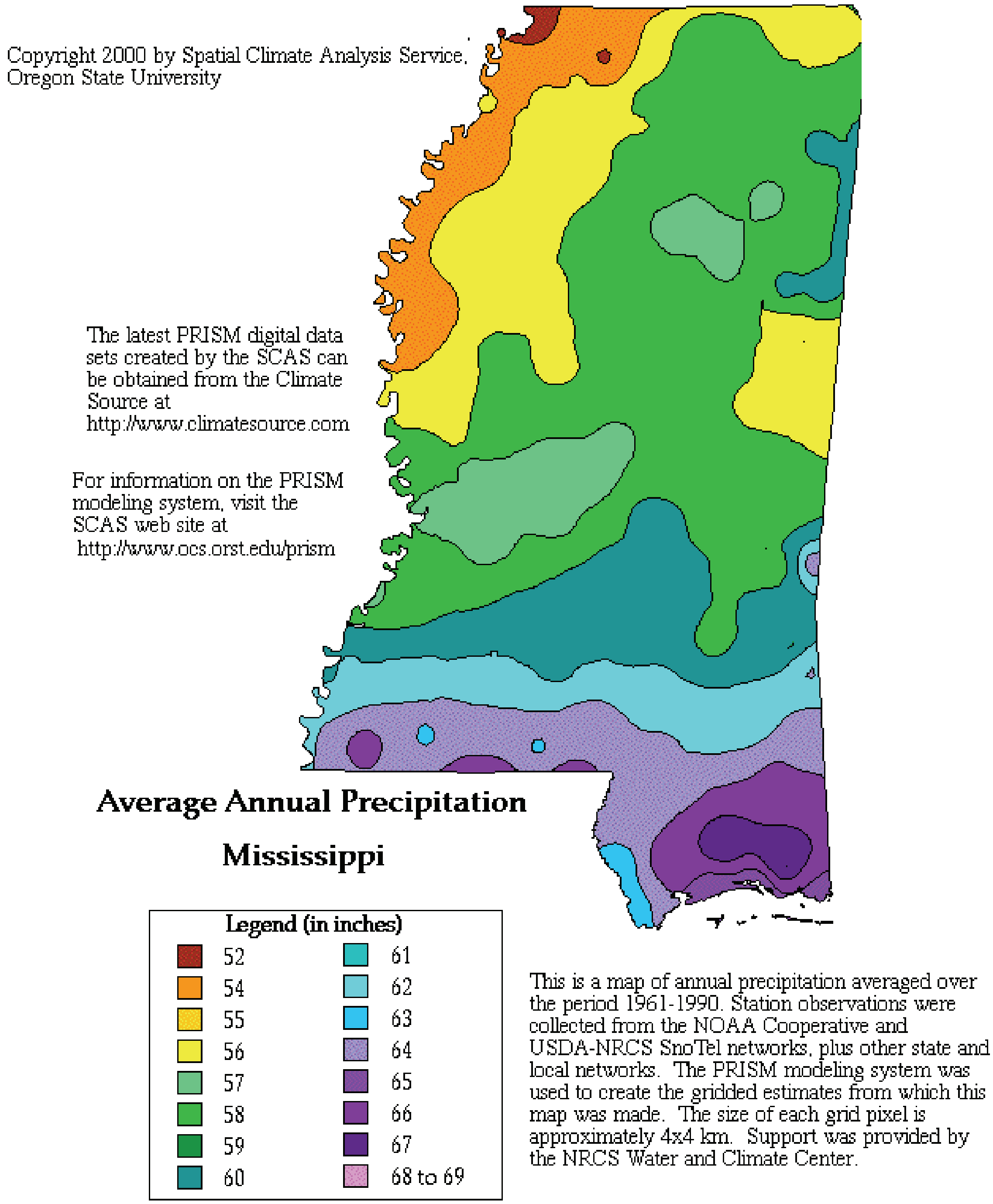

Figure 3.1. Rainfall patterns in Mississippi. Images obtained from the Spatial Analysis Service, Oregon State University.

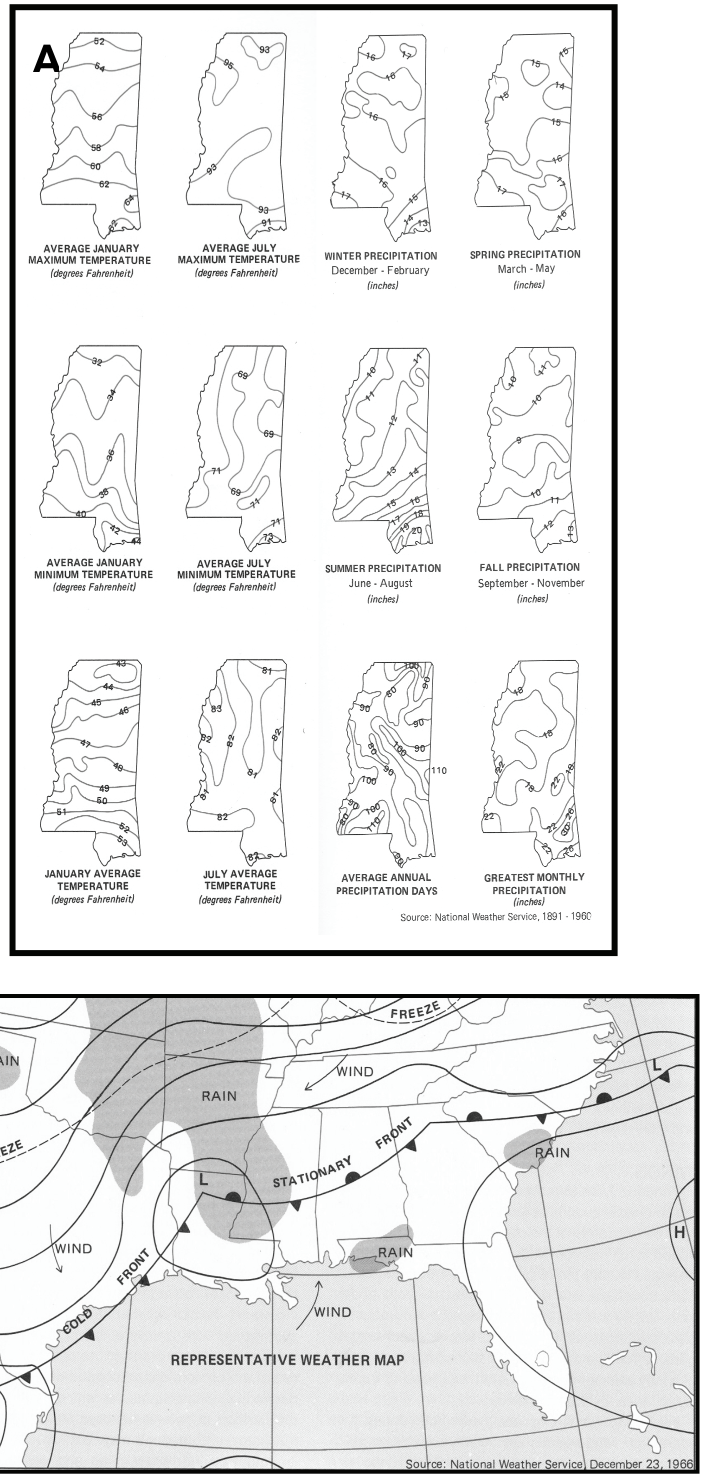

Figure 3.2. A) Seasonal temperature and precipitation variation in Mississippi (Cross et al. 1974). B) Chart of typical winter weather conditions, with stationary and cold fronts, December 1966 (Cross et al. 1974).

3.1.1. Tropical cyclones

The Alabama-Mississippi coast is among North American coastal sectors most frequently exposed to tropical storms and cyclones, including severe (Category 3 - 5) hurricane activity (Muller and Stone 2001). Wieland (1994) cites 67 tropical cyclones between 1871 and 1979 that impacted the area within 185 km (100 nautical mi) of the Mississippi Sound. From 1871 through 1980, a mean of 2.2 tropical storms made landfall about every 18.5 km (10 nautical mi) stretch of the coast (Schroeder 1996, Sullivan 1986, U.S. Army Corps of Engineers 1970, 1981). In Mississippi, the highest tidal surge elevation, documented during Category 5 Hurricane Camille in 1969, was 6.9 m (22.6 ft); the highest still water level was around 4.7 m (16 ft). Maximum wind gusts in the center of the hurricane reached 306 kph (190 mph), while the highest sustained winds were at 257 kph (160 mph) (U.S. Army Corps of Engineers 1970). Tropical storms and hurricanes that impacted the Mobile Bay – Grand Bay area (Chermock 1974) included those of 1895 (Bayou la Batre, Alabama); 1893, 1901, 1902, 1906, 1912, 1915, 1916, 1934, 1939, 1947, 1948, 1950, 1956, 1960, 1964, 1968 (Mobile Bay area, Alabama); 1947 (Pascagoula, Mississippi); and 1998 (Ocean Springs, Mississippi). Hurricane Katrina (2005), by far the most extensive and catastrophic storm ever recorded on the Gulf, was reduced in speed, making landfall "only" as a high-Category 3 cyclone in the Pearl River Delta with 217 kph (135 mph) maximum gusts. Moving slowly, it inundated a large portion of the Mississippi coast, including the entire NERR. Storm surge elevation at Bay St. Louis, Mississippi reached +8.2 m (National Weather Service, 2006 and other sources).

Atlantic and GOM storms generally hit the coast between late July and early October, with most major hurricanes making landfall between early August and mid-September. Due to storm tide currents and overwash, major hurricanes cause intensive erosion on the islands and unprotected shores of the mainland, and the backshore dunes are usually washed away. Overwashed by storm tides and waves, the islands are especially susceptible to segmentation and submergence. Hurricane activity decreases during El Niño Southern Oscillation (ENSO) events, which are characterized by above-normal temperatures and strong westerly winds in the eastern Pacific and weak northeasterly (trade) winds in the Atlantic. In contrast, during La Niña years when east Pacific waters cool and trade winds increase, hurricane frequency and strength increase. Hurricane probability is 23 % during El Niño events as opposed to 63 % during La Niña intervals (e.g., Bove et al. 1998). Alternating wet and arid, dusty West African climate phases also influence hurricane development.

Tropical storms and hurricanes that made landfall at or just west of Grand Bay, such as the September 1906 hurricane, had the greatest erosive impact on the relict Escatawpa Delta and its islands. Major storms that crossed west of Grand Bay, as Frederic in 1979 did, also played a major erosive role. Devastating, high-Category 3 Hurricane Frederic that overwashed Dauphin Island, flooded the entire Grand Bay area to 1.8 - 2.0 m (6 - 7 ft; U.S. Army Corps of Engineers 1981). In the course of the landfall of Category 1 - 2 Hurricane Georges in 1998, bay funneling effects resulted in a record + 4.2 m storm surge elevation in the NW corner of Grand Bay, well east of the storm center. This value was higher than that observed in the hurricane's eye or adjacent to it in the east, the area usually most impacted by storm tides. Before quickly diminishing early on 16 September 2004, Hurricane Ivan's maximum winds reach only 83.1 kpm

(51.6 mph) with gusts to 124.6 kpm (77.4 mph) in Grand Bay NERR (Christine Walters, Personal communication).

3.2. LATE FALL, WINTER, AND EARLY SPRING SEASON (late Oct - Mar)

Convective thunderstorm activity diminishes before the cold fronts start moving into the GOM region in September to October. The Bermuda High associated with the Atlantic subtropical anticyclone system shifts east-southeastward and the activity of northern fronts intensifies. Prevailing winds from September through March-April are from the N to NW. The thermometer dips below freezing on a mean of 11 days annually, mostly during polar frontal activity.

Cooler and drier northerly winds, diminished shower and thunderstorm activity, and more frequent early morning and late evening - night fog dominates the weather. Precipitation in the dry, early fall months is usually reduced, with a maximum mean total during October and November of 30.5 cm and a minimum of 12.7 cm (Reuscher 1998). Between December and March mean precipitation ranges from 20.3 to 22.9 cm per month. The mean temperature in October and November ranges between 16 - 20° C with winter (December through February) temperatures ranging between 5 - 17° C and a mean of 11° C. In March, warm fronts and cloud cover are frequent, and mean temperature is 10° C. Thunderstorms and tornadic activity increase during this period (Reuscher 1998).

3.2.1. The impact of cold fronts and extreme cold episodes

The cool Pacific maritime ("migrating cyclone") and the cold polar Canadian ("Arctic Surge") weather fronts are initiated and controlled by movement of the Polar Front Jet Stream. Each cold front is preceded by warm GOM winds from the S, SE (Figure 3.2B). The fronts form in response to the increasing temperature contrast between air from the cooling interior and the warm GOM airmasses. By pushing dense cold air beneath them, the fronts force the warm GOM airmasses up.

Fronts sweep over the coast more frequently and intensively after mid-November to early December. They enter from the west-northwest across Texas and Louisiana (maritime fronts) and from the northwest (polar or Arctic fronts) as frequently as every 4 - 6 days. During frontal passages, also called *cold-air outbreaks*, temperature and rainfall decrease, but their intensity varies both within one season and year to year. Completely "dry" winter fronts are not unusual. Precipitation ranges between 20.3 - 22.9 cm per month and is influenced by variable frontal activity between late November and March. Thirteen fronts crossed the Mississippi coast between 6 December 1989 and 22 February 1990, with the rain total per front during this period ranging between 8 - 103 mm. An additional 202 mm fell on 15 - 16 March 1990. Substantial ground water-related beach erosion occurs by sapping and runoff channels during major rainfall events that coincide with tides lowered by the frontal north winds (Otvos 1999, Figure 3.3).

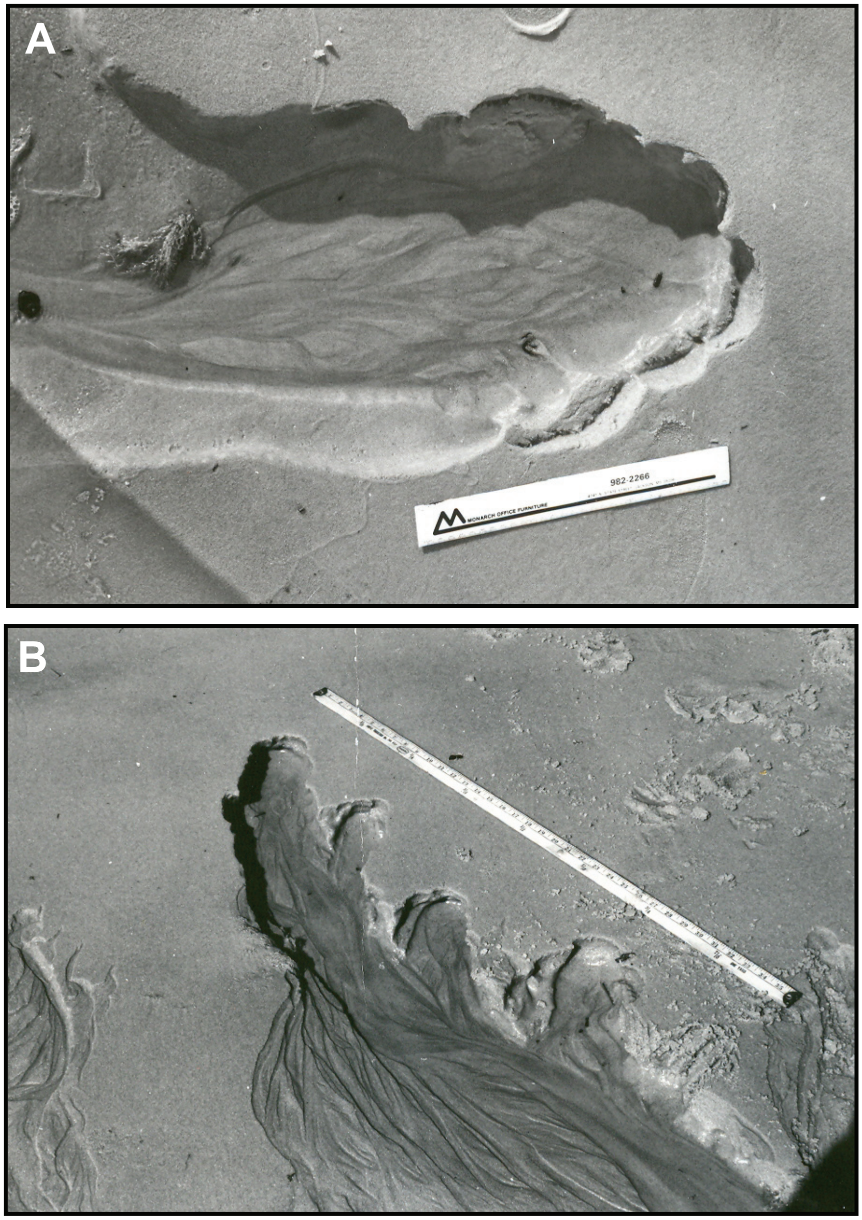

Figure 3.3. Beach erosion at East Belle Fontaine Beach, MS, west of Grand Bay (Otvos 1999) caused by greatly depressed tidal levels due to frontal north winds coupled with ground water sapping and channel erosion by intensive runoff from major rain events during wet winter months.

Strong southerly airflow, torrential rain, a squall line often with violent thunderstorms, and an occasional tornado characterize the pre-frontal stage. During frontal passage, the wind changes from a southerly *pre-frontal* direction to a north- northwest direction in the *frontal* stage. As the front passes and the high-pressure airmass takes over, the wind shifts and blows from the northeast. Wind speeds may double during this switch (Stone et al. 2004). Atmospheric forcing in the prefrontal stage pushes water into the estuaries, which is followed by the very low tides of the post-fontal stage. The abrupt hydrological and temperature changes have a major but only temporary impact on the estuarine and nearshore biota. The usually very low, late frontal and post-frontal tides prevent wave erosion of the mainland shore during these phases.

Fast moving Arctic (polar) fronts result in lower mean wave height than the Pacific maritime fronts, and the associated sediment transport rates are also lower. After the frontal passage, short-period southerly waves dominate. Waves driven by the Pacific fronts are more energetic, with significant heights during both the pre- and post-frontal phases (Pepper and Stone 2004). A day or two after Arctic frontal passage, the winds die down and calm prevails over coastal waters. The water surface becomes mirror-like, and wide swaths of subtidal sandflats and oriented sand bars are exposed by the lowered water level. In the absence of cloud cover, night radiation from the land surface results in bitter cold for up to 1 - 3 days following frontal passage. Nearshore waters along bay margins and lakes may freeze over during rare extreme cold events that last for more than a single day. For example, temperatures as low as -17.2 to -16.6° C were documented in Bay St. Louis and Biloxi between 1887 - 1944 (Brown et al. 1944). Temperatures dropped to -16.6 to -16.1° C on 13 - 14 February 1899 in Biloxi according to the local newspaper. At Citronelle, Alabama, inland from Mobile Bay and therefore in a somewhat colder winter setting, the record low was -18.8° C (-2° F; Chermock 1974). Sub-freezing temperatures of -7° C (19.4° F) or colder occur every other year on the more landward Mobile Bay shores, with even colder temperature of -12° C "every five years" (Schroeder 1996).

The Grand Bay area, closer and more exposed to the GOM and less effected by the colder interior, is characterized by milder winter temperatures. January and February are the most common months during which rare snow flurries are likely to occur. Snow usually remains on the ground for a few hours, if at all. Traces of snow occur in December and March as well. More frequent at short distances inland, significant snowfalls occur on the coast about every 10 - 30 years. For example, the 16 February 1895 cold snap brought 15.2 cm (6 in) of snow to the area, and significant snowfall also occurred during the "Blizzard of 1899" (Bergeron 1987), in February 1936, March 1954 (Anonymous 1954), December 1963, and February 1973. During the "Big Freeze of 1898" that lasted three days, Back Bay (Biloxi, Mississippi) and the channel between Deer Island and Biloxi froze over. Thicker nearshore ice supported people standing on it, and frozen fish were hacked from the bay ice or picked from open water. Except for channels remaining open in the middle of the bay, Back Bay froze over again on 13 - 14 February 1899 and 27 January 1940 (Bergeron 1987).

In comparison with wider lagoons and bays such as Santa Rosa Sound, FL, the fetch distance of northerly winds across Pt. aux Chenes and Grand Bay is very minor and post-frontal waves have only limited impact on the marsh island chain in the mouth of Grand Bay. The pre-frontal south winds, however, have significant velocity and certainly impacted the Escatawpa Delta. Erosion of the relict Delta and the segmentation and destruction of the successor island chain was significantly influenced by the effects of frequent late fall to winter storms over many centuries. Coastal flooding and beach erosion take place along the northern GOM and its barrier islands. Due to strong northerly and northwesterly winds, the tide levels on the mainland shore may fall in excess of 1 m (Otvos 1999).

Fog and tornadic activity are associated with frontal passage. Colder air between November and March cools the GOM surface, and the significant temperature difference that prevails between air and water often induces thick, advective-radiation fog episodes of greatly varying intensity and duration. This fog typically occurs between the late afternoon and midmorning hours in the late fall and winter. Between November and April fog occurs 1.0 - 2.0 % of the time (Reuscher 1998).

3.2.2. A climate phase of generally warmer winters, 1900 - 1940, and the coastal citrus industry

For a few decades in the early 20th century, the cultivation of citrus varieties, most sensitive to freezes and therefore significant as a climate indicator, played a major role in Mississippi and Alabama coastal agriculture. Citrus cultivation was established following the severe freezes of 1896 - 1899 and came to commercial prominence only after 1914. Satsuma tangerines (mandarines) appear to have been the dominate produce. Occasionally surviving freezes as low as - 7.8°C, satsuma trees thrive under subtropical to warm temperate climates with cooler but not severe winters. A variety of other citrus fruits were also grown on the coast, including oranges, kumquats, grapefruits, and lemons. The orchards endured the 1915 hurricane and the freezes of December 1917 - January 1918, and the late 1920s. Despite freezes, the Depression, and competition from Florida, coastal citrus cultivation, especially for local markets, survived until the deep freeze of 1940. A thousand-acre citrus farm operated at De Lisle, Mississippi, survived as late as the mid-1930s (Federal Writers Project 1939).

Picture postcards from 1909 depict large groves in Biloxi, Mississippi (Figure 3.4). Significant citrus cultivation occurred in the Pass Christian, De Lisle, and Lyman, MS areas (Federal Writers Project, 1939, p. 29, 129-130). A 16.2 hectare citrus orchard, one of several in that area, was located at Landon, just north of the intersection between present Interstate I-10 and Highway 49 in Orange Grove, Harrison County, Mississippi (Bell 2002). At least two orchards, one on 12.1 hectares, were established in Ocean Springs, Mississippi by 1915 (Hines 1972, Bellande 1994). In 1917, more than 80 growers cultivated citrus fruit in western Jackson County (Ellison 1989). Just north of Grand Bay, citrus trees probably dated back to the mid-19th century at Orange Grove. The town received its name in 1886 from its celebrated crop. Before the trees were killed in the first recorded deep freeze of 9 March 1885, they reached trunk diameters of 30.5 – 38.1 cm. On 13 February 1899 temperatures dropped to -15.6 °C and again wiped out the remaining orchards, this time for good (Rodgers 1989).

In Alabama, names of towns, such as Satsuma, Orange Beach, and perhaps Citronelle hint at extensive citrus cultivation in the early 20th century. As in Mississippi, the south Alabama citrus industry died with the deep freeze of 1940. Some 55 years later, the satsuma agro-industry staged a remarkable commercial comeback in Mobile and Baldwin Counties, AL. With effective in-tree microsprinkler antifreeze systems installed, recently one million pounds of satsuma-mandarines were produced by 25 growers in one year.

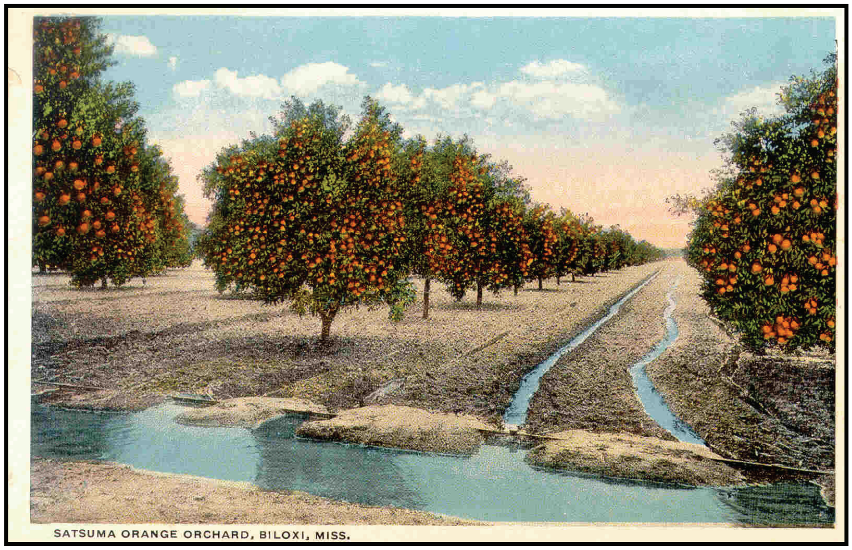

Figure 3.4. Orange orchards in Biloxi (1909) reflect a period of mostly mild winters on the Mississippi Coast in the early 20^{th} century (Picture postcards courtesy Mrs. Murella H. Powell, Biloxi Public Library Local History Collection).

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CHAPTER 4

HYDROLOGY

Mark S. Woodrey

Differences in the hydrology, or the movement of water, of wetlands create the unique physiochemical conditions that make them dissimilar from well-drained terrestrial systems and deepwater aquatic systems. Hydrologic pathways such as precipitation, surface runoff, groundwater, tides, and flooding rivers transport energy and nutrients to and from wetlands (Mitsch and Gosselink 2000). Water depth, flow patterns, and duration and frequency of flooding influence the biochemistry of the soils and are major factors in the selection of the biota of wetlands. Because hydrology plays such an important role in understanding wetland ecosystems, Mitsch and Gosselink (2000) state "*Hydrology is probably the single most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes.*" Thus, a basic, and preferably detailed, understanding of the hydrology of an area is essential to the management and conservation of specific wetland sites.

Understanding the hydrology throughout the Grand Bay National Estuarine Research Reserve (NERR) and National Wildlife Refuge (NWR) is critical to our understanding of the ecology of the area, and thus, is important for the long-term management and conservation of the resources of the site. To begin to understand the hydrology of the Grand Bay NERR, I first provide a brief overview of the hydrology of the Grand Bay NERR/NWR area. Second, I review and summarize three efforts specifically concerning the hydrology of the Grand Bay area. Finally, I end the chapter with a brief discussion and a list of monitoring and research projects which will fill data gaps in our understanding of the hydrology of the area. Ultimately, data generated from these suggested studies will be incorporated into future modeling efforts, allowing us to predict various ecological outcomes based on potential or realized changes in the water resources of the reserve.

4.1. GENERAL OVERVIEW OF HYDROLOGY IN THE GRAND BAY AREA

The Grand Bay NERR/NWR is one of the most biologically productive estuarine systems in the Gulf of Mexico region. This area falls within the Coastal Streams Basin Watershed, which is located adjacent to south Mississippi's coast line (Mississippi Department of Environmental Quality 2007). According to the National Oceanic and Atmospheric Administration's Coastal Geospatial Data Project, the reserve/refuge is part of the East Mississippi Sound Estuarine Drainage Area (National Oceanic and Atmospheric Administration 2007). Estuarine Drainage Areas are that component of an estuary's watershed that empties directly into the estuary and is affected by tides. Regardless of the name of the watershed, the important issue is that the Grand Bay NERR/NWR is part of a larger system (i.e., watershed), and the hydrology of this area must be thought of in the broader context to fully understand and appreciate external influences on the ecology of this site.

Because this area is an estuarine ecosystem, there are many factors which possibly influence the hydrology of this site. The difficulty in understanding the hydrology of this area is due to the many and complex factors influencing water movement within this system. For example, the daily fluctuations due to astronomical tides (about 0.6 m) can be overridden by meteorological conditions (Mississippi Department of Marine Resources 1998). Strong southerly winds can push water into this system, creating unseasonably extreme high tide events. Conversely, strong winds from the north pushes water out of the area, resulting in exposed sand and mud flats. The relative contributions of and interactions between surface and sub-surface water flow from the surrounding upland areas further complicates our understanding and interpretation of hydrologic impacts on the flora and fauna of the area. Thus, attempts to better understand the various components of the hydrologic budget are critical in the development of predictive models which can be used to direct future management activities of the Grand Bay NERR/NWR.

Researchers placing a ground water well on a ravaged shell midden in the aftermath of Hurricane Katrina. Photo credit: Mark Woodrey.

4.2. HYDROLOGIC STUDIES/EFFORTS OF THE GRAND BAY NERR/NWR AREA

The hydrologic pathways, inputs and outputs, and overall water budget for the Grand Bay NERR/NWR is poorly understood. However, three distinct efforts have been directed specifically at addressing the hydrology of this site. In May 2004, The Nature Conservancy of Alabama hosted a one-day workshop focused on coastal savanna hydrology of the Grand Bay conservation area, including the Grand Bay NERR/NWR. Two studies, one addressing flooding of the community of Pecan, Mississippi, located along the northern border of the site, and another using modeling efforts to begin to understand the hydrology of the area, were completed in 2004 and 2006, respectively. Each of these efforts are briefly summarized in the following sections.

4.2.1. Coastal Savanna Hydrology Experts Workshop

In May 2004, the Nature Conservancy of Alabama hosted a one-day expert's workshop focused on the hydrology of coastal savanna ecosystems (The Nature Conservancy of Alabama 2004).

This workshop was aimed at gaining a more detailed understanding of issues surrounding the hydrology of the Nature Conservancy's Grand Bay conservation area in coastal Alabama and Mississippi. The objectives of the workshop included the development of a strawman hydrologic model to illustrate the current understanding of how this system should work and what forces are impeding this system from functioning in full. Initially, the group developed a basic cross-sectional diagrammatic model to identify the key processes driving the occurrence and condition of the conservation targets, including seepage bogs and freshwater wetlands, coastal marshes, and independent streams.

Two cross-sectional diagrammatic models were developed for the Grand Bay conservation area. The Eastern and Western Grand Bay Model is the one which applies directly to the Grand Bay NERR/NWR area (Figure 4.1). The main element in this model is that the change in elevation from the estuary to the uplands is very gradual. The scope of this model is focused on local recharge areas contained within the boundaries of the Grand Bay conservation area. Further, the group decided to create a model that illustrates how this system should function in the absence of extensive human impacts, so that threats could be considered as alterations to the forces illustrated in the model.

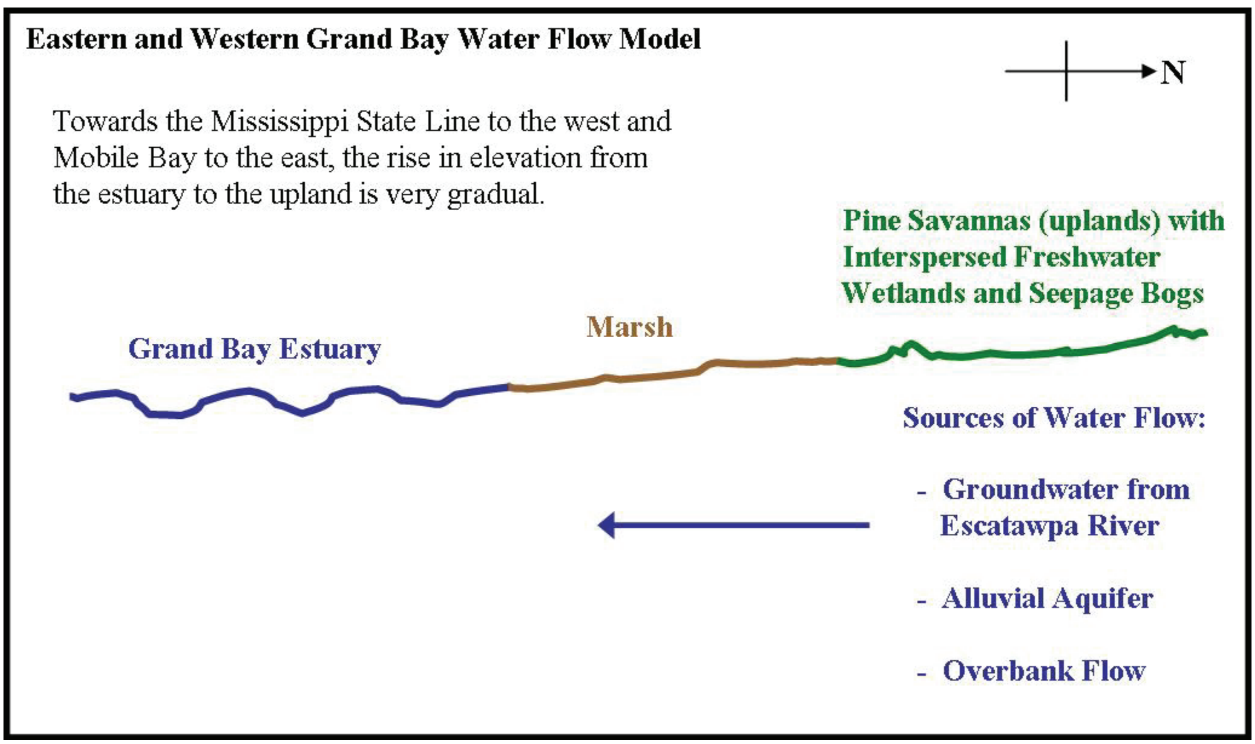

Figure 4.1. Cross-sectional diagrammatic model for water flow in the eastern and western areas of the Grand Bay estuary (redrawn from The Nature Conservancy of Alabama 2004).

The participants identified several key ecological characteristics for which more information was needed to complete a detailed model of the system, including soil layers/types, hydrologic base and freshwater/saltwater interface. The soil characteristics for the Grand Bay area are fairly complex and variable, prohibiting generalizations about soil layer throughout the system. Generally, upland surface soils are sandy and well-drained whereas lowland surface soils are also generally sandy with a higher organic content than upland soils. The Grand Bay area is characterized by intermittent perched water tables that lead to the development and occurrence of seepage bogs (i.e., pitcher-plant bogs). The Grand Bay conservation area is a net discharge area for the underlying aquifer, which extends north into several counties. At a local scale, the uplands forests (i.e., pine savannas) are a recharge area for the coastal marshes and adjacent estuary. Local recharge is driven by precipitation, which may be threatened by public water supply, private, and commercial well withdrawals. The freshwater hydrologic base meets the infiltrating saltwater of the adjacent estuary in a dynamic line below the lowland coastal marshes and pine savannas of Grand Bay. This interface shifts north and south, driven mostly by seasonal variations in freshwater inflow and tidal fluctuations. In addition the identification of key ecological characteristics, the most important outcome from this meeting was the development of research and information needs that are outlined in the section 4.3 below.

4.2.2. Pecan, Mississippi Community Hydrology Study

In August 2004, Batson & Brown, Inc., Consulting Engineers, completed a study of the hydrology of the Pecan, Mississippi Community in southeastern Jackson County (Batson and Brown, Inc. 2004). The focus area of this study is bounded by the Seaboard Railroad (formerly the L&N Railroad) to the south and U.S. Highway 90 to the north. The major emphasis of this study is the flooding of the Community of Pecan and the causes for these flood events. The primary source of flooding in the Pecan Study Area is from both Franklin Creek and the un-named Franklin Creek Tributary.

Prior to 1950, Franklin Creek flowed in a southwesterly direction and entered the study area about a mile east of the Mississippi-Alabama state line and the Franklin Creek Tributary flowed into this area in a northeasterly direction. In an apparent attempt to minimize flooding of the study area, Franklin Creek was relocated along the north side of the highway. However, during large floods, some of the Franklin Creek water continues to flow into the study area, exacerbating the flooding at this site.

The U.S. Geological Survey calculated flood flows and surveyed the flood water surface elevations at the waterway openings along U.S. Highway 90 and the railroad for the flood of 12 April 1961. The peak flow for Franklin Creek was calculated to be about 2,570 cubic feet per second (cfs) of which about 852 cfs entered the Pecan Study Area and about 1,718 cfs continued to flow in Franklin Creek channel north of U.S. Highway 90. The peak flow for Franklin Creek Tributary was calculated to be about 2,000 cfs which all flowed into the Pecan Study Area. This flooding event was estimated to be about a 15 - 20 year event on Franklin Creek and about a 40 year event on Franklin Creek Tributary. This study recommends at least two potential actions to reduce flooding of the Pecan Study Area. First, increasing the capacity of the Franklin Creek channel north of U.S. Highway 90 may significantly reduce flooding of the area. Second, flooding of the area could be reduced by diverting the Franklin Creek Tributary flood flows south of the Seaboard Railroad by constructing a levee. However, little is currently known about the ecological impacts of these recommendations and the potential consequences for the Grand Bay NERR/NWR. Thus, an effort to better understand the potential implications, perhaps through some type of a modeling exercise, would provide a scientific basis for the management of these periodic floodwaters.

4.2.3. Guidelines for Development of a Grand Bay Hydrology and Water Quality Simulation Model

With increasing development of coastal lands, the most critical research needs associated with coastal management and Grand Bay are an understanding of fundamental wetland system processes. This is especially true of the hydrology and potential non-point source (NPS) pollution intimately associated with those processes. Given the complexity of the dynamic interactions between various hydrologic components in Grand Bay's wetland areas, which act over a broad range of spatial and temporal scales, simulation modeling provides one tool for the development of science-based assessment of their behavior and response to management (Liu et al. 2006).

Given our limited understanding of the hydrology of the Grand Bay NERR/NWR as well as a lack of data, researchers from Mississippi State University initiated a simulation modeling study to provide guidance to the reserve staff for the development of a comprehensive hydrology and water quality model for the reserve (Liu et al. 2006). Liu et al. (2006) recommend the use and development of both a watershed model and a receiving water model in order to have a comprehensive model for the Grand Bay NERR/NWR. In addition, they also recommend the water receiving model be coupled with a water quality model to allow for the dynamic simulation of water quality processes at the reserve. Their modeling effort focused on surface water quality only and hence the effects of groundwater on flow regime have not been accounted for in this current effort.

The development of an effective Grand Bay hydrology modeling program requires a significant amount of research and planning. The development of a water quality model requires extensive data collection and analysis, water sample collections, literature review, model selections, model calibration, and validation. Consequently, such model development can be expensive and time consuming. Prior to initiating development of a computational model it is prudent to thoroughly evaluate the study area relative to its amenability to model development. The extrapolation of modeling techniques and field study data from similar study areas can reduce the development time and cost while increasing the chances of development of a useful and practical model. Significant time and resources have been expended to develop a comprehensive hydrologic, hydrodynamic, and water quality model of St. Louis Bay estuary, which is similar to the Grand Bay estuary (Huddleston et al. 2003). Thus, Liu et al. (2006) used their experience with St. Louis Bay and extended their modeling efforts to Grand Bay to outline guidance for the development of a comprehensive hydrology and water quality model.

Based on the more extensive datasets for St. Louis Bay, Liu et al. (2006) provided guidance for the development of hydrologic models and made several recommendations with regards to data needs for the Grand Bay NERR/NWR area. For example, watershed models can be used to simulate hydrological processes and to calculate flow and water quality time series. However, data on soil types and distributions across the area are necessary to make these calculations. Further, simulations of water transportation require data on the shoreline geometry as well as bottom bathymetry, data which are not currently available for the site. In addition, the development of a coupled modeling system for an estuary and watershed requires an extensive dataset including geophysical and geochemical data. Data on water discharge from adjacent streams and rivers as well as off-shore circulation patterns also influence the hydrology of a site and thus need to be incorporated into any modeling effort for the Grand Bay NERR/NWR. However, as with many other hydrology–related parameters, the scarcity of empirical data for the Grand Bay NERR/NWR area is the most important limiting factors for development of mathematical model.

In summary, Liu et al. (2006) outline several steps toward the development of a hydrological and water quality model for any estuary and associated watershed: (1) Identify the major environmental problems in the study area to determine the modeling purpose; (2) Create and segment the modeling domain for a receiving water model; (3) Develop and calibrate the watershed hydrological model; (4) Develop and calibrate the hydrodynamic model in the Bay; (5) If observed data is not enough to estimate the upstream pollutant boundary condition, develop and calibrate the watershed water quality model to calculate upstream boundary condition; and (6) Develop and calibrate the Bay water quality model. The observed water quality data, especially reliable and accurate data, are very important to calibrate and evaluate the performance of the developed model. The analysis and assessment of water quality data can help identify the major environmental problem in the study area and determine the modeling purpose. Unfortunately, datasets for the Grand Bay NERR/NWR are limited, because the system-wide monitoring program was only recently initiated. However, Liu et al. (2006) provide an excellent framework which can and should direct the reserve's efforts to better understand the hydrology of the area.

4.3. MONITORING AND RESEARCH NEEDS

Issues relating to the hydrology of the Grand Bay NEWRR/NWR are poorly known and not well understood. Thus, the development of a list of data gaps/needs will aid and direct reserve staff and other researchers towards collecting data in a systematic and efficient manner to better understand how water relates to the ecology of the reserve site. Below is a list of hydrology-related projects developed by the NERR staff. This non-prioritized list also closely follows the research needs identified as part of the Coastal Savanna Hydrology Experts Workshop (The Nature Conservancy of Alabama 2004) although the needs identified in this workshop were not specific to the Grand Bay NERR/NWR.

- Identify threats to the natural hydrology of the area – specifically test the hypothesis that overall discharge to the areas seepage bogs is decreasing due to upland groundwater withdrawals
- Collect baseline data on the existing conditions of conservation targets across the reserve site and correlate with hydrologic data
- Determine the extent of hydrologic alterations from excessive groundwater withdrawals by compiling existing data on the extent of private, agricultural, and recreational water withdrawals and collect better data on industrial withdrawals
- Determine the extent of hydrologic alterations from excessive groundwater withdrawals by developing a water budget for groundwater at the reserve by

quantifying the sources and sinks such as recharge, evapotranspiration, stream flow, and withdrawals for groundwater

- Determine the extent of hydrologic alterations from excessive groundwater withdrawals by defining the hydrogeology of the system, such as aquifer hydraulic parameters, stratigraphy, potentiometric surface, etc
- Determine the extent of hydrologic alterations from development by determining the minimum water quality needed to protect the viability of conservation targets such as pine savanna matrix, seepage bogs and freshwater wetlands, coastal marshes, and independent streams
- Determine the extent of hydrologic alterations from development by determining how impervious surface changes the overall recharge rate of the NERR/NWR
- Determine the extent of hydrologic alterations from development by developing a projected land use model, building on existing land use and project growth data for Jackson County, Mississippi

Groundwater parameters are measured from a well placed in a Grand Bay NERR salt marsh. Photo credit: Sam Walker.

- Map the extent and distribution of various land use/land cover categories for the East Mississippi Sound Estuarine Drainage Area Watershed
- Explore the hydrologic alterations associated with rural development such as the impacts of failed septic systems
- Determine the difference in recharge rates for pine savannas versus more closed type forest types that result from fire suppression
- Re-establish the natural hydrology of wet pine savanna and pine flatwood habitat types by (1) filling ditches that were historically created to drain water from land to be used for agricultural and livestock purposes, (2) minimizing the impacts of fire breaks, and (3) rehabilitating dirt roads and ATV trails that are not used for resource management or research.
- Acquire data on shoreline geometry and bathymetry
- Study the interplay between fore, sea level rise, and hurricane return intervals
- Determine the rate of sea level rise in the Grand Bay NERR/NWR area

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CHAPTER 5

HISTORICAL LAND AND WATER USE INSIDE AND ADJACENT TO THE RESERVE

Gregory A. Carter

5.1. INTRODUCTION

5.1.1. Pre-Historic Jackson County and Vicinity

Wallace (1989) provides a conception of pre-historic resource use by humans in present-day coastal Mississippi including Jackson County, which contains the Grand Bay National Estuarine Research Reserve (NERR) (Figure 5.1), beginning about 10,000 years ago with the end of the Pleistocene Ice Age. In the era termed by archaeologists as the Paleo-Indian Cultural Period, Native Americans hunted mammoth and other large animals, and supplemented their diet with nuts, berries, other fruits, and bark. Following large-animal herds for survival, they traveled in small bands of about 25 people and established no permanent shelters or settlements. Only occasionally would one of these nomadic bands encounter other people.

By about 5,000 years ago, mammoth had disappeared from the area, necessitating a change in major food source for the Native Americans. New food sources were provided as the flow of meltwater from the Wisconsin glaciation, which formed the modern Pascagoula and Escatawpa rivers, subsided. Local waters warmed, fostering the development of abundant shellfish populations. Relying on shellfish as a major food source, Native Americans were no longer required to follow animal herds and began to live in larger groups. The development of pottery in the late Poverty Point Cultural Period (ca. 1000 B.C. to 375 B.C.) was a tremendous advance, facilitating the warming of food and transport of liquids.

From about 375 B.C. to 1500 A.D., the Native American population increased and spread from major waterways to small creeks and lakes. Cultivated crops became a major food source, and trade was conducted over large distances. Dwellings, temples and earthen mounds were constructed and increasingly larger communities were formed. The complex and extensive Mississippian Culture had developed by about 1500 A.D. When Europeans first arrived in present-day Jackson County, it was occupied by the Pascagoula, Biloxi, Capinan, Moctobi and other Native American communities.

Archaeological evidence, including the remains of villages and camp sites, shows that people of each Culture named above lived in Jackson County. Even so, excavations have not been sufficient to gauge the extent of the Native American population in Jackson County. Many prehistoric habitation sites have been or are currently being destroyed. Consequently, the many questions remaining about prehistoric Native American life in Jackson County may remain unanswered.

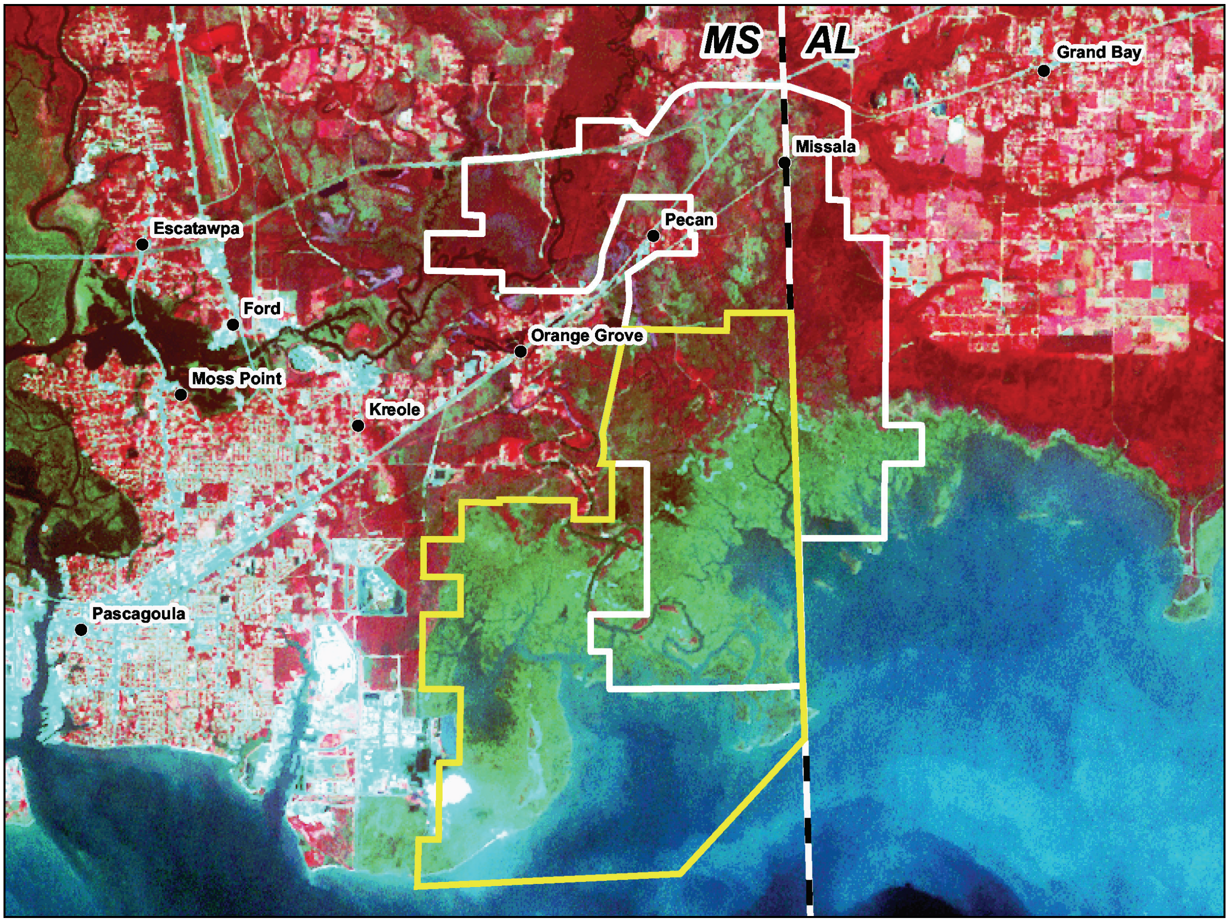

Figure 5.1. The Grand Bay NERR in Jackson County, Mississippi is located within the yellow boundary. The border between Jackson County and Mobile County, AL is indicated by the dashed line running north-to-south (top-to-bottom). The Grand Bay National Wildlife Refuge is located in both Mississippi and AL within the white boundary.

5.1.2 European Settlement

Strickland (1989) provides an outline of major events in the European settlement of Jackson County. In 1699, the French established the first European colony within the modern borders of Mississippi at Old Biloxi, and built Fort Maurepas at Ocean Springs where Biloxi Bay flows into the Mississippi Sound. By 1712, the population of Old Biloxi was 500. In 1718, extensive land grants were made toward the development of New France, and a settlement of 300 people was established at Pascagoula in 1721.

By treaty in 1763, the present-day Jackson County area became part of British West Florida. The British awarded numerous land grants in 1768, most to the north in present-day George County. British rule of the area was, however, short-lived. The area became part of the District of Feliciana, Parish of Pascagoula, Spanish West Florida in 1779 when British troops were expelled by Spanish forces under General Galvez.

Congress created the Mississippi Territory in 1798. However, Jackson County, being south of the 31st parallel, remained part of Spanish West Florida until 1810 when it declared itself part of the Republic of West Florida. In 1811, this Republic was added to the Territory of Orleans. In 1812, Jackson County became part of the District of Mobile, which was added to the Mississippi Territory. When Mississippi became a state in 1817, post-Revolution immigration had increased the population of Jackson County to 863. The area encompassed by Jackson County at its creation in 1812 decreased steadily over the years as portions were ceded to Alabama in 1817, Harrison County in 1841 and Greene County in 1847. Jackson County reached its present size in 1910 when its northern portion was ceded to form George County.

A small, handcrafted sailboat heads out of Bayou Heron to the open Gulf waters. Photo credit: Jennifer Buchanan.

5.2. LAND AND WATER USE

5.2.1. Lumber, Pulp and Paper

DeAngelo (1989a, 1989b) describes the development of the lumber, pulp and paper industries in Jackson County. The early abundance of virgin forest was the foundation of Jackson County industrial development. In the earliest days of European settlement, harvested trees were used in shipbuilding. The area's first large industry – sawmill operation – was fueled by cutting away the virgin forest over a period of nearly a century from about 1874. In 1880, the "piney woods" between the Pearl and Pascagoula rivers in coastal Mississippi was comprised of 75 percent longleaf pine (*Pinus palustris*). Other species of commercial value were shortleaf (*Pinus echinata*), loblolly (*Pinus taeda*) and slash pines (*Pinus elliotii*), cypress (*Taxodium* sp.), white oak (*Quercus alba*), gum (*Nyssa* sp.), hickory (*Carya* sp.), poplar (*Populus* sp.), magnolia (*Magnolia* sp.), ash (*Fraxinus* sp.), beech (*Fagus* sp.) and other hardwood species. Cleared land accounted for the remaining area. Then as now, longleaf and slash pines were among the commercially most valuable pines in North America. The wood of these species is strong and resists decay owing to high resin contents. Thus, it was highly desirable for naval and other construction uses.

Numerous lumber mills were established in Jackson County during the 1800's. By 1860, longleaf pine logs and lumber from Mississippi were being sold in the Midwestern and Eastern U.S. and in Europe. Although some mills were destroyed in the Civil War, twenty-five, mostly small mills operating in the Pascagoula and Moss Point areas produced about 60,000,000 board-feet of lumber in 1877. Because of its proximity to rivers and lakes, Moss Point was an ideal location for sawmills. Pine logs and hewn timbers were floated, or "rafted" to Moss Point and Scranton (later know as Pascagoula) mills during spring and fall floods of the Leaf, Chickasawhay, Escatawpa and Pascagoula rivers. When a major lumber boom began in 1880, eleven Moss Point mills operated with a total production capacity of 220,000 board-feet per day. At this time, the value of timber products from Jackson County ranked second in the state.

Logging and rafting practices in Jackson County changed little during 1840-1910. In 1900, the county supplied 80 percent of lumber shipped from the Mississippi Coast. However, its sawmill industry began to decline when a hurricane felled 20 percent of the pine forest in 1906. In some locations, one-third to two-thirds of trees were lost. Several mills were forced to close. As the 20th Century progressed and virgin timber dwindled, additional mills ceased operation. The "big mill" period in Jackson County ended with the sawing of the last log at the Dantzler Moss Point Mill in 1938.

As the virgin tracts of pine were disappearing, means to utilize smaller trees in pulp and paper production were sought. In 1913, Southern Paper Company began operating its Moss Point Mill, the first pulp and paper mill in Mississippi. At this time, the South was not a paper-producing region. However, the "Carlson Process" had been developed to enable the production of pulp from native Southern, or "pitch" pine timber. Southern Paper Company was purchased by International Paper Company in 1928, and the Moss Point Mill remained in operation until 2001.

5.2.2. Pecans

Wixon (1989) summarizes the rich history of pecan (*Carya illinoensis*) growing in Jackson County. The pecan nut was a critically important food for Native Americans prior to European arrival and was esteemed by eighteenth century settlers. However, the asexual propagation techniques which fostered highly productive orchards did not begin development until the nineteenth century. Pecan is a species native to North America but not to Jackson County. Seeds from New Orleans and Texas were planted, and Jackson County growers devised grafting methods to produce improved varieties and crop yields. At least 35 varieties developed in Jackson County have served as the basis of the pecan industry. These include the most widely planted of all, variety Stuart, which originated with a Mobile, Alabama seed source and was first offered commercially around 1892. Nearly all pecan varieties are crossed with variety Stuart. It, along with variety Schley which was developed also in Jackson County, has proved to be the most popular and productive of pecan varieties throughout the entire industry. The Schley "paper shell" pecan is considered to be the all-time most significant contribution to the industry. The original Schley tree stood in Pascagoula until it was cut down during the construction of a gymnasium at Pascagoula High School. While pecan trees in Jackson County have, over the decades, been destroyed by hurricanes and construction, they have not been replaced. The County is no longer a commercial producer of pecans.

5.2.3 Citrus and Grazing

The following history of land use in the Orange Grove area north and west of the Grand Bay NERR boundary (Figure 5.1) is provided by Rodgers (1989a). French settlers in the early 1800's introduced citrus, fig and pecan trees to the area. Citrus flourished south of Orange Grove owing to the favorable climate which prevailed for many years after planting. There had not been a killing freeze recorded on the Coast until March 5, 1885 when some trees, having trunk diameters as large as 30 - 38 cm, were killed. The remaining citrus trees were wiped out on February 13, 1899, when the temperature dropped to -16 °C. While other citrus growers along the Coast replanted, Orange Grove planters shifted to establishing pecan orchards. Eventually, these rivaled the pecan orchards located in Ocean Springs and other coastal areas. Open ranges south of Orange Grove were used by cattle owners for grazing.

5.2.4 Water Resources

A native of Pecan, Mississippi, Mr. Clyde Brown regularly harvested oysters from Reserve waters. Photo credit: Jennifer Buchanan.

From the reliance of pre-historic Native Americans on shellfish as a primary food source to the enjoyment of coastal waters by present-day recreational boaters, the utilization of Mississippi coastal waters has been continuous for thousands of years. In about 1892, Mr. Henry Stork settled in Pecan and established a family seafood business on Bayou Heron (Rodgers 1989b) near the present-day eastern boundary of the Grand Bay NERR. This grew into a large business and was partially responsible for the establishment of the Pecan railroad depot, also known as Swartwout Station, which was needed for transporting large harvests of mullet, flounder and other seafood (Rodgers 1989b). The fishing business declined over the years as larger, deeper-draft boats which could not pass through the shallow bays and bayous sold their catches to competing businesses in the Pascagoula River area (Jones 2001).

Eleuterius and Criss (1991) describe the bays, bayous and marshes found along the southeastern coast of Jackson County, their uses, value, and losses due to coastal erosion. Most of these areas are included in the Grand Bay NERR and comprise the last remaining pristine estuary in Mississippi. The authors note that although access to these areas can be difficult, recreational fishing for seatrout (*Cynoscion* spp.), redfish (*Sciaenops ocellatus*), Atlantic croaker (*Micropogonias undulatus*) and flounder (*Paralichthys lethostigma*) occurs year-round. Subsistence and commercial harvesting of these finfish along with shrimp (Penaeidae), blue crabs (*Callinectes sapidus*), and oysters (*Crassostrea virginica*) also occurs in the area.

5.3 MONITORING AND RESEARCH NEEDS

- Extensive archaeological excavations to gain a better understanding of pre-historic Native American and early European settlement communities
- More extensive interviews with descendants of early inhabitants to fill current knowledge gaps
- Research of archival land records and other pertinent documents

ACKNOWLEDGMENTS

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CHAPTER 6

HISTORICAL WATER QUALITY

Thomas F. Lytle and Julia S. Lytle

The Grand Bay National Estuarine Research Reserve (NERR), Moss Point, Mississippi lies at the eastern end of Mississippi Sound and is not in the direct path of the predominant westerly flow of waters from the Pascagoula River, Biloxi Bay and most of the industrial and residential development of the Mississippi Coast. However, Grand Bay may receive input from Mobile Bay to the immediate east and may also be impacted from discharges from the Bayou Casotte industrial complex to the immediate west. Because of its remote location, Grand Bay has for the most part been skirted in most studies of water quality in the Sound. Therefore, the prevailing water quality in this bay is not well known and cannot be accurately assessed from evidence found in previous studies at sites well removed from this Reserve location. Water quality should be comprehensively addressed to document the present condition of this Reserve.

6.1. THE CONCEPT OF WATER QUALITY

Water quality traditionally has been defined as a measure of how well the concentrations of chemical constituents in a water body fit an "acceptable" concentration range. This acceptable range is usually established through a series of bioassays using a relatively small number of pertinent organisms and is defined as concentrations predicted to cause minimal harm to most organisms in a water body. There are many limitations with this concept; nevertheless this water quality assessment procedure has been the tool often used in predicting the health of an ecosystem. The U.S. Environmental Protection Agency since 1990 with inception of its Environmental Monitoring and Assessment Program (EMAP) has taken a much broader approach to protecting marine environments and now includes water quality measurements as an important but only one of several tools in building biocriteria that will assess the health of an ecosystem (www.epa.gov/emap/index.html).

6.2. WATER QUALITY PARAMETERS

Water quality measurements generally always include the physical measurements of salinity, pH, temperature, turbidity or suspended solids and also concentrations of dissolved oxygen. In addition, water quality measurements often include the micronutrients that sustain aquatic plant life. Nitrogen nutrients are nitrate, nitrite, ammonia (ionic and unionized), and organic nitrogen, which can be further speciated to particular classes of organic nitrogen compounds; phosphorus nutrients include orthophosphate, total phosphorus that can be further subdivided into several classes of inorganic and organic phosphates, and silicon micronutrients that include the various forms of dissolved and particular silicates. Other measurements may include alkalinity, sulfate, dissolved and particulate organic carbon, sulfide, cyanide and sometimes chlorophylls. Less often measured because of difficulty in analysis are those variables that actually pose the gravest health risks when safe levels are exceeded and include heavy metals, pesticides, hydrocarbons and other toxic organic compounds.

6.3. SOURCES OF WATER CONTAMINANTS TO EASTERN MISSISSIPPI SOUND

Micronutrients can become contaminants through runoff of agricultural fertilizers or from residential and industrial wastes. There are no extensive agricultural regions in the drainage basins in South Mississippi so micronutrients are mostly introduced from residential and industrial waste treatment discharges. In a study of transport of various contaminants into, across and out of Mississippi Sound, Lytle and Lytle (1985) surveyed all National Pollutant Discharge Elimination System permits in effect in the early 1980's for South Mississippi and found that besides micronutrients in municipal waste discharges, the principal discharge contaminant was likely to be hydrocarbons. Their study therefore focused on hydrocarbons, both aliphatic and aromatic. Heavy metals and pesticides at that time were considered to be a minor contaminant risk. Because most organics quickly become adsorbed to particulate materials that become incorporated into sediments, this study directed most of the sampling and analysis to hydrocarbons in sediments. Because the environmental climate has changed substantially since 1985, data on heavy metals and toxic organics other than hydrocarbons are much in need.

6.4. WATER QUALITY SURVEYS IN MISSISSIPPI SOUND

A listing of the measured variables and sampling strategy for all major water quality studies in the Mississippi Sound are shown in Table 6.1. The Gulf Marine and Estuarine Inventory study (GMEI) (Christmas 1973) was the first long-term and extensive monthly sampling for surface water quality throughout the Mississippi Sound with sites near Grand Bay. Later, Lytle (1972) conducted monthly surface water quality measurements only in Back Bay Biloxi, however a broader range of water quality variables was included than in earlier studies. Lytle (1978a, 1978b) also measured a thorough group of water quality variables including heavy metals in St. Louis Bay at the western end of Mississippi Sound. In their study of sediment contaminants in the Mississippi Sound, Lytle and Lytle (1985) also conducted studies to determine how well sediments could be leached and increase loads of micronutrients in overlying waters during sediment disturbance events. Background levels of nutrients in many coastal regions including rivers and bayous of the eastern Mississippi Sound were included in that study.

The U.S. Geological Survey has maintained a series of sites in all rivers of Mississippi and their tributaries for monthly sampling and analysis of water quality in a monitoring study that has been ongoing since 1964. Only printed data are available through 2002 (Morris et al. 2002), but all data are accessible at http://ms.water.usgs.gov. Though no station is in the immediate vicinity of Grand Bay, these data, particularly which are from the Pascagoula River, may demonstrate possible trends in water quality deterioration in the region of the eastern Mississippi Sound and suggest the types of water quality measurements that should be included in a water quality survey of the Grand Bay NERR.

Table 6.1. Water Quality Measurements in Grand Bay and Other Regions of Mississippi Sound[1].

[1]Studies noted here lasted at least one year with a major component of water quality measurements in the Mississippi Sound and specifically in regions near the Grand Bay NERR.

[2]Gulf Marine and Estuarine Inventory (Christmas, 1973) established 46 sites many of which were revisited in 2001 and 2002 to update this inventory under new sponsorship of the Mississippi Department of Marine Resources Tidelands Program.

[3]National Aeronautics and Space Administration (Lytle 1972) study of Back Bay Biloxi.

[4]E.I. DuPont de Nemours sponsored study of St. Louis Bay (Lytle 1978a, Lytle 1978b). All but trace metals were sampled monthly from 11 stations with 8 of these used for trace metal collection sites. Metals were measured in soluble and particulate form in all water collections.

[5]Lytle and Lytle (1985) study of Mississippi Sound. Water samples for water quality measurements were collected from 45 sites during 1979 - 1984.

[6]U.S. Geological Survey collections begun in 1964 and continuing to present. Last printed report covers 2002 collections with more recent data accessible at the website, http://ms.water.usgs.gov.

[7]Environmental Monitoring and Assessment Program (EMAP) of U.S. Environmental Protection Agency with data accessible at the website, http://www.epa.gov/emap/index.html. Navigate to Louisianan Province water quality data.

Measurement	**GMEI[2]**	**NASA[3]**	**DuPont[4]**	**Lytles[5]**	**U.S.G.S.[6]**	**EMAP[7]**
study years	1969	1972	1978	1979-84	1964-present	1991-1994
[1]sampling frequency	Monthly	monthly	monthly	as needed	monthly	yearly
geographic region	throughout Sound	Back Bay Biloxi	St. Louis Bay	Throughout Sound	coastal rivers	Sound & 3 bays
sampling near Grand Bay NERR	yes	no	no	yes	no[6]	yes
sampling depth	surface	surface	surface, 0.8, 1.4, 2m	surface	surface	surface & bottom
Standard parameters						
pH	●	●	●		●	
dissolved O_2 (mg/L)	●	●	●		●	●
salinity (psu)	●	●	●			●
temperature (°C)	●	●	●			●
suspended solids		●	●		●	●
Turbidity (NTU)			●		●	●
Transmissivity						●
Fluorescence						
Alkalinity			●		●	
inorganic C			●		●	
organic C			●	●		
Biochemical oxygen demand					●	
chemical oxygen demand					●	
micronutrients						
Nitrate	●	●	●	●	●	
Nitrite			●	●	●	
Ammonia			●	●	●	
kjeldahl N				●	●	
other n forms					●	
orthophosphate	●	●	●	●	●	
total phosphorus	●	●	●		●	

Measurement	GMEI[2]	NASA[3]	DuPont[4]	Lytles[5]	U.S.G.S.[6]	EMAP[7]
other P forms						
Silicates			●	●		
major ions						
Sulfate			●		●	
Chloride		●	●		●	
Calcium		●			●	
Magnesium					●	
Sodium					●	
Potassium					●	
Fluoride					●	
trace metals						
aluminum					●	
Antimony			●		●	
Arsenic			●		●	
Berellium					●	
Boron					●	
Cadmium			●		●	
Chromium			●		●	
Cobalt			●		●	
Copper			●		●	
Iron		●	●		●	
Lead			●		●	
Manganese					●	
Mercury			●		●	
Molybdenum			●		●	
Nickel			●		●	
Selenium			●		●	
Silver					●	
Strontium			●		●	
Thallium					●	
Titanium			●			
Vanadium			●		●	
Zinc			●		●	
chlorophylls		●				
Pesticides					●	

Surface and bottom water surveys were conducted from 1991-1994 in Mississippi as part of the U.S. Environmental Protection Agency EMAP in the Louisianan Province (Table 6.1). Of the 12 Mississippi Sound sites sampled in this time frame, one was very close to Grand Bay, occurring just slightly south and east of Grand Bay NERR. Only a very limited number of water quality variables were measured at these sites as most effort was expended to examine sediments.

Overall the data that have been accumulated about water quality in the Mississippi Sound show only spotty areas of real concern and most of those are regions that are close to and in the path of transport of industrial or municipal discharges. However, the past is not necessarily a gauge of the present or future condition of water quality in any region, particularly with many new potential sources of pollution arising all along the Mississippi coast. It is therefore important that a status report based upon a well conceived and executed baseline water quality study be generated and further that the baseline study be an integral part of a bioassessment program directed to current bioassessment/biocriteria goals of the U.S. Environmental Protection Agency.

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CHAPTER 7

WATER QUALITY

S. Christine Walters and Kevin S. Dillon

7.1. BACKGROUND OF SYSTEM-WIDE MONITORING PROGRAM: ABIOTIC FACTORS

SWMP technician performing the monthly sonde rotation in Bayou Cumbest. Photo credit: Mark Woodrey.

The data presented in this chapter were collected as part of the National Estuarine Research Reserve's System-Wide Monitoring Program (SWMP). This three phrase program was developed in 1995 to provide coastal ecologists and managers quantitative data to assess short-term variability and long-term change in estuarine conditions (Owen and White 2005, National Oceanic and Atmospheric Administration 2006). Phase 1 (Abiotic Factors) focuses on monitoring a suite of water quality and meteorological parameters over a range of spatial and temporal scales. A minimum of four water quality data loggers are continuously deployed at four permanent locations across each reserve to record measurements of conductivity, salinity, temperature, pH, dissolved oxygen, turbidity, and water level at fifteen minute intervals. At these same four water quality sampling stations, each reserve also collects monthly measurements of water column nutrients (e.g., nitrate, nitrite, ammonia, and ortho-phosphate) and chlorophyll-a concentrations, In addition, diel sampling (12 samples per a 25 hour time period) for nutrients and chlorophyll-a occurs at a minimum of one site each month.

To ensure the collection of accurate, high quality SWMP data, the reserve system established the Centralized Data Management Office (CDMO), located at the North Inlet-Winyah Bay National Estuarine Research Reserve in South Carolina (Owen and White 2005). The CDMO makes SWMP data available for public use by assimilating each reserve's data in a system-wide web portal where users can access archived data and metadata for each reserve (http://cdmo.baruch.sc.edu/). Recently, the reserve system implemented a near-real-time telemetry network which transmits data from one water quality monitoring station and the meteorological station for each reserve directly to the CDMO for dissemination via the internet (http://cdmo.baruch.sc.edu/QueryPages/GoogleMap.csm/).

7.2 SURFACE WATER QUALITY

Continuous surface water quality data [water depth, water temperature (ºC), salinity (psu), dissolved oxygen (mg/L and % saturation), pH, and turbidity (NTU)] are collected at four sites within the Grand Bay National Estuarine Research Reserve (NERR): Bayou Heron, Bayou Cumbest, Crooked Bayou (from January 2004 to August 2005), Pt. aux Chenes (beginning August 2005) and Bangs Lake (Figure 7.1). The National Estuarine Research Reserve System-Wide Monitoring Program (SWMP) protocol requires the collection of at least 85 % of all possible data points. With a mean depth between 0.6 - 0.9 meters for 70 - 80 % of the waterways in the Grand Bay NERR and a mean tidal range of 0.6 meters, water quality monitors located in shallow bayous, like Crooked Bayou, are often out of water and result in a significant loss of data. In order to comply with SWMP protocol and to characterize the more seaward open waters of the Pt. aux Chenes Bay, the water quality station from Crooked Bayou was moved to Pt. aux Chenes in August 2005. Measurements were made at each station every 30 minutes from January 2004 to June 21, 2006 and every 15 minutes after June 21, 2006 by a YSI 6600 Extended Deployment Sonde. The data summarized and presented in this chapter are only for the calendar year 2004.

7.2.1. Water temperature

*A fish kill of predominantly mullet (*Mugil *spp.) occurred in Bayou Heron in the winter of 2005 due to unseasonably cold temperatures, low tides, and low dissolved oxygen. Photo credit: Gretchen Waggy.*

Water temperatures ranged from 4 to 15 ºC during the winter to a maximum of near 35 ºC during the summer (Figure 7.2). Daily fluctuations at any one station were typically 4 - 5 ºC, and typical seasonal changes in water temperature were observed at all stations. Peak summer temperatures were observed in July while minimum temperatures were measured during December. Daily surface water temperature fluctuations were tidal in nature with episodic changes due to weather systems moving through the area (Figure 7.3).

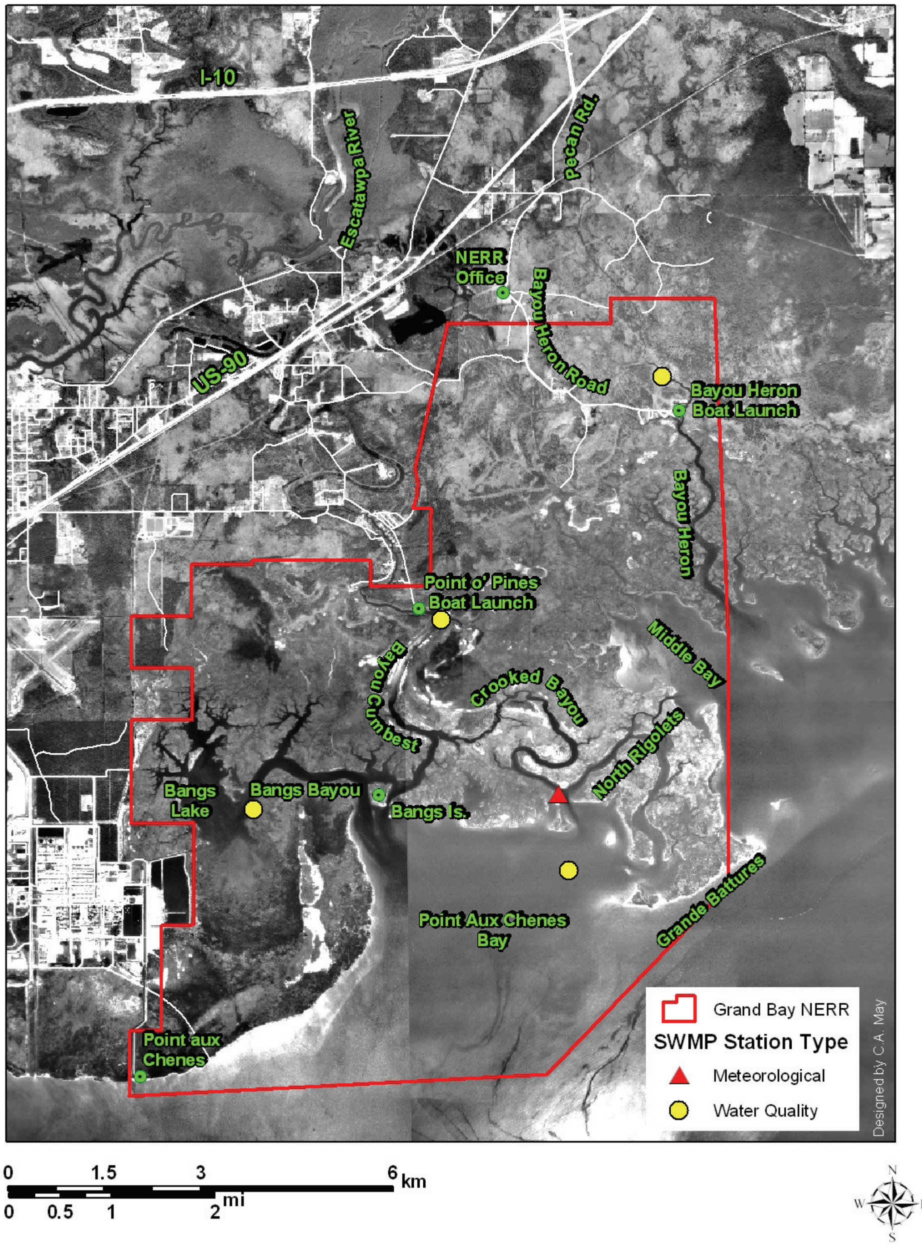


Figure 7.1. Grand Bay NERR SWMP locations. ▲ = Meteorological (weather station); ● = Water Quality (YSI 6600 Extended Deployment Sondes).

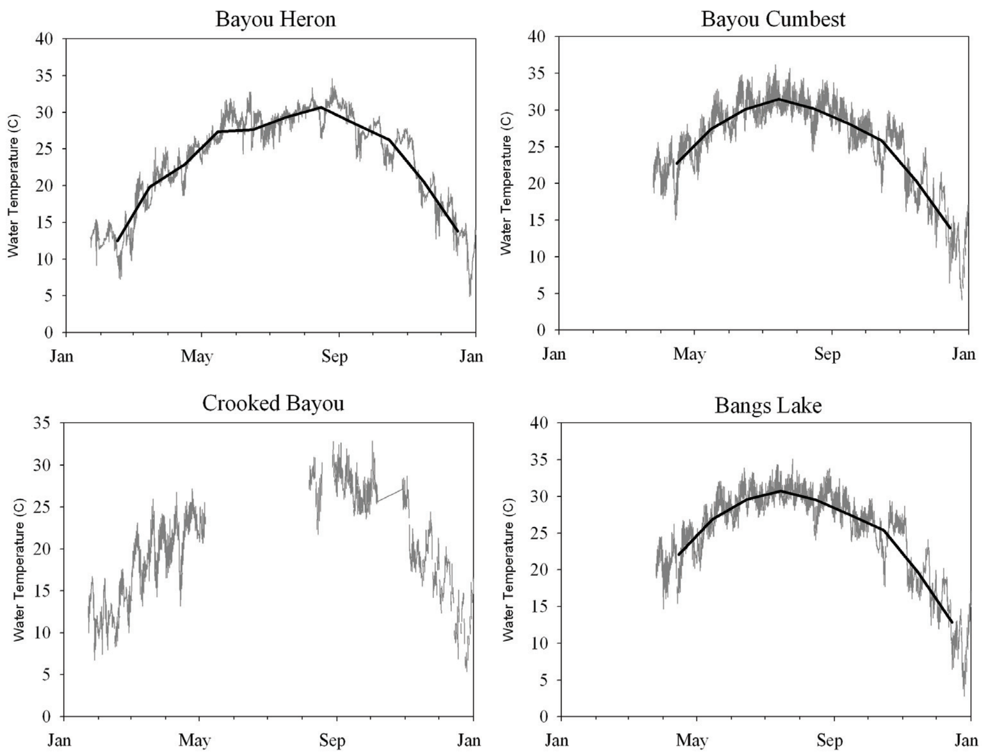


Figure 7.2. Water temperature (ºC) for Bayou Heron, Bayou Cumbest, Crooked Bayou, and Bangs Lake from February 25 to December 31, 2004. Grey line represents measured values. Black lines represent mean monthly temperature. Due to several data gaps, the mean monthly temperature was not plotted for Crooked Bayou.

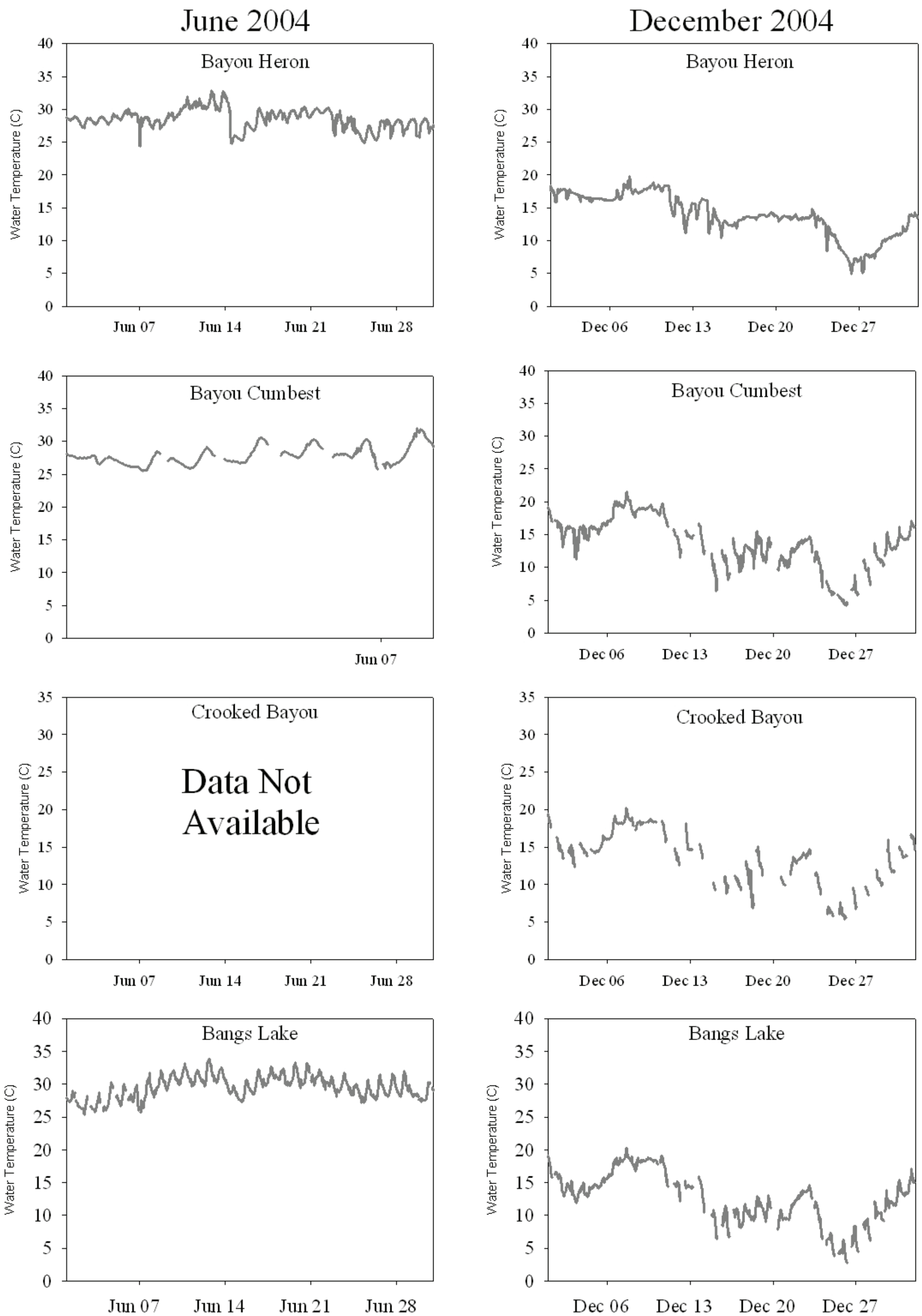


Figure 7.3. Water temperature readings for each station during representative summer and winter months.

7.2.2. Salinity

Unlike many estuarine systems, the Grand Bay NERR has no major freshwater inflow, hence the rapid changes in salinity are due to local runoff and possibly groundwater seepage (Figure 7.4). Salinity in the reserve can range from near zero to about 25 psu at the more inshore stations, Bayou Heron and Bayou Cumbest, to values of 10 to near 30 psu at the more seaward stations, Bangs Lake, Crooked Bayou and Pt. aux Chenes. The lowest salinities are found landward during the summer wet season where salinities of 0 to 10 psu dominate during June and July (Bayou Heron and Bayou Cumbest). Shorter depressions in salinities are observed at all stations due episodic rain events. Tidal shifts in salinity are also observed at all stations (Figure 7.5).

The most extreme changes in salinity were measured at the most landward station, Bayou Heron (0 to 21 psu). Winter shifts in salinity were more dramatic than those during the summer (Figure 7.5) likely due to winter storm winds that push water out of the Grand Bay NERR.

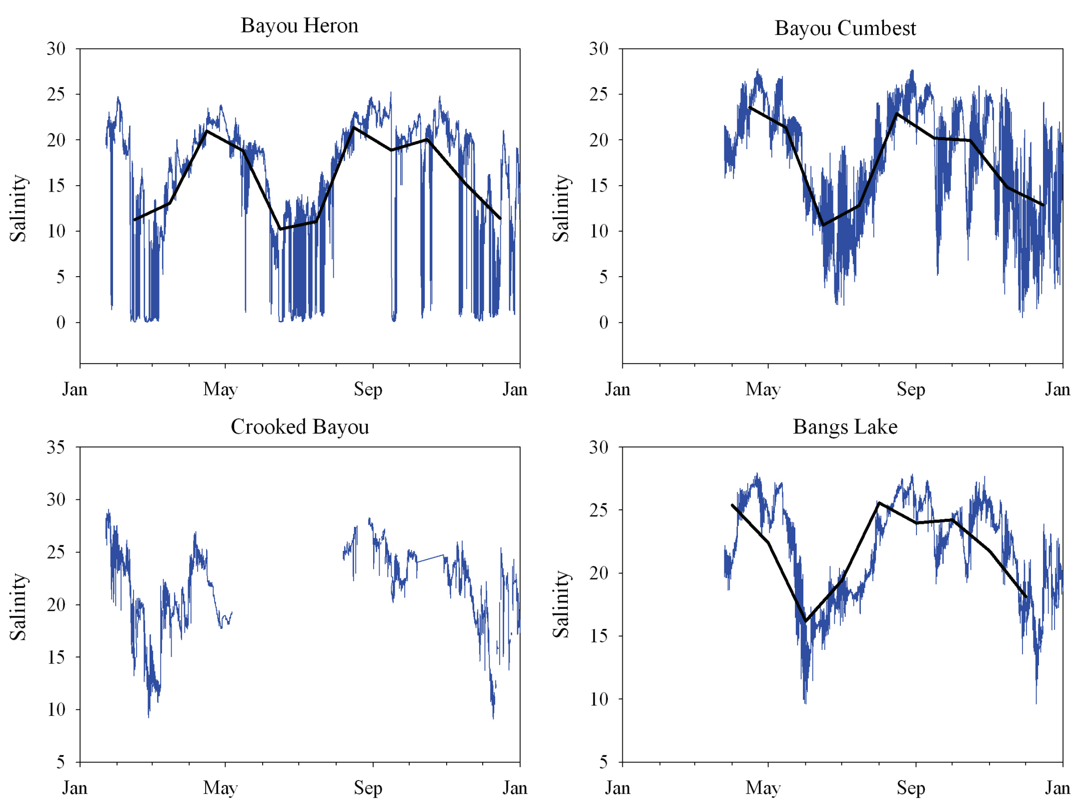


Figure 7.4. Salinities (psu) for Bayou Heron, Bayou Cumbest, Crooked Bayou, and Bangs Lake from February 25 to December 31, 2004. Blue line represents measured values. Black lines represent mean monthly salinity. Due to several data gaps, the mean monthly salinity was not plotted for Crooked Bayou.

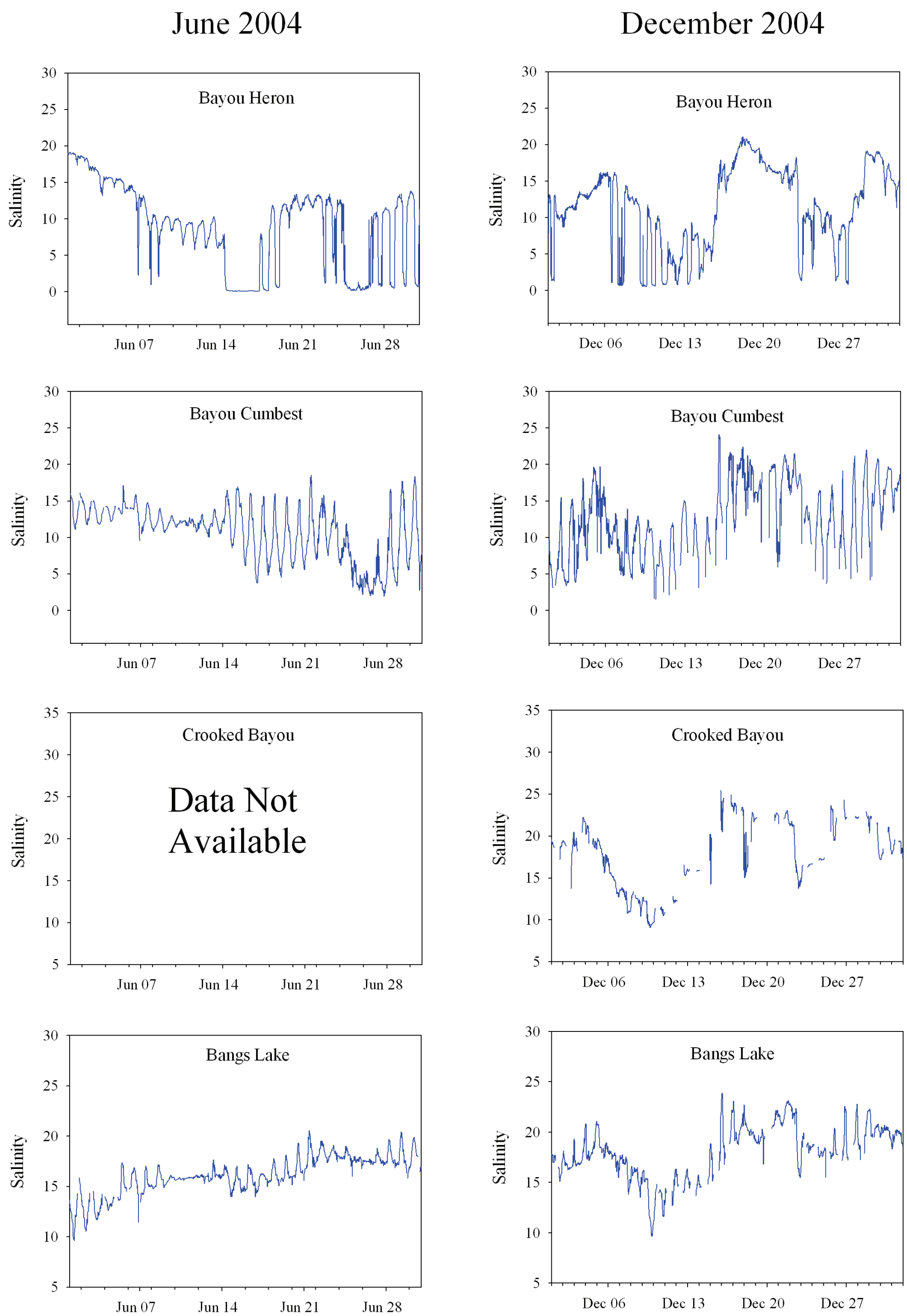


Figure 7.5. Plot of salinity (psu) for each station during representative summer and winter months.

7.2.3. Dissolved Oxygen (DO) Concentrations

DO concentrations were the highest (10-14 mg/L) during the winter months when water temperatures were lowest (Figure 7.6). Low DO concentrations during the summer were common in Bayou Heron, often becoming anoxic (0-2 mg/L) for prolonged periods (days to weeks) due to higher temperatures and restricted water exchange (Figure 7.7). Deeper stations with greater water exchange (Bayou Cumbest) and more seaward stations (Crooked Bayou and Bangs Lake) had daily DO minimums of 3-4 mg/L and maximums of 6-8 mg/L during the summer. At these stations, diel changes in DO are observed due to daylight oxygen production by phytoplankton and nighttime respiration (Figure 7.7). This pattern is persistent when tidal activity is at a minimum indicating the change is primarily driven by biological processes (Figure 7.8).

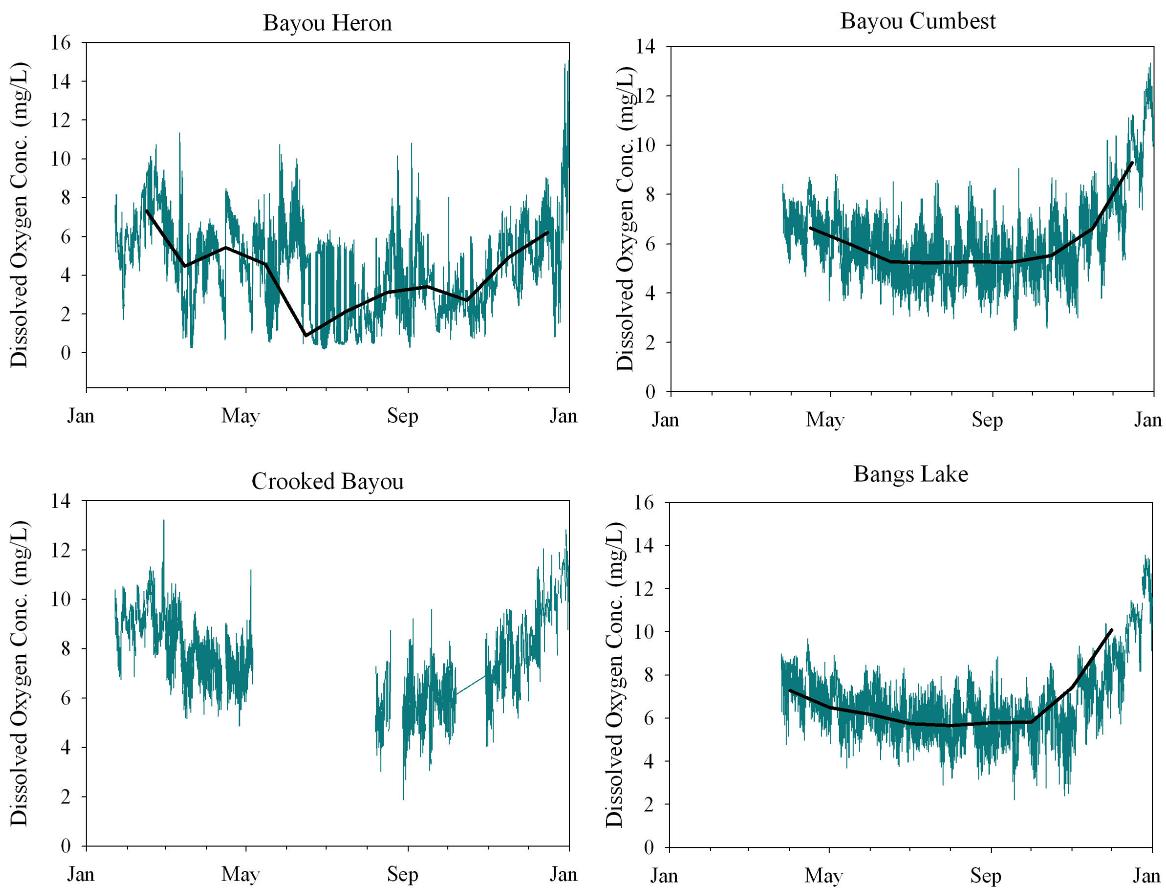


Figure 7.6. Dissolved oxygen concentration for Bayou Heron, Bayou Cumbest, Crooked Bayou, and Bangs Lake from February 25 to December 31, 2004. Blue line represents measured values. Black lines represent mean monthly dissolved oxygen. Due to several data gaps, the mean monthly dissolved oxygen was not plotted for Crooked Bayou.

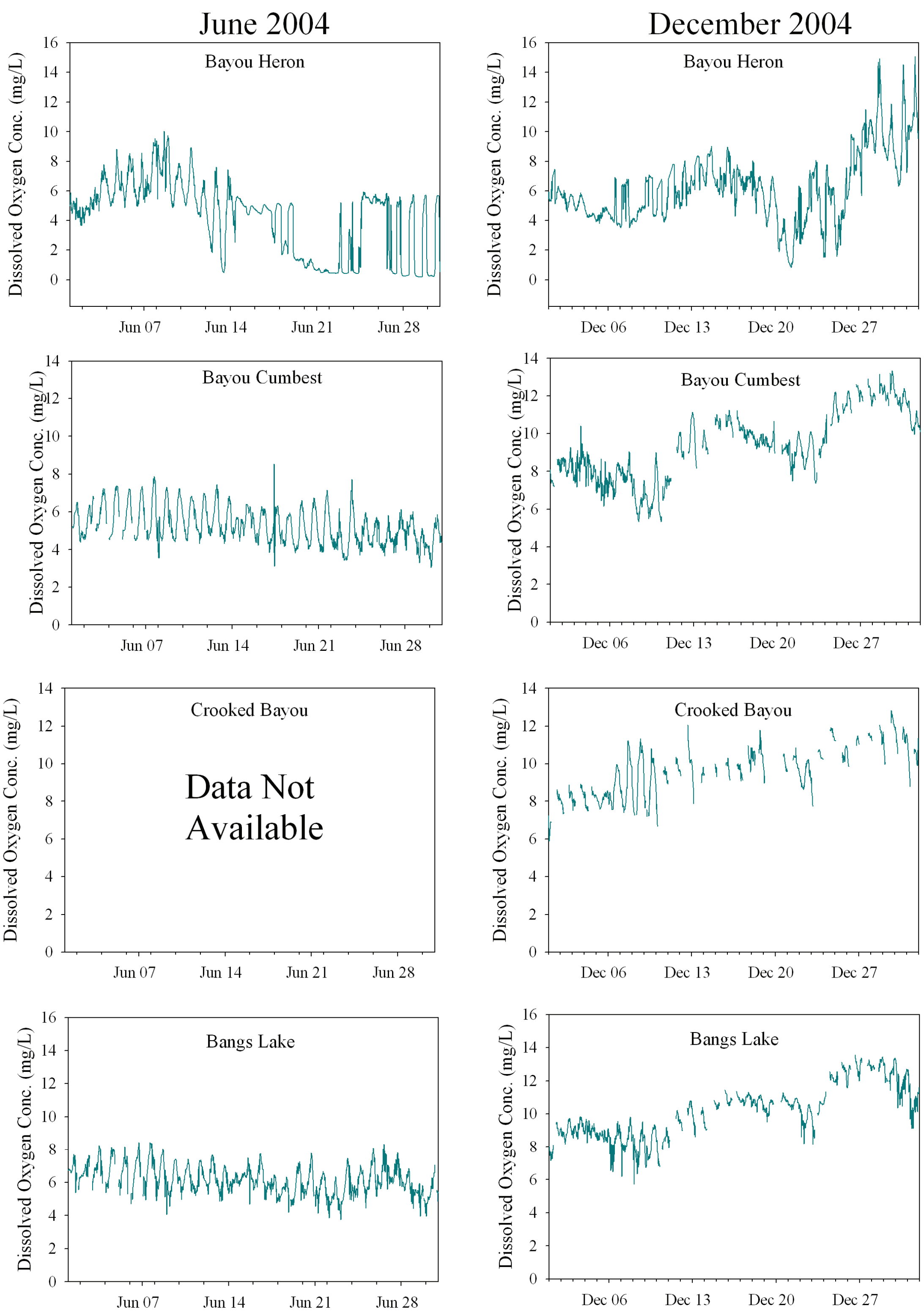


Figure 7.7. Dissolved oxygen concentrations for each station during representative summer and winter months.

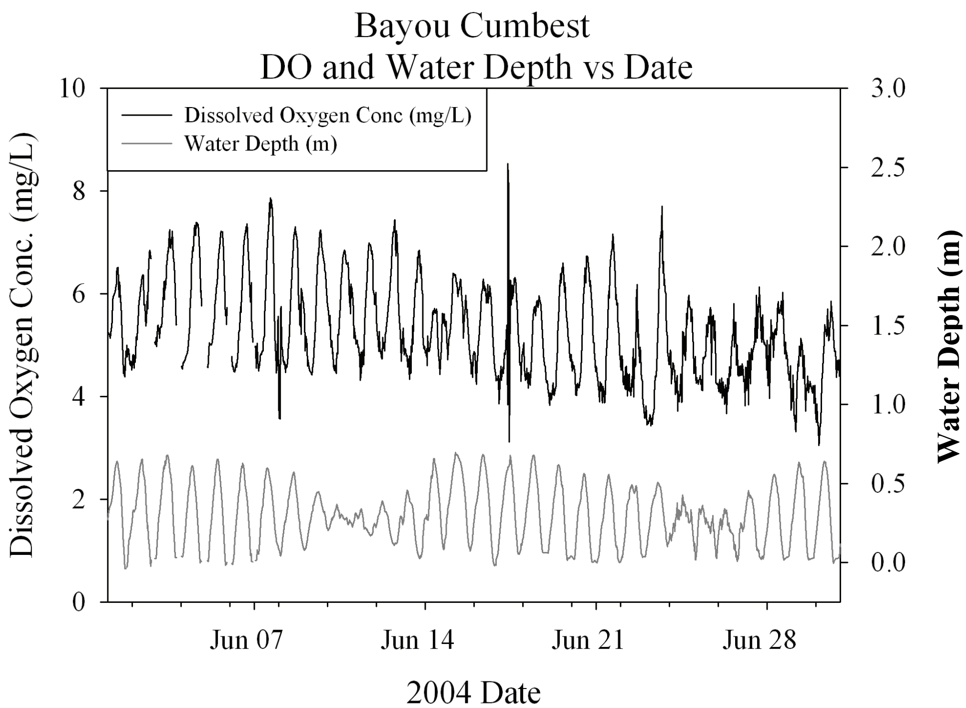


Figure 7.8. Dissolved oxygen concentration and tidal water level fluctuation for Bayou Cumbest during June 2004.

7.2.4. pH

The pH of surface water at Bayou Heron decreases from 7 to 5 after local rain events and resultant runoff from the marshes and uplands (Figure 7.9). As rainwater pH typically ranges from 4 to 6, the large decrease in pH compared to the other stations shows that this station is dominated by stormwater runoff after rain events. Daily measurements show that low pH conditions can persists for several days (Figure 7.10). Other stations' pHs ranged from 7 to 8 over tidal cycles and appear to be due to tidal movement of marine water in and out of the system.

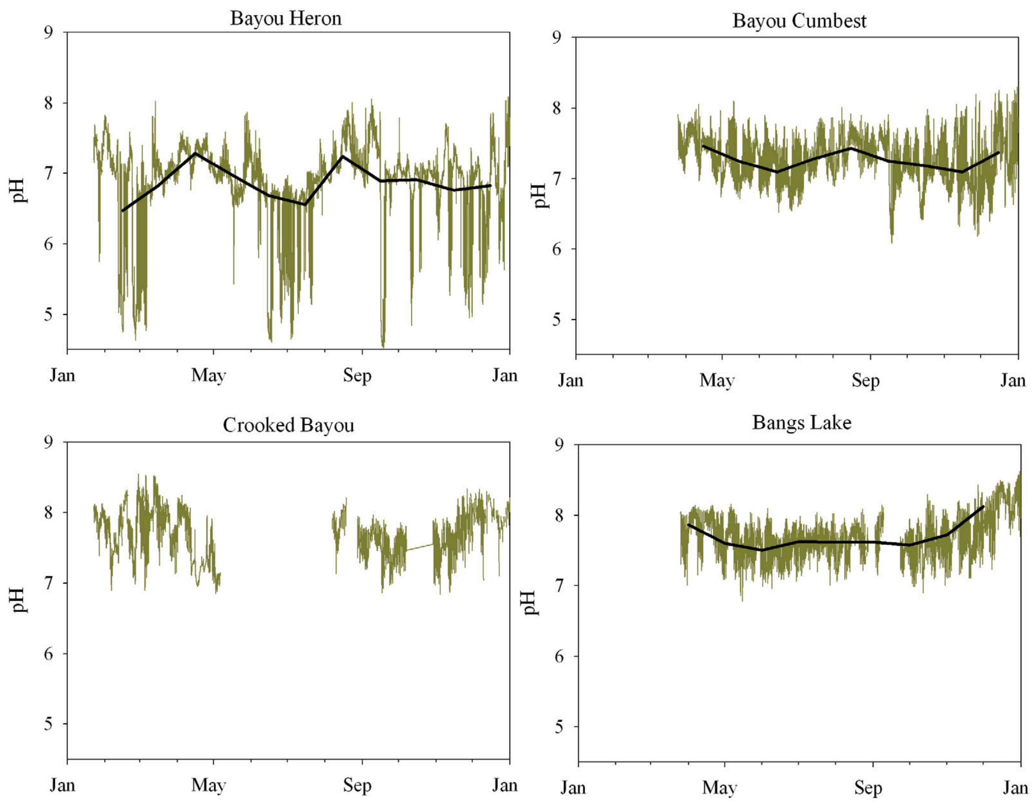


Figure 7.9. Plot of pH for Bayou Heron, Bayou Cumbest, Crooked Bayou, and Bangs Lake from February 25 to December 31, 2004. Olive green line represents measured values. Black lines represent mean monthly pH. Due to several data gaps, the mean monthly pH was not plotted for Crooked Bayou.

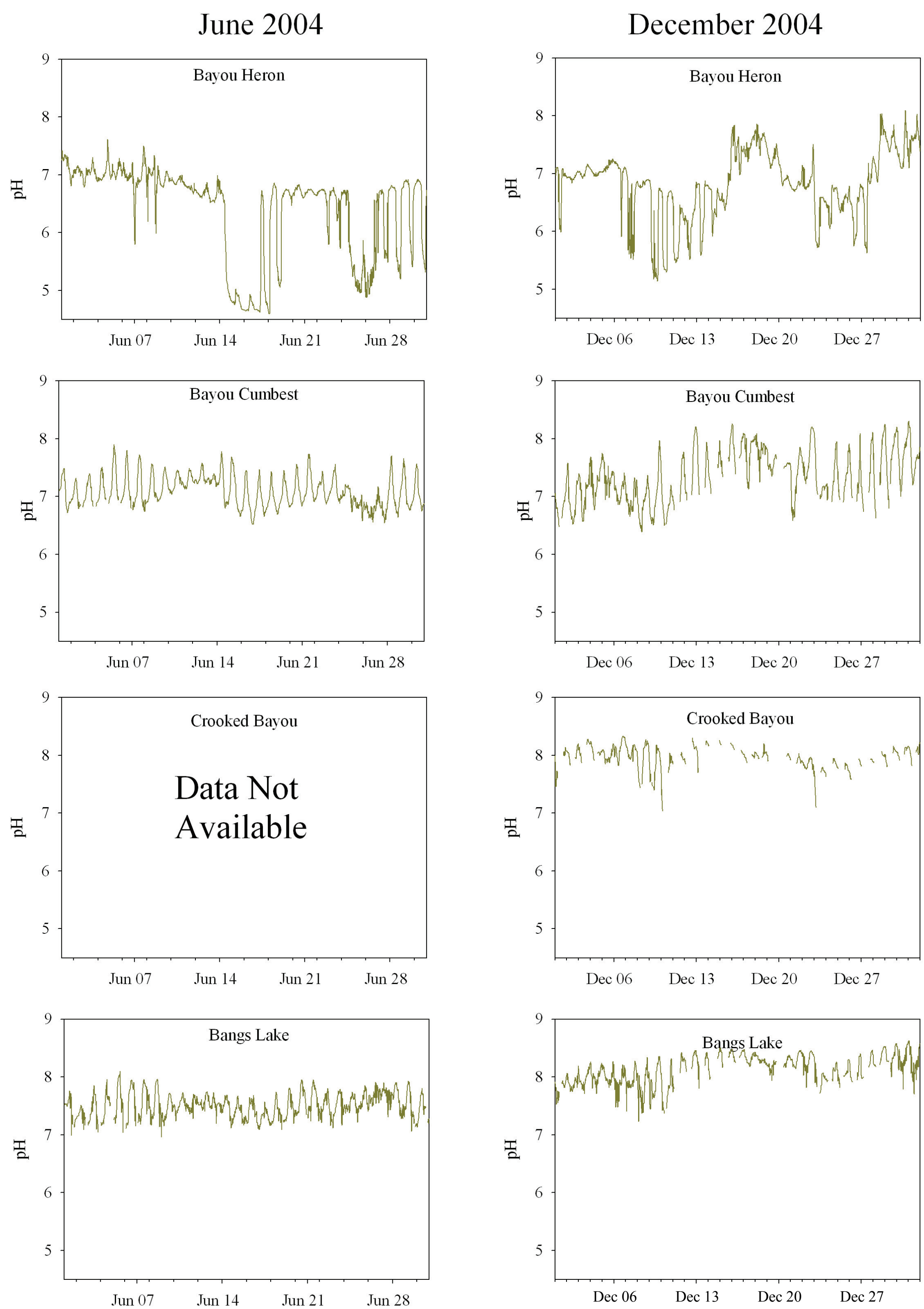


Figure 7.10. Plot of pH for each station during representative summer and winter months.

7.2.5. Turbidity

Turbidity values were typically lowest inland at Bayou Heron, higher in deeper creeks (Bayou Cumbest) and maximal at the more open water location, Bangs Lake (Figure 7.11). It appears that sediments at Bangs Lake are more easily resuspended by winds compared to other locations, which either have deeper water depths and/or are more sheltered by vegetation. It is unclear whether different types of phytoplankton are affecting turbidity levels either directly by altering water column spectral characteristics or by “cementing” the benthos together preventing sediment resuspension. Daily measurements show no tidal trend (Figure 7.12) indicating large fluctuations in turbidity are often driven by wind events.

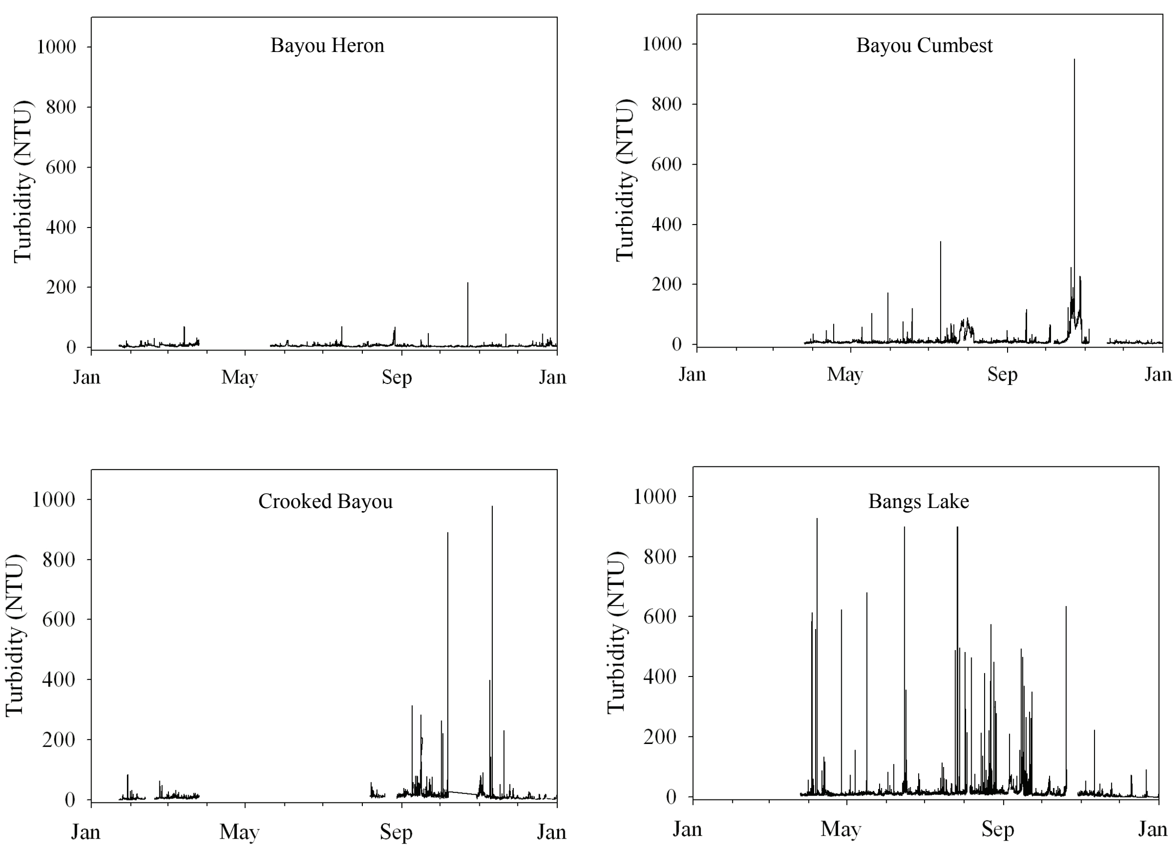


Figure 7.11. Turbidity readings (NTU) for Bayou Heron, Bayou Cumbest, Crooked Bayou, and Bangs Lake from February 25 to December 31, 2004.

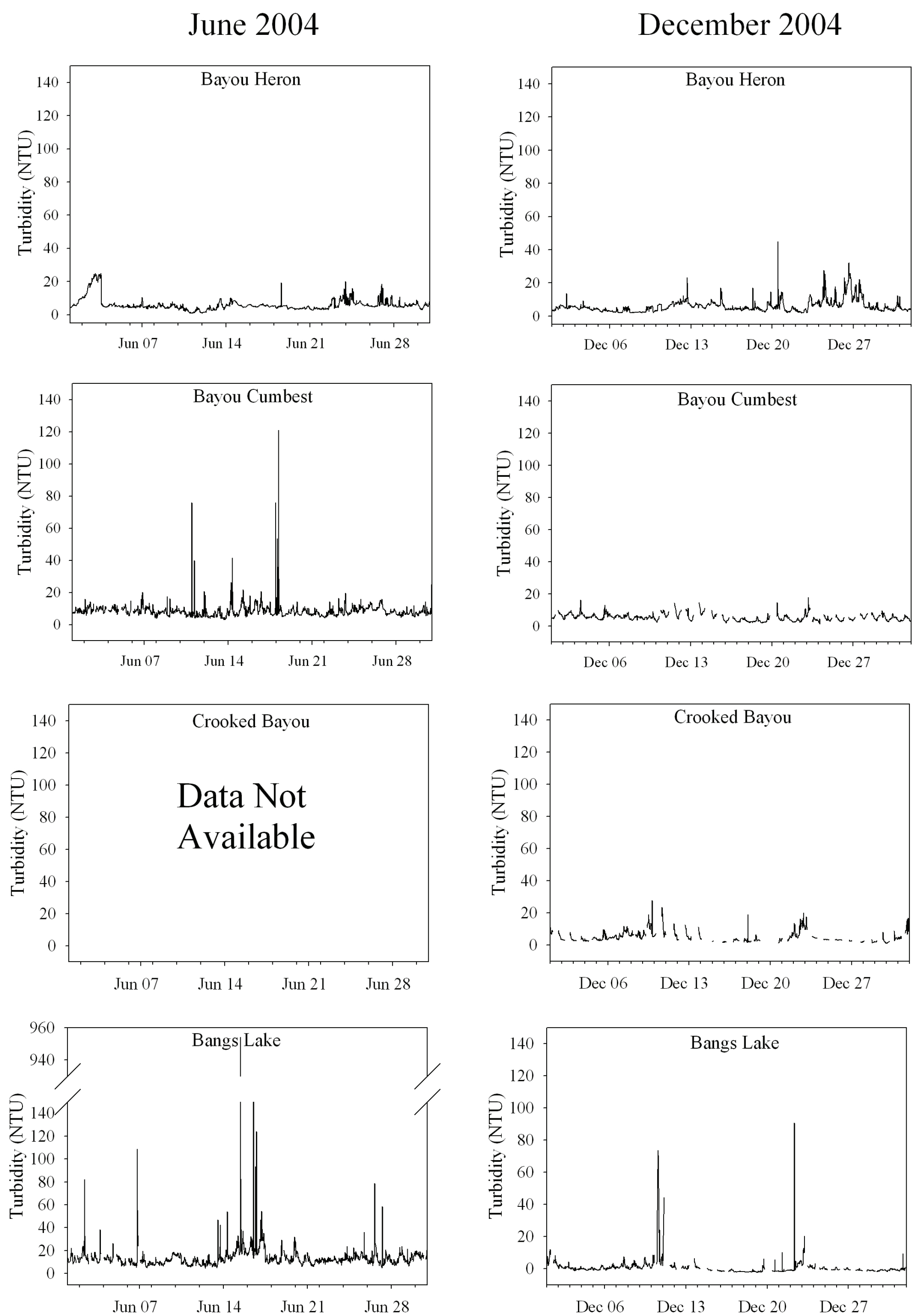
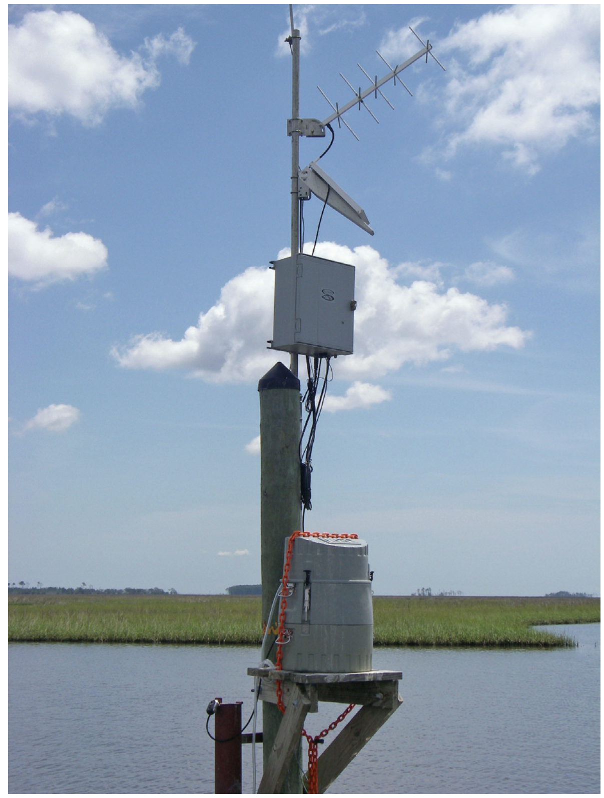


Figure 7.12. Turbidity readings (NTU) for each station during representative summer and winter months. Note the high values for Bangs Lake are on a much larger scale relative to the other measurements.

7.2.6. Nutrients

Measured nutrient [ammonium (NH_4), nitrate (NO_3), nitrite (NO_2), and phosphate (PO_4)] concentrations of surface waters in the Grand Bay NERR are typically low or undetectable. NH_4 is the dominant form of inorganic nitrogen with a concentration range of 0 - 24 µM (0 - 0.34 ppm) throughout the system although typical concentrations are < 5 µM (0.07 ppm). NO_3 concentrations in the estuary were rarely greater than 2 µM although a maximum concentration of 10 µM was observed in December 2005 in Bayou Heron, which is located at the mouth of a small creek that is greatly influenced by marsh runoff. Dissolved organic nitrogen (DON) concentrations in reserve can be much greater than those of dissolved inorganic nitrogen (DIN) species. During October and November 2003, total dissolved nitrogen concentrations were 20 - 30 µM throughout the estuary while DIN concentrations were near or below the limits of detection (Figure 7.13).



ISCO water sampler and telemetered data sonde in Bangs Lake. Photo credit: Christine Walters.

During April 2005, there was a large amount of PO_4 introduced to Bangs Lake from a neighboring gypsum stack. This spill greatly reduced the pH of surface waters in Bangs Lake and increased PO_4 concentrations to 144 µM (4.7 ppm). Concentrations fell to about 20 µM in May 2005 and remained between 10 and 20 µM until September when concentrations dropped to < 2 µM (Figure 7.14). An increase of PO_4 was observed during November 2005 in Bangs Lake likely due to residual gypsum runoff that was washed into Bangs Lake by rainfall.

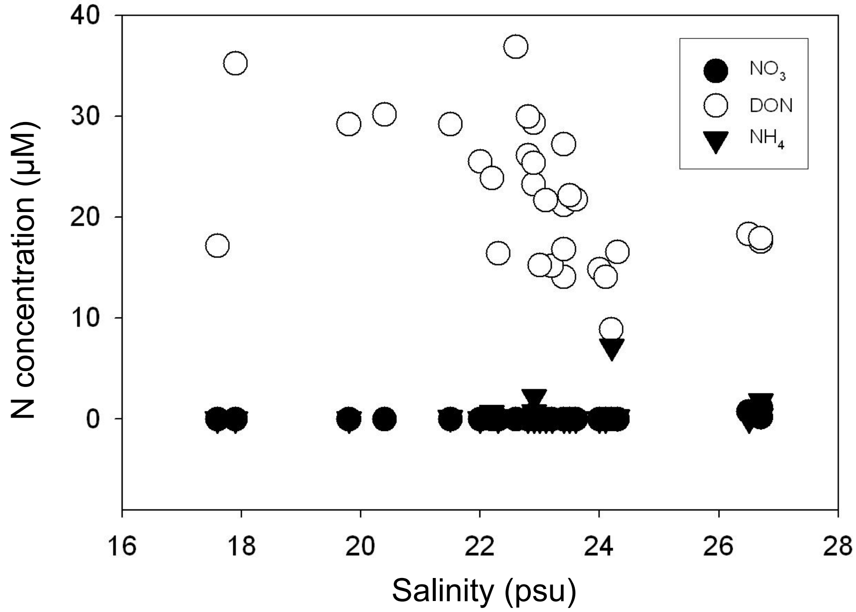


Figure 7.13. NH_4, NO_3, and DON concentrations measured throughout the estuary (30 stations) during October 2003 (Kevin Dillon, Unpublished data).

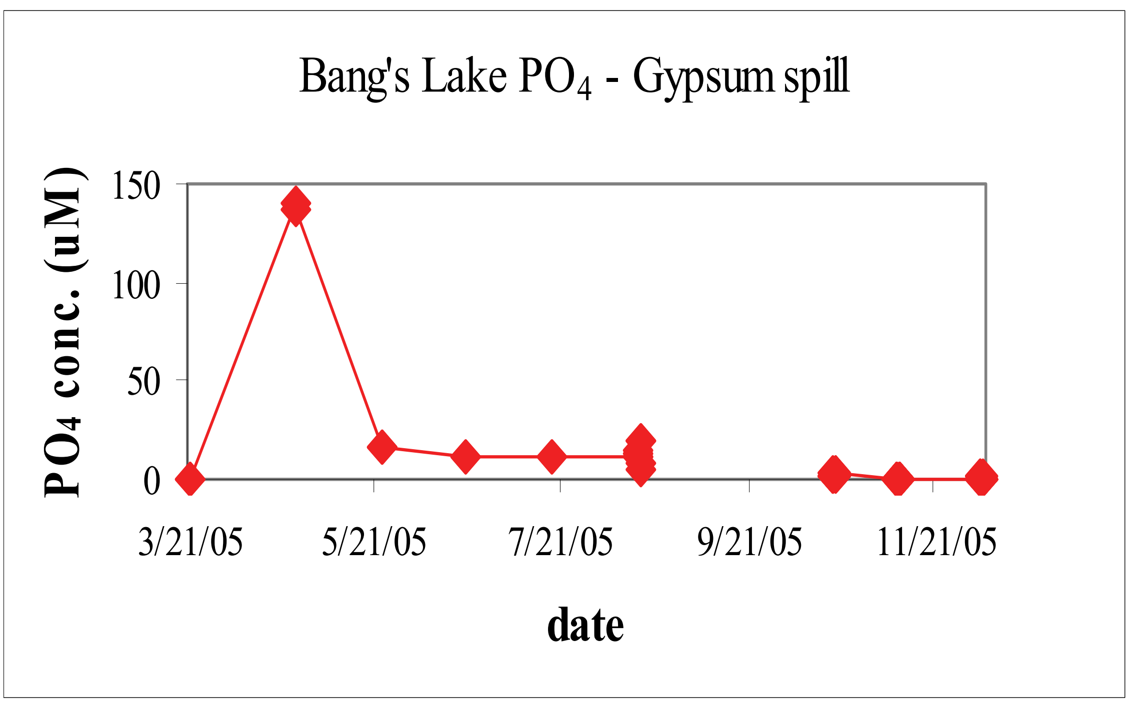


Figure 7.14. Phosphate concentrations at the Bang's Lake station before and after a phosphate spill from a neighboring gypsum stack in April 2005.

7.3. MONITORING AND RESEARCH NEEDS

This piling, to which a data sonde was attached, was thought to have been hit by a boat. The SWMP technician dove underwater to retrieve the sonde. Photo credit: Mark Woodrey.

Recently, DON concentrations have been added to parameters measured during monthly SWMP measurements. DON appears to be the dominant form of dissolved nitrogen in the water column, therefore to characterize this DON pool is essential to understand the N dynamics in the system. In the future, possible dominant N sources (overland runoff, groundwater seepage, and atmospheric deposition) should be examined to characterize the nitrogen species and their contributions to the ecosystem N budget. Dissolved organic carbon concentrations are also being added to the SWMP monitoring program. DOC/DON ratios can provide information on sources of dissolved organic matter (DOM) to a system. Often, terrestrial sources will have higher DOC:DON compared to marine sources such as seagrasses and phytoplankton. Marsh grasses may fall somewhere in the middle. Characterizing the stable isotopes of C and N at sources and in the water column may also provide information on biogeochemical cycling within the system. Coupling source characterization with temporal water column dynamics will provide insight into which sources fuel biological production throughout the year.

Accurate measurements of chlorophyll *a* (chl *a*) are also needed to assess primary production in the estuary. Problems have been encountered with a spectrophotometric method used to measure chl *a* concentrations from 2004 to 2006. A fluorometric method (EPA method 445) has a much greater sensitivity and has been adopted to measure chl *a* concentrations within Grand Bay NERR waters starting in March 2007.

Another missing piece on the biogeochemical puzzle of the Grand Bay NERR's nutrient and carbon budgets is characterizing the particulate organic matter (POM) pool. POM can serve as a potential food source to microbes, fungi, zooplankton, and benthic invertebrates (such as oysters) and may fuel secondary production in Grand Bay NERR waters. Turbidity is tightly correlated with POM concentrations and may be able to be used as a proxy for POM between monthly samplings once their relationship to one another is defined. This relationship is likely to change temporally as phytoplankton production and sediment resuspension due to wind events are both likely to vary seasonally.

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CHAPTER 8

POLLUTION IMPACTS

Julia S. Lytle and Thomas F. Lytle

8.1. CONTAMINANT OVERVIEW OF NORTHERN GULF OF MEXICO

The unique and fragile ecosystem of this salt panne on Middle Bayou has been destroyed by local ATV riders who use the site as a "mud bogging" area. Photo credit: Gretchen Waggy.

The Mississippi Sound is located along the north-central Gulf of Mexico. It is an elongated, shallow embayment bordered on the north by a series of estuaries, the Grand Bay, the Pascagoula, the Biloxi and St. Louis Bay and the Pearl River, and on the south by a chain of offshore islands. The shallow waters within the Mississippi Sound are rich in nutrients and are highly productive. The estuaries provide the nursery grounds for many important fishes, and they are a habitat for wildlife.

Rapid urbanization and industrial expansion along the north-central Gulf of Mexico have resulted in the degradation of coastal ecosystems due to multiple environmental stressors: anthropogenic inputs from point and nonpoint sources, habitat alterations, low oxygen concentrations, high turbidity, physical disturbances from recreational and commercial uses, contaminated sediments, and eutrophication (Gearing et al. 1976, Lytle and Lytle 1976, 1977, 1979, 1982, 1983, 1985, 1987, 1987a, 1987b, 1989, 1990a, 1990b, 1998, Lytle et al. 1979).

8.2. CONTAMINANT SOURCES

Contaminants from lawns, golf courses, agricultural fields, sewage drainage overflows, septic tanks, highways, parking lots, accidental spills on our waterways, permitted industrial discharges, and many other point sources eventually reach our estuaries by rivers and creeks that drain the terrain. Most chemical contaminants that reach the estuaries eventually accumulate in fine-grained sediments, and, when sedimentation rates are fast, contaminated particles are covered up so that oxygen is not readily available. The resulting anaerobic condition slows degradation. Therefore, these contaminated sediments accumulate and act as toxic sinks. Sediments yield the maximum scientific information about pollution in a region because of their tenacity for pollutants, their capacity to retain pollutants in a locale for long periods of time, their preservation of the pollution history of an area, and their potential toxicity over extended intervals of time.

If contaminated sediments are disturbed, they become a toxic source to the overlying waters and can impact the health of organisms exposed to these contaminants. The contaminants can be moved back and forth within the Mississippi Sound by tides, storm events, hurricanes, and during anthropogenic activities that disturb the sediments.

Dead and dying fish and invertebrates fill this rapidly evaporating puddle that has formed in an ATV track on a Middle Bayou salt panne. Anthropogenic impacts drastically affect these dynamic areas. Photo credit: Gretchen Waggy.

The National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program has monitored chemical concentrations of contaminants in marine sediments at about 200 sites around the nation's coastline since 1984 (National Research Council 1989). This agency reported that contaminated marine sediments are widespread and are a potential threat to the human health and the environment. Contaminated sediments were defined as those that contain chemical substances of concentrations that pose a known or suspected environmental or human health threat.

8.3. CONTAMINANT INPUTS AND ACCUMULATIONS IN MISSISSIPPI SOUND SEDIMENTS

In the early 1980s, a four-year study was designed to identify the major organic pollutants and their distributions in the Mississippi Sound, to identify their sources, and to assess their potential impact (Lytle and Lytle 1985). Results of this intensive study produced a complete analytical assessment of hydrocarbons (aliphatic and aromatic) and other sediment contaminants in the Mississippi Sound and riverine ecosystem. Surface sediments from 78 sites within the Mississippi Sound and 45 ten-foot sediment cores were analyzed for aliphatic and aromatic hydrocarbons and other organic compounds. Cores were analyzed at 3-6 cm intervals or at various geological strata with depth to determine pollution history. Because currents within the Mississippi Sound generally flow in a westward direction and because the estuarine system east of the Pascagoula River had very little industrial activity and no residential development, only two sampling sites were located near the present Grand Bay National Estuarine Research Reserve (NERR), one in Bayou La Batre, Alabama and the other on the north side of Dauphin Island, Alabama.

Results of this study indicated that there were high accumulations of hydrocarbons in localized regions of the Mississippi Sound and in some areas of the estuaries. This was not surprising since hydrocarbons were the major permitted waste releases from industries at that time. Also, hydrocarbons are often major constituents of sewage wastes, and with the rapid population growth along the coast, sewage treatment plants are overloaded and cannot handle sewage loads after heavy rainfalls. Localized sites in the Pascagoula River ecosystem contained extremely high concentrations of aliphatic and aromatic hydrocarbons, and some of the sites were in areas that had high probability for disturbance. An Environmental Stress Index (ESI) was calculated for each site in the study based on rated factors such as settling characteristics, sediment disturbance probability, leachability, toxicity and biota susceptibility (Lytle and Lytle 1987). Sediments closest to the Grand Bay NERR indicated relatively low levels of total hydrocarbons, and for that reason they were not selected for further evaluation required for an ESI rating.

An Atlantic stingray in Bangs Lake which died due to a phosphorus spill on the western boarder of the Grand Bay NERR. Photo credit: Gretchen Waggy.

In 1990, the Environmental Protection Agency (EPA) created a research program (Environmental Monitoring and Assessment Program, EMAP) to develop research tools to use for monitoring and assessment of the current health conditions of our nation's coastal ecosystems and to use the data to predict risks to our natural resources. Samples were collected from around the entire Gulf of Mexico from 1991 to 1994. Sampling sites were chosen randomly in grid-like fashion to represent a small region of the ecosystem rather than choosing sites near point sources of contamination. Nine stations were sampled in Mississippi waters, six in the open Mississippi Sound, one in the Pascagoula River, one in Back Bay Biloxi and one in St. Louis Bay. One of these stations, the one nearest Grand Bay NERR, was sampled all four years. This station was just south and east of the Grand Bay NERR site in Alabama waters. Among the data sets from this site are water column data, sediment contaminants with grain-size composition, and toxicity data. Toxicity tests run in 1991 used *Ampelisca abdita* and *Mysidopsis bahia* as test organisms. Results indicated possible toxicity, but these tests were abandoned since later tests showed no significant differences between test sites and control sites.

8.4. PHOSPHATE CONTAMINANTION EVENT

On the morning of 14 April 2005, a catastrophic pollution event occurred along the western border of Grand Bay NERR. A breach occurred in the levee surrounding the retaining ponds at a fertilizer manufacturing company located west of Bangs Lake. Approximately 17.5 million gallons of polluted water were released from the ponds. The fertilizer company could not estimate how much of the released pollution traveled to Bangs Lake and how much traveled to Bayou Casotte, the industrial waterway farther to the west. The released wastewater had a pH of 2.2 - 2.4 and contained elevated levels of phosphorus (4000 - 5000 ppm), ammonia (280 - 350 ppm), and fluoride. The breach was apparently caused in part, by unusually high rainfall (> 43 cm) during 31 March - 11 April and new levee construction.

Damages from this event included flora and fauna. Approximately 8 hectares of tidal marsh and 77 hectares of upland habitats were killed or seriously damaged from the chemicals in the polluted water. The average oyster mortality in Bangs Lake was estimated to be 74 % (Mississippi Department of Marine Resources, Unpublished data). Mississippi Department of Environmental Quality (MDEQ) sampled the fish and decapod populations and extrapolated their results to the area of Bangs Lake. They estimated damage to the local fisheries to be $432,294 based on the 2005 market value of the species found dead (MDEQ, Unpublished data).

Algal bloom in Bangs Lake due to a phosphorus spill. Photo credit: Chris May.

The Grand Bay NERR System Wide Management Program (SWMP) station in Bangs Lake located 2 km away from the spill site, recorded pH readings as low as 3.7 as the tide fell on the night of April 14. Because the monitor was above low tide for this particular tidal cycle, it is unknown how low the pH level fell as the untreated water ebbed out of the lake. However, SWMP data does document a three point drop in the pH level of the lake in the first hour of the ebbing tide, devastating most aquatic life forms. Eleven days later, when researchers became aware of the unreported spill, SWMP nutrient samples were taken from the lake. Phosphate levels were about 5000 times greater than they had been the month before and chlorophyll *a* was nonexistent. Five weeks later when another set of nutrient samples were taken, phosphate levels remained about 500 times greater than before the spill and chlorophyll *a* was still nonexistent 2 km from the spill site.

8.5. NUTRIENT LOADS

Oyster reefs throughout the Mississippi Sound were monitored for fecal coliform loads over a three-year period in the late 1960s (Cook and Childer 1970). High coliform counts were reported near reefs at Bangs Lake and Pt. aux Chenes Bay indicating sewage contamination. Coliform organisms are biological indicators of fecal materials associated with sewage. At that time, it was thought that septic systems along the upper reaches of Bayou Cumbest were functioning inefficiently, and recommendations were made to find ways to reduce fecal contamination. Also associated with sewage are high nutrient loads and contaminants found in sewage such as polynuclear aromatic hydrocarbons, heavy metals, pesticides, hormones and organic solvents.

8.6. MONITORING AND RESEARCH NEEDS

The Grand Bay NERR, located in coastal southeastern Mississippi, and the adjoining marshes and wetlands of southwest Alabama comprise a coastal region less affected by man's activities than in the more populated and urbanized regions. For this reason, in the past, fewer environmental studies included sampling for contaminants in this estuary. Baseline contaminant data are critical to be able to evaluate changes and assess future inputs. Minimal baseline data should include hydrocarbons, pesticides, and heavy metals. Organic carbon loads in the NERR sediments are also unknown. Carbon fractions such as total organic carbon, dissolved organic carbon, dissolved inorganic carbon and sediment carbonates are important variables to understand and to use to predict the toxicant fate and bioavailability of contaminants.

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CHAPTER 9

HABITAT TYPES AND ASSOCIATED ECOLOGICAL COMMUNITIES OF THE GRAND BAY NATIONAL ESTUARINE RESEARCH RESERVE

Ronald G. Wieland

9.1. BACKGROUND/INTRODUCTION

The Grand Bay National Estuarine Research Reserve (NERR) encompasses one of the largest blocks of estuarine and coastal terrestrial habitats in Mississippi. These habitats can be quantified into meaningful ecological units to help increase our understanding of the Grand Bay NERR and its relationship to coastal environments of the northern Gulf of Mexico (GOM) region. Parsing the ecosystem into habitat types helps to define its ecological character, composition, size, condition and context. The process helps recognize the benefits the coastal ecosystem provides to native species and the regional economy of Alabama and Mississippi.

The habitat type is a unit of landscape where environmental factors exhibit a degree of homogeneity (sameness) and maintain similar quantities and oscillations. An ecological community (EC) embodies the association of plants and animals assembled within this distinctive environment, called a habitat type (HT). Conversely, habitat types can be separated from each other by differentiating the environmental factors of each type. Seawater salinity is a major factor affecting aquatic biota. At a gross level, marine habitat types can be separated from estuarine types by describing the differences in salinity levels of their waters. Organisms respond to the environmental differences, showing a preference for areas most conducive to survival.

Habitat types are defined by physical factors and are designed to encapsulate unique environments. In turn, biotic associations form around the stresses, constraints, and resources of the habitat type. Organisms that survive are most “fit” to live within the environmental constraints of each habitat type. Competitive exclusion as well as symbiotic relationships may occur among its suite of occupants. The ecological community is the composite of species that have adapted to the habitat type, and thus are considered an association of a particular set of environmental factors, which are encapsulated by the habitat type. Unfortunately, the boundaries between habitat types/ecological communities are often difficult to detect due to the gradual changes in the environment and species composition and the imperfect correlation that species have with environmental factors.

Environmental factors influencing estuarine areas can fluctuate rather widely in estuarine systems, often confounding efforts to define meaningful entities. Livingston (1984) pointed out the extreme complexity of classifying aquatic populations and communities of temperate estuaries according to the physical properties of their environment. The difficulty was attributed to the normal variability of the factors that defined the environment, especially that of temperature and salinity. Geologic and climatic perturbations change the environmental makeup of the habitats. Natural phenomena such as hurricanes, cold fronts, changes in the development of the Loop Current, create episodes that are stressful or beneficial to marine and estuarine communities of the northern GOM, likely causing significant changes in the composition of the associated species. Fortunately, several environmental factors have an overriding influence on the biota and create useful reference points for defining the habitat types.

A standard method of classifying habitat types has been established for wetlands. The value of this classification for categorizing environmental characteristics is much greater than its limitations. Annual mean values of the most important environmental factors are used for delineating habitat types in estuaries. Preferably, the limits defined for the range of values for each environmental factor are set to correlate with the ecological tolerances of species inhabiting each habitat type.

9.2. CLASSIFICATION OF GRAND BAY NERR HABITAT TYPES

Cowardin et al. (1979) developed a basic classification scheme for all types of wetland habitats found throughout the United States. The scheme formed the basis for the U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI). Dethier (1992) recommended several modifications to NWI to make its classification hierarchy more consistent and applicable to marine environments. A modified classification of estuarine and marine habitat types was developed for Mississippi coastal wetlands by combining features from both systems that are applicable to the northern Gulf (Wieland 1994).

The hierarchical levels of the classification for estuarine and marine habitats are system (marine and estuarine types), subsystem (tidal regimes—intertidal and subtidal), class (substrate—sand, mixed-fine, mud, reef), subclass (energy levels—exposure to waves, currents, and winds), and modifiers (i.e., water depth, salinity, etc.). To complement the habitat type descriptions, diagnostic, characteristic, and common species of plants and animals that occupy the habitat types are described as an association or ecological community.

The estuarine system consists of waters that are semi-enclosed by land but have open, partly obstructed, or sporadic access to the ocean, in which seawater is at least occasionally diluted by freshwater runoff from land. It extends upstream and landward to where ocean-derived salts near the water surface measure < 0.5 psu during the period of low flow, and downstream or out to sea to where freshwater dilution is minimal (salinity seldom falls < 30 psu) (Dethier 1992). Mississippi Sound, Biloxi and St. Louis embayments, brackish portions of rivers, and adjacent intertidal marshes and open beaches, essentially constitute the estuarine system of Mississippi. Due to the brackish nature of the bays and creeks of the Grand Bay NERR, marine habitats are not present on the reserve.

Table 9.1. Major environmental factors, including salinity, water depth and substrate class, are key to classifying marine and estuarine habitats of Mississippi. Shaded habitat types occur on the Grand Bay National Estuarine Research Reserve. [1] By definition, nearshore refers to depths of < 2 m for estuarine habitats and < 10 m for marine habitats. Offshore refers to habitats deeper than 2 m and 10 m, respectively. [2] Letters in parenthesis refer to: (P) Polyhaline, (M) Mesohaline, (O) Oligohaline, and (U) Unclassified.

	MISSISSIPPI COAST MARINE AND ESTUARINE CLASSIFICATION							
	INTERTIDAL					SUBTIDAL		
	Euhaline	Polyhaline	Mesohaline	Oligohaline/ Freshwater	Mixohaline	Nearshore[1]	Offshore	Channel or Embayment
MARINE	GULF OF MEXICO (south of barrier islands)							
Unconsolidated Sand Mixed-fine Mud REEF ARTIFICIAL	**No Marine Habitats Exist within the Grand Bay NERR**							
ESTUARINE	MISSISSIPPI SOUND AND COASTAL WETLANDS							
Unconsolidated						Mixohaline[2]		
Sand	Salt Flat	Artificial Beach			Unvegetated Sand Shore	Sand Bottom	Sand Bottom	Tidal Pass (P);
Mixed-fine						Muddy Sand Bottom	Muddy Sand Bottom	
Mud					Unvegetated Mud Shore	Mud Bottom	Mud Bottom	Embayment - Mud Bottom (M or P)
Unclassified								Mainland Coast Pond/Lake
		Spartina zone Saline Marsh		Intermediate Marsh				Tidal Creek (U)
		Juncus zone Saline Marsh	*Juncus* zone Brackish Marsh	Tidal Freshwater	Seagrass Bed			Tidal River (U)
			Salt meadow High Marsh		Dredged Bottom			Widgeon Grass Bed (M)
			Estuarine Shrublands		Algal Bed			American Wild celery Bed (O)
								Barrier Island Pond/Lagoon (U)
ESTUARINE FRINGE								
Unclassified			Shell Middens -Shrub Woodland					
				Maritime Slash Pine				
				Wet Coastal Prairie				
REEF						Mollusk Reef		

At the subsystem level, the intertidal category encompasses habitats found above the boundary marked by extreme low water of spring tides and below the boundary marked by the upper advancement of saline water from annual storm events. All lands exposed to air and at least annually submerged are included in the intertidal subsystem. The second category, subtidal, refers to all areas below extreme low water of spring tide.

Types of bottom (substrata) and energy level (i.e., the amount of exposure to wind, waves and currents) are the two class-level subdivisions. The four classes of substrata are consolidated, unconsolidated, artificial, and reef (Dethier 1992). The bottoms of Mississippi's coastal waters and intertidal areas are almost exclusively unconsolidated sediments, confined to the finer-grained types, described at the subclass level as mud, and mixed-fine groups. Sandy and organic substrates are less frequently encountered. Gravelly or mixed-coarse sediments are limited to small pockets of shoreline. “Muddy sand” is interchangeable with "mixed-fine in this discussion."

Vittor (1982) demonstrated the need for the “mixed-fine” category for classifying subtidal areas. In benthological studies, it is conventional to group silt and clay particles together as a "mud" category as silt and clay provide equivalent micro-environments to benthic invertebrates. Using detrended correspondence analysis, Lunz and Horstman (1981) and Vittor (1982) showed that clean sand, muddy sand, and mud habitats were correlated to the composition of benthic assemblages.

Three substrate classes were proposed for defining habitat types of northern GOM waters. The classes were designed to match the classes already in use by geologists and benthologists Folk (1954) and Otvos (1976): mud bottom (0 to 50 % sand); muddy sand bottom (50 % to 85 % sand); and sand bottom (85 % or more sand) (Wieland 1994). Four energy/closure classes have been defined for estuarine habitats: open, partially enclosed, lagoon, and channel/slough (Dethier 1992); habitats exhibiting all of the energy/closure classes are known to occur in the Grand Bay NERR estuary. Nearshore areas along Pt. aux Chênes Bay and around the Rigolets have open shorelines exposed to moderate to long fetch and receive some wind, waves and/or currents. The nearshore areas positioned in bays or on the protected leeward side of headlands, bars and spits are categorized as partially enclosed. The extra protection reduces wave action and circulation from established long shore waves and currents. . Bangs Lake and a few smaller ponds are classified as lagoons, which are protected, largely enclosed ponds or embayments that have a reduced or limited access to the open sea and to the full force of local tides. All bayous of the Grand Bay NERR including Bayou Cumbest and Bayou Heron are classified under the channel/slough category, referring to their narrow width, protected position and general access to tidal surges.

Categories of degree and duration of flooding of tidal marshes and depth of the subtidal water column help classify estuarine habitats. Tidal flood frequency and periodicity qualifiers that fit the northern GOM intertidal (eulittoral) zone are the frequently flooded, irregularly flooded categories. The low marsh zone is considered to be frequently flooded and mid-marsh zone, irregularly flooded. The backshore habitat type or the high marsh zone is a supratidal area that is rarely flooded, approximately on annual or biennial frequency, in contrast to the almost daily to monthly frequency of the low and mid-marsh zones, respectively. Further discussion on the application of these categories is found in the community and habitat type descriptions found below.

Species composition of benthic, demersal, and nektonic organisms often corresponds to a water depth gradient. Subtidal areas for estuaries fall into two categories: very shallow or nearshore (0 - 2 m) and shallow or offshore (2 - 10 m); nearshore marine habitats have depths ranging from 0 - 10 m and several additional offshore depth categories. The nearshore zone relates to areas in which waves and currents normally stir and sort bottom sediments.

The classes commonly used for defining salinity in this chapter generally follow Cowardin et al. (1979). The categories were amended slightly to differentiate the salic features of the intertidal marsh habitats. The term "salic" refers to the increase of salinity in the soil medium. A "salic horizon" is a zone of secondary enrichment of salts in soils where capillary rise and evaporation of water concentrate salts at or near the soil surface (U.S. Department of Agriculture 1975; Table 9.2). The salinity levels of the marsh substrates may be strikingly different from that of ambient water of surrounding tidal channels and lagoons (Eleuterius 1984). The importance of salic soil features on marsh ecophysiology prompted its use as criterion for defining tidal marsh habitats (Wieland et al. 1998). Sources of salt that is deposited in the salt panes are brackish waters that occasionally flood the pannes and seepage of salt laden groundwater into the flats from sandy rises that often adjoin the areas. Evaporation and transpiration removes moisture from the substrate but the salts remain.

Table 9.2. Salinity modifiers, as defined by Cowardin et al. 1979 (subtidal) and U.S. Department of Agriculture Natural Resource Conservation Service, Soil Survey Manual (intertidal; U.S. Department of Agriculture 1975), as applied in Mississippi Natural Heritage Program's ecological community classification system. [1]U.S. Department of Agriculture Natural Resource Conservation Service, Soil Survey Manual (U.S. Department of Agriculture 1975). [2]Category created in addition to the customary Natural Resources Conservation Service classes to accommodate the high salinity of salt flat substrates.

Salinity Modifiers	**Salinity**	
Subtidal	**(psu)**	**dS/m[1]**
Hyperhaline	> 40	> 59.7
Euhaline	30-40	44.8-59.7
Mixohaline (brackish)	0.5-30	0.7-44.8
Polyhaline	18-30	26.9-44.8
Mesohaline	5-18	7.5-26.9
Oligohaline	0.5- 5	0.7-7.5
Fresh	< 0.5	< 0.7
Intertidal		
Nonsaline	0-1.3	0-2
Very Slightly Saline	1.3-2.7	2-4
Slightly Saline	2.7-5.4	4-8
Moderately Saline	5.4-10.7	8-16
Strongly Saline	10.7-50	16-75
Excessively Saline[2]	> 50	> 75

The greatest salinity levels are found on exposed sand flats, or salt panes during the summer and fall seasons, when evaporation and transpiration rates are the greatest. Whereas salt flats may have salinity concentrations that are greater than 100 psu at 30 cm depth, surface concentrations can often range higher than 200 psu. However, for a typical black needlerush (*Juncus roemerianus*) marsh in the Grand Bay NERR, salinity concentrations at 30 cm depth ranged from 20 - 40 psu. At the surface, the concentration would vary more radically, exhibiting up to 30 - 50 psu in the summer and fall, and 10 - 20 psu in the winter and spring seasons (Eleuterius 1984).

Species associations help to validate the characterization of habitat types. Species most influential and/or diagnostic in a community are listed as the name of the association. Species showing a high degree of fidelity to particular habitat features are useful for defining species assemblages and characterizing habitats; they are called "diagnostic" because they are predictably present on specified habitat types. Usually no single species is diagnostic of a habitat type but correlated occurrences of several species can be characteristic (Vittor 1982, Dethier 1992). A species can be diagnostic of several habitat types when it occurs in a combination with different co-dominants. Dominant species should not be the only ones employed for defining the communities of estuarine and marine habitats as suggested by Cowardin et al. (1979), because it is unusual to have a few dominant species. These communities are more likely to have multiple species that share dominance (Dethier 1992).

Non-motile benthic organisms have proven to be useful diagnostic species for subtidal habitats (Vittor 1982). Benthic organisms may be sessile, creeping, or burrowing. Those organisms are often rigidly and permanently attached to the substrate to prevent removal from their appropriate habitats by wave or tidal action. Mussels, barnacles, certain polychaetes, corals, encrusting bryozoans, sponges, and hydroids are considered sessile. Creeping or free-moving forms include many echinoderms, crustaceans, mollusks, and marine worms. Burrowing forms include clams, sea anemones, and polychaete worms, which live in sediment in either temporary or permanent tubes.

9.3. HABITAT TYPES AND ASSOCIATED ECOLOGICAL COMMUNITIES OF THE GRAND BAY NATIONAL ESTUARINE RESEARCH RESERVE

The Grand Bay NERR supports two ecological systems, palustrine and estuarine. Different methodologies have been employed for classifying the palustrine areas. Recently a framework has been established for a standard national vegetation classification system in the United States (FGDC 1997). The Nature Conservancy's National Vegetation Classification (Grossman et al. 1998) was adopted as the standard classification of ecological communities for the United States. Weakley et al. (1998) developed the classification for the terrestrial vegetation of the Southeastern Region of the United States. Mississippi Natural Heritage Program participated in developing the Southeastern Regional classification and maintains a similar statewide List of Ecological Communities for Mississippi (http://www.msnaturalscience.org/). Habitat types of Mississippi's estuarine and marine areas are differentiated by the major environmental factors as shown in Table 9.1. The communities and habitat types of the Grand Bay NERR are listed and briefly defined and summarized in Table 9.3.

Table 9.3. Habitat types of the Grand Bay NERR (from Mississippi Ecological Community list) [1]Map No./Code refers to the number and ecological community codes discussed in the text and correspond to the habitat type and ecological communities in Figure 9.1. [2]Aerial extent of habitat types, were completed with the assistance of Maris Technical Center (1998). [3]Distinguishing features are provided to describe habitat types. [4]Species associations are presented as a string of species that characterize the community. [5]State conservation rank as defined in text.

Map No./ Code[1] Hectares[2]	**Cover Type/Ecological Community/Habitat Type/Species** Habitat Type Description[3] Association[4]
	Mesic Palustrine Forests
1[1] CD223M[1] 3[2]	Oak - Mixed Hardwood Ridge Bottom Forest Mesic or wet toe slopes and first and second terraces of alluvial floodplain, more extensive on larger rivers, soils generally fertile loam or sandy loam, i.e. Smithton soil series[3]. *Quercus (michauxii, nigra, pagoda, alba) - Carya cordiformis - Asimina trilobata*[4] (S3)[5]
2 CD242M 52	Slash Pine Flatwoods/Savanna with Wiregrass Mesic to wet, gentle sloping coastal lowlands and flats, Ultisols soils containing argilic subsoil horizons; the Smithton soils representative: level to nearly level poorly drained soils that formed in loamy marine or fluvial sediment on lowlands and stream terraces of the Coastal Plain. The ground water fluctuates between the surface and a depth of 0.3 m in late winter and early-spring. Soil texture is fine loam. *Pinus (elliottii, palustris) - Aristida beyrichiana* (S2)
	Wet Palustrine Forests
3 CF270W 401	Disturbed Wet Savanna Habitat Vegetation disturbances caused by land management activities: logging, grazing or other land uses have reduced the ecological integrity of community; variety of soils and landforms evident; community is usually restorable by management, time, or the restoration of ecologcial processes. *Pinus elliotii - Ilex* sp. - *Cyrilla racemiflora* (SM)
4 CF200W 78	Old Settlement Wet Forest/Savanna Habitat Disturbed landscape, degraded, weedy vegetation; old settlement areas; ruderal vegetation, or vegetation dominated by alien species. *Pinus* sp. - *Ilex* sp. - *Andropogon* sp. - *Vitis* sp. - *Smilax* sp. (SW)
5 CF261W 129	Wet Pine - Pond Cypress Savanna Representative soils include Croatan, Johnston, and Hyde series; wet coastal depressions, flats, and gentle lower slopes that receive subsurface lateral flow from adjacent areas; textures include mucky loam, sandy loam, or highly decomposed organic materials; poorly drained to very poorly drained soils with seasonally high water table; acidic and nutrient poor soils (very low base saturation values). *Taxodium ascendens - Pinus elliotii - Woodwardia virginica* (S2)
6 CF241W	Wet Slash (Longleaf) Pine Savanna/Forest/Flatwoods Representative soil series: Myatt and Ocilla; low stream terraces and wet to mesic upland flats; fine sandy and loamy marine sediments; shallow water table depth during

64 winter and spring; acidic, nutrient poor, argilic subhorizon.
Pinus (ellioti, palustris) - Ctenium aromaticum - Andropogon sp. - *Cyrilla racemiflora - Arundinaria gigantea* (S2)

Shrub Wetlands, Herb Bogs, Wet Savanna (Prairie)

7 Wetland Scrub – Shrub
CH285W Cutover coastal palustrine woodlands that are succeeding back to pine woodlands; vegetation modified by a variety of land uses or lack of fire.
3 *Myrica cerifera - Ilex vomitoria - Ilex coriacea* - mixed arborescent (SM)

Inland Freshwater Marshes

8 White Waterlily - Jointed Spikesedge Herbaceous Vegetation
CI293I Saturated freshwater wetlands in ponded depressions of coastal drainages, old riverine oxbows, or beaver dams; areas semipermanently flooded
13 *Nymphaea odorata – Eleocharis equisetoides - Sagittaria lancifolia* (S1)

Swamp Forests

9 Wet Pond Cypress Depression
CJ262W Atmore, Croatan, and Johnston soils; depressions that receive runoff from upslope and collect water during the winter and spring seasons; areas semipermanently flooded, drying down in the fall season; ox-bow lakes and abandoned stream channels;
40 *Taxodium ascendens - Saurus cernuus - Cladium mariscus* spp. *jamaicense* (S2)

Upland Maritime Communities

10 Maritime Live Oak Forest
CM521M Mesic sandy maritime uplands, usually adjacent to estuarine marshes; often situated on old beach ridges, most of which have been extensively developed. (Although this community is normally found on upland habitats, the small tract in the reserve that supports this community is probably palustrine.)
1 *Quercus virginiana - Q. hemisphaerica* (S1)

Estuarine Fringe Wetlands

11 Estuarine Shrublands
CN520M Estuarine, supra-tidal, shrubland, loamy or sandy substrates, partially enclosed, mixohaline; Lack of fire helps maintain shrublands; Peripheral to high marsh vegetation.
36 *Baccharis halimifolia - Myrica cerifera - Iva frutescens* (S3)

12 Maritime Slash Pine Flatwoods/Savanna
CN243W Smithton, Myatt, and Johns soil series; deep, poorly drained, slowly permeable soils; seasonally high water table during winter and spring; lowlands adjacent to intertidal wetlands; lands exposed to storm surges; situated on shallow, old beaches and riverine terraces; understory tolerant of occasional influx of brackish waters.

573 *Pinus elliottii - Spartina patens - Andropogon glomeratus var. glaucopsis* (S1)

13 Shell Midden Shrub/Woodland

CN521M Estuarine, supra-tidal, shrub/woodland, coarse shell substrates, partially enclosed, mixohaline; Native American shell midden sites.

11 *Juniperus virginiana* var. *silicicola - Sideroxylon lanuginosum* (S1)

14 Wet Coastal Prairie

CN294W Emergent moderate diversity vegetation, organic or fine-loamy soils, salic conditions absent, fringe estuarine marshes behind maritime pine flatwoods; Diversity compromised by the aperiodic influx of brackish water during storm events; Bayou, Hyde, and Myatt soil series; soils deep, poorly drained, slow permeability.

132 *Panicum virgatum - Rhynchospora corniculata - Xyris* sp. *- Cladium mariscus* ssp. *jamaicense* (S1)

Intertidal Estuarine Communities

15 Frequently Flooded Saline Marsh (Low Marsh)

CO696I Estuarine, intertidal, partially enclosed, emergent low diversity vegetation, organic muck or fine-loamy Soils, Interstitial soil salinity corresponds to salinity of adjacent subtidal areas, polyhaline

151 *Spartina alterniflora* (S2)

16 Irregularly Flooded Saline Marsh (Mid-Marsh)

CO694I Estuarine, intertidal, partially enclosed, emergent low diversity vegetation, organic muck or fine-loamy soils, interstitial soil salinity corresponds to salinity of adjacent subtidal areas, polyhaline

2887 *Juncus roemerianus - Distichlis spicata* (S3)

17 Salt Flat (including Salt Panne)

CO695I Estuarine, intertidal, emergent (short) halophytic vegetation (called "panne" if mostly barren), sandy or fine-loamy soils, excessively saline soils, partially enclosed, euhaline.

171 *Salicornia virginiana - Distichlis spicata - Salicornia bigelovii - Suaeda linearis* (S3)

18 Saltmeadow Cordgrass Herbaceous Coastlands (High Marsh)

CO697W Estuarine, rarely flooded, backshore or supratidal (high marsh), slightly saline soils, increased freshwater & reduced exposure to brackish water; exposed to storm surges.

286 *Spartina patens - Panicum virgatum - Baccaris halimifolia* (S2)

19 Unvegetated Mud Shore

CO603I Estuarine, intertidal, mud, open or partially enclosed (mud flat, bar, or beach); Exposed during normal low tides.

16 *Uca minax - Sesarma reticulatum - Littoridinops palustris - Tagelus plebeius* (S3)

20 Unvegetated Sand Shore

CO602I Estuarine, intertidal, shell or sand, open or partially enclosed, flat, bar or beach, foreshore (swash zone), (south shore of barrier islands is marine habitat).

16 *Lepidactylus* sp. - *Paraonis fulgens* - *Emerita talpoida* - *Malaclemys terrapin* (S1)

Submerged Aquatic Vegetation Beds

21 Widgeon Grass Bed

CP692U Estuarine, subtidal, submerged aquatic vegetation, partially enclosed, very shallow to shallow, mesohaline

147 *Ruppia maritima* - *Halodule wrightii* (S2)

Mollusk Reef

22 Mollusk Reef

CQ601U Estuarine, subtidal, or intertidal; Open to partially enclosed, shallow, polyhaline or mesohaline; Shell material required for establishment of reef on soft bottoms; Self perpetuation of oysters continue on shell of original stock.

300 *Crassostrea virginica* (S3)

Estuarine Embayments, Lakes, Ponds, Tidal Channels

23 Mainland Coast Pond/Lake

CR605U Estuarine, subtidal, lagoon, pond or lake, mainland locale, mud or muddy sand bottom, mixohaline.

186 *Callinectes sapidus* - *Hobsonia florida* - *Littoridinops palustris* - *Texadina sphinctostoma* (S3)

24 Tidal Creek

CR601U Estuarine, subtidal, tidal creek channel; Mostly mud or muddy sand bottom.

345 *Geukensia demissa* - *Melampus bidentatus* - *Butorides virescens* - *Fundulus jenkinsi* (S3)

Mississippi Sound Unconsolidated Bottom Communities

25 Mississippi Sound - Nearshore Mixed-fine Bottom

CS603U Estuarine, subtidal, open, very shallow muddy bottom, polyhaline

1394 *Scolopios fragilis* - *Heleobops* - *Bowmaniella* spp. - *Macoma mitchelli* (S4)

26 Mississippi Sound - Offshore Mixed-fine Bottom

CS606U Estuarine, subtidal, open, shallow muddy sand bottom, polyhaline

135 *Hemipholis elongata* - *Micropholis atra* - *Phascolion strombi* - *Nuculana concentrica* (S4)

NO	ECCODE	STATE ECOLOGICAL COMMUNITY
1	CD223M	Oak - Mixed Hardwood Ridge Bottom Forest
2	CD242M	Slash Pine Flatwoods/Savanna with Wiregrass
3	CF270W	Disturbed Wet Savanna Habitat
4	CF200W	Old Settlement Wet Forest/Savanna Habitat
5	CF261W	Wet Pine - Pond Cypress Savanna
6	CF241W	Wet Slash (Longleaf) Pine Savanna/Forest/Flatwoods
7	CH285W	Wetland Scrub - Shrub
8	CI293I	White Waterlily - Jointed Spikesedge Herbaceous Vegetation
9	CJ262W	Wet Pond Cypress Depression
10	CM521M	Maritime Live Oak Forest
11	CN520M	Estuarine Shrublands
12	CN243W	Maritime Slash Pine Flatwoods/Savanna
13	CN521M	Shell Midden Shrub/Woodland
14	CN294W	Wet Coastal Prairie
15	CO696I	Frequently Flooded Saline Marsh
16	CO694I	Irregularly Flooded Saline Marsh
17	CO695I	Salt Flat (incl. Salt Panne)
18	CO697W	Saltmeadow Cordgrass Herbaceous Coastlands (High Marsh)
19	CO603I	Unvegetated Mud Shore
20	CO602I	Unvegetated Sand Shore
23	CR605U	Mainland Coast Pond/Lake
24	CR601U	Tidal Creek
25	CS603U	Mississippi Sound - Nearshore Mixed-fine Bottom
26	CS606U	Mississippi Sound - Offshore Mixed-fine Bottom

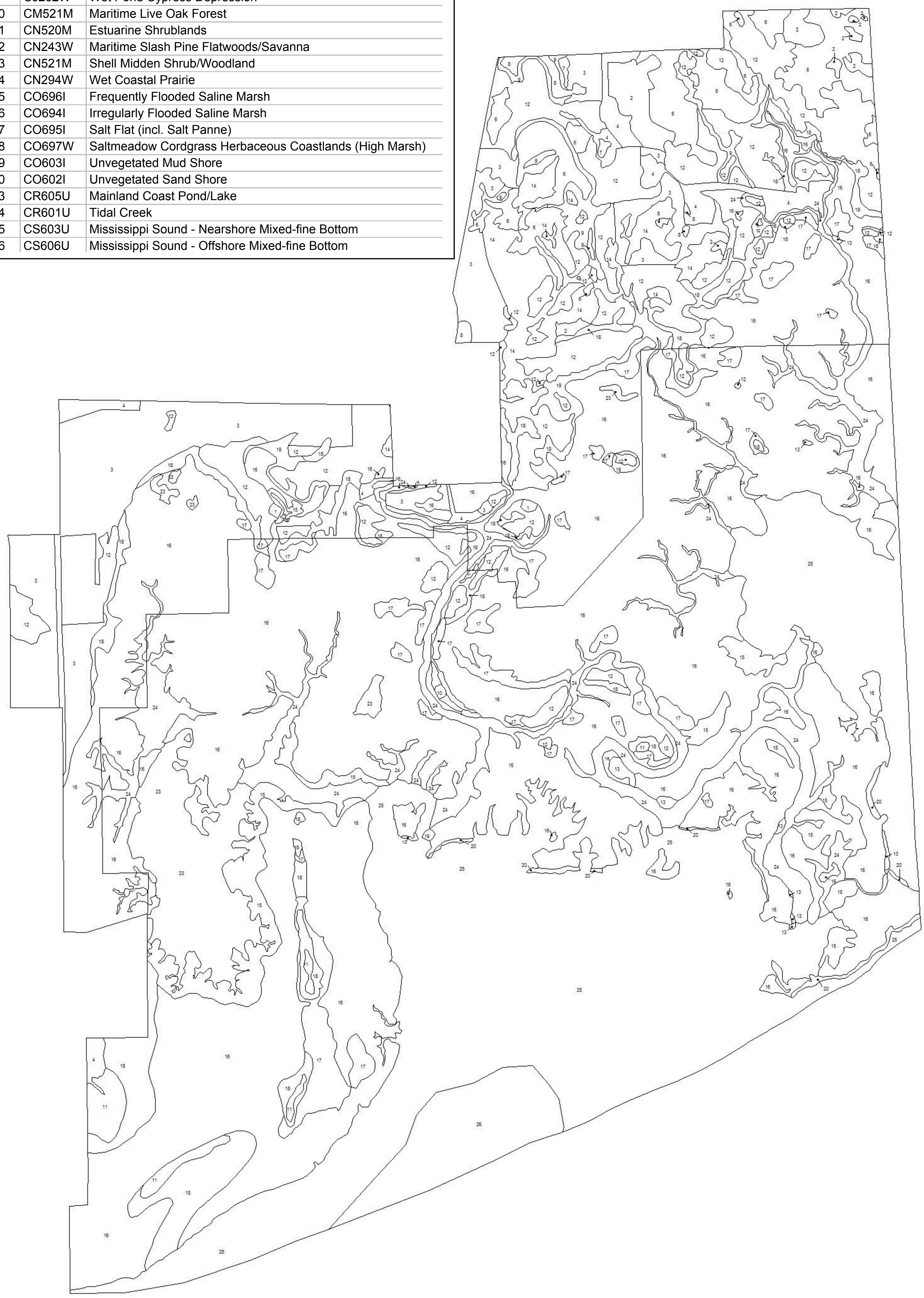


Figure 9.1. Habitat types and ecological communities of the Grand Bay NERR (based on Wieland 1994, Wieland et al. 1998).

The Grand Bay NERR is a diverse coastal ecosystem consisting of four major classes of wetlands: palustrine (11 %), estuarine fringe (11 %), intertidal estuarine (49 %), and subtidal estuarine (29 %) (Figure 9.2). The major classes of wetlands are further subdivided into general cover types: freshwater marsh (2 %), disturbed/developed woodland (7 %), and flatwoods/savanna/prairie/swamp (12 %). Forty-nine percent of the reserve is estuarine marshland and less than 1 % is shoreline or estuarine shrubland. Subtidal areas include nearshore areas (27 %) and offshore areas (2 %) (Figure 9.3). To help assess their abundance or rarity, the area and linear dimensions of habitat types are listed for the reserve and compared to totals determined for Mississippi coastlands (Table 9.4).

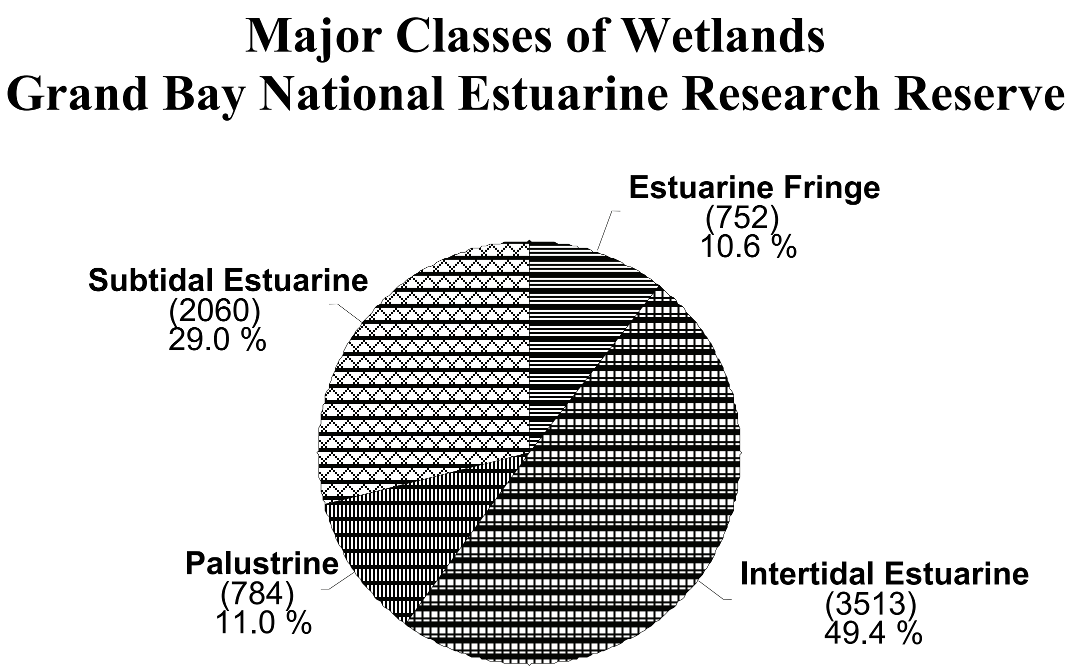


Figure 9.2. Major classes of wetlands in Grand Bay National Estuarine Research Reserve. The numbers in parentheses ( ) indicate the number of hectares for each wetland class.

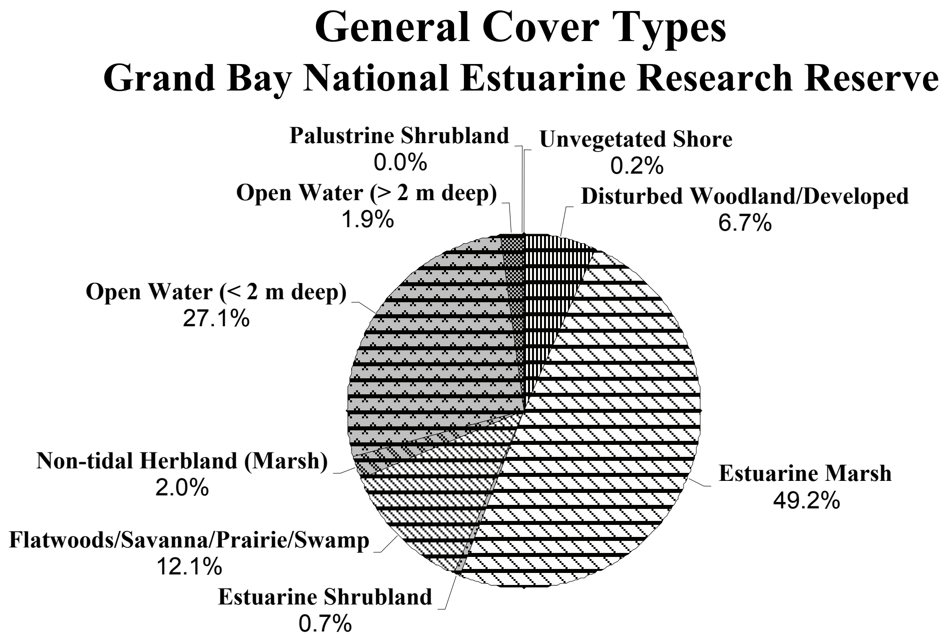


Figure 9.3. General habitat types, shown by percent (%), in Grand Bay National Estuarine Research Reserve.

Table 9.4. A compilation of area and linear estimates for marine and estuarine habitats of the Grand Bay National Estuarine Research Reserve and the Mississippi Coast. [1]Estimates by Eleuterius (1973) and Costanza et al. (1983). [2]Number of habitat types within the Mississippi Sound; other numbers in parenthesis refer to total occurrences. [3]Scattered, sporadic clutches, mostly non-continuous beds; restricted beds occur in Bangs Lake. Seagrass estimates by Eleuterius (years shown in brackets). [4]U.S. Fish and Wildlife Service (1996).

	Mississippi		Grand Bay NERR	
	(ha)	(km)	(ha)	(km)
Estuarine and Coastal Fringe				
Intertidal	27,000		3,513	
Subtidal	175,499		2,060	
Estuarine Area (Total)	202,497		5,573	
Coastal Fringe	?		752	
Palustrine	?		784	
Total			7,109	
Marine				
Intertidal	80-100	60	0	0
Subtidal				
Nearshore	25,000		0	
Offshore	460,000		0	
Upper	210,000		0	
Lower	250,000		0	
Artificial Reef (5)	?		0	
Reef	~5,000		0	
Estuarine Beach/Shores				

Artificial Beach	288	64	0	0
Natural Sand Beach				
Mainland				
Urbanized	9	9	0	0
Non-urbanized	11	11	16	4
Barrier Island (Sound)	60	60	0	0
Mud Flats [1955]	248			
[1978]	152			
			16	
Shoreline (Total)	627	344	?	?
Estuarine Emergent Vegetation				
Marsh Type				
Salt Flat	~200		171	
Saline Marsh	10,899		3,324	
Brackish//Intermediate	14,702		0	
Intermediate Marsh	2,200		0	
Tidal Freshwater Marsh[1]	300- 1,500		0	
Shell Midden (18)	~20		10	
Coastal Mainland Marshes	26,226		3,495	
Estuarine Subtidal				
Mississippi Sound (10)[2]	213,000		1,528	
Nearshore (<2 m Depth)	53,250		1,394	
Offshore (> 2 m Depth)	159,750		135	
Embayments (2)	8,356		0	
Mainland Coast Pond/lake (138)	1,513		186	
Barrier Is. Pond/lagoon				
Petit Bois & Tidal (6)	40		0	
Horn Islands Nontidal (74)	56		0	
Tidal Creeks (142)	2197	516	345	160
Tidal Rivers (7)	1,827	141		0
Estuarine Subtidal (Other)				
Mollusk Reef				
Cond./in Approved Water	3,641		47[3]	
Restricted	103		209	
Prohibited	215		0	
Total	4,000		256	
Barrier Is. Seagrass Bed [1968]	3,600		----	
[1985]	1,800		----	
Cat Is. Macros. Algae Bed [1969]	2,000		----	
Widgeon Grass Bed and Am. Wildcelery Bed [1973]	2,000		147 0	
Seagrass Beds (Total) [1973]	8,100		147[4]	

9.3.1. Palustrine Habitats

The highest elevational marker within the Grand Bay NERR is the five-foot contour (1.5 m) (U.S.G.S. Kreole and Grand Bay SW Quadrangle Maps). Soils of this lowland plain are hydric and are classified in the following series: Atmore, Bayou, Croatan, Hyde, Johns, Johnston, Lenoir, Myatt, Ocilla, and Smithton (U.S. Natural Resources Conservation Service 1998) (Table 9.5). All series are considered "aquic," a term describing conditions of continuous or periodic saturation and reduction. The hydric soils of the reserve support wet cypress, pine savanna, open coastal prairie, and flatwoods vegetation.

Table 9.5. Name and taxonomy of soil mapping units of palustrine and estuarine areas of the Grand Bay National Estuarine Research Reserve. Axis is the main estuarine soil and Smithton occurs in both estuarine and palustrine systems.

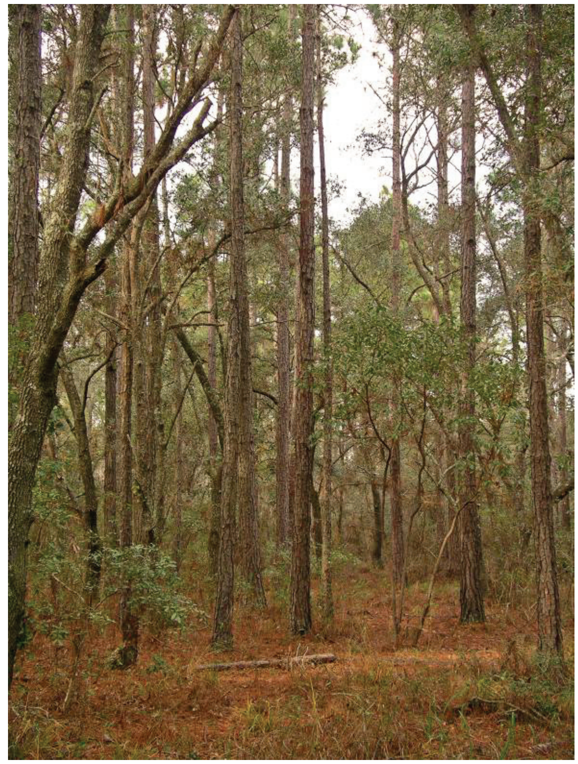
Mapping Unit Name	Taxonomy
Atmore loam 1 to 3 percent slopes	Coarse-loamy, siliceous, semiactive, thermic Plinthic Paleaquults
Axis mucky sandy clay loam, frequently flooded (main estuarine soil)	Coarse-loamy, mixed, superactive, nonacid, thermic Typic Sulfaquents
Bayou sandy loam 0 to 1 percent slopes	Coarse-loamy, siliceous, semiactive, thermic Typic Paleaquults
Croatan and Johnston soils, frequently flooded	1) Loamy, siliceous, dysic, thermic Terric Haplosaprists; and 2)Coarse-loamy, siliceous, active, acid thermic Cumulic Humaquepts
Hyde silt loam	Fine-silty, mixed, active, thermic Typic Umbraquults
Johns loamy fine sand, 0 to 2 percent slopes	Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Aquic Hapludults
Lenoir silt loam, 0 to 1 percent slopes	Fine, mixed, semiactive, thermic aeric Paleaquults
Myatt loam, 0 to 1 percent slopes, occasionally flooded	Fine-loamy, siliceous, active, thermic Typic Endoaquults
Ocilla loamy sand, 0 to 2 percent slopes, occasionally flooded	Loamy, siliceous, semiactive, thermic aquic Arenic Paleudults
Smithton loam, 0 to 1 percent slopes, occasionally flooded (estuarine and palustrine systems)	Coarse-loamy, siliceous, semiactive, thermic Typic Paleaquults

Mississippi has over one-hundred fifty ecological communities grouped into six Ecological Systems: Terrestrial, Palustrine, Lacustrine, Riverine, Estuarine, and Marine. The Terrestrial System refers to upland soils and associated landscapes. . Two of the six systems, Palustrine and Estuarine are present; the remaining systems are not represented on the reserve. Palustrine lands are hydric areas with hydric soils that developed under conditions of saturation, flooding or ponding for long enough periods to develop anaerobic conditions in the upper soil profile. For soils to be considered hydric, the period of saturation must occur during the growing season. The concept of hydric soils includes soils formed under sufficiently wet conditions to support the growth and regeneration of hydrophytic vegetation (U.S. Natural Resources Conservation Service 2005).

Soil mapping units of Grand Bay NERR palustrine areas include nine delineations (Table 9.5). All of the named series are Ultisols except the Johnston and Croatan series, which are Histosols and Inceptisols, respectively. Ultisols are often regarded as non-fertile because of long term exposure to excessive weathering. These soils are typically found in humid coastal areas of GOM. The release of bases by weathering usually is equal to or less than their removal by leaching. Bases are mostly held in the vegetation and the upper few centimeters of the soil profile. Base saturation in most soil of the Ultisols order decreases with increasing depth because vegetation concentrates bases at a shallow depth.

Eleven percent (1,937 ha) of the Grand Bay NERR is palustrine wetland. Of seven potential community alliances found in the Palustrine System, five are present on the Grand Bay NERR:

mesic palustrine forests, wet palustrine forests, shrub wetlands, inland freshwater marshes, and swamp forests.



Oak Grove Birding Trail. Photo credit: Gretchen Waggy

The habitat type and communities are described below. The communities are organized by eleven major groups, i.e., marsh, pine woodland, swamp forest, intertidal and subtidal. Over fifty percent of Mississippi's major community groups are found in the Grand Bay NERR. The heading of the following section is sequentially numbered to correspond to the habitat type/community numbers presented in Figure 9.1 and Table 9.3. The table contains a brief description of the habitat type and the full name of the ecological community along with the number of hectares identified for each community. The six-digit code and the community name correspond to the Ecological Community List of Mississippi.

The S-code in parenthesis refers to the state conservation rank or State Rank of the community as defined: critically imperiled (S1), imperiled (S2), vulnerable (S3), apparently secure (uncommon) (S4), and secure (common) (S5). In addition to the numbered ranks, communities are classified on the basis of disturbance criteria and are coded (SM) or (SW).

The classification system separates natural/semi-natural types from "cultural" types. The natural/semi-natural types are coded numerically; modified or managed types are coded with the letter M and cultural types, the letter W. Natural/semi-natural types will require a smaller degree of management and restoration than the other types to remain in or improve their natural condition. The modified or managed types are considered restorable but will require more extensive efforts and the cultural types are generally not considered restorable but reclaimable. "Cultural" types include planted/cultivated vegetation types or converted habitats, and often are dominated by exotic species. For cultural and modified vegetation, the classification and mapping units are at a much coarser scale than for natural and semi-natural vegetation. Based on these rankings, 21 % of the total area of the reserve is occupied by communities that are imperiled, 53 %, vulnerable, 20%, apparently secure, and 6%, modified or cultural.

<u>Mesic Palustrine Forests (D)</u>

1. CD223M Oak - Mixed Hardwood Ridge Bottom Forest (S3)

Two small terraces along distributory channels of the ancient Escatawpa River delta support vegetation somewhat typical of coastal bottomland hardwood forests. The community is found on loamy stream terraces (~ 0.7 m elevation) that support Smithton soils. Smithton soils are very deep, poorly drained and have moderately slow permeability. The hardwood species of this community are common to Mississippi hardwood forests but are less often encountered on the

Grand Bay NERR. They include *Quercus stellata* (post oak), *Quercus nigra* (water oak), *Quercus virginiana* (live oak), *Liquidambar styraciflua* (sweetgum), and *Diospyros virginiana* (common persimmon). It is possible that disturbance caused by logging or temporary settlements helped establish this community. Alternatively, the community may persist because it is protected from wildfire.

2. CD242M Slash Pine Flatwoods/Savanna with Wiregrass (S2)
Smithton loam soils, found on slight rises of the coastal landscape, also support the pine-wiregrass savanna community. The clayey sub-horizon of Smithton soils perch moisture in its upper horizon, causing them to remain saturated for long periods. They have loamy textures. Being on slight rises, the soils are somewhat better drained than soils of the wet coastal prairies and other pine savannas. The habitat type remains wet during the spring but generally becomes dry later in the summer and fall.

The community is identified by the dense sward of *Aristida stricta* (a threeawn grass) growing amidst the well-spaced slash pine. Other important understory species are *Panicum virgatum* and *Ilex glabra* (inkberry). Its diverse understory contains numerous rare herbs. The community is considered to be fire-dependent. Threeawn is highly combustible when dry and produces abundant seed when burned. In southeastern Mississippi, this pine/wiregrass savanna is quite patchy and is largely isolated to natural areas of Jackson County. More extensive tracts of this community are found in Alabama and Florida. The slash pine/wiregrass community is best exemplified by stands growing adjacent to Highway 90 at the Mississippi-Alabama border. Several large patches are found on the Mississippi Sandhill Crane National Wildlife Refuge.

Wet Pine Savanna with pitcher plants. Photo credit: Gretchen Waggy

<u>Wet Palustrine Forests (F)</u>
3. CF270W Disturbed Wet Savanna Habitat (SM)
The community is defined on the basis of accumulative disturbances that have altered the stature and composition of the vegetation. Logging activities, livestock grazing, lack of fire, ditching, etc., have resulted in a reduction in the diversity of the herb layer. Exotic species are more abundant. The community persists in a seminatural state where structure of vegetation has been noticeably changed through human activities, but the species composition is unchanged. Efforts to restore this community could prove fruitful because many of the plants native to the community are still present. Slash pine is the dominant overstory tree. The understory is distinguished from other sanvanna communities by the presence of a larger number of weedy species.

4. CF200W Old Settlement Wet Forest/Savanna Habitat (SW)
The community type represents altered wet savannas. The type contains all savannas exposed to major disturbances such as cultivation, grazing by domestic livestock, or homestead

developments. Stands are often infested with exotic weeds, such as *Imperata cylindrica* (cogongrass) and *Sapium sebiferum* (Chinese tallow tree). The largest blocks of this type occur on old homestead sites adjacent to Bayou Heron Road. The Old Settlement type has been altered to such a degree that reclamation of sites will be required.

5. CF261W Wet Pine - Pond Cypress Savanna (S2)
This community is situated on lowland flats (Hyde soil series) and depressions (Croatan and Johnston soil series) of wide terraces and floodplains. These nutrient poor soils are derived from loamy textured marine and fluvial sediments. They are composed of very strongly acidic soils with a variety of textures--mucky loam, sandy loam, or highly decomposed organic materials. . They are poorly drained to very poorly drained and exhibit standard aquic characteristics of seasonally high water tables, which persist through the winter and into the spring season. Their prolonged saturation produces consistent gleyed coloration in the upper soil horizons. Gleyed soils are identified by the presence of bluish or greenish colors through the soil mass. Gleying occurs under reducing (anoxic) conditions that reduces iron to its ferrous state. The elevated water table of Hyde soils is often more persistent because of the presence of an argillic subhorizon, defined by the relative high concentration of clay in subsoil horizons.

Taxodium ascendens (pond cypress) prefers wet, saturated soils and is regularly encountered in wet flats and at the base of gentle slopes. Soils of this habitat remain saturated and flooded through much of the growing season. *Taxodium ascendens* and *Nyssa biflora* (swamp tupelo) become more abundant than *Pinus elliottii* (slash pine) under wetter conditions. Stands considered part of this community should contain at least a twenty percent cover of pond cypress. *Ilex myrtifolia* (myrtle dahoon), *Aronia arbutifolia* (red chokeberry), *Nyssa biflora* and *Persea palustris* (swamp bay) are some of the shrubs encountered. Associated herbs include *Aristida palustris* (longleaf threeawn), *Carex striata* (Walter's sedge), *Dichanthelium scabriusculum* (woolly rosette grass), *Woodwardia virginica* (Virginia chainfern), *Oxypolis filiformis* (water cowbane), and *Rhynchospora elliottii* (Elliott's beaksedge). Excellent examples of this community are found in the northeastern portion of the Grand Bay NERR.

6. CF241W Wet Slash (Longleaf) Pine Savanna with Broomsedge (S2)
Soils of the Ocilla and Myatt soil series are deep, poorly to somewhat poorly drained and moderately to slowly permeable. Typical habitats for this community are low stream terraces and lowland flats. Soils are medium- to moderately-fine textured sandy and loamy marine sediments. Depth to the water table ranges from 30 to 80 cm for periods of two to six months. They experience occasional flooding during major storms. This habitat type is located on mesic habitats that are somewhat better drained than other savanna types.

This community is quite similar in stature and composition to the Maritime Slash Pine Flatwoods/Savanna (12. CN243W) but has a greater diversity of forbs and grasses. The community limited amounts of *Spartina patens* (saltmarsh cordgrass) and an increased presence of other grasses, especially *Andropogon* sp. and herbs. Some of the additional grasses encountered are *Muhlenbergia capillaris* var. *tricopodes* (cutover muhly), *Panicum virgatum*, *Dichanthelium scabriusculum* and patches of *Aristida stricta*. Additional field surveys will be neccessary to better differentiate the pine savanna types of the reserve.

Shrub Wetlands, Pocosin, Herb Bogs (H)

7. CH285W Wetland Scrub - Shrub (SM)

The Wetland Scrub – Shrub community or native shrub thicket, occurs on cutover wet pine savannas of the lower coastal plain. Only a few such shrub thickets are present on the reserve. Woodland communities with high percent cover of shrubs (25 to 50 %) are not classified as part of this community. Because of their small size, shrub thickets are indistinguishable on aerial photography and are under-represented in this mapping effort. Shrubs encountered include *Myrica cerifera* (southern bayberry), *Ilex myrtifolia*, *Ilex glabra*, *Ilex vomitoria* (yaupon), *Magnolia virginiana* (sweetbay), and the exotic species, *Sapium sebiferum*. Several of the shrubs of the cutover lands are similar those growing in the high marshes of the estuary.

Abundant sunlight at ground level and saturated-infertile soils of natural savannas are factors that promote a high diversity of its herbaceous understory. Fire plays a significant role in maintaining a high diversity. Fires reduce the height, density and shade of shrubs. . However, in the last fifty years of settlement, fires have been practically eliminated from their role in shaping the coastal savannas. Logging caused additional destabilization of the wet savanna community. Shrub encroachment was left unchecked until recently when the link between fire and biodiversity was established. Fortunately within the last several decades, Grand Bay NERR was occasionally exposed to wildfire and protection efforts have been practiced for several decades. The savannas have not experienced significant losses of their diverse flora. Today, shrub encroachment is manageable, although thickets are forming on some disturbed areas. Shrub encroachment will continue to be a threat to the area unless fire is prescribed on a more frequent basis.

Inland Freshwater Marshes or Spring Marsh (I)

8. CI293I White Waterlily - Jointed Spikesedge Herbaceous Vegetation (S1)

A few low flats and depressions on the Grand Bay NERR often remain flooded during the growing season. The continuous inundation promotes hydrophytic vegetation. Several oxbow lakes near Bayou Cumbest and Highway 90 and artificial ponds on the reserve support this community. Inland Freshwater Marshes covers about 13 ha in the reserve. The depth of the marshes varies seasonally but is typically between 0.4 and 1 m deep.

Hawks Marsh, a freshwater marsh in the northern part of the Reserve. Photo credit: Gretchen Waggy

The colorful *Nymphaea odorata* (American white waterlily) and *Eleocharis equisetoides* (jointed spikesedge) are the dominant species in these freshwater marshes. They often grow in separate marsh zones; American white waterlily preferring wetter conditions than the jointed spikesedge. Additional wetland associates are *Sagittaria lancifolia* (bulltongue arrowhead), *Crinum americanum* (seven sisters), *Myriophyllum pinnatum* (cutleaf watermilfoil), *Cladium mariscus* ssp. *jamaicense* (Jamaica swamp sawgrass) and *Juncus roemerianus*. The wetlands are often fringed by *Taxodium ascendens* with a complement of wetland herbs such as *Panicum virgatum* and *Cladium mariscus* ssp. *jamaicense*. Ditching of the Grand Bay NERR coastal plain has undoubtedly diminished the extent of these wetlands.

<u>Swamp Forests (J)</u>

9. CJ262W Wet Pond Cypress Depression (S2)

Like the freshwater marsh community, this pond cypress community is also confined to wet depressions that normally hold water through much of the growing season. Soils of the wet depressions are designated as Atmore, Croatan and Johnston series. The Wet Pond Cypress Depression are found in the deepest segments of the abandoned, partially filled channels of the ancient Escatawpa River. The stringers of swamp forest that transect the Grand Bay NERR are readily discernible on medium scale aerial photography. Long periods of flooding prevents the establishment of a grassy understory and favors submergent types of vegetation such as *Ludwigia pilosa* (hairy primrosewillow), *Sagittaria lancifolia*, *Saururus cernuus* (lizards tail), *Eriocaulon decangulare* (tenangle pipewort), and *Juncus roemerianus*. The community often occurs on the edges of oxbow ponds that contain the White Water Lily - Jointed Spikesedge Herbaceous community.

<u>Upland Maritime Communities (M)</u>

10. CM521M Maritime Live Oak Forest (S1)

The Maritime Live Oak Forest on Kenny's Island on Bayou Cumbest. Photo credit: Mark Woodrey

Maritime Live Oak Forests occupy well-drained coastal sand ridges. Maritime Live Oak Forest has been mapped on one small area of the Grand Bay NERR, known locally as "Kenny's Island." The community is situated on a narrow levee along a bend of Bayou Cumbest. The site is somewhat elevated from the stringer of maritime pine woodland that occupies the rest of the levee. The hydric nature of the reserve's coastlands inhibit widespread establishment of natural live oak stands. Live oaks prefer well-drained sandy soils. They do well along estuarine shorelands because they are very tolerant to strong winds, salt spray and spring tide flooding. The habitat supports *Quercus virginiana* (live oak) trees and a variety of other hardwoods. Maritime Live Oak Forest is one of the rarest communities of Mississippi. Ancient beach ridges along the mainland shore of Mississippi Sound once supported a narrow band of live oak forest. Extensive development on the sand ridges has reduced the natural live oak stands to only isolated small tracts. There are a few additional plantings of live oak in old settlements. *Quercus virginiana* is a common and preferred tree of coastal settlements because of its stately presence and resilience to strong winds.

9.3.2. Estuarine Intertidal Habitats

Estuarine habitats have been delineated into three broad categories: estuarine fringe, intertidal estuarine, and subtidal estuarine. Tides along the Mississippi coastline are diurnal, variable, and subdued, only averaging 50 cm in height. Changes in the daily range are associated with the moon's declination. When the moon is over or near the equator the tide has its lowest range. Tides with the greatest range occur at 13 ¾ day intervals when the moon is near its maximum declination. Occasional directional winds or storm events affect normal tidal amplitudes, causing an increase or decrease in marsh flooding. North winds blow tidal waters away from the land causing tides far below predictions. Approximate range for spring tide is 76 cm and neap tide is 30 cm (Christmas 1973). Extreme surges of up to 8 m heights can occur during hurricanes (Stout 1984). Estuaries along the northern GOM experience irregular marsh flooding due to the low tidal amplitude. Consequently, the marshes have long periods of exposure.

Until relatively recent times, the Escatawpa River emptied into Grand Bay. The waters brought sediments and nutrients into the shallow-based delta. After the Pascagoula River captured the Escatawpa River, the influx of river sediments to the Grand Bay delta ceased. Bayou Cumbest, The old Escatawpa River channel, presently known as Bayou Cumbest, became one of the larger tidal creeks found on the reserve. With the loss of freshwater flow and sedimentation from the Escatawpa River, the delta has experience considerable erosion and subsidence. The 1853 U.S. Coast Survey Chart shows a continuous, 7.8 km long , 182 hectare spit that extended from marshy South Rigolets Island. Of the original spit, only a very small islet at the western end of the chain remains (Otvos 1976). Shoreline erosion along Pt. aux Chênes Bay and the Rigolets has been averaging about 3 m per year.

<u>Estuarine Fringe Wetlands (N)</u>

11. CN520M Estuarine Shrublands (S3)

This community is commonly encountered as a narrow fringe of shrubs between the high marsh and ancient beach ridges or riverine levees, where the maritime pine flatwoods community is encountered. The community occupies soils of the Smithton series, which typically experience moderate periods of saturation. They consist of acidic, loamy sediments that are low in fertility.. Estuarine shrubland is a minor community on the reserve, which contains few patches large enough to map. An example of the shrublands can be found on a slightly elevated sand ridge between Point aux Chênes Bay and Bangs Lake. The common species of this habitat are *Myrica cerifera*, *Baccharis halimifolia* (eastern baccharis) and *Iva frutescens* (bigleaf sumpweed), all of which sporadically occur in the high marsh zone. With ground disturbance, the high marsh community tends to increase in shrub cover.

12. CN243W Maritime Slash Pine Flatwoods/Savanna (S1)

Maritime Slash Pine Flatwoods/Savanna on Crooked Bayou. Photo credit: Mark Woodrey.

The Maritime Slash Pine Flatwoods community marks a scenic backdrop to the monotypic, black needlerush marshes of Grand Bay NERR. The flatwoods are situated on ancient low beach ridges (0.5 to 1 m high), immediately inland from the large swath of tidal marshes. Since the Escatawpa River has been captured by the Pascagoula River, its former channel has regressed to a short, lazy tidal creek called Bayou Cumbest. The loamy or sandy textured soils of the levees along the bayou are elevated enough to support a series of linear patches of these pinelands that extend for some distance into the sprawling black needlerush marshes.

Smithton, Myatt and Johns soils help define the habitat type of this community. Theese deep, poorly drained, and slowly permeable soils are found on level to nearly level stream terraces and upland flats of the Coastal Plain. They are grayish brown, have fine loamy textures and are saturated during the winter and spring. Small depressions and flat areas hold water for short periods during wet seasons. A seasonally high water table is within 30 cm of the soil surface from December through April. The wet conditions produce mottles of yellowish brown colors. The soils have strong- to very strong acidic reactions.

Pinus elliottii and the dominant grass of this community, *Spartina patens,* can tolerate seasonally wet or saturated soils and periodic storm surges. The dominance of *Spartina patens* distinguishes this community from other savanna types. Longleaf pine *(Pinus palustris)* is absent from this community. *Spartina patens* relinquishes its dominance a short distance inland but occasionally will persist several miles inland along creek channels and bayous. The inland populations may have established after severe hurricane events. Freshwater conditions do not seem to inhibit its growth.

Andropogon glomeratus var. *glaucus* (purple bluestem), *Eryngium yuccifolium* (button eryngo), *Panicum virgatum*, *Cladium mariscus* ssp. *jamaicense*, and *Cynanchum angustifolium* (gulf coast swallowwort) are common associates. Additional common species of the Maritime Slash Pine Flatwoods/Savanna Community are *Dichanthelium scabriusculum*, and several shrubs, especially *Myrica cerifera*, *Baccharis halimifolia*, and *Ilex vomitoria*. If not burned on a periodic basis, the community becomes brushy and increasingly inaccessible to pedestrians. *Imperata cylindrica* is expanding rapidly along the coastal marsh fringes and poses a serious threat to this community. Due to their isolation and inaccessibility, these maritime woodlands have remained relatively undisturbed.

13. CN521M Shell Midden Shrub/Woodland (S1)

Shell mounds, or middens, which occur along the coast of Mississippi, mostly originated as refuse shell heaps deposited during prehistoric periods of human occupation. The shelly substrate provides a unique calcium-rich habitat for a variety of plants, a few of which are found nowhere else in Mississippi. The presence of pot shards intermixed with the shell fragments of middens gives evidence to their origin. Around 4,000 years ago, Native Americans began occupying coastal portions of Mississippi. Radio carbon dating indicates that the age of the shell material is between 1,200 to 2,900 years BP, a date which corresponds to the region's occupation by early hunter-gatherer societies (Eleuterius and Otvos 1979). In South Carolina, both natural and anthropogenic causes are suggested for shell deposits found along its Atlantic coast line. Some were formed by wave action that reworked offshore shell deposits and oyster reefs into shell banks situated along the backshores of outer beaches. Other shell piles were attributed to the early tribes that occupied the area. (Dorroh 1968, South Carolina Shellfish Management Program 1979).

Indian middens or "kitchen middens," are the accumulation of shells disposed during food gathering activities. Shells most frequently found in the middens are *Rangia cuneata*, with lesser quantities of *Crassostrea virginica* (eastern oyster) and *Littoraria irrorata* (marsh periwinkle; Eleuterius and Otvos 1979). Several dozen shell middens, which commonly contain shells over 20 cm long, are located in estuarine areas of the coastal counties of Mississippi and Alabama. Eighteen shell middens have been documented in the area including the Hancock County marshes, Back Bay of Biloxi, the Pascagoula River Marsh, and in the Grand Bay area (Mississippi Marine Resources Council 1977). The largest midden is 0.75 ha in size, but most are much smaller, closer to 0.1 ha in size. The middens' heights commonly are only 1 to 1.5 m above mean low water, but shells can reach depths of 4.5 m (Eleuterius and Otvos 1979).

*Shell midden on Bayou Heron with a Southern Red Cedar (*Juniperus virginiana *var.* silicola*). Photo credit: Gretchen Waggy*

The shell middens have been affected by gradual geologic processes of accretion and subsidence. Accretion of Hancock County marshes ended around 1,800 years ago. Subsequently, coastal erosion became more prevalent, causing a reduction in their size. Compaction of the alluvial materials leads to subsidence of the marshlands and shell middens. The shell middens on the south end of Bangs Island and in the Grand Batture area are exposed to significant wave erosion. Soils of shell middens are shallow (4 - 8 cm), very dark, calcareous, and rich in nutrients. Roots have reworked and mixed soil horizons to a depth of 16 cm (Eleuterius and Otvos 1979).

The shell midden vegetation stands above and contrasts conspicuously with the surrounding saline marsh. Eleuterius and Otvos (1979) documented the floristic aspects of the shell middens in Hancock County marshes. Sixty-two plants (seven trees, twenty-two shrubs, and thirty-three herbs) were identified from five shell middens. The plants often form a dense, impenetrable shrub thicket. Little zonation is evident, except at the periphery of the midden area where estuarine shrubs form a narrow hedge of plants. *Baccharis halimifolia, Borrichia frutescens* (sea ox-eye)*, Ilex frutescens, Lycium carolinianum,* and *Myrica cerifera typically* fringe these middens. Trees such as *Quercus virginiana*, *Juniperus virginiana* var. *silicola*, *Celtis laevigata, Diospyros virginiana, Morus rubra,* and *Zanthoxylum clava-herculis* are scattered on the middens. Some trees are broken and sculpted by the prevailing southeasterly winds and coastal storms.

The middens are often shrub dominated and include calciphilic species such as *Aesculus pavia*, *Bumelia lanuginosa, Erythrina herbacea*, and *Yucca aloifolia*. Woody vines such as *Ampelopsis arborea*, *Cissus incissa, Matelea carolinensis, Campsis radicans*, and *Similax bona-nox* trail profusely through the understory and subcanopy. A diverse collection of weedy herbs are also present, including *Chaerophyllum tainturieri*, *Erigeron philadelphicus*, *Toxicodendron radicans* ssp. *radicans*, and *Vicia ludoviciana*. *Elymus virginicus* is the only calciphilic herb identified by Eleuterius and Otvos (1979). Twelve of the sixty-two species (19 %) identified by Eleuterius and Otvos (1979) are calciphiles. Accumulation of oyster shells over the past 300 years by European man has not led to the establishment of the same calciphiles that were found on Indian middens.

Sargeretia minutiflora is found only on coastal shell midden habitats of the South Atlantic and northeastern GOM. It is speculated that *Junipercus silicicola*, *Erythrina herbacea*, *Aesculus pavia*, and *Morus rubra,* may have been propagated by the prehistoric users of these middens. Several of these plants are found on both inland terrestrial and coastal estuarine middens (Eleuterius and Otvos 1979). There is a remarkable similarity of vegetation on the shell middens of the Hancock County marshes and the middens of the Grand Bay NERR. The coastal middens are estimated to cover approximately ten hectares. Because of their proximity to boating channels, some shell middens receive numerous visitors annually. The heavily visited sites have been degraded by trampling and littering and may require additional protection to ensure the diverse composition of plants is maintained. Several of the middens have been infested with *Imperata cylindrica*, an extremely aggressive exotic weed.

14. CN294W Wet Coastal Prairie (S1)

Large prairie-like openings are found behind a fringe of woodlands that occupy an ancient shallow beach shoreline. Grand Bay NERR has over 130 ha of Wet Coastal Prairie. The wetness of this habitat is apparently due to the barrier caused by the beach ridgeline, which form a barrier to freshwater drainage from the broad inland flats.. The prairies are found on very poorly drained flats and depressions, where the community forms a mosaic with wet pine savanna. Wet prairie is a form of freshwater marsh because its soils remain saturated for extended periods during the winter and spring seasons and periodically during the growing season.

The Bayou, Hyde and Myatt soil series define the wet coastal prairie habitat type. The soils were formed in loamy sediments of marine origin. Soils are poorly drained due to slow permeability of the subhorizons. The soils are grayish colored, exhibit very strong acid reactions in the upper horizons and have a very low base saturation rate, which provides evidence to their infertility. The cycles of periodic saturation and dewatering causes distinct light yellowish brown, very dark gray and red mottles. The proximity of the wet prairies to the tidal marshes suggests that the estuary may influence the soil chemistry. The reason for their presence on the reserve is not well understood and deserves additional study.

The areas are designated as prairies to express their mostly treeless condition. Herb composition is quite similar to wet savanna communities and the Intermediate Marsh Ecological Community, which is defined by an abundance of *Cladium mariscus* ssp. *jamaicense*. Shrubs are usually of minor extent. Although the wet prairies are situated near the high tidal marsh zone, *Spartina patens* is uncommon in the wet prairies, likely a response to extended periods of saturation. The dominant species encountered are *Panicum virgatum*, *Andropogon glomeratus* var. *glaucopsis*, *Dichanthelium scabriusculum*, *Rhynchospora corniculata* (shortbristle horned beaksedge), and *Xyris* sp. (yelloweyed grass). Patches of *Cladium mariscus* ssp. *jamaicense* and *Aristida stricta* are often encountered. Species diversity of the wet prairies is higher than that of the tidal marshes and maritime pine savannas but substantially lower than the more inland wet pine savannas. Compared to the wet savanna ecological community, the lower diversity may be due to the lack of exposure to fire or to occasional inundation with brackish water during storm events. *Sarracenia alata* or *Sarracenia psittacina*, the two most common pitcher plants found in Mississippi occur in abundance near the northern boundary of the Grand Bay NERR yet have not been observed in the wet coastal prairies. On the wetter sites, the prairie community grades into pond cypress wetlands or the White Waterlily - Jointed Spikesedge community. The efforts to drain the coastal plain of the Grand Bay NERR during the mid-1900s has likely changed the composition of the coastal prairies and may be the causal factor for the high cover of *Panicum virgatum*. The disturbance has allowed *Imperata cylindrica* to become well established along the spoil banks of the drainages.

<u>Intertidal Estuarine Communities (Estuarine Marshes) (O)</u>

In the early 1960’s (1960-1965), few reports discussing the ecology of tidal marshes were available. Significant research was conducted during the 1970’s and 1980’s to help fill this knowledge gap. *Coastal Ecological Systems of the United States* by Odum et al. 1974 provided a baseline of information about tidal marshes but pointed out the large gaps in our understanding of estuarine ecosystems. By the late 1980’s knowledge of the ecological and economic importance of estuarine ecosystems had improved. However by then, increasing pressure on coastal lands for residential, commercial, and industrial development led to additional disturbance and destruction of coastal wetlands. Filling, bulk heading and exposure to additional pollution reduced the quality of the GOM estuaries (Meyer-Arendt and Gazzier 1990). Some of these stressors continue to influence their quality. The need for a conservation strategy is increasingly evident, especially considering that the ecological “health” of estuaries is closely linked to fish and shellfish production, wildlife habitat, and recreation. The designation of the Grand Bay site as a research reserve is a response to the need for advancing knowledge of estuaries.

Cooper (1974) provided an overview of the classification and ecology of North America's salt marshes, pointing out the vegetative patterns and associated environmental processes. Salt marshes were defined as beds of emergent salt tolerant plants rooted in intertidal areas. They are mainly found in shallow, relatively protected flats that are frequently inundated and drained according to the rise and fall of the tide.

Marshall (1974) noted the differences between regularly flooded and irregularly flooded marshes. Regular flooding referred to inundation occurring normally at every high tide. Irregularly flooded referred to areas occasionally submerged because of spring, wind-driven, or storm-related tides. These terms related to the periodicity of flooding in a regional context rather than zonal differences along a marsh shoreline. It is possible to have a regularly flooded zone of an irregularly flooded marsh. Mississippi coastal lands support irregularly flooded marshes (Marshall 1974).

Flooding and exposure during regular intervals (areas near low or mean high tide) or irregular intervals (areas slightly above mean high tide) create a highly stressful environment for salt marsh vegetation. Salinity, drainage, and temperature exert strong selective control over species tolerant of such conditions. Many animals, on the other hand, are more able to adapt to these conditions or have the option to move when conditions become intolerable. However, only a few plants can survive an environment with such fluctuating circumstances. Salt marshes spread along the North American shores of the Atlantic and Pacific Ocean support similar kinds of herbs. *Spartina*, *Juncus*, and *Salicornia* genera contain species that have an almost universal occurrence in salt marshes, as do animal groups containing fiddler crabs and mussels (Cooper 1974).

Upper reaches of Middle Bayou and surrounding Juncus/Spartina *salt marsh. Photo credit: Gretchen Waggy*

Salt marshes of North America are of two major types: (1) the East and Gulf Coast marsh type, and (2) the West Coast marsh type. East and Gulf Coast marshes lie on the edge of a gently sloping coastal plain. A steep continental shelf along the west coast creates conditions mostly unfavorable for salt marsh development, except for accretion areas at the mouths of rivers. Salt marshes along the East Coast and GOM fall into three main types. Gross differences in substrate type are largely responsible for the differences in marsh composition. The northern-most type, found only in

Canada, is supported by compacted substrates resulting from soft rock decay; the portion extending along the coast from New England to New Jersey has primarily fibrous peat substrates that lie adjacent to slowly eroding hard rock landforms; the Southeast Atlantic Coast and Gulf Coast serve as repositories for large quantities of silt originating from the wide sedimentary plain. The intertidal coast is made up of broad flats of soft, gray, muddy alluvial substrates that accumulate along the mouths of rivers and within bays and sounds.

Species dominance patterns are similar for the three marsh types. *Spartina alterniflora* (smooth cordgrass) occurs "from about mean sea level to mean high tide." Two species dominate at the high tide line, *Juncus gerardii* (a rush) occurs chiefly north of Chesapeake Bay and *J. roemerianus* dominates marshes south of the Bay. *Spartina patens, Distichlis spicata* (inland saltgrass) and several species of *Salicornia* sp. occur just above the mean high water mark.

Different species zonation is observed along the northern section of the South Atlantic Coast than the southern part. The different vegetation patterns is caused by major differences in tidal amplitude. Irregularly flooded marshes fringe the inner shores of North Carolina's large brackish sounds and along parts of Virginia, where the tidal amplitude is limited, usually less than 0.3 m. These marshes often experience large changes in water salinity. *Spartina alterniflora* fringes the edges of tidal creeks. At higher intertidal areas, *Juncus roemerianus* occurs in large pure stands. The next slightly higher zone is dominated by extensive stands of *Spartina patens*. The *Juncus roemerianus* zone exhibits the highest salinity of the three zones; *Spartina patens* zone has the lowest salinity. The description provided by Cooper (1974) for the shores of North Carolina and parts of Virginia indicates a striking similarity to the reports describing marshes of the northeastern Gulf Coast. The similar vegetation patterns is due to the weak tidal influence experienced by both regions.

For areas along Georgia and South Carolina, where the tidal amplitude is much greater, Spartina *alterniflora* is found in much larger areas. South of Cape Lookout, North Carolina, to Jacksonville, Florida, tidal amplitude varies from 0.6 to 1.5 m but can reach as high as 2.4 m in Georgia and South Carolina. Large stands of *Spartina alterniflora* dominate this coastal section. *Spartina alterniflora* exhibits a variety of growth forms that correspond to flooding frequency. From mean sea level to the top of levees along creeks, *Spartina alterniflora* reaches its tallest stature, averaging from 1.2 to 2.4 m. On the top of the natural levee a zone of medium sized plants (0.6 to 1.2 m) occurs. Away from the tidal creek, *Spartina alterniflora* decreases to less than 0.3 m in height. *Juncus roemerianus* gains dominance on zones slightly higher in elevation, and evidently, in areas receiving regular seepage of freshwater.

The zonation is caused by the increase in salinity in the zone of short grasses. The "tall growth" zone is more frequently flooded and maintains salinity levels close to that of the adjacent water.. The short growth zone is flooded less and exposed to the sun in a dewatered state for longer periods. During exposure, salts increase in concentration as moisture evaporates from the exposed ground surface and is transpired from plants. The highest portions of the marsh are flooded only on spring and storm tides and have long periods of exposure and salt buildup. In bare sand flats, salinity values more than twice sea strength are regularly recorded. Above the *Spartina* and *Juncus* zones, which end sequentially around the elevation of mean spring high tide, *Spartina patens* abruptly becomes the dominant species. *Spartina patens* along with other species, most commonly *Distichlis spicata, Borrichia frutescens, Solidago sempervirens*, and *Iva frutescens*, prefer the sandy, drier soils and lower salinity of the High Marsh Zone. Further upstream, where waters are predominantly fresh, a different and more diverse suite of species takes hold (Cooper 1974).

The Gulf Coast marshes extending from Cedar Key, Florida, to Louisiana, are "composed of essentially the same species but their proportions are slightly different" (Cooper 1974). The pattern of *Spartina alterniflora* confined to a narrow fringe along intertidal creeks, *Juncus roemerianus* occurring in extensive stands just above mean high water, and *Spartina patens* at a slightly higher level is repeated along the northeastern Gulf Coast. Mid-, or *Juncus*-dominated, marshes are the predominant type found throughout the Grand Bay NERR (Figure 9.4).

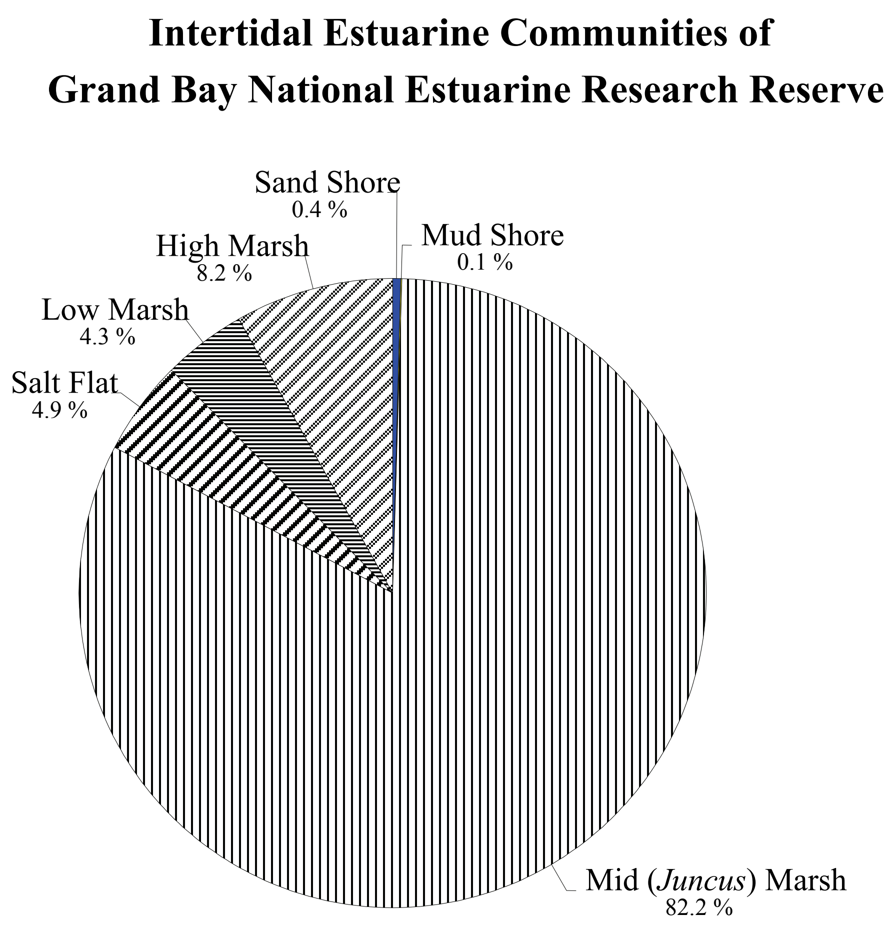


Figure 9.4. Intertidal estuarine communities, shown by percent (%), of Grand Bay National Estuarine Research Reserve. The communities shown here total 3,512 hectares.

15. CO696I Frequently Flooded Saline Marsh (Low Marsh) (S2)

The Frequently Flooded Saline Marsh occurs from -24 cm to +54 cm relative to the Mean Low Water (MLW) line. This zone is inundated from 10 - 87 % of time and is flooded by high tides frequently (from 38 % to 98 % frequency) depending on location within zone. The zone is mostly narrow and fringes the vast irregularly flooded marsh zone but is not present on high energy sand beaches (Eleuterius 1973a).

Spartina alterniflora practically always occurs in a narrow fringe along tidal creeks near their entrance to Mississippi Sound. Few patches are larger than 1 ha in size. This zone is estimated to occupy about 150 ha of estuarine habitat in the Grand Bay NERR. The substrates are soft and mucky whereas substrates of the Mid-Marsh occupies are firm. The Low Marsh fringing Bangs Lake and the North Rigolets area represent the largest patches of this community. Mapped areas do not accurately represent the rather widespread existence of this type because of their small size (Eleuterius 1973a).

This zone represents a near-monoculture stand of *Spartina alterniflora.* The most robust plants occur near mean sea level. Plant height and robustness are reduced as the zone extends inland. These size differences are more evident on broad and gently sloping shorelines. An algal community is associated with this zone.

The lower boundary of the *Spartina alterniflora* zone is open water, where *Ruppia maritima* (widgeon grass) sometimes is present. The upper boundary of the zone is at the interface between *Spartina alterniflora* and *Juncus roemerianus* dominated stands. Short *Spartina alterniflora* frequently extends about 1 meter into the *Juncus roemerianus* stands but its density is greatly reduced. The boundary between the low and mid-marsh is usually abrupt with *Distichlis spicata* occasionally dominant at the boundary (Eleuterius 1973a).

16. CO694I Irregularly Flooded Saline Marsh (Mid-Marsh) (S3)

The range in elevation of the Irregularly Flooded Saline Marsh Community is from +54 cm to +75 cm, relative to the Mean Low Water (MLW) line In contrast to the Low Marsh, this zone is exposed for more than 90 % of the time. The percent of time of inundation, annually, is from 0.9 - 5.4 %. Inundation is considered an irregular event. Depending on location in the zone, 4 - 26 % of the high tides cause inundation. On higher areas of the mid-marsh zone, flooding only occurs during spring tides and storm events. The irregular flooding of the Mid-Marsh causes a build up of salts because of the long and frequent periods of exposure (± one month) and evaporation (Eleuterius 1973a).

The Mid-Marsh zone substrates are classified as Axis soils, a minor series found only in Mobile County Alabama, Jackson County Mississippi, and several counties in Virginia (Table 9.5). Axis soils are Entisols, which show little horizon development. They have a dark grayish-brown, mucky- sandy clay loam surface over dark gray sandy loam subsoil. The surface horizon consists of 8 to 12 % organic materials and occasionally qualifies as an organic horizon. They are often saturated, have a neutral reaction and have an appreciable amount of sulfides close to the soil surface. If drained, the soils become extremely acidic and sterile.

Irregularly flooded saline marsh is the most expansive ecological community of the reserve, covering 2,900 ha (38 %) (Figure 9.5). *Juncus roemerianus* (black needlerush) forms a near monocultural stand and ranges in height from 0.5 to 1.5 m. *Limonium carolinianum* (Carolina sea lavender), *Distichlis spicata* and *Aster tenuifolius* (saline aster) are often present.

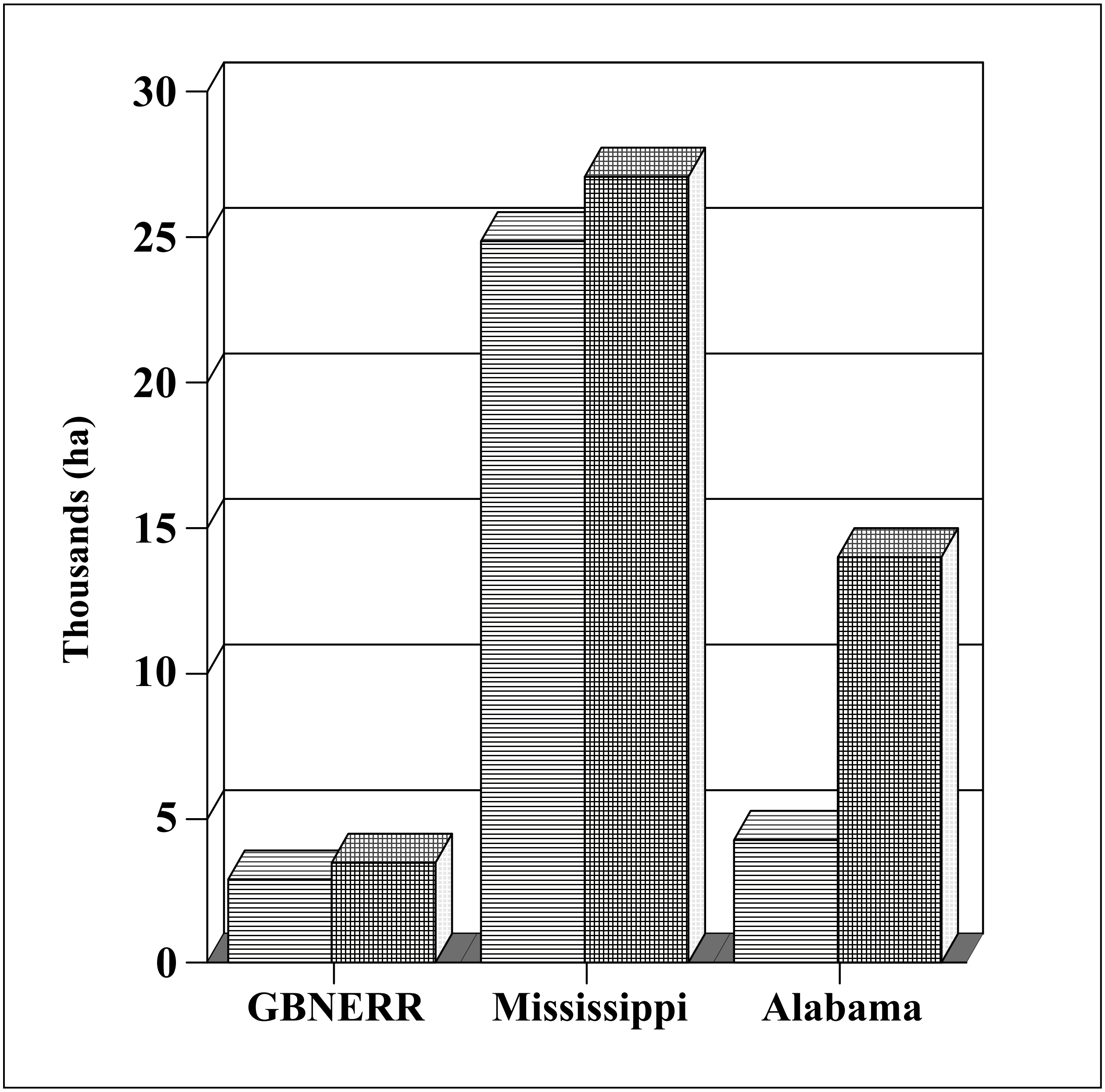


Figure 9.5. Comparison of mid-marsh (*Juncus* marsh; lighter color) and total tidal marsh area (ha; darker color) (adopted from Stout 1984).

In the Mid-marsh zone, *Juncus roemerianus* grows tallest on substrates with the lowest salinity.. At the interface between the mid- and high marsh, *Juncus roemerianus* decreases in density and height as soil salinity increases. In some cases, competition from other species reduces its abundance. *Spartina alterniflora* is commonly found intermixed with *Juncus roemerianus* at the zone's lower boundary. *Spartina patens, Scirpus robustus* (alkali bulrush), and *Scirpus americanus* (American bulrush) often intermix with *Juncus roemerianus* near the zone's upper boundary. The lower boundary is at the point where *Spartina alterniflora* becomes the dominant species; the upper boundary is at the point where *Juncus roemerianus* no longer dominates the community. Salt flats occur sporadically through out the intertidal flats of the reserve.

The Mid-marsh community, dominated by *Juncus roemerianus*, is considered a separate community from the *Juncus* community that occurs in mesohaline waters, such as around bays and at the mouths of the Pascagoula and Pearl Rivers. The marshes found in mesohaline waters are called brackish marsh on Mississippi's Ecological Communities List. The brackish marsh is distinguished from Irregularly Flooded Saline Marsh on the basis of substrates exhibiting lower mean salinity levels. The Irregularly Flooded Saline Marsh community occurs almost exclusively on Axis soils. The Brackish Marsh community is largely isolated to organic soil of the Handsboro series.

17. CO695I Salt Flat (including Salt Panne) (S3)

Large salt panne on Point aux Chenes covered with Salicornia *spp. Adult and juvenile White Ibises congregate on these pannes in the summer and fall to forage. Photo credit: Gretchen Waggy*

The Salt Flat Ecological Community represents a zone of sandy hypersaline soil within the Saline Marsh region and usually occurs slightly upland from the *Juncus* mid-marsh zone. The community is rarely inundated with water. During the long periods of exposure, soluble salts built up in the upper soil horizons. The interstitial soil water salinity reaches euhaline levels, at greater than 30 psu. The Salt Flat community lacks dense or tall vegetation, as found in other parts of the mid-marsh. The increased periods of exposure to solar radiation causes soil temperatures to increase to severe levels. The higher temperatures and drying winds on the exposed areas cause an increase in evapotranspiration rates. Consequently, the salt build up is greater on the Salt Flat community than on adjacent vegetated areas of the tidal marsh. Subsurface moisture will seep from adjacent uplands towards the dryer pannes and import additional salts to the salt flats.

The community usually supports short, halophytic plants. Where the salinity is extremely high, few species can tolerate the hypersaline conditions. The site becomes barren and devoid of vegetation.. The species diversity of the community is low, with five species consistently present: *Salicornia virginica* (Virginia glasswort), *Salicornia bigelovii* (saltwort), *Batis maritima* (turtleweed), *Distichlis spicata*, and *Suaeda linearis* (annual seepweed). Associated with the community are several peripheral species including*, Juncus roemerianus, Limonium carolinianum, Aster tenuifolius,* and *Sabatia stellaris* (rose of Plymouth) (Eleuterius 1972). A majority of salt flat occurrences in Mississippi are located in the Grand Bay NERR, which contains 170 hectares of salt flat community.

18. CO697W Saltmeadow Cordgrass Herbaceous Coastlands (High Marsh) (S2)
Saltmeadow Cordgrass Herbaceous Coastlands represent the high marsh zone, which is inundated less than 0.5 % of time and is flooded only during high spring tides and major storm events. This rare flooding leads to reduced levels of soil salinity for two reasons. The salt meadows are rarely exposed to brackish water and the increased periods of exposure increases the opportunity for rainfall to leach soluble salts from the soil profile. At the Grand Bay NERR, the high marsh covers 286 ha in a narrow band along the upper rim of the mid-marsh zone.

Spartina patens, Spartina americanus, and *Spartina robustus* occur on the fringe of the *Juncus* marsh (Eleuterius 1973a) and can be considered a part of the "high marsh" zone. The high marsh zone is dominated by one grass in particular, *Spartina patens*. Abundance of this grass is the main key to identifying the high marsh community.. Occasionally *Spartina patens* is intermixed with *Juncus roemerianus* (black needlerush) along the lower boundary of the high marsh. *Spartina patens* is often found growing adjacent to salt flats, and sometimes intermixed with other salt tolerant species. Additional herbs commonly found in this habitat are *Andropogon glomeratus* var. *glaucopsis*, *Cynanchum angustifolium*, *Panicum virgatum*, and *Sisyrinchium atlanticum* (eastern blue-eyed grass). A mixture of shrubs is often interspersed with *Spartina patens* such as *Myrica cerifera* (southern bayberry), *Baccharis halimifolia*, and *Iva frutescens*. The exotic *Imperata cylindrica* is occasionally found in this habitat. *Phragmites australis* (common reed) is rarely encountered.

The lower boundary of the high marsh is the transition to the *Juncus* dominated mid-marsh zone. The transition can be abrupt or gradual depending on slope and flooding frequency. The community is considered high marsh when *Juncus* becomes a subdominant species. Small trees of *Pinus elliottii* are occasionally encountered within the high marsh community. The upper boundary of the high marsh is marked by the transition where shrubs or trees become abundant or gain dominance. The Maritime Slash Pine Flatwoods/Savanna Ecological Community is regularly positioned just behind the high marsh zone. Estuarine Shrubland community is occasionally found inland to the saltmeadow cordgrass community.

<u>Intertidal Estuarine Communities (Mud and Sand Shores and Flats) (O)</u>
19. CO603I Unvegetated Mud Shore (S3)
The Unvegetated Mud Shore Ecological Community consists of muddy intertidal flats, exposed tidal creek channels and beach segments that are devoid of vegetation. Mud shores consist of highly erodible silt and clay sized particles and often, a high percentage of organic matter. Along the mainland coast of Mississippi, most unvegetated tidal creek shores are mud shore habitats. Persistently strong seaward winds can amplify the wave retreat during low tide, causing exposure of a larger area of the shoreline. If not regularly exposed on a daily basis, the flats are not considered true intertidal flats (Peterson and Peterson 1979). Nevertheless, they temporarily provide quality-feeding grounds for shorebirds.

This habitat type covers approximately 103 hectares of Mississippi shoreland. The area has been estimate by multiplying the total length of tidal creeks in the state, estimated at 515 km, by mean width of the creek shoreline, estimated at 1 m. Tidal creek length of the Grand Bay NERR is estimated to be 160 km. At 1.0 m width of exposed channel, the total area of exposed mud shore would be about 16 hectares. According to Constanza et al. (1983), who summarized National Wetland Inventory data, Mississippi Gulf Coast mud flats covered 248 ha in 1955, but only 152 ha in 1978. The narrow shorelines are too small to delineate on the map in Figure 9.1.

Mud flats are characterized by salinity level, tidal amplitude, turbulence, exposure to wave action, and nutrient availability (detritus and soluble nutrients). Salinity of Grand Bay NERR subtidal areas is low polyhaline, but varies from season to season. Normal tides in the central GOM are low, averaging from 0.3 m in the Pearl River area to 0.55 m in Biloxi Bay (Christmas 1973).

Embayment, riverine estuary, bayou, and most salt marsh shorelines are protected from the open winds. In the protected areas, the shorelines are more stable but some actively erosion is likely. Muddy sediment is easily suspended by wave action, even in protected areas. This increases the turbidity of flood tide waters and reduces penetration of sunlight. Turbidity inhibits phytoplankton and benthic algae productivity. Areas with sandy substrates tend to have less turbidity (Peterson and Peterson 1979).

Significant erosion of mud shores along the Mississippi coast has occurred in areas directly exposed to winds. The narrow mainland shoreline between Waveland - Clermont Harbor and the Pearl River Delta is almost exclusively soft, easily erodible marsh substrates. Along Pt. aux Chênes, Point Clear, and St. Joseph Point, forming part of the Mississippi Sound shoreline, erosion rates are high, averaging 2 to 3 m/yr (Otvos 1976). At these locations, the muddy shorelines are the remnants of eroded salt marsh substrate.

Estuarine habitats, especially shoreline areas, are very dynamic. Seasonal climate changes, variable weather patterns, and diurnal tides help to shape the coastal shoreland. Daily temperature variation represents a large percentage of the total annual variation. High temperatures, inundation and exposure create a harsh physical environment for both plants and animals. During low tide, exposure of the substrate to sun, air and wind, causes rapid temperature shifts, increased desiccation, overheating and death to many invertebrates. Environmental rigors increase from the subtidal zone to the top of the mud shore (Peterson and Peterson 1979).

Mud shores can appear to be quite barren if the common contingent of crabs or birds happens to be absent. Upon closer inspection, mud flats prove to support a wide diversity of species from bacteria, algae, and diatoms to mollusks, crabs, and a plethora of birds. Peterson and Peterson (1979) concluded that intertidal flats were important for what “consistently happens” on them rather than what is permanently found there. Mudflats along the North Carolina Coast support a diverse group of life forms,, at least temporarily (Peterson and Peterson 1979). Similar species groups are likely found along Mississippi’s coastland. General categories of inhabitants are microalgae, fungi, bacteria, microfauna, meiofauna, macrofauna, other invertebrates, fish, and birds. Unvegetated Mud Shore Ecological Communities serve as important nursery grounds for fisheries where high tides frequently cover the area. However, mud shores along the central Gulf Coast provide less valuable fish habitat (Constanza et al. 1983).

Unvegetated sand and mud shore with Dunlins feeding in the foreground and White Pelicans behind. Photo credit: Gretchen Waggy

Birds are clearly the most conspicuous element of the intertidal mud shore. Birds using the intertidal flats can be classified into six different feeding guilds: 1) waders (i.e., herons, egrets, ibises, yellowlegs); 2) shallow-probing and surface searching shorebirds (sandpipers, plovers, knots, oystercatcher); 3) deep-probing shorebirds (godwits, willets, curlews); 4) aerial-searching birds (terns, gulls, skimmers, pelicans, king-fishers); 5) floating and diving water birds (ducks, grebes, geese, loons, cormorants); and 6) birds of prey (osprey, hawks, eagles, owls). Mud and sand flats are critically important for wading and deep- and shallow-probing birds that feed almost exclusively in these areas. The intertidal flats are of greater significance than salt marshes, seagrass beds, and other estuarine areas especially for the probing and wading shorebirds, but also for some of the other guilds of birds (Peterson and Peterson 1979). The large variety of shorebirds found in the Grand Bay NERR is indicative of the importance of mud shores to the estuary.

20. CO602I Unvegetated Sand Shore (S1)

The Unvegetated Sand Shore or Natural Sand Beach Ecological Community occurs along the northern edge of the barrier island chain, around Deer and Round Islands and along a few erosional strips of Mississippi's mainland, Bellefontaine Beach and Grand Batture Islands in Jackson County (Otvos 1976). Unvegetated Sand Shore habitats of the barrier islands along Mississippi Sound reach about 60 km in length. Beaches of the northern barrier islands are narrow, often quite steeply sloped, and locally contain vertical cliffs. Well-sorted, fine to coarse sand, composed of quartz and minor amounts of shell and heavy minerals, constitute these beaches (Waller and Malbrough 1976). Sand dunes commonly adjoin them. A few minor segments of sand beaches exist along the Hancock County marsh shoreline at Point Clear (0.6 km long, 0.6 ha total area) and 1.5 km to the southwest of Point Clear.

The sand beaches of the Grand Bay NERR extend for approximately 4 km and cover approximately 15 ha. Sand and shell fragments constitute the Grand Batture beaches. The beaches are used as nesting beaches by the diamondback terrapin (*Malaclemys terrapin*), a threatened aquatic turtle that is found at the Grand Bay NERR. Meyer-Arendt and Gazzier (1990) noted erosion rates of between two and three meters per year for southeast facing marshes of Hancock County and Pt. aux Chênes. Other reports indicate even higher rates (4.6 m/yr) for Grand Batture headland. These headlands as surveyed in 1853 consisted of 180 ha of barrier spits. By the 1950's they had been reduced to a patch of shallow shoals (Meyer-Arendt and Kramer 1991). The remaining natural beach segments along the mainland consist of soft, easily erodible marsh deposits (Otvos 1976).

9.3.3. Estuarine Subtidal Habitats

The Grand Bay NERR area is situated on the northeastern flank of the Mississippi Sound. The Mississippi Sound is described as a lagoon of marine origin. The Sound extends about 130 km along the coasts of Louisiana, Mississippi, and Alabama, ranges from 11 to 24 km wide, has a mean water depth of 3.6 m (Vittor 1982), and has a total surface area of 213,000 ha. Twenty five percent of the Sound is less than 2 m deep (Nearshore Habitat); 99 % is less than 6.1 m deep (75 % is Offshore Habitat) (Higgins and Eleuterius 1978). The subtidal estuarine areas of the Grand Bay NERR contain a variety of habitats including: submerged aquatic vegetation beds; mollusk reefs; estuarine embayments, lakes and ponds; tidal channels; and Mississippi Sound unconsolidated bottom habitats.

Salinity levels of the Mississippi Sound have been classified into zones (Perry and Christmas 1973) and mapped in a hydrographic atlas (Eleuterius and Beaugez 1979). The mean seasonal surface and bottom salinity levels of estuarine waters of Pt. aux Chênes Bay in the Grand Bay NERR have been recorded as 15 psu (practical salinity units; spring), 23 psu (summer), 27 psu, (fall), and 25 psu (winter). From these averages, it can be concluded that Pt. aux Chênes Bay waters would be classified as Zone 4 level, generally falling in the low polyhaline level (Cowardin et al. 1979). Bayou Cumbest, Bayou Heron, tidal creeks, Bangs Lake, Middle Bay and other shallow water bodies have somewhat lower seasonal salinity levels, likely in the high mesohaline range.

The eastern part of the Sound, which includes part of the Grand Bay NERR site, is dominated by water inflow from Mobile Bay and Petit Bois Pass and generally contains waters higher in salinity than those found further west along the Mississippi mainland. The general current movement on both northern and southern shores of the Sound is westward and sufficiently strong to induce a gradual westward drift of sand sized sediments (TerEco 1979).

Submerged Aquatic Vegetation Beds (P)

21. CP692U Widgeon Grass Bed (S2)

The Submerged Aquatic Vegetation or Embayment Seagrass Bed Ecological Community is found in bays, along banks of bayous, and on mud flats, i.e., areas off Pt. aux Chênes Bay, Biloxi Bay, and St. Louis Bay in Mississippi (Eleuterius 1973b, 1987, 1990). The grassbeds of this ecological community are dominated by a single non-emergent species of seagrass, *Ruppia maritima* (widgeon grass). Widgeon grass has sharply pointed thread-like leaves and almost equally thin rhizomes. Widgeon grass produces an abundance of tiny flowers at the tips of elongated peduncles that elevate flowers to an exposed position at the water surface. The exposure of the flower to the atmosphere at the water surface enables it to complete the process of pollination. Following fertilization, the peduncle recoils and submerges the inflorescence, which remains submerged during the development of the seed. *Ruppia maritime* prolifically disseminates seed, whereas most other seagrasses reproduce vegetatively. (Britton and Morton 1989).

Widgeon Grass bed in Grand Bay at low tide. Photo credit: Chris May.

Widgeon Grass is found along the Atlantic Coast of North America from northern Canada to northern Mexico (Britton and Morton 1989). It is found in great abundance in the northern Gulf Coast from Florida to Texas, but diminishes in importance in Mexico (Zieman and Zieman 1989, Borom 1979, Eleuterius 1987, Britton and Morton 1989). The north shore of Lake Pontchartrain supports an abundance of *Ruppia* (Montz 1978).

Although *Ruppia maritima* survives in euryhaline waters in Texas and Florida (Zieman and Zieman 1989), it prefers low-salinity waters in Mississippi, (2 - 10 psu) (Eleuterius 1973b, 1987). Franks (1970) observed thick growths in nearshore polyhaline waters off of Horn Island. Its occurrence in oligohaline or freshwater situations in Louisiana clearly indicates that it is well adapted to areas with lower salinity (Zieman and Zieman 1989).

Eleuterius (1973b) noted widgeon grass usually occurs on shallow (0.1 m to 1 m) muddy bottoms adjacent to a muddy beach or marsh. It thrives best in shallow areas where the leaves remain submerged at the lowest tide levels (Britton and Morton 1989) but can survive at a depth of around 2 m (Montz 1978). Often the beds are exposed during low tide along the edges of *Juncus* salt marshes (Eleuterius 1990). *Ruppia maritima* persists in areas of poor light penetration and high turbidity better than other seagrasses (Zieman and Zieman 1989).

The range of *Ruppia maritima* beds have fluctuated dramatically in Mississippi over the past 40 years. Hurricanes, such as Hurricane Camille, push high salinity waters through beds and subsequently heavy stream discharges eroded many of the beds established in rivers and bayous. Few patches of widgeon grass were found along Mississippi Coast through 1968 and 1969, with only small patches located in the extreme upper reaches of tidal bayous and rivers. However, seventeen years later the distribution of *Ruppia* beds had dramatically increased; luxuriant patches were found in areas previously devoid of seagrasses (Eleuterius 1987). Eleuterius (1973b) estimated that two thousand hectares of *Ruppia maritima* and *Vallisneria americana* (American wildcelery) seagrass beds existed in the Mississippi Sound. In 1987, Eleuterius observed that *Ruppia maritima* was more widely distributed than other seagrasses.

In 1992, U.S Fish and Wildlife Service mapped widgeon grass beds on the Grand Bay NERR and found 21 patches scattered across the reserve (U.S. Fish and Wildlife Service 1996). The patches ranged in size from less than one hectare to 100 hectares and totaled 147 hectares. The beds were found in protected areas behind the Grand Batture Headland and in Middle Bay, where the largest patch was located (Table 9.4).

Mollusk Reef (Q)

22. CQ601U Mollusk Reef (S3)

In the GOM, *Crassostrea virginica* usually occurs in subtidal areas or on the lower intertidal banks of mesohaline bays and bayous occasionally extending into the edges of *Spartina* marshes (Heard 1982). Physical factors affecting the growth of oysters are substrate, temperature, salinity, turbidity, and abundance and type of food species (McGraw 1980, Shabica and Watkins 1982). Sedimentation studies on Biloxi Bay oyster reefs by Hoskin (1972) and Otvos (1976) found that substrates from these Mollusk Reefs had mean gravel (shell) content of only 10 %. In addition, the textures of sediments associated with these reefs typically were sandy mud, sandy clay, and gravelly, muddy sand.

In 1984 only 14 hectares of mollusk reef was reported in the Grand Bay NERR (U.S Army Corps of Engineers 1984). Small patchy reefs have been reported in the center and southern portions of Bangs Lake, around the fringes of Middle Bay, especially along its north shore, along bayous and inlets south of Crooked Bayou (Jose Bay) and along Bayou Cumbest (Tommy Van Devender, Per. Com.). Due to its high salinity and loose unconsolidated substrate, Pt. aux Chênes Bay does not support oysters in water greater than one meter deep. In 1998, the Department of Marine Resources estimated that about 260 ha of Mollusk Reef were located in the Grand Bay NERR (Table 9.4).

Estuarine Embayments, Lakes, Ponds, Tidal Channels (R)

23. CR605U Mainland Coast Pond/Lake (S3)

The Mainland Coast Pond/Lake Community is part of the estuarine marsh complex found along the coastal mainland. Tidal marsh ponds originate from basin flooding caused by a rise in the sea level or by the blockage of tidal marsh creeks. Subsequently the blocked creeks form into a network of elongated ponds (Chabreck 1988). The lakes are very shallow, ranging from a few decimeters to a few meters in depth, and have substrates that are predominately muddy (Minshew et al. 1974). The habitat characteristics of tidal marsh lakes are probably closely similar to those for tidal marsh creeks, rivers, and inland embayments. There are over 140 Mississippi mainland coast tidal marsh lakes and ponds. Over 40 are named on topographic maps. Examples of water bodies are Bangs Lake, Graveline Bay Lake, Beardslee Lake, and Campbell Lagoon. The total estimated area of all occurrences of this ecological community type in Mississippi is 1,513 ha, most of which are tidal marsh pools and lakes. Forty-one of ponds are situated within swamp forest vegetation. The Grand Bay NERR site contains 186 ha of this habitat type.

24. CR601U Tidal Creek (S3)

Tidal creeks or tidal bayous are estuarine water channels; larger river channels influenced by tides are not included in this habitat type. Mississippi estuaries support three types of tidal creeks: 1) tidal marsh creeks primarily draining sea level (or slightly higher) marshes; 2) coastal tidal creeks serving as minor conduits for freshwater discharge from surrounding uplands; and 3) riverine estuary bayous serving as supplementary distributary channels within a riverine estuary. Tidal creeks form a dendritic pattern in tidal marshes and serve as conduits for rapidly discharging water during falling tides (Chabreck 1988). The tidal creek habitat type refers to open water channels that do not support a significant growth of submergent vegetation.

Constanza et al. (1983), in listing National Wetland Inventory (NWI) statistics, noted that the cumulative area of rivers, streams, and bayous in the Mississippi Sound hydrologic unit was 1,827 ha in 1978, down from 1,980 ha in 1955. Collectively, the Grand Bay NERR site has a total of 160 km of tidal marsh creeks and coastal tidal creeks. The total area of tidal creeks is quite small. Tidal creeks are nevertheless important habitats, considering the large numbers of species that use them. Tidal creeks serve as an interface between subtidal and intertidal habitats and allow species access to the mid-marsh zone. Tidal bayous are good habitats to find rails, hooded mergansers, a variety of herons, and other birds. Juvenile fish and invertebrates use tidal creeks to enter and exit the marshes during high tide.

The character of tidal creeks is influenced by tide levels and type of sedimentary materials. Sandy mud or muddy sand substrates are typical for most tidal creeks. The salinity of the tidal creeks normally falls within the polyhaline and mesohaline levels. Streams are classified as the Freshwater Creek Ecological Community or Tidal Freshwater Marsh Ecological Community when salinity falls below these levels. Other important environmental factors include salinity, temperature, pH, dissolved oxygen, and turbidity. For tidal creeks with small flow rates and shallow depth, temperatures get much warmer due to solar heating in summer and more readily freeze in winter (Eleuterius 1974).

Mississippi Sound Unconsolidated Bottom Communities (S)

25. CS603U Mississippi Sound - Nearshore Mixed-fine Bottom (S4)

Mississippi Sound - Nearshore Mixed-fine Bottom Ecological Community refers to subtidal areas which are less than 2 m in depth and have bottoms that are muddy sand (substrates with 50 - 85 % sand). Total area of Mississippi Sound within the Grand Bay NERR that is less than 2 m deep is 1,394 ha. The shallow depths allow for sandier sediments, more sediment mixing, and higher turbidity from wind and waves. The texture of nearshore substrates has not been classified for the Grand Bay NERR. Substrates have been classified for offshore areas throughout Mississippi Sound (Ludwick 1964, Vittor 1982). Areas of the Mississippi Sound falling in Alabama were mapped by Lamb and Isphording (1980), who completed a transect just adjacent to the Grand Bay NERR, along the border of Mississippi and Alabama. They determined that silty sand, which falls in the muddy sand bottom category, occurs east of Middle and Jose Bays.

26. CS606U Mississippi Sound - Offshore Mixed-fine Bottom (S4)

Mississippi Sound - Offshore Mixed-fine Bottom refers to subtidal areas that are greater than 2 m deep and have substrates with textures of 50 - 85 % sand. The Grand Bay NERR site has only a small subtidal area over 2 m deep (135 ha) (See U.S.G.S. Grand Bay SW Quadrangle Map). Extrapolating from studies by Ludwick (1964), Lamb and Isphording (1980) and Vittor (1982), substrate texture for this part of Grand Bay NERR is expected to be poorly-sorted medium silt to very fine sands, which fall in the muddy sand category. Microorganisms most characteristic of the muddy sand habitat often associate positively to sand percentage, kertosis (a measure of skewness of data), and depth. Surface and subsurface feeders are the predominant feeding types of this habitat. Other benthic organisms are suspension feeders, scavengers, or carnivores. The largest biomass of this community of organisms is attributed to echinoderms and polychaetes.

The community supports an outstanding benthic community (Vittor's 1982). Notably the density of microorganisms is much higher than that of the mud habitats and the species richness is highest among the three offshore habitats of Mississippi Sound.

9.4. MONITORING AND RESEARCH NEEDS

Being part of a relatively undisturbed area of the Mississippi coastal landscape Grand Bay NERR was chosen as the best location for an estuarine research site in Mississippi. The need for the conservation of coastal wetland communities and species that form the fabric of the landscape is another driving force for the establishment of the Grand Bay National Estuarine Research Reserve. The enjoyment of seeing an abundance of native plant and animal species and a view of a landscape displaying ecological patterns and processes in a mosaic of communities is a benefit that will continue to accrue far into the future of this management area.

Several suggestions for research opportunities in the Grand Bay NERR are listed below, although this list is not a comprehensive review of opportunities associated with this chapter.

- Compare soil characteristics of the salt marsh zones, especially interstitial soil salinity, with vegetation composition
- Further characterize habitats especially the high marsh, pine flatwoods/savanna, wet coastal prairie, and freshwater marshes
- Determine gradient of plant diversity along a transect extending from subtidal areas to inland wet pine savannas
- Conduct additional surveys for plant and animal species of conservation concern
- Complete a more detailed classification of Grand Bay NERR vegetation using high resolution aerial photography
- Monitor widgeon grass (*Ruppia maritima*) beds
- Map bottom texture of subtidal areas
- Determine the danger of abandoned crab pots to mortality of non-target species, remove pots when located
- Conduct additional survey work to improve the accuracy of habitat type maps and locate additional areas of rare community types (slash pine with wiregrass)
- Study the mud shore community and determine its importance to the ecology of the tidal marshes

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CHAPTER 10

VEGETATION

Shelia Brown

The Grand Bay National Estuarine Research Reserve (NERR) encompasses 7,446 hectares and represents an extremely significant area of the Northern Gulf Coast region. The property contains tidal and nontidal wetlands and maritime forest communities. The tidal wetlands include brackish and salt marshes, while the nontidal wetlands consist of wet pine savannas, coastal bayheads, cypress swamps and freshwater marshes. Nontidal wetland habitats grade into and interface with the tidal marshes. The diversity of vegetation is represented in the partial list of plants in Appendix 10.A.

Grass Pink Orchid. Photo credit: Gretchen Waggy.

10.1 TIDAL WETLANDS

10.1.1 Salt Marshes

Spartina alterniflora (smooth cordgrass), *Juncus roemerianus* (black needlerush), and *Spartina patens* (saltmeadow cordgrass) dominate the southern most regions of the Grand Bay NERR bordered by the Mississippi Sound. These tidal marsh plants are distributed over most of the salinity range from brackish to saline marshes (Mississippi Department of Marine Resources 1998). Elevation and tidal inundation influences the distinct zonation of these plants. The estuarine areas are composed of low, mid, and high marsh zones. In the low marsh areas regularly flooded by tidal activity, the mesohaline habitat consists of smooth cordgrass. The mid-marsh zone irregularly flooded by tidal activity is dominated by black needle rush which typically occupies more than 90 % of the zone in pure stands or intermixed with *Distichlis spicata* (salt grass) in oligohaline areas. Salt grass may occur in pure stands or with *Scirpus robustus* (salt-marsh bulrush) and *Scirpus americanus* (common three-square) (Eleuterius 1973). The oligohaline and mesohaline regions are typically dominated by saltmeadow cordgrass. Some high marsh regions have intermingled associations of the saltmeadow cordgrass, salt grass and *Salicornia virginica* (glasswort) and the short form of black needlerush. Other high marsh inhabitants are *Limonium carolinianum* (sea lavender), *Agalinis maritima* (salt-marsh false foxglove), *Fimbristylis caroliniana* (spike sedge), and *Borrichia frutescens* (sea ox-eye). *Spartina spartinae* (gulf cordgrass) is found in GBNERR marshes and the presence of this high marsh plant in the Reserve represents the eastern limit of its distribution.

10.1.2 Salt Flats and Pannes

Virginia glasswort. Photo credit: Gretchen Waggy.

Scattered across the Reserve are small but distinct, sparsely vegetated zones with pore salinities ≥ 30 psu. These areas are called salt pannes or flats, which are usually associated with the high marsh, but also occur along tidal creeks, Indian middens, and oligohaline and mesohaline marshes. The hypersaline soils in these areas restrict both plant species growth and diversity (Stout 1984). The pannes form as tidal water collects in the depressions, and the subsequent evaporation of the trapped water causes the high soil salt concentration. Species of these areas are salt tolerant species and include two species of glassworts, the perennial *Salicornia virginica* (Virginia glasswort) and the annual *Salicornia bigelovii* (dwarf saltwort). *Batis maritima* (saltwort) and *Suaeda linearis* (annual seep weed) are typically found on the fringes of these habitats. Plants that frequently border these flats or pannes are sea lavender, *Aster tenuifolius* (saline aster), *Sabatia stellaris* (marsh pink), salt grass, gulf cordgrass, *Baccharis halimifolia* (saltbush), *Iva frutescens* (marsh elder) and sea ox-eye.

10.1.3 Open Water Habitats

The muddy to sandy bottoms in the southeastern portion of the Reserve support submerged aquatic vegetation (SAV) beds of *Ruppia maritima* (widgeon grass), a species found in saline waters less than 10 psu, and one seagrass, *Halodule wrightii* (shoalgrass). These two species are the only aquatic "grasses" still found in relative abundance in the Mississippi Sound (Moncreiff et al. 1998) as well as within the Grand Bay NERR boundaries (Chris May, Personal communication).

Widgeon grass reproductive shoots from Middle Bay, Grand Bay NERR. Photo credit: Chris May.

10.1.4 Maritime Forest

The maritime forests are located along Heron Bayou, Bayou Cumbest, and Crooked Bayou. The dominant overstory species is *Pinus elliottii* (slash pine) with some *Quercus virginiana* (live oak), and *Magnolia* spp. A variety of understory species are found with *Myrica cerifera* (wax myrtle) and *Ilex vomitoria* (yaupon holly) as the dominate species. Often salt tolerant shrubs marsh elder and saltbush border these areas.

10.1.5 Native American Shell Middens

Coral Bean in flower. Photo credit: Gretchen Waggy.

The Native American shell middens found along the bayou system are diverse plant communities bordered by sedges, grasses and shrubs typical of the marshes. Community structure is similar to that reported by Eleuterius and Otvos (1979) for Hancock county middens. Middens are documented to have at least 62 species of plants. An exact inventory of plants for GBNERR middens has not been reported. Live oak, *Juniperus virginiana* (eastern red cedar), *Diospyros virginiana* (American persimmon), *Morus rubra* (red mulberry), and *Zanthoxylum clava-herculis* (Hercules' club) are trees established on the middens. Common shrubs include marsh elder, wax myrtle, saltbush, and sea ox-eye. Small shrubs of *Erythrina herbacea* (coral bean), *Yucca aloifolia* (Spanish bayonet), *Aesculus pavia* (red buckeye) and the vines *Ampelopsis arborea* (peppervine), *Smilax bona-nox* (saw greenbrier), *Toxicodendron radicans* (eastern poison ivy), *Vicia ludoviciana* (Deer pea or Louisiana vetch) dominate. *Sideroxylon lanuginosa* (buckthorn bumelia), coral bean and *Physalis angustifolia* (ground cherry) represent unique plants of the middens (Department of Marine Resources 1998).

10.2. NON-TIDAL WETLANDS

10.2.1 Wet Pine Savanna

Orange Milkwort. Photo credit: Gretchen Waggy.

Eleuterius and Jones (1969) reported that the herbaceous flora of coastal savannas is characterized by about 285 species representing 64 families. Wet pine savannas are dependent upon fire to maintain what is likely the most diverse habitat type in the United States with plant densities of up to 20 species/0.25 meter^2 (Brewer 1998). The proliferation of the pitcher plants and native orchids of the savannas make these habitats unique and valuable floristic zones (Eleuterius and Jones 1969). Two types of savannas exist in the GBNERR. Hydric savannas are found in areas of slight depression at the base of slopes and mesic savannas are found on the flat region of the Reserve. The hydric savannas are covered by water or saturated to the surface for several months of the year, while mesic savannas are not saturated to the surface for long periods throughout the year (Department of Marine Resources 1998). Vegetation distribution is similar in both hydrologic regimes with a few indicator species in the mesic. Woody shrub species such as *Ilex glabra* (inkberry), yaupon holly, and *Vaccinium* spp. (sparkleberry and blueberry) often intermingle with overstory species in the more mesic savannas (Brewer 1998). The wet pine savannas may have *Pinus palustris* (Longleaf pine) and slash pine as overstory vegetation.

Shrubs are poorly developed in the fire-managed areas and are extensive in the regions not burned for prolonged periods. Inkberry, *Ilex coriacea* (large gallberry), wax myrtle, sparkleberry and blueberry, *Gaylussacia* spp. (huckleberry), various *Hypericum* spp. (St. Johnswort), *Styrax americana* (snowbell), and *Cyrilla racemiflora* (swamp titi) are the predominant shrubs found in these areas. Both longleaf pine and slash pine trees coexist with *Taxodium ascendens* (pond cypress), *Taxodium distichum* (bald cypress), *Acer rubrum* (red maple), *Nyssa biflora* (swamp tupelo or black gum), and *Magnolia virginiana* (sweetbay magnolia) in depressions and areas with greater soil moisture.

Whitetop Pitcher Plants. Photo credit: Gretchen Waggy.

Unique to the wet pine savannas are carnivorous plant species, which are adapted to moist, acidic and low nutrient soils. The most abundant of the four species of pitcher plants found on the property is *Sarracenia alata* (pale yellow pitcher plant). Other members of the genus are *Sarracenia leucophylla* (whitetop pitcher plant), and the much more ephemeral species *Sarracenia psitticina* (parrot's beak pitcher plant), and *Sarracenia purpurea* (purple or sidesaddle pitcher plant). The Reserve may have hybrid plants of the *Sarracenia* genus present. Other less conspicuous carnivorous plants found are the butterworts and sundews: *Pinguicula planifolia* (Chapman's butterwort), *Pinguicula lutea* (yellow butterwort), *Drosera brevifolia* (dwarf sundew), *Drosera capillaris* (pink sundew), *Drosera filiformis* (thread-leaf sundew), and *Drosera tracyi* (Tracy's sundew). Semi aquatic species of *Utricularia* spp. (bladderwort) exist within the Reserve.

A wide variety of herbaceous perennials are conspicuous on the savanna and include pteridophytes *Woodwardia areolata* (netted chain fern), *Woodwardia virginica* (Virginia chain fern), *Osmunda regalis* (royal fern) and *Lycopodium* spp. (club mosses). Grasses present are *Ctenium aromaticum* (toothache grass), *Schizachyrium* spp. (bluestem), *Andropogon* spp. (broomsage), *Astrid* spp. (threeawn), *Panicum* spp. (panicgrass), and *Paspalum* spp. Sedges include the genera *Rhynchospora* (beaked sedges) and *Scleria* (nut sedges) and *Eleocharis* (spikerush). Other non-carnivorous flora includes *Eriocaulon* spp. (pipewort), *Eupatorium* spp.

(thoroughwort), *Xyris* spp. (yellow-eyed grasses), *Aletris lutea* (yellow colic root), *Lachnanthes caroliana* (redroot), *Lophiola americana* (golden crest), *Bigelowia nudata* (flat-topped goldenrod), *Rhexia mariana* (meadow beauty), *Proserpinaca* spp. (mermaid-weed), *Polygala* spp. (milkwort), *Asclepias* spp. (milkweed), A*ster* spp., and *Balduina* spp. (honeycombhead).

The Grand Bay Savanna is one of the 24 sites designated Stage 1 by The Nature Conservancy (TNC, 2001) in the East Gulf Coastal Plain Ecoregional Plan. Regions are designated as Stage 1 based on significant biodiversity, high level of threat to the continued existence, the ecological systems are intact, and are high leverage sites where it is feasible for TNC to work.

10.2.2 Cypress and Bayhead Swamps

Cypress swamps within the GBNERR are characterized primarily by the presence of water tolerant trees and shrubs. Similar to marshes in hydrology, swamps contain dominant woody vegetation. Species found within these areas are pond cypress, and to a lesser extent bald cypress, *Nyssa sylvatica biflora* (black gum), *Magnolia virginiana* (sweetbay magnolia), *Persea palustris* (red bay), red maple. Shrub species such as swamp titi, large gallberry, inkberry, yaupon holly, *Itea virginica* (sweetspire), *Lyonia lucida* (fetterbush), and *Viburnum* spp. are often found bordering the wetter areas of the swamps. Grass and sedge species in the genera of *Carex* sp., *Panicum* sp., and *Rhynchospora* sp. edge the swamps.

Meadowbeauty growing in a wet pine savanna. Photo credit: Gretchen Waggy.

Bayhead communities occur in the lower coastal plain areas of the state, and they develop in branch heads of streams and swamp borders. The bayhead swamps drain better than the cypress swamps yet share similar community structure. The soils are sandy and acidic and are saturated or inundated throughout most of the growing season. Vegetation consists mostly of water-tolerant trees - including various kinds of "bays." Sweetbay magnolia, *Nyssa sylvatica* var. *biflora* (black tupelo), *Persea palustris* (redbay) predominate in bayhead swamps. The understory typically consists of species such as: swamp titi, large gallberry, inkberry, yaupon holly, *Lyonia lucida* (fetterbush), *Leucothoe axillaris* (dog-hobble), *Leucothoe racemosa* (swamp sweetbells), and *Viburnum* spp. Ferns are often found in the shadier areas bordering drainage areas of the bayheads. Common residents are netted chain fern, Virginia chain fern, royal fern, and cinnamon fern.

10.2.3 Freshwater Marshes

Students in a Grand Bay NERR freshwater marsh during a wetland plant identification class. Photo credit: Gretchen Waggy

In some areas of the Reserve, there are tidal freshwater marshes and swamps. In these regions, the lower salinity levels support higher plant biodiversity than observed for the salt marshes. Tidal freshwater marshes and swamps are located in areas where there is tidal influence, but the tidal flux is not significant enough to alter the salinity of the water from fresh to brackish but does influence water level (Department of Marine Resources 1999). Freshwater marshes are found in depressions of the wet pine savanna regions or in transition zones of the bayheads (Department of Marine Resources 1998). These marshes appear as pure stands of plants or as mixed associations of grasses, sedges and rushes. *Panicum virgatum* (switchgrass) and sedges of the genera of S*cleria* sp., *Rhynchospora* sp., and *Cladium* sp. are the species commonly observed. The wettest depressions of these freshwater marshes contain *Nymphaea odorata* (fragrant water lily), *Sagittaria lancifolia* (lance leaved arrowhead) or *Sagittaria graminea* (grassy arrowhead), *Eleocharis equisetoides* (jointed spikerush) and *Crinum americanum* (swamp lily).

10.3 INVASIVE SPECIES

The presence of invasive species represents a major threat to the biodiversity of the Reserve, and in particular, significant to rare and common species. Six of the ten worst invasive weeds of Mississippi (Winter et al. 2001) are conspicuous and abundant within the Reserve. The invasive species include *Alternanthera philoxeroides* (alligator weed), *Triadica sebifera* (Chinese tallow tree), *Lonicera japonica* (Japanese honeysuckle), *Ligustrum sinense* (Chinese Privet), *Imperata cylindrica* (cogon grass) and *Eichornia crassipes* (water hyacinth). Other invasive species include *Lygodium japonicum* (Japanese climbing fern), *Cassia obtusifolia* (sicklepod), *Crotalaria spectabilis* (showy rattlebox), *Panicum repens* (torpedo grass), *Sesbania herbacea* (hemp sesbania or bigpod), and *Cinnamomum camphora* (camphor tree). The two most prevalent and widespread invasive species on the property are Chinese tallow tree and cogon grass. In disturbed areas along highways, roads, and trails of the Reserve, monospecific stands of cogon grass exist and appear to be encroaching on savanna and scrub regions. The Chinese tallow trees are present in pure stands and intermingle with other plant communities. Some Chinese tallow trees are now present in marsh zones.

10.4 PLANTS OF INTERST

Fifty species of special interest plants (Table 10.1) grow or are suspected to grow within the Reserve boundary. These plants are recognized and ranked by status by the TNC (2001). Many of these species are rare and endangered species, and include carnivorous plants and orchids. In addition two plants species found in the reserve represent the eastern most edge of their range: gulf cordgrass of the tidal marshes and creeks and *Bumelia lycioides* (ironwood or buckthorn bully) of the middens (Department of Marne Resources 1998). Widgeon grass is a significant submerged aquatic species found in high salinity areas (Department of Marine Resources 1998).

Orchid species of the Reserve represent a significant group of plants of concern. These include *Calopogon barbatus* (bearded grass pink), *Calopogon pulchellus* (grass pink), *Calopogon multiflorus* (many-flowered grass pink), *Cleistes divaricata* (spreading pogonia), *Platanthera blephariglottis* var. *conspicua* (white fringed orchid), *Platanthera integra* (yellow fringeless orchid), *Platanthera nivea* (snowy orchid), *Spiranthes longilabris* (giant ladies' tresses), and *Spiranthes praecox* (greenvein ladies' tresses). Grand Bay NERR has a great opportunity to sustain orchid and carnivorous species through fire management strategies.

Pink Sundew. Photo credit: Gretchen Waggy

10.5 MONITORING AND RESEARCH NEEDS

The Nature Conservancy (Beck 2000) has included salt marshes (polyhaline, mesohaline, and oligohaline), tidal fresh marshes and intertidal scrub/forest as priority habitats in their ecoregional plan of the Northern Gulf of Mexico. These habitats represent targeted habitats for conserving biodiversity. As part of this ecoregion rich in biodiversity and habitat diversity, I make the following survey, inventory, and research recommendations for the GBNERR:

- Inventory of vegetation to include phenology and genetic studies.
- Restoration and maintenance of wet pine savanna / pine flatwood habitat types through fire management and tree thinning.
- Control of invasive species, particularly congongrass and Chinese tallow, in wet pine savanna, pine flatwoods, and freshwater wetlands.
- Employ hyperspectral analyses for biological and historical references.
- Establish a seed bank for restoration purposes.
- Conduct a quantitative inventory and survey of plants found on Native American shell middens.
- Determine the effects of fire on tidal marshes.
- Restore the submerged aquatic vegetation beds (*Ruppia maritima*) that were present in Bayou Cumbest prior to Hurricane Katrina.

Table 10.1. Rare Plants Documented from the Grand Bay National Estuarine Research Reserve in Jackson County, Mississippi Ranked by Global Status (Rangewide) and Mississippi Status* (The Mississippi Natural Heritage Program ranking system definitions given at bottom of the table.)

Scientific Name	Common Name	Global Rank					Mississippi Rank				
		G2	G3	G4	G5	Q	S1	S2	S3	S4	S5
Agalinis aphylla	Coastal Plain False-Foxglove		√	√				√	√		
Agalinis filicaulis	Thin Stemmed False-Foxglove		√	√				√?			
Agalinis linifolia	False-Foxglove			√?							
Aristida spiciformis	Pine-Barren Three-Awned Grass			√			√?				
Aster chapmanii	Chapman's Aster	√	√								
Burmannia capitata	Bluethreads		√								
Calopogon barbatus	Bearded Grass-Pink				√?						
Calopogon multiflorus	Many-Flowered Grass-Pink		√								
Canna flaccida	Golden Canna				√?						
Carex striata	Walter's Sedge			√			√	√			
Chamaecyparis thyoides	Atlantic White-Cedar			√				√			
Chasmanthium nitidion	Shiny Spikegrass		√?								
Cleistes divaricata	Spreading Pogonia			√					√		
Coreopsis nudata	Georgia Tickseed		√?				√	√			
Eriocaulon texense	Texas Pipewort			√				√	√		
Helianthus heterophyllus	Wetland Sunflower		√	√							
Hibicus coccineus	Brilliant Hibiscus			√?				√			
Hypericum mytifolium	Myrtle-Leaved St. John's Wort			√	√			√			
Hypericum reductum	Atlantic St. John's Wort				√						
Ilex amelanchier	Sarvis Holly			√							
Ilex myritifolia	Myrtle Holly				√?				√	√	
Juniperus silicicola	Southern Red Cedar				√			√			
Lachnocaulon digynum	Pineland Bogbutton		√								
Linum macrocarpion	Flax	√?									
Lycium carolinianum	Christmas Berry			√			√?				
Macranthera flammea	Flame Flower		√								
Marshallia tenuifolia	Narrow-Leaf Barbara's Buttons			√	√			√			
Ophioglossum petiolatum	Stalked Adder's-Tongue				√				√		
Pieris phillyreifolia	Climbing Fetter-Bush		√				√				
Pinguicula planifolia	Chapman's Butterwort		√					√			
Plantanthera blephariglottis var. *conspicua*	Large Water Fringed Orchid			√				√			

Plantanthera integra	Yellow Fringeless Orchid			√					√	√	
Plantanthera nivea	Snowy orchid										
Polygala crenata	Crenate Milkwort			√?							
Ptilimnium costatum	Eastern Bishop-Weed		√	√							
Quercuzs minima	Dwarf Live Oak						√				
Rhynchospora trachi	Tracy's Beakrush			√			√				
Ruellia noctiflora	Night-Flowering Ruellia	√	√								
Sageretia minutiflora	Tiny-Leaved Buckthorn			√				√			
Sapindus marginatus	Flordia Soapberry						√	√			
Sarracenia leucophylla	White-Topped Pitcher Plant		√					√	√		
Sarracenia purpurea	Purple Pitcher Plant						√				
Schizachyrium scoparium var. *divergens*	Eastern Little Bluestem										
Setaria corrugata	Coastal Fox-Tail										
Spiranthes longitabris	Giant Spiral Ladies'-Tresses		√					√	√		
Xyris drummondii	Drummond's Yellow-Eyed Grass		√								
Xyris scabrifolia	Harper's Yellow-Eyed Grass		√								

Definitions of Heritage Ranks

The Mississippi Natural Heritage Program uses the Heritage ranking system developed by The Nature Conservancy. Each species is assigned two ranks; one representing its rangewide or global status (G rank), and one representing its status in the state (S rank). Species with a rank of 1 are most critically imperiled; those with a rank of 5 are most secure.

Global Ranking System

G1—Crucially imperiled globally (5 or fewer occurrences).

G2—Imperiled globally (6 to 20 occurrences).

G3—Either very rare and local throughout its range or found locally in a restricted range (21 to 100 occurrences).

G4—Apparently secure globally.

G5—Demonstrably secure globally.

Rank Qualifiers

? —Inexact Numeric Rank

Q—Questionable Taxonomy

State Ranking System

S1—Critically imperiled in Mississippi because of extreme rarity (5 or fewer occurrences of very few remaining individuals or acres) or because of some factor(s) making it especially vulnerable to extirpation from Mississippi.

S2—Imperiled in the state because of rarity (6 to 20 occurrences or fewer remaining individuals or acres) or because of some factor(s) making it very vulnerable to extirpation from Mississippi.

S3—Vulnerable in the state either because rare or uncommon, or found only in a restricted range in Mississippi (on the order of 21 to 100 occurrences).

S4—Apparently secure in Mississippi with many occurrences.

S5—Demonstrably secure in Mississippi and essentially "ineradicable" under present conditions.

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Appendix 10.A. Partial list of plants of the Grand Bay National Estuarine Research Reserve. This species list is a compilation of information from *Selected Plants of the Grand Bay National Estuarine Research Reserve and Grand Bay National Wildlife Refuge* 2004, Mississippi Department of Marine Resources 1998, Eleuterius 1973 and 1974, and personal observations.

Family	**Scientific Name**	**Common Name**
Aceraceae	*Acer rubrum* L.	Red Maple
Agavacea	*Yucca aloifolia* L.	Spanish Bayonet
Alismataceae	*Sagittaria graminea* Michx	Grassy Arrowhead
	Sagittaria lancifolia L	Bulltongue or Lance-leaf Arrowhead
Amaryllidaceae	*Crinum americanum* L.	Swamp Lily
	Hypoxis juncea Smith	Fringed Yellow Star-grass
	Zephyranthes atamasco (L.) Herb.	Rain Lily
Anacardiaceae	*Rhus copallium* L.	Flameleaf or Winged Sumac
	Rhus glabra L.	Smooth Sumac
	Toxicodendron pubescens P. Mill (Hentze)	Atlantic Poison Oak
	Toxicodendron radicans (L.) Kuntze	Eastern Poison Ivy
Apiaceae	*Centella asiatica* (L.) Urban.	Coinwort
	Centella erecta (L.) Fern.	Spadeleaf, Coinwort
	Eryngium intergrifolium (L.) Walter	Blue-flower Coyote Thistle
	Eryngium yuccifolium var. yuccifolium Michx.	Button Eryngo, Rattlesnake Master
	Hydrocotyle bonariensis Lamark	Water Pennywort
	Hydrocotyle umbellata L.	Many-flowered Pennywort
	*Oxypolis filiformis (*Walt.) Britt.	Water Cowbane, Dropwort
	Ptilimniun capillaceum (Michx.) Raf.	Mock Bishop's-weed
	Sium suave Walter	Water Parsnip
Aquifoliaceae	*Ilex cassine* L.	Dahoon Holly
	Ilex glabra (L.) Gray	Inkberry
	Ilex myrtifolia Walt.	Myrtle-leaved Holly
	Ilex opaca Ait.	America Holly
	Ilex vomitoria Ait.	Yaupon Holly
Araliaceae	*Aralia spinosa* L.	Devil's Walking Stick
Arecaceae	*Sabal minor* (Jacq.) Pers.	Dwarf Palmetto
	Serenoa repens (Bartr.) Small	Saw Palmetto
Asclepiadaceae	*Asclepias michauxii* Dcne.	Michaux's Milkweed
	Asclepias lanceolata Walt.	Red Milkweed
	Asclepias longifolia Michx.	Longleaf Milkweed
	Cynanchum angustifolium Pers.	Gulf Coast Swallow-wort
	Matelea sp. Aublet	Milkvine
Aspidiaceae	*Dryopteris ludoviciana* (Kunze) Small	Louisiana Shield Fern

Family	**Scientific Name**	**Common Name**
Asteraceae	*Ambrosia artemisifolia* L.	Annual Ragweed
	Aster chapmanii (Torr. & Gray) Nesom	Chapman's or Savanna Aster
	Aster dumosus (L.)	White Bushy Aster
	Aster tenuifolius L.	Saltmarsh Aster
	Baccharis angustifolia Michaux.	Saltwater False Willow
	Baccharis halimifolia L.	Salt Bush
	Balduina uniflora Nutt.	Savanna Honeycomb
	Bidens mitis (Michx.) Sherff.	Marsh Beggar Ticks
	Bigelowia nudata (Michx.) de Candolle	Rayless Goldenrod
	Borrichia frutescens (L.) DC.	Seaside Tansy, Sea Oxeye
	Carphephorus pseudoliatris Cass.	Bristleleaf Chaffhead
	Chaptalia tomentosa Ventenat	Sunbonnet
	Cirsium horridulum Michx.	Yellow Thistle
	Cirsium lecontei Torre.& Gray	Le Conte's Thistle
	Cirsium muticum Michx.	Swamp Thistle
	Conoclinium coelestinum (L.) de Candolle	Mistflower, Wild Ageratum
	Coreopsis linifolia Nutt.	Texas Tickseed
	Coreopsis nudata Nutt.	Georgia Tickseed
	Erechtites hieracifolia (L.) Raf.	American Burnweed
	Erigeron philadelphicus L.	Philadelphia Fleabane
	Erigeron quercifolius Lam.	Oakleaf Fleabane
	Erigeron strigosus Muhl. ex Willd.	Daisy Fleabane
	Erigeron vernus (L.) Torre. & Gray	Early Whitetop Fleabane
	Eupatorium capillifolium (Lam.) Small	Dog Fennel
	Eupatorium leucolepis (DC) Torr. & Gray	Justice weed
	Eupatorium perfoliatum L.	Common Boneset
	Eupatorium rotundifolium (L.)	Roundleaf Thoroughwort
	Eupatorium serotinum Micx.	Lateflowering Thoroughwort
	Euthamia tenuifolia (Pursb.) Nutt.	SlenderGoldenrod, Goldentop
		Narrowleaf Sunflower
	Helianthus angustifolis L.	Variableleaf Sunflower, Savanna
	Helianthus heterophyllus Nutt.	Honeycomb
		Southeastern Sneezeweed
	Helenium pinnatifidum (Nutt.) Rydb.	Savanna Sneezeweed
	Helenium vernale Walt.	Bigleaf Sumpweed
	Iva frutescens L.	Weedy Dwarf Dandelion
	Krigia caespitosa (Raf.) Chambers	Lettuce
	Lactuca sp. L.	Blazing Star
	Liatris spicata (L.) Willd.	Barbara's Butttons, Marshallia
	Marshallia tenuifolia Rafinesque	Climbing Hempvine
		Stinking Camphorweed
	Mikania scandens (L.) Willd.	Rosy Camphorweed
	Pluchea foetida (L.) DC.	Rabbit Tobacco
	Pluchea rosea Godfrey	
	Pseudognaphalium obtusifolium (L.) Hill. &	Canada Goldenrod
	Burtt.	Sweet Goldenrod
	Solidago canadensis var. scara Torr. & Gray	Wrinkleleaf Goldenrod
	Solidago odora Schoepf.	Seaside Goldenrod
	Solidago rugosa P. Mill.	Spiny Sow Thistle
	Solidago sempervirens var. *mexicana* (L.) Fern.	Common Sow Thistle
	Sonchus asper (L.) Hill	Scaleleaf Aster
	Sonchus oleraceus L.	Rice Button Aster
	Symphyotrichum adnatum (Nutt.) Ness.	Saline Aster

Family	**Scientific Name**	**Common Name**
	Symphyotrichum dumosum (L.) Ness.	
	Symphyotrichum tenuifolium (L.) Ness.	
Bataceae	*Batis maritima* (L)	Turtleweed, Saltwort
Bignoniaceae	*Bignonia capreolata* L.	Crossvine
	Campsis radicans (L) Seem ex Bureau	Trumpet Creeper
Blechnaceae	*Woodwardia areolata* (L.) T. Moore	Netted Chainfern
	Woodwardia virginica (L.) Sm.	Virginia Chainfern
Boraginaceae	*Onosmodium bajariense var. hispidissimum* Michx	Smooth Onosmodium, Softhair marbleseed
Brassicaceae	*Lepidium virginicum* L.	Virginia Pepperweed
Bromeliaceae	*Tillandsia usneoides* L.	Spanish Moss
Burmanniaceae	*Burmannia capitata* (Gmelin) Martius	Southern Bluethreads
Cactaceae	*Opuntia humifusa* Raf.	Prickly Pear, Devil's Tongue
Calycanthaceae	*Calycanthus floridus* L.	Carolina Allspice
Campanulaceae	*Lobelia brevifolia* Nutt.	Shortleaf Lobelia
	Lobelia cardinalis L.	Cardinal Flower
	Lobelia floridana Chapman	Florida Lobelia
	Trodanis perfoliata (L.) Nieuwl.	Venus Looking-glass
Cannaceae	*Canna flaccida* Salisbury	Golden Canna
Caprifoliaceae	*Lonicera japonica* Thunb.	Japanese Honeysuckle
	Sambucus canadensis L.	American Elderberry
	Sambucus nigra L.	Common Elderberry
	Viburnum nudum var, *cassinoides* (L.) Torr.&Gray	Possomhaw
Caryophyllaceae	*Spergula arvensis* L.	Corn Spurry
Chenopodiaceae	*Salicornia bigelovii* Torr.	Dwarf Saltwort
	Salicornia virginica L.	Virginia Glasswort
	Suaeda linearis (Ell.) Moq.	Sea Blite, Annual Seepweed
Clethraceae	*Clethra alnifolia* L.	Summersweet
Clusiaceae (Hypericaceae)	*Hypericum brachyphyllum* (Spach) Stued.	Coastal Plain St. Johnswort
	Hypericum cistifolium Lam	Roundpod St. Johnswort
	Hypericum fasciculatum Lam.	Peelbark or Marsh St. Johnswort
	Hypericum hypericoides (L.) Crantz	St. Andrew's Cross
	Hypericum myrtifolium Lam.	Myrtleleaf St. Johnswort
	Hypericum reductum (Svens.) P. Adams	Atlantic or Dwarf St. Johnswort
	Hypericum tetrapetalum Lam.	Four petal St. Johnswort
	Triadenum virginicum (L.) Raf.	Virginia Marsh St. Johnswort

Family	**Scientific Name**	**Common Name**
Commelinaceae	*Commelina* sp. L.	Dayflower
	Tradescantia hirsutiflora Bush	Hairy flower Spiderwort
Convolvulaceae	*Ipomoea cordatotriloba var cordatutriloba* Dennst.	Tievine
	Ipomoea purpurea (L.) Roth.	Common Morning-glory
	Ipomoea sagittata Poir.	Satl Marsh Morning-glory
	Ipomoea trichocarpa Ell.	Coastal Morning-glory
	Calystegia sepium (L.) R.Br.	Hedge False Bindweed
Cupressaceae	*Chamaecyparis thyoides* (L.) Britton	Atlantic Whitecedar
	Juniperus virginiana (L.) *var.silicicola* (Small) J. Silba	Southern Redcedar
Cyrillaceae	*Cyrilla racemiflora* L.	Titi, Leatherwood
Cyperaceae	*Carex albolutescens* Schw.	Greenwhite Sedge
	Carex complanata Torr.& Hook.	Hirsute Sedge
	Carex glaucescens Ell.	Southern Warty Sedge
	Carex striata Michx.	Walter's sedge
	Carex verrucosa Muhl.	Warty sedge
	Carex vulpinoides Michx	Fox Sedge
	*Cladium maricus (*L.) Pohl. ssp*. jamaicense (*Crantz.) Kukenth.	Jamaica Swamp Sawgrass
	Cladium mariscoides (muhl.) Torr.	Smooth Sawgrass
	Cyperus virens Michx.	Green Flat Sedge
	Eleocharis baldwinii (Torr.) Chapman	Baldwin's Spikerush
	Eleocharis cellulosa Torr.	Coastal Spikerush
	Eleocharis equisetoides (Ell.) Torr.	Jointed Spikesedge
	Eleocharis erythropoda Steud.	Red-footed Spikerush
	Eleocharis obtusa (Willd.) Schultes	Blunt Spikerush
	Eleocharis quadrangulata (Michx.) R. & S	Square-stem Spikerush
	Eleocharis rostellata Torr.	Beaked Spikerush
	Eleocharis tortilis (Link) Schultes	Twisted Spikerush
	Eleocharis tuberculosa (Michx.) R.& S.	Cone-cup Spikerush
	Fimbristylis caroliniana (Lam.) Fern.	Carolina Fimbry
	Fimbristylis castanea (Michx.) Vahl.	Marsh Fimbry
	Fimbristylis spadicea auct. non (L.) Vahl.	Chestnut Sedge
	Fuirena squarrosa Michx.	Hairy Umbrella Sedge
	Rhynchospora baldwinii Gray	Baldwin's Beaksedge
	Rhynchospora breviseta (Gale) Chan.	Shortbristle Beaksedge
	Rhynchospora cephalantha Gray	Bunched Beaksedge
	Rhynchospora chapmanii M.A. Curtis	Chapman's Beaksedge
	Rhynchospora corniculata (Lam.) Gray	Shortbristle Horned Beaksedge
	Rhynchospora elliottii A. Dietr.	Elliott's Beaksedge
	Rhynchospora fascicularis (Michx,) Vahl.	Fasciculate Beakrush
	Rhynchospora globularis (Chapm.) Small	Globe Beaksedge
	Rhynchospora gracilenta Gray	Slender Beaksedge
	Rhynchospora inexpansa (Michx,) Vahl.	Nodding Beaksedge
	Rhynchospora inundata (Oakes) Fern.	Narrow-fruit horned Beaksedge
	Rhynchospora latifolia (Baldw. ex Ell.) Thomas	Whitetop Sedge
	Rhynchospora macrostachya Torr. ex Gray	Tall Beaked Rush

Family	**Scientific Name**	**Common Name**
	Scirpus americanus Pers.	American Bulrush
	(Schoenoplectus americanus (Pers.) Volk, Schinz, Kellar)	
	Scirpus olneyi *Gray*	Olney's Threesquare Rush
	Scirpus robustus Pursh.	Saltmarsh or Sturdy Bulrush
	(Schoenoplectus robustus (Pursh.)Strong)	
	Scripus validus Vahl.	Soft-stem Bulrush
	Scleria baldwinii (Torr.) Steud.	Baldwin's Nutrush
Droseraceae	*Drosera brevifolia* Pursh.	Dwarf Sundew
	Drosera capillaris Poiret.	Pink Sundew
	Drosera tracyi Diels	Tracy's Sundew
	Drosera filiformis Raf,	Thread-leaved Sundew
Ebenaceae	*Diospyros virginiana L.*	American Persimmon
Ericaceae	*Gaylussacia* sp. HBK.	Huckleberry
	Lyonia lucida (Lam.) K. Koch	Fetterbush
	Rhododendron serrulatum (Small) Millais	Swamp Azalea
	Vaccinium arboreum Marsh.	Sparkleberry
	Vaccinium ellotii Champ.	Elliot's Blueberry, Mayberry
Eriocaulaceae	*Eriocaulon compressum* Lam.	Flatten Pipewort
	Eriocaulon decangulare L.	Ten-angled Pipewort
Euphorbiaceae	*Triadica sebifera* (L.) Small	Chinese Tallow Tree, Popcorn Tree
Fabaceae	*Albizia julibrissin* Druz.	Silktree
	Amorpha fruiticosa L.	Indigo-bush
	Baptisia alba (L.) Vent.	White Wild Indigo
	Senna obtusifolia (L.) Irwin & Barney	Sicklepod
	(Cassia obtusifolia L.)	(Sicklepod, Coffee Weed)
	Centrosema virginianum (L.) Bentham	Spurred Butterfly Pea
	Crotalaria spectabilis Roth.	Showy Rattlebox
	Erythrina herbacea L.	Coral Bean
	Galactia volubilis (L.) Britt.	Downy Milkpea
	Neptunia lutea (Leavenworth) Benth.	Yellow Puff
	Sesbania herbacea (P. Mill.) McVaugh	Bigpod *or* Hemp sesbania
	Trifolium repens L.	White Clover
	Vicia ludoviciana Nutt.	Louisiana Vetch
	Vicia minutiflora F G Diet.	Pygmyflower Vetch
	Wisteria sinensis (Sims) Swett	Chinese Wisteria
Fagaceae	*Quercus minima* (Sarg.) Small	Dwarf Live Oak
	Quercus myrtifolia Willd.	Myrtle Oak
	Quercus nigra L.	Water Oak
	Quercus stellata Wangenh.	Post Oak
	Quercus virginiana P. Mill.	Live Oak
Gentianaceae	*Bartonia paniculata* (Michx.) Muhl.	Twining Screwstem
	Sabatia stellaris Pursh.	Marsh Pink

Family	**Scientific Name**	**Common Name**
Geraniacea	*Geranium carolinianum* L.	Carolina Geranium
Grossulariaceae	*Itea virginica* L.	Sweetspire
Haemodoraceae	*Lachnanthes caroliana* (Lam.) Dandy	Redroot
	Lophiola aurea Ker-Gawl.	Goldencrest
Haloragaceae	*Myriophyllum heterophyllum* Michx.	Two-leaf Watermilfoil
	Myriophyllum pinnatum (walt.) B.S.P.	Cutleaf Watermilfoil
	Proserpinaca pectinata Lam	Comb-leaf Mermaid-weed
Hamamelidaceae	*Liquidambar styraciflua* L.	Sweetgum
Hippocastenaceae	*Aesculus pavia* L.	Red Buckeye
Hydrocharitaceae	*Vallisneria americana* Michx.	Eelgrass
Iridaceae	*Iris virginica* L.	Virginia Iris
	Sisyrinchium angustifolium Mill.	Narrowleaf Blue-eyed Grass
	Sisyrinchium atlanticum Bickn.	Eastern Blue-eyed Grass
	Sisyrinchium exile Bickn.	Yellow Blue-eyed grass
	Sisyrinchium minus Engelm. & Gray	Least or Dwarf Blue-eyed Grass
	Sisyrinchium rosulatum Bickn.	Annual Blue-eyed Grass
Juglandaceae	*Carya illinoinensis* (Wangenh.) K. Koch	Pecan
Juncaceae	*Juncus acuminatus (Michx.) Taper*	Tip Rush
	Juncus bufonius L.	Toad Rush
	Juncus coriaceous Mach.	Leathery Rush
	Juncus dichotomus Ell.	Branched Rush
	Juncus effusus L.	Soft Rush
	Juncus marginatus Rostk.	Grassleaf Rush
	Juncus polycephalus Michx.	Manyhead Rush
	Juncus roemerianus Scheele	Black Needle Rush
	Juncus tenuis Willd.	Path Rush
	Juncus trigonocarpus Stued.	Redpod Rush
	Juncus validus Coville	Roundhead Rush
Lamiaceae	*Hyptis alata* (Raf.) Shinners	Clustered Bushmint
	Lycopus rubellus Moench. (*Lycopus angustifolius* Ell.)	Taperleaf Water Horehound
	Salvia lyrata L.	Lyre-leafed Sage
	Scutellaria integrifolia L.	Skullcap, Helmet Flower
	Teucrium canadense L.	Canada Germander
Lauraceae	*Cinnamomum camphora* (L.) Spren	Camphor Tree
	Persea borbonia (L.) Spreng.	Redbay
	Persea palustris (Raf.) Sarg.	Swamp Bay
Lentibulariaceae	*Pinguicula lutea* Walt,	Yellow Butterwort
	Pinguicula planifolia Chapm.	Chapman's Butterwort
	Utricularia purpurea Walt.	Eastern Purple Bladderwort
	Utricularia subulata L.	Zigzag Bladderwort

Family	**Scientific Name**	**Common Name**
Liliaceae	*Aletris lutes* Small	Yellow Colicroot
	Allium canadense var. mobilense (Regel) Ownbey	Meadow Garlic
	Lilium catesbaei Walt.	Pine Lily, Catesby Lily
	Nothoscordum bivalve (L.) Britt.	Crow Poison
	Yucca aloifolia L.	Spanish Bayonet
	Zigadenus densus (Desr.) Fern.	Crow Poison
Linaceae	*Linum* sp.	Flax
Loganiaceae	*Polypremum procumbens* (L.)	Juniper Leaf
Lycopodiaceae	*Lycopodiella alopecuroides* (L.) Cranfil	Foxtail Club Moss
	Lycopodiella caroliniana (L.) Pichi.-Serm.	Slender Club Moss
Lygodiaceae	*Lygodium japonicum (*Thunb. ex Murr.) Sw.	Japanese Climbing Fern
Lythraceae	*Lythrum* sp.	Loosestrife
Magnoliaceae	*Magnolia grandiflora* L.	Southern Magnolia
	Magnolia virginiana L.	Sweetbay Magnolia
Malvaceae	*Hibiscus aculeatus* Walt	Crimson-eyed Rose Mallow
	Hibiscus moscheutos L.	Swamp Rose Mallow
	Kosteletzkya virginica (L.) K. Prel. ex Gray	Saltmarsh or Seashore Mallow
Melastomataceae	*Rhexia alifanus* Walt.	Savannah Meadowbeauty
	Rhexia mariana L.	Maryland Meadowbeauty
	Rhexia virginica L.	Handsome Harry
Menispermaceae	*Cocculus carolinus* (L.) DC.	Carolina Coralbead
Menyanthaceae	*Nymphoides aquatica* (J.F. Gmel.) Kuntze	Banana Plant
	Nymphoides cordata (Ell.) Fern.	Floating Heart
Moraceae	*Morus rubra* L.	Red Mulberry
	Ficus sp. L.	Fig
Myricaeae	*Morella caroliniensis* (P. Mill.) Small	Evergreen Bayberry
	Morella cerifera (L.) Small *(Myrica cerifera* L.)	Wax Myrtle, Southern Bayberry
Najadaceae	*Najas guadalupensis* (Spreng.) Magnus	Southern Naiad
	Najas minor All.	Brittle Waternymph
Nymphaeaceae	*Nuphar luteum* (L.) Sibth. & Smith	Spatterdock
	Nymphaea odorata Ait.	Fragrant Waterlily
Nyssaceae	*Nyssa biflora* Walt.	Swamp Tupelo
Oleaceae	*Chionanthus virginicus* L.	Fringe Tree
	Fraxinus pennsylvanica Marsh.	Green Ash
	Ligustrum sinense Lour	Chinese Privet

Family	**Scientific Name**	**Common Name**
Onagraceae	*Gaura filipes* Spach.	Slender Beeblossom
	Ludwigia glandulosa Walter	Glandular Seedbox
	Ludwigia linearas Walter	Narrow-leafed Seedbox
	Ludwigia octovalvis (Jacq.) Raven	Narrow-leaf Water Primrose
	Ludwigia pilosa Walt.	Hairy Primrose
	Oenothera humifusa Nutt.	Seabeach Evening Primrose
Orchidaceae	*Calopogon barbatus* (Walter) Ames	Bearded Grass Pink
	Calopogon pallidus Chapman	Pale Grass Pink
	Calopogon pulchellus Salisb. R. Br.	Grass Pink Orchid
	Calopogon multiflourus (Lindl.)	Many Flowered Grass Pink
	Calopogon tuberosus (L.) BSP	Tuberous Grass Pink
	Cleistes divaricata (L.) Ames	Spreading Pogonia
	Platanthera blephariglottis var conspicua (Willd.) Lindley	White Fringed Orchid
	Platanthera integra (Nutt.) Sprengel	Yellow Fringeless Orchid
	Platanthera nivea (Nutt.) Sprengel	Snowy Orchid
	Pogonia ophioglossoides (L.) Ker-Gawl.	Rose Pogonia
	Spiranthes longilabris Lindley	Gaint Ladies' Tessses
	Spiranthes praecox (Walt.) S. Wats	Greenvein Ladies' Tresses
	Spiranthes vernalis	Spring Ladies' Tresses
Osmundaceae	*Osmunda cinnamomea* L.	Cinnamon Fern
	Osmunda regalis L.	Royal Fern
Oxalidaceae	*Oxalis dillenii* Jacquin	Sorrel
Pinaceae	*Pinus elliottii* Englem.	Slash pine
	Pinus palustris P. Mill.	Longleaf Pine
Plantaginaceae	*Plantago major* L.	Common Plantain
	Plantago virginica L.	Virginia Plantain
Plumbaginaceae	*Limonium carolinianum* (Walt.) Britt.	Sea Lavender
Poaceae	*Andropogon glaucopsis* Ell. *(Andropogon glomeratus var glaucopsis* Ill. C. Mohr)	Purple Bluestem
	Andropogon virginicus L.	Broom Sedge
	Aristida beyrichiana (A. stricta) (Michx,) Trin,&Rupr.	Wire Grass
	Aristida palustris (Chapman) Vasey	Longleaf Threeawn
	Aristida spiciformis Ell.	Bottlebrush Threeawn
	Axonopus fussifolius (Radd.) Kulhm.	Common Carpet Grass
	Briza minor L.	Little Quaking Grass
	Ctenium aromaticum	Toothache Grass
	Cynodon dactylon (L.) Pers.	Bermuda Grass
	Dichanthelium dichotomum var. ensifolium (Baldw. Ex Ell) Gould & Clark	Cypress Panic Grass
	Dichanthelium ensifolium (Bald.&Ell.) Gould	Sword-leaf Witchgrass
	Dichanthelium erectifolium (Nash) Gould & Clark	Erectleaf Panic Grass

Family	Scientific Name	Common Name
	Dichanthelium scabriusculum (Ell.) Gould & C.A. Clark	Woolly Rosette Grass
	Dichanthelium scoparium (Lam.) Gould	Velvet Panicum
	Dichanthelium villosissimum Nash	Hairy Panic Grass
	Distichlis spicata (L.) Green	Saltgrass
	Echinochloa crus-galli (L.) Beauv.	Barnyard Grass
	Echinochloa walteri	Coast Cockspur Grass
	Elymus virginicus L.	Virginia Wildrye
	Eragrostis elliottii Watson	Field Love Grass
	Hydrochloa caroliniensis Beauv.	Water Grass
	Imperata cylindrica (L.) Palisot	Cogon Grass
	Limnodea arkansana (Nutt.) L.H. Dewey	Ozark Grass
	Microstegium vimineum (Trinius) Camus	
	Muhlenbergia capillaries (Lam.) Trin. var.	Cutover Muhly, Hairawn Muhly
	trichopodes (Ell.) Vasey	Torpedo Grass
	Panicum repens L.	Warty Panic Grass
	Panicum verrucosum Muhl.	Switchgrass
	Panicum virgatum L.	Common Reed
	Phragmites australis (Cav.) Trin. ex Steud.	Annual Rabbit-foot Grass
	Polypogon monspeliensis (L.) Desf.	Sugarcane Plumegrass
	Saccharum giganteum (Walt.) Pers.	Little Bluestem
	Schizachyrium scoparium (Michx.) Nash	Foxtail, Knotroot Bristle Grass
	Setaria geniculata (Wild.) Beauv.	Yellow Bristle Grass
	Setaria parviflora (Poir) Kerg.	Indian Grass
	Sorghastrum natans (L.) Nash	Smooth Cord Grass
	Spartina alterniflora Loisel.	Big Cord Grass
	Spartina cynosuroides (L.) Roth	Saltmeadow Cord Grass
	Spartina patens (Ait.) Muhl.	Gulf Cordgrass
	Spartina spartinae (Trin.) Merr. ex A.S. Hitchc.	Prairie Wedgescale
	Sphenopholis obtuse (Michx.) Scribn.	Smutgrass
	Sporobolus indicus (L.) R.Br.	Osceola's Plume
	Zigadeus densus (Desr.) Fern.	Wildrice
	Zizania aquatica L.	
Polygalaceae	*Polygala crenata* James	Scalloped Milkwort
	Polygala cruciata L.	Drums Heads, Candy Root
	Polygala cymosa Walter	Tall or Yellow Milkwort
	Polygala grandiflora Walter	Showy Milkwort
	Polygala lutea L.	Orange Milkwort
	Polygala nana (Michx.) DC.	Dwarf Milkwort, Bachelor's Button
Polygonaceae	*Polygonum hydropiperoides* Michx.	Swamp Smartweed
	Polygonum setaceum Baldw.	Bog Smartweed
	Rumex crispus L.	Curly Dock
	Rumex obtusifolius L.	Broad-leaved Dock
Pontederiaceae	*Eichhornia crassipes)Martius) Solms*	Water Hyacinth
	Pontederia cordata L.	Pickerelweed
Portulacaceae	*Portulaca pilosa* L.	Rose Purslane
Primulaceae	*Anagallis arvensis* L.	Scarlet Pimpernel

Family	**Scientific Name**	**Common Name**
Punicaceae	*Punica* sp. L. (cultivar)	Pomagranate
Rhamnaceae	*Sageretia minutiflora* (Michx.) C. Mohr	Smallflower Mock Buckthorn
Rosaceae	*Aronia arbutifolia* (L.) Pers.	Red Chokeberry
	Crataegus sp.	Hawthorn
	Photinia pyrifolia (Lam.) Roberts&Phipps	Red Chokecherry
	Prunus umbrellata Ell.	Hog Plum
	Rubus argutus Link	Sawtooth Blackberry
	Rubus cuneifolius Pursh	Sand Blackberry
	Rubus trivialis Michaux	Southern Dewberry
Rubiaceae	*Diodia virginiana* L.	Buttonweed
Ruppiaceae	*Ruppia maritima* L.	Widgeongrass
Rutaceae	*Zanthoxylum clava-herculis L.*	Hercules' Club
Salicaceae	*Salix nigra* Marshall	Black Willow
Sapindaceae	*Sapindus saponaria* var. *saponaria* L.	Wingleaf Soapberry
Sapotaceae	*Bumelia lanuginosa* (Michx.) Pers.	Gum Bumelia
	Sideroxylon lanuginosum Michx.	False Buckthorn
Sarraceniaceae	*Sarracenia alata*	Yellow Pitcher Plant
	Sarracenia leucophylla Raf.	Whitetop Pitcher Plant
	Sarracenia psitticina Michx.	Parrot's Beak Pitcher Plant
	Sarracenia purpurea L.	Sidesaddle Pitcher Plant
	Sarracenia rosea Naczi, Case	Rose Pitcher Plant
Saururaceae	*Saururus cernuus* L.	Lizard's Tail
Scrophulariaceae	*Agalinis aphylla* (Nutt.) Raf.	Coastal Plain False-Foxglove
	Agalinis filicaulis (Benth.) Pennell	Thin Stemmed or Jackson False-Foxglove
	Agalinis linifolia (Nutt.) Britton	False-Foxglove
	Agalinis maritima (Raf.) Raf.	Saltmarsh False-Foxglove
	Bacopa monnieri (L.) Pennell	Coastal Water-hyssop
	Gratiola pilosa Michaux	Shaggy Hedge-hyssop
	Verbascum thapsus L.	Common Mullein
Smilacaceae	*Smilax auriculata* Walt	Earleaf Greenbrier
	Smilax bona-nox L	Saw Greenbrier
	Smilax laurifolia L	Laurel Greenbrier
	Smilax rotundifolia L.	Roundleaf Greenbrier
	Smilax walteri Pursh	Coral Greenbrier
Solanaceae	*Lycium carolinianum* Walt.	Christmasberry, Carolina Desertthorn
	Physalis angustifolia Nutt	Coastal Groundcherry
	Solanum carolinense L.	Carolina Horsenettle

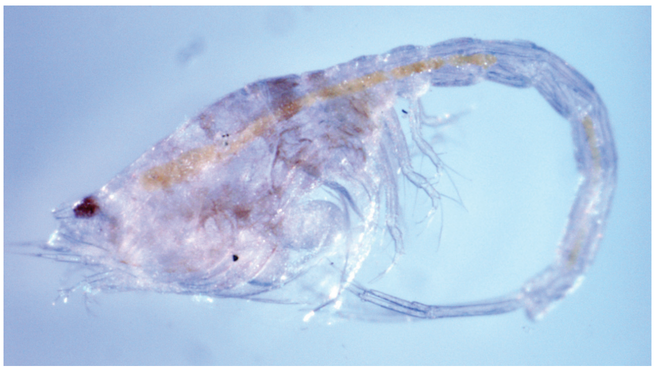
Family	**Scientific Name**	**Common Name**
Sphagnaceae	*Sphagnum* sp.	Sphagnum
Styracaceae	*Styrax americana* L.	Snowbell
Taxodiaceae	*Taxodium ascendens* Brogn.	Pond Cypress
	Taxodium distichum (L,) L. C. Rich	Bald Cypress
Typhaceae	*Typha angustifolia* L.	Narrowleaf Cattail
	Typha latifolia	Broadleaf Cattail
Ulmaceae	*Celtis laevigata* Willd.	Sugarberry
	Celtis tenuiflolia Nutt	Dwarf Hackberry
Verbenaceae	*Callicarpa americana* L.	American Beautyberry
	Phyla nodiflora (L.) Greene	Turkey Tangle Frogfruit
	Verbena brasiliensis Vell.	Brazilian Vervain
	Verbena rigida Spreng.	Rough Verbena
Violaceae	*Viola lanceolata* L.	Lance-leaved Violet
	Viola septemloba LeConte	Southern Coastal Violet
Viscaceae	*Phoradendron serotinum* (Raf.) M. C. Johnst.	Christmas Mistletoe
Vitaceae	*Ampelopsis arborea* (L.) Koehne	Peppervine
	Cissus incisa Des Moulins (*C. trifoliata*)	Cow Itch, Possum Grape
	Parthenocissus quinquefolia (L.) Planch.	Virginia creeper
	Vitis rotundifolia Michx.	Muscadine
Xyridaceae	*Xyris caroliniana* Walt.	Carolina Yelloweyed Grass
	Xyris laxifolia var. *iridifolia* (Chapman) Dral.	Irisleaf Yelloweyed Grass

CHAPTER 11

MACROINFAUNA

Chet F. Rakocinski and Jerry A. McLelland

11.1. GENERAL OVERVIEW OF NORTHERN GULF OF MEXICO MACROINFAUNA



Cyclaspis varians. *Photo credit: USM-GCRL Benthic Ecology Lab*

The benthic environment plays a pivotal role in the regeneration of nutrients in estuaries through various benthic-pelagic coupling mechanisms involving both physical and biotic processes (Twilley et al. 1999). Macroinfauna mediate trophic functioning of the estuarine ecosystem in ways that affect rates, directions, pathways of exchange and transformations of energy and materials, including nutrients, between the water column and the sediment (Hansen and Kristensen 1997). Consequently, the estuarine macroinfauna provides an important trophic link to fisheries production. Furthermore, macroinfaunal communities represent ideal environmental sentinels because (1) they reside within the sediments where stressors concentrate, (2) as sedentary organisms, they cannot easily avoid stressors, and (3) they occur on appropriate spatial and temporal scales for detecting anthropogenic impacts (Rakocinski et al. 1997). Indeed, macroinfaunal communities provide effective indicators of estuarine condition and biotic integrity in the northern Gulf of Mexico (GOM) (Flint and Younk 1983, Gaston and Nasci 1988, Engle et al. 1994, Rakocinski et al. 1997, 2000, Gaston et al. 1998, Brown et al. 2000).

Early macroinfaunal studies within the Mississippi Sound region focused on the effects of dredging (Taylor 1972, 1978, Vittor 1974, 1978, Lackey et al. 1973, Markey 1975). Two historical macrofaunal studies conducted in this region include the comprehensive "Cooperative Gulf of Mexico Estuarine Inventory and Study – Mississippi" (GMEI) (Christmas 1973), and the final report entitled, "Benthic Macroinfauna Community Characterizations in Mississippi Sound and Adjacent Waters", (MCCMS) (Shaw et al. 1982). Station 68 of the GMEI study was located in the southwestern border of the Grand Bay National Estuarine Research Reserve (NERR). Among the various gear used in the GMEI study was a Petersen Dredge, which samples macroinfauna. The GMEI report lists various macroinfaunal species, including the common bivalves, polychaetes, and crustaceans, that were collected throughout the Sound during the inventory.

The MCCMS benthic study by Shaw et al. (1982) entailed an intensive macrofaunal survey based on replicate 0.09 m^2 box corer samples from 102 stations distributed throughout Mississippi Sound and Mobile Bay during both fall and spring seasons. Unfortunately, none of their stations fell directly within the area now designated as the Grand Bay NERR. This study was motivated by concerns regarding the effects of dredging on marine resources; it is notable not only for it's magnitude, but also for the rigorous statistical approach employed. Through the use of several multivariate methods, the authors classified the macroinfauna into characteristic assemblages. The MCCMS study identified 828 macroinfaunal taxa, many of which were deemed opportunistic early colonists, as well as others that were deemed restrictive later colonists. Many of the taxa were regarded as eurytolerant. Besides a successional pattern, the authors also recognized assemblage-level divisions based on salinity and sediment properties, and to some extent, depth. Moreover, they noted that assemblages were richer and macrofaunal organisms more abundant in the cooler months in this region.

Graduate Research Fellow assisting with invertebrate sampling on a mudflat in the Grand Bay NERR. Photo credit: Mark Woodrey.

Early benthic studies by investigators at The University of Southern Mississippi Gulf Coast Research Laboratory (USM-GCRL) documented spatio-temporal patterns in the macroinfauna of subtidal salt-marshes and bayous of the Mississippi coast (McBee and Brehm 1979, 1982). Later benthic studies by the USM-GCRL Invertebrate Zoology Section were conducted near and around the barrier islands in the Mississippi Sound region (Rakocinski et al. 1991, 1995). Much recent work has been conducted using macroinfaunal indicators in the northern GOM by the U.S. Environmental Protection Agency (EPA) under the auspices of the Environmental Monitoring and Assessment Program – Estuaries (EMAP-E) (Heitmuller and Valente 1991, Summers et al. 1991, 1993, Macauley et al. 1994). As an outcome of this initiative, various papers were published using macroinfaunal communities for environmental assessment throughout the northern GOM (Engle et al. 1994, Rakocinski et al. 1997, 2000, Gaston et al. 1995, 1998, Brown et al. 2000). The use of a probabilistic sampling design for the EMAP-E monitoring program precluded extensive coverage of specific subregions in the northern GOM; however, EMAP-E supported some intensive subsidiary studies (e.g. REMAP) of the macroinfauna in the Mississippi Sound region, for example in the Back Bay of Biloxi.

11.2. GRAND BAY NERR MACROINFAUNA

Benthic sediments account for a large portion of the bayous, bays and shoreline areas within the 18,000 acre Grand Bay NERR. However, macroinfaunal information specifically for the Grand

Bay NERR is limited. Fortunately, two macroinfaunal studies have been completed recently in the Grand Bay NERR, one which sampled subtidal sediments of Bayous Cumbest and Heron as well as adjacent waters in mid-summer 2002 (Rakocinski and Zapfe 2005), and the other from intertidal mudflat habitats near marshes that become exposed during periods of extreme low tides in winter/spring 2004 (McLelland 2004). The former study was conducted as a pilot study for the development of macrobenthic process-indicators and supported by the U.S. EPA STAR Program. The latter study was motivated by the interest in the availability of food resources available for shore birds overwintering in the Grand Bay NERR, and was supported by the Mississippi Department of Marine Resources.

11.2.1 U.S. EPA Macrobenthic Indicator Study

Megalomma bioculatum. *Photo credit: USM-GCRL Benthic Ecology Lab.*

Field work for the U.S. EPA macrobenthic indicator study was conducted from the 18th through the 20th of July 2002, coinciding with the summer index period of the Mississippi National Coastal Assessment Program. A 7.5 km transect was set up within each of two parallel bayou systems, Bayou Heron and Bayou Cumbest (Figure 11.1). Five sites were located along each transect, and sites were placed at distance octaves proceeding from the upper bayous to the adjoining bays (i.e. 0.5, 1.0, 2.0, and 4 km between stations). Sites were spaced closer in the upper regions of the systems, where organic loading and dissolved oxygen (DO) stress were more likely to occur.

Bayou Heron is in a comparatively pristine area, but this system exhibits relatively low DO in the uppermost dead-end portion. Bayou Cumbest is thought to be affected by moderate residential wastewater runoff. The latter system is also subject to considerable land use as evidenced by altered shorelines in its upper reaches. Bayou Cumbest is also a larger, less dendritic system with higher flow rates than Bayou Heron. We hypothesized that differences in both land use and geomorphology should contribute to generally higher levels of nutrient loading in Bayou Cumbest relative to Bayou Heron (Rakocinski and Zapfe 2005). Three pairs of benthic grabs (modified Van Veen; 0.04 m^2) were taken at each site for macroinfauna (3 grabs) and sediment properties (3 grabs); water quality profiles were also obtained. Macroinfaunal samples were passed through a 0.5 mm mesh standard sieve to remove fines in the field. Labeled macroinfaunal samples were preserved in buffered 10 % formalin and returned to the laboratory for processing. Detailed field methods are provided in Rakocinski and Zapfe (2005).

Phascolion *sp. Photo credit: USM-GCRL Benthic Ecology Lab.*

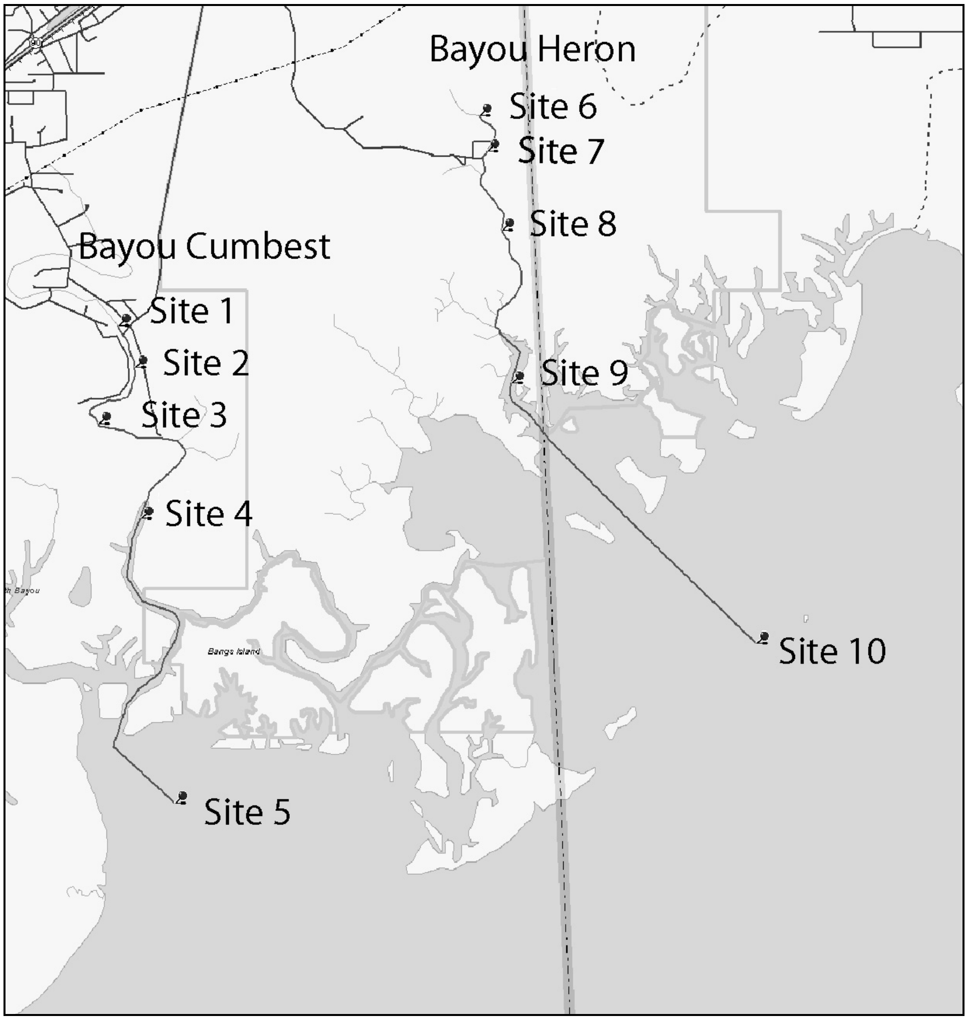


Figure 11.1. Map of sites sampled for U.S. EPA STAR Pilot Study (Figure from Rakocinski and Zapfe 2005).

Macrobenthic sample sorting followed established Quality Assurance-Quality Control (QA-QC) procedures. Standard Operating Procedures were developed for completing three progressive stages of laboratory processing of sorted macrobenthic organisms: size fractionation, taxonomic identification, and volumetric determinations as described in Rakocinski and Zapfe (2005). Macrofaunal size fractions were transferred to taxonomic experts for identification of the organisms, usually to species. Organisms were assigned a taxonomic code and counted, resulting in the breakdown of size fractions into taxonomic categories (taxon-size fractions). This level of detail allowed calculations of conventional indicators as well as macrobenthic process-indicators, including production estimates. Corresponding sediment samples were processed for pore water nutrients, sediment composition, grain size analysis, and Total Organic Carbon (TOC).

11.2.2 U.S. EPA Macrobenthic Results

Chone *sp. Photo credit: USM-GCRL Benthic Ecology Lab.*

Interesting spatial variation in the macroinfauna was evident within the Grand Bay NERR system, and both longitudinal and cross-system patterns were apparent (Tables 11.1 - 11.3). Overall, macrobenthic production increased from upestuary to downestuary sites. The production to biomass (P:B) values were higher at upestuary sites, reflecting the tendency for downestuary sites to contain macroinfaunal communities consisting of larger and longer lived organisms (Rakocinski and Zapfe 2005). Moreover, macrobenthic production was clearly higher within Bayou Cumbest than in Bayou Heron: values ranged over one order of magnitude, from 8,248 to 83,758 μg m^{-2} d^{-1} in the Bayou Cumbest system; and only from 95 to 13,037 μg m^{-2} d^{-1}, in the Bayou Heron system (Table 11.2) (some values from Rakocinski and Zapfe 2005 revised). This difference was consistent with suspected differences in nutrient enrichment. The lowest production value occurred at the uppermost site in Bayou Heron, which was located near the dead-end upper portion of the main channel. Discernable spatial variation in the macroinfaunal community probably tracked variability in the trophic condition of the ecosystem. For example, downestuary macroinfaunal communities appeared to be relatively stable compared to communities at upper sites which may be subject to more direct effects of nutrient loading and hypoxia (Gonzalez-Oreja and Saiz-Salinas 1999).

A total of 2,125 macrofaunal organisms were distributed among 106 taxa identified in the EPA macrobentic indicator study, including 46 polychaetes, 23 mollusks, 19 crustaceans, and four echinoderms. The overall macroinfaunal density was 1,715 m^{-2}. Thirteen taxa made up at least one percent or greater of the total number of organisms. These included two crustaceans - *Americamysis bahia* (1.13 %) and *Ampelisca abdita* (3.48 %); the aquatic insect, *Tanypus clavatus* (1.5 %); two mollusks - the gastropod *Acteocina canaliculata* (2.12 %) and the bivalve *Macoma mitchelli* (1.08 %); Nemerteans (2.16 %); and seven polychaetes - *Cossura delta* (1.32 %), *Glycinde solitaria* (1.08 %), *Mediomastus ambiseta* (22.92 %), *Owenia fusiformis* (2.07 %), *Paraprionospio pinnata* (1.08 %), *Scoletoma verrilli* (2.87 %), and *Streblospio gynobranchiata* (42.21 %). Spatial distributions of the abundant taxa reflected noted spatial differences in production (Table 11.1). For example, the deposit feeding bivalve, *Macoma mitchelli* was generally concentrated in the mid to lower portions of Bayou Cumbest, whereas the two dominant polychaetes, *Mediomastus ambiseta* and *Streblospio gynobranchiata* were more prevalent in the upper portions of both systems and were also especially abundant within the Bayou Cumbest system.

Table 11.1. List of taxa occurring in modified Van Veen grab samples from the EPA macroindicator study. Station labels arranged from left to right follow upper to lower estuary locations (see Fig. 11.1). BC = Bayou Cumbest system; BH = Bayou Heron system. Table entries are per grab (0.04 m^2) means ± 1 standard error.

TAXON	BC-1	BC-2	BC-3	BC-4	BC-5	BH-6	BH-7	BH-8	BH-9	BH-10
Bryozoans										
Aeverrillia armata	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Amathia alternata	-	-	-	-	-	-	-	0.33 ± 0.33	-	-
Cnidarians										
Campanulina sp.	1.00 ± 1.00	-	-	-	-	-	-	-	-	-
Cerianthiopsis sp.	-	-	-	-	-	-	-	-	-	1.00 ± 1.00
Crustaceans										
Acanthohaustorius sp.	-	-	-	-	-	-	-	-	-	0.33 ± 0.33
Amakusanthura magnifica	-	-	-	-	-	-	-	-	0.33 ± 0.33	-
Americamysis bahia	1.33 ± 0.88	0.66 ± 0.33	1.33 ± 0.67	0.33 ± 0.33	-	0.33 ± 0.33	2.33 ± 2.33	-	1.00 ± 1.00	0.67 ± 0.33
Ameroculodes miltoni	-	-	-	-	0.33 ± 0.33	-	-	-	-	2.67 ± 2.67
Ampelisca abdita	1.67 ± 0.33	4.00 ± 1.53	7.33 ± 2.33	1.00 ± 0.58	1.33 ± 0.88	-	-	8.00 ± 4.73	1.33 ± 0.33	-
Ampelisca sp.	0.33 ± 0.33	-	-	-	-	-	-	-	-	-
Ampelisca sp. C	-	-	-	-	1.00 ± 0.58	-	-	-	-	0.33 ± 0.33
Apocorophium louisianum	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Balanus improvisus	-	-	-	-	-	-	-	-	0.33 ± 0.33	-
Bowmaniella dissimilis	-	-	-	-	-	-	-	-	-	0.67 ± 0.67
Callinectes sapidus	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Cyclaspis varians	-	0.67 ± 0.33	0.33 ± 0.33	0.67 ± 0.33	-	-	0.33 ± 0.33	-	-	-
Edotea triloba	0.33 ± 0.33	0.33 ± 0.33	-	-	-	-	-	-	-	-
Listriella barnardi	-	-	-	-	1.33 ± 0.33	-	-	-	-	0.67 ± 0.33
Ogyrides alphaerostris	-	-	-	0.67 ± 0.67	0.33 ± 0.33	-	-	-	-	-
Oxyurostylis smithi	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Pinnixa sp.	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Unid. Decapod larvae	-	-	-	-	0.33 ± 0.33	-	-	-	-	0.33 ± 0.33
Unid. Ostracoda	0.67 ± 0.67	-	-	-	-	-	-	-	0.33 ± 0.33	1.00 ± 0.00
Echinoderms										
Hemipholis elongata	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Leptosynapta crassipatina	-	-	-	-	-	-	-	-	-	0.33 ± 0.33
Mellita quinquiesperforata	-	-	-	-	0.33 ± 0.33	-	-	-	-	0.33 ± 0.33
Microphiopholis atra	-	-	-	-	2.00 ± 0.58	-	-	-	-	-
Insects										

Tanypus clavatus	0.33 ± 0.33	-	-	10.33 ± 5.24	-	-	-	-	-	-
Tanypus sp.	-	-	-	4.00 ± 4.00	-	-	-	-	-	-
Unid. Chironomid larvae	-	0.33 ± 0.33	-	-	-	-	-	-	-	-
Unid. Tanypodinae	-	-	-	-	-	-	-	0.33 ± 0.33	-	-
Mollusks										
Acteocina canaliculata	-	-	-	0.33 ± 0.33	13.33 ± 8.35	-	-	-	1.33 ± 0.88	-
Diplodonta sp.	-	-	-	0.33 ± 0.33	-	-	-	-	-	-
Ensis minor	-	-	-	-	-	-	-	-	-	0.33 ± 0.33
Gemma gemma	-	-	-	-	-	-	-	-	-	0.67 ± 0.67
Littoridinops monroensis	-	-	0.33 ± 0.33	-	-	-	-	-	-	-
Littoridinops sp.	-	-	-	-	-	0.33 ± 0.33	-	-	-	-
Macoma mitchelli	-	-	1.33 ± 0.33	2.33 ± 0.67	3.33 ± 2.40	-	-	0.67 ± 0.67	-	-
Mulinia lateralis	-	0.67 ± 0.67	0.33 ± 0.33	-	3.00 ± 0.58	-	0.33 ± 0.33	-	0.33 ± 0.33	-
Mysella planulata	-	-	-	-	0.67 ± 0.33	-	-	-	-	-
Odostomia weberi	-	-	-	0.33 ± 0.33	-	-	-	-	-	-
Parastarte triquetra	-	-	-	-	-	-	-	-	-	0.67 ± 0.67
Neverita duplicata	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Rangia cuneata	0.67 ± 0.67	-	-	-	-	-	-	-	-	-
Rictaxis punctostriatus	-	-	-	1.00 ± 0.58	2.67 ± 0.33	-	-	-	0.33 ± 0.33	-
Semele nuculoides	-	-	-	-	2.33 ± 2.33	-	-	-	-	-
Tagelus plebius	-	-	-	-	-	-	0.33 ± 0.33	0.33 ± 0.33	-	-
Teinostoma cf *biscaynense*	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Tellina sp.	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Thais haemastoma	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Turbonilla sp.	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Unid. Bivalvia	0.33 ± 0.33	-	-	0.33 ± 0.33	0.33 ± 0.33	-	-	-	-	0.33 ± 0.33
Unid. Gastropoda	-	-	-	-	0.33 ± 0.33	-	0.33 ± 0.33	0.33 ± 0.33	0.33 ± 0.33	-
Unid. Hydrobiidae	1.67 ± 1.20	1.67 ± 0.88	-	-	-	-	-	-	-	-
Nemerteans										
Nemertea sp. B	-	-	-	0.67 ± 0.33	-	-	-	-	-	-
Nemertea sp. C	-	-	-	-	0.67 ± 0.67	-	-	-	0.33 ± 0.33	-
Unid. Nemertea	0.67 ± 0.67	1.33 ± 1.33	1.00 ± 0.58	3.33 ± 2.40	4.67 ± 1.45	-	0.67 ± 0.33	-	0.67 ± 0.33	1.33 ± 0.33
Phoronids										
Phoronis sp.	-	-	-	-	2.33 ± 0.33	-	-	-	-	1.67 ± 0.33
Polychaetes										
Ancistrosyllis hartmanae	-	-	-	-	0.33 ± 0.33	-	-	-	-	-

Aphelochaeta sp.	-	-	-	-	1.33 ± 0.88	-	-	-	2.00 ± 0.58	-
Apoprionospio pygmaea	-	-	-	-	-	-	-	-	-	0.33 ± 0.33
Aricidea bryani	-	-	-	-	-	-	-	-	-	0.67 ± 0.33
Aricidea philbinae	-	-	-	-	1.00 ± 0.58	-	-	-	0.33 ± 0.33	0.33 ± 0.33
Armandia agilis	-	-	-	-	-	-	-	-	-	1.00 ± 0.58
Capitella capitata	-	0.33 ± 0.33	-	-	-	-	-	-	-	-
Chaetozone sp. B	-	-	-	-	-	-	-	-	-	0.33 ± 0.33
Chone sp.	-	-	-	-	-	-	-	-	0.33 ± 0.33	-
Clymenella torquata	-	-	-	-	5.67 ± 0.33	-	-	-	-	-
Cossura delta	1.00 ± 1.00	-	2.00 ± 0.58	3.67 ± 2.67	-	-	-	-	2.67 ± 0.67	-
Cossura soyeri	-	-	-	-	0.67 ± 0.67	-	-	-	-	-
Galathowenia oculata	-	-	-	-	0.33 ± 0.33	-	-	-	-	0.33 ± 0.33
Glycera americana	-	-	-	-	1.00 ± 1.00	-	-	-	-	-
Glycinde solitaria	-	0.33 ± 0.33	-	3.00 ± 0.58	0.67 ± 0.33	-	0.33 ± 0.33	0.33 ± 0.33	2.33 ± 0.33	0.67 ± 0.33
Heteromastus filiformis	-	1.00 ± 1.00	0.67 ± 0.67	0.33 ± 0.33	-	-	-	-	1.00 ± 0.58	-
Hobsonia florida	0.67 ± 0.67	0.33 ± 0.33	0.33 ± 0.33	-	-	-	-	-	-	-
Laeonereis culveri	-	-	-	-	-	-	-	-	1.00 ± 0.58	-
Leitoscoloplos foliosus	-	-	-	-	-	-	-	-	1.00 ± 0.58	-
Leitoscoloplos fragilis	-	-	1.00 ± 1.00	-	-	-	-	-	2.67 ± 2.67	0.33 ± 0.33
Leitoscoloplos sp.	-	-	-	1.67 ± 1.67	-	-	-	-	0.33 ± 0.33	-
Magelona pettiboneae	-	-	-	-	-	-	-	-	0.33 ± 0.33	0.33 ± 0.33
Magelona sp.	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Malmgreniella taylori	-	-	-	-	2.67 ± 0.33	-	-	-	-	-
Mediomastus ambiseta	35.67± 25.69	10.67 ± 1.86	35.67± 15.17	48.67± 20.18	14.67 ± 5.61	-	4.67 ± 2.19	10.67 ± 9.21	1.67 ± 0.67	-
Megalomma bioculatum	-	-	-	-	0.67 ± 0.67	-	-	-	0.33 ± 0.33	-
Melinna maculate	-	-	-	-	0.33 ± 0.33	-	-	-	0.33 ± 0.33	-
Micropthalmus sczelkowii	0.33 ± 0.33	-	1.33 ± 0.67	1.00 ± 1.00	-	-	-	-	-	-
Neanthes succinea	-	-	-	0.67 ± 0.67	-	-	-	-	-	-
Owenia fusiformis	-	-	-	-	9.67 ± 2.40	-	-	-	-	5.00 ± 1.53
Parandalia americana	-	-	0.33 ± 0.33	-	-	-	-	-	0.33 ± 0.33	-
Paraprionospio pinnata	-	-	-	2.67 ± 1.33	4.00 ± 1.53	-	-	-	0.67 ± 0.33	0.33 ± 0.33
Pectinaria gouldii	-	-	-	0.33 ± 0.33	-	-	-	-	-	-
Prionospio perkinsi	-	-	-	-	-	-	-	-	0.33 ± 0.33	0.67 ± 0.67
Sabaco elongates	-	-	-	-	0.33 ± 0.33	-	-	-	1.67 ± 1.67	-
Scoletoma sp.	-	-	-	-	0.67 ± 0.67	-	-	-	-	-

Scoletoma verrilli	-	-	-	-	20.00 ± 5.51	-	-	-	0.33 ± 0.33	-
Sigambra bassi	-	-	-	-	-	-	-	-	0.33 ± 0.33	-
Sigambra sp.	-	-	0.33 ± 0.33	-	-	-	-	-	-	-
Spiochaetopterus costarum	-	-	-	-	-	-	-	-	1.00 ± 0.58	-
Spiophanes bombyx	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Streblospio gynobranchiata	115.0± 29.30	43.67± 20.87	81.00± 28.16	26.33± 12.54	0.33 ± 0.33	0.33 ± 0.33	32.33± 13.48	-	-	-
Unid. Maldanidae	-	-	-	-	0.33 ± 0.33	-	-	0.33 ± 0.33	1.33 ± 0.67	-
Unid. Nereididae	-	-	-	0.33 ± 0.33	-	-	-	-	-	-
Unid. Polychaeta	-	-	-	-	0.33 ± 0.33	-	-	-	0.33 ± 0.33	-
Unid. Spionidae	-	-	-	-	0.67 ± 0.33	-	-	-	-	0.33 ± 0.33
Sipunculids										
Phascolion sp.	-	-	-	-	0.33 ± 0.33	-	-	-	-	-
Turbellarian										
Unid. Turbellaria	-	-	-	-	2.00 ± 1.00	-	-	-	-	-

Other longitudinal and cross-system patterns were apparent from summary measures of the taxonomic data (Table 11.2). Diversity (H'-base 2) increased from upper to lower estuary sites in both Bayous Cumbest and Heron. Diversity (H') per grab ranged among sites from 1.05 ± 0.25 to 4.00 ± 0.26 vs. from 0.33 ± 0.33 to 3.83 ± 0.13, for Bayou Cumbest and Bayou Heron respectively (Table 11.2). Species richness (for all three grabs) also increased from the upper to the lower estuary, and was noticeably higher in the Bayou Cumbest system (Table 11.2). Species richness (S) ranged from 16 to 55 versus from 3 to 30, for Bayou Cumbest and Bayou Heron respectively. Infaunal densities were also considerably higher in the Bayou Cumbest system than in the Bayou Heron system with densities ranging from 1,606 m^2 to 3,914 m^2 versus 24 m^2 to 1,009 m^2, respectively (Table 11.2).

Table 11.2. Macroinfaunal summary measures for EPA macrobenthic samples. BC = Bayou Cumbest system; BH = Bayou Heron system.

Macroinfaunal Summary	BC-1	BC-2	BC-3	BC-4	BC-5	BH-6	BH-7	BH-8	BH-9	BH-10
Diversity (H';base 2) (0.0413 m^2)	1.05 ± 0.25	1.70 ± 0.21	1.71 ± 0.14	2.71 ± 0.31	4.00 ± 0.26	0.33 ± 0.33	1.10 ± 0.40	1.69 ± 0.26	3.83 ± 0.13	3.51 ± 0.21
Species Richness (S) (0.1239 m^2)	16	14	16	25	55	3	9	9	34	30
Total Number (0.1239 m^2)	485	199	403	347	341	3	125	64	86	72
Est Production (mcrogm m^2 • d)	21,956	8,248	29,327	22,140	83,758	95	4,890	4,073	10,277	13,037

Accompanying environmental variables for the EPA study included various sediment and water column properties (Table 11.3). Generally, higher percentages of fines and water occurred within sediments from the upper portion of the estuary and the highest amounts of sand occurred in lower portion of the estuary. Sediments contained higher percentages of $CaCO_3$ in the Bayou Heron system; 0.768 ± 0.208 vs. 5.312 ± 2.419 (per site $\bar{x}$ ± 1SE). Pore water total phosphates, ammonia, and nitrate/nitrite were all generally lower in the Bayou Cumbest system; 0.186 ± 0.089 vs.1.012 ± 0.288 (per site $\bar{x}$ ± 1SE) (mg/L total phosphates), 1.696 ± 0.392 vs. 3.442 ± 0.899 (per site $\bar{x}$ ± 1SE) (mg/L ammonia), 36 ± 10.4 vs. 218 ± 126.7 (per site $\bar{x}$ ± 1SE) (ug/L nitrate/nitrite). Salinity and water temperatures were both fairly high and uniform throughout the Grand Bay NERR area at the time of sampling for the EPA study. Bottom salinity ranged from 20.2 to 25.0 psu and bottom water temperature ranged from 31.1 ºC to 34.5 ºC. Finally, surface chlorophyll concentration was typically higher in the upper portion of the estuary than in the lower portion with values ranging from 7.4 to 34.4 µg/L (Table 11.3).

Table 11.3. Environmental variables measured for EPA macrobenthic samples. BC = Bayou Cumbest system; BH = Bayou Heron system.

Environmental Variable	BC-1	BC-2	BC-3	BC-4	BC-5	BH-6	BH-7	BH-8	BH-9	BH-10
Latitude (ºN)	30.396	30.392	30.387	30.377	30.348	30.417	30.413	30.406	30.390	30.364
Longitude (ºW)	88.445	88.443	88.447	88.442	88.438	88.403	88.402	88.400	88.400	88.372
Depth (m)	1.1	1.0	1.6	1.6	1.8	1.5	2.0	2.0	1.2	1.2
Percent Sand	12.4	91.1	34.6	44.8	52.9	2.8	5.0	19.0	42.6	96.4
Percent Silt	36.7	4.7	56.4	22.2	40.9	44.4	62.6	47.8	45.2	2.4
Percent Clay	50.9	4.2	9.0	33.0	6.2	52.8	32.4	33.2	12.2	1.2
Percent $CaCO_3$	1.26	0.05	0.87	0.62	1.04	13.64	3.66	1.33	7.53	0.40
Percent TOC	4.41	0.70	3.56	1.48	0.28	2.26	2.97	1.95	1.08	0.08
Percent H_2O	67.5	29.9	62.1	49.0	30.7	70.8	71.4	55.7	40.5	19.8
Grain size (mm)	0.004	0.255	0.025	0.037	0.065	0.004	0.008	0.016	0.044	0.107
Nitrate/Nitrite (µg/L)	25	56	61	4	34	56	83	216	708	27
TKN (mg/L)	4.52	2.23	1.57	1.91	1.41	12.91	9.35	1.60	1.39	7.64
Ammonia (mg/L)	3.12	1.32	1.27	1.90	0.87	4.50	5.99	2.88	0.58	3.26
Ortho Phosphate (mg/L)	0.27	0.04	0.04	0.04	0.04	1.48	1.37	0.04	0.04	0.06
Total Phosphate (mg/L)	0.53	0.20	0.06	0.07	0.07	1.75	1.52	0.75	0.13	0.91
Bottom H_2O Temp (ºC)	34.4	34.5	32.5	32.6	32.1	31.7	32.4	31.6	32.7	31.1
Bottom DO (mg/L)	6.49	6.32	4.87	4.13	5.26	3.07	4.42	3.98	5.76	6.28
Bottom Salinity (psu)	20.3	20.2	21.3	24.9	25.3	22.0	22.9	23.5	25.0	25.0
Surf Chlorophyll (µg/L)	13.8	13.6	11.8	8.3	7.7	34.4	7.4	8.6	7.5	10.6
Surface Turbidity (NTU)	14.4	9.9	18.4	13.7	14.7	5.8	4.0	7.3	6.5	10.3

11.2.3 Grand Bay NERR Intertidal Mudflat Study

Field work for the Grand Bay Intertidal Mudflat study commenced on 27 January 2004, and continued over five biweekly periods (McLelland 2004; Figure 11.2). The main focal area was the Grand Batture Island (GB03), on the southern boundary of the Grand Bay NERR. This site consisted of an extensive mudflat surrounded by fringing *Spartina* spp. marsh grass, and drained out to an increasingly sandy shoal along the waters edge. This low-lying mudflat area is alternately flooded and exposed during tidal activity and the exposure time is lengthened during winter months when north winds prevail. Three bird feeding zones moving away from the fringing vegetation corresponded to benthic sample stations: soft mud (GB03-A), sandy mud and scattered oyster shell (GB03-B) and firm sand (GB03-C). Two additional mudflat sites included Catch-Em-All Bar (GB01), located on a corner of North Rigolets Bayou, and GB02, a fairly protected site located near the mouth of a small tidal creek feeding the western edge of Bangs Lake.

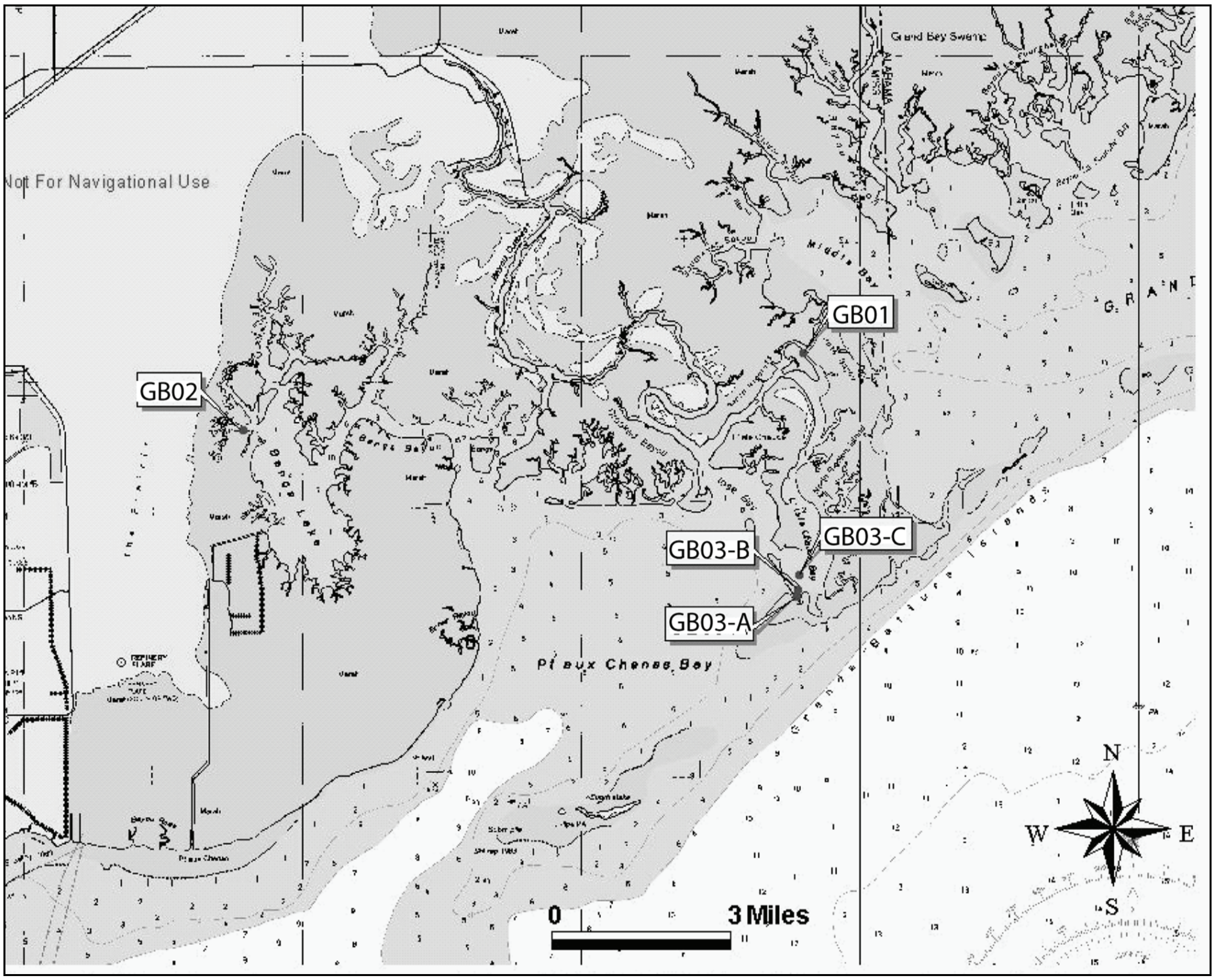
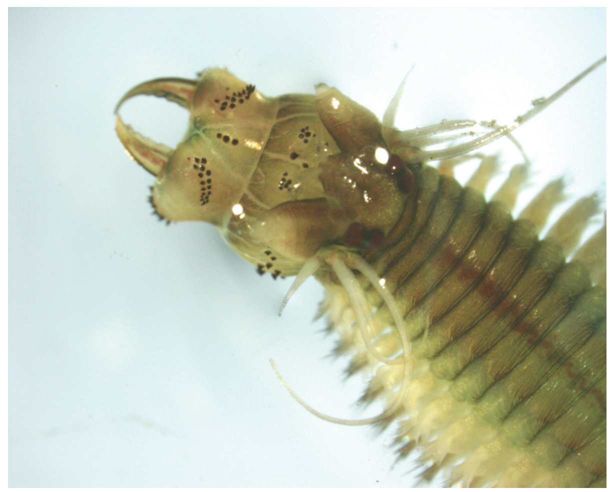


Figure 11.2. Station locations of the Grand Bay NERR mudflat invertebrate study.

The sample design enabled comparisons of the three stations on Grand Batture Island as well as between the other two mudflat sites within the Grand Bay NERR. At each station, three sediment cores were taken using 0.016 m^2 stainless steel box cores with 0.5 mm mesh screen at the closed end. Although additional samples were taken using a 1 mm kicknet to document motile epibenthic organisms in the vicinity of bird feeding activity, these samples will not be elucidated in this chapter. Core samples were processed in the field using 0.5 mm mesh sieves. All samples were preserved with 10 % formalin. In the laboratory, organisms were removed from the detritus, sorted into major groups and transferred to 95 % ethanol. Later they were counted and identified to species or lowest possible taxonomic category. Using a YSI 95, salinity, water temperature, dissolved oxygen, pH and conductivity were measured prior to sampling.

11.2.4 Grand Bay NERR Intertidal Mudflat Results

The three stations on Grand Batture Island differed both in sediment characteristics and in the composition of the benthic community. The soft mud station was characterized by larger numbers of the nereid polychaete *Laeonereis culveri* than the other stations, which made up most of the macroinfaunal biomass at this station. The large capitellid polychaetes *Heteromastus filiformis* and *Capitella capitata* also contributed greatly to the infaunal biomass at the soft mud station. In January, the sandy mud station on Grand Batture Island had the highest density and number of taxa due to dominance by high abundances of the small oligochaete *Paranais littoralis* as well as the polychaetes, *Mediomastus ambiseta* and *Streblospio gynobranchiata*. Considerable numbers of *C. capitata* and very small ostracods also occurred at this station. The more frequently inundated outer sand station was occupied by high numbers of mollusks, particularly the small clam *Gemma gemma*, a common food item for browsing shorebirds. This station was also occupied by a substantial number of capitellid polychaetes and the deposit feeding clam, *Macoma mitchelli*. Between January and February, densities and species richness increased at the soft mud and sandy mud stations, whereas they decreased at the outer sand station. However, in March and April, densities decreased at the two inner stations, while densities increased at the outer sand station.



Neanthes succinea. *Photo credit: USM-GCRL Benthic Ecology Lab.*

The firm mudflat at Catch-Em-All Bar had high densities of organisms in January and February but densities fell dramatically by early March, and then rebounded to intermediate levels later in March and April. The macroinfauna at this site consisted primarily of small worms, although considerable numbers of amphipods (*Apocorophium louisianum*) were also present from January through early March. Thereafter large oligochaetes in the family Enchytraeidae occurred there. Sediments at the Bangs Lake mudflat contained a large fraction of detritus, as was also reflected by the organisms within box core samples. Several tube builders were abundant at this site, including the tanaid, *Hargeria rapax*, the polychaete, *Hobsonia florida*, and the amphipod, *Apocorophium louisianum*. The cryptic isopod, *Edotea triloba*, and several other amphipod species also occurred here. Aquatic insects also were abundant including two species of chironomids (*Tanypus clavatus* and *Dicrotendipes* sp.) and a small unidentified brown beetle (Order: Coleoptera).

Over the course of the Grand Bay NERR intertidal mudflat study, salinity varied from 11.36 psu to 23.52 psu; it was generally lowest in early March and fairly stable during the rest of the study period. Water temperature increased over the study period and ranged from 11.0 to 24.23 °C. Dissolved oxygen values were generally fairly high and ranged from 4.14 to 8.44 mg/L.

11.2.5 Comparison between Macroinfaunal Studies

Apocorophium louisianum. *Photo credit: USM-GCRL Benthic Ecology Lab.*

The two recent Grand Bay NERR macroinfaunal studies can be broadly contrasted in terms of seasonal, habitat, and spatial differences. The U.S. EPA macrobenthic indicator study commenced during the summer index period in subtidal habitats located throughout the Grand Bay NERR estuary, whereas the Grand Bay NERR intertidal mudflat study commenced across the winter and spring seasons from intertidal habitats located in a more restricted portion of the Grand Bay NERR. One hundred and six taxa were identified from the spatially extensive, U.S. EPA macrobenthic indicator study, which was restricted to the mid-summer season when macrofaunal diversity and abundance can be low. In contrast, 89 taxa were identified from the spatially restricted Grand Bay NERR intertidal mudflat study, which was conducted across an extended period in winter and spring when macrofaunal diversity and abundance can be high (Table 11.4). The U.S. EPA macrobenthic indicator study covered a wide range of subtidal habitats; whereas the Grand Bay NERR intertidal mudflat study was restricted to a narrower range of intertidal habitats.

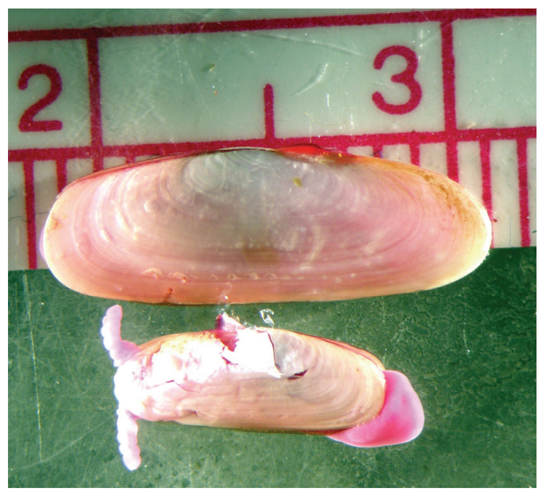
Table 11.4. List of taxa occurring in box core samples from the Grand Bay NERR intertidal mud study.

Phylum	Class	Taxon
Annelida	**Oligochaeta**	*Paranais litoralis*
		Tubificoides heterochaetus
		Tubificoides sp.
		Unid. Enchytraeidae
		Unid. Naididae
		Unid. Tubificidae
		Tubificoides heterochaetus
	Polychaeta	*Ancistrosyllis jonesi*
		Aphelochaeta sp.
		Aricidea philbinae
		Chone sp.
		Capitella capitata
		Cossura delta
		Drilonereis sp.
		Eteone foliosa
		Eteone heteropoda
		Fabricinuda trilobata
		Glycinde solitaria
		Heteromastus filiformis

		Hobsonia florida
		Laeonereis culveri
		Leitoscoloplos fragilis
		Leitoscoloplos sp.
		Linopherus ambigua
		Magelona pettiboneae
		Mediomastus ambiseta
		Microphthalmus sczelkowii
		Neanthes succinea
		Parahesione luteoloa
		Paranaitis gardineri
		Parandalia americana
		Pectinaria gouldii
		Polydora cornuta
		Polydora socialis
		Scolelepis texana
		Sigambra bassi
		Streblospio gynobranchiata
		Unid. Syllidae
Arthropoda	**Chelicerata**	Unid. Araneae
	Cirripedia	*Balanus improvissus*
	Insecta	*Dicrotendipes* sp.
		Tanypus clavatus
		Unid. Ceratopogonidae
		Unid. Coleoptera
		Unid. Dolichopidae
		Unid. Ephemeroptera
		Unid. Hydrophilidae
	Malacostraca	*Americamysis bahia*
		Ameroculodes miltoni
		Ampithoe valida
		Ampelisca abdita
		Ampelisca holmesi
		Apocorophium louisianum
		Callinectes sapidus
		Edotea triloba
		Exosphaeroma diminutum
		Gammarus mucronatus
		Grandidierella bonnieroides
		Hargeria rapax
		Melita nitida
		Palaemonetes pugio
		Unid. Penaidae
		Unid. Ostracoda
Bryozoa	**Gymnolaemata**	*Alcyonidium polyoum*
		Amathia alternata
Chordata	**Osteichthyes**	Unid. Gobiidae
		Menidia sp.
Mollusca	**Bivalvia**	*Amygdalum papyrium*
		Ensis minor

		Gemma gemma
		Macoma mitchelli
		Mulinia lateralis
		Periploma margaritaceum
		Rangia cuneata
		Tagelus plebius
		Tellina sp.
		Unid. Bivalvia
	Gastropoda	*Acteocina canaliculata*
		Bulla striata
		Epitonium albidum
		Odostomia weberi
		Onobops jacksoni
		Parvanachis obesa
		Neverita duplicata
		Rictaxis punctostriatus
		Unid. Hydrobiidae
		Unid. Nudibranchia
Nemertea		Unid. Nemertea
Platyhelminthes	**Turbellaria**	Unid. Turbellaria

Despite the great differences in habitat and season between these two studies, they still shared many taxa (Tables 11.1 and 11.4). A total of 43 taxa appeared in both studies, although six were higher taxonomic categories. The 43 shared taxa included such common species as the amphipods, *Ampelisca abdita* and *Apocorophium louisianum*; the isopod, *Edotea triloba*; the chironomid larva, *Tanypus clavatus*; the gastropods, *Acteocina canaliculata*, *Odostomia weberi*, *Neverita duplicata,* and *Rictaxis punctostriatus*; the bivalves, *Ensis minor*, *Gemma gemma*, *Macoma mitchelli*, *Rangia cuneata*, *Mulinia lateralis*, *Tagelus plebius*, and *Tellina* sp.; Nemerteans; and 19 polychaetes, including *Aphelochaeta* sp., *Aricidea philbinae*, *Capitella capitata*, *Chone* sp., *Cossura delta*, *Glycinde solitaria*, *Heteromastus filiformis*, *Hobsonia florida*, *Laeonereis culveri*, *Leitoscoloplos fragilis*, *Leitoscoloplos* sp., *Magelona pettiboneae*, *Mediomastus ambiseta*, *Micropthalmus sczelkowii*, *Neanthes succinea*, *Parandalia americana*, *Pectinaria gouldii*, *Sigambra bassi*, and *Streblospio gynobranchiata*. These taxa may be regarded as macroinfaunal generalists within the Grand Bay NERR ecosystem.



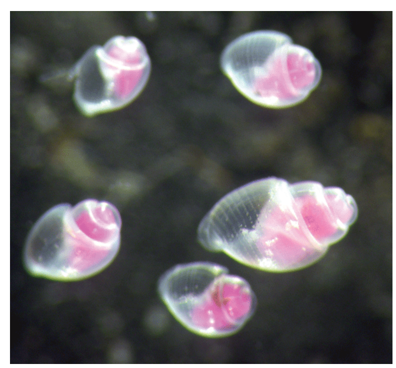
Tagelus *sp. The pink coloration is due to rose bengal used during the sample sorting process to stain organisms. Photo credit: Jerry McLelland.*

Of the 106 taxa occurring in the summer subtidal benthic study 63 were unique (Tables 11.1 and 11.4), including the crustaceans, *Cyclaspis varians*, *Ogyrides alphaerostris*, *Oxyurostylis smithi*, and *Pinnixa* sp; the echinoderms, *Hemipholis elongata*, *Leptosynapta crassipatina*, *Mellita* *quinquiesperforata*, and *Microphiopholis atra*; the polychaetes, *Apoprionospio pygmaea*, *Aricidea bryani*, *Armandia agilis*, *Cossura soyeri*, *Galathowenia oculata*, *Glycera americana*, *Leitoscoloplos foliosus*, *Malmgreniella taylori*, *Megalomma bioculatum*, *Melinna maculata*, *Owenia fusiformis*, *Paraprionospio pinnata*, *Prionospio perkinsi*, *Sabaco elongatus*, *Scoletoma* sp., *Scoletoma verrilli*, *Spiochaetopterus costarum*, and *Spiophanes bombyx*; and the sipunculid, *Phascolion* sp. Many of these taxa occurred in the lower portion of the Grand Bay NERR estuary.

Of the 89 taxa occurring in the winter-spring intertidal mudflat study 46 were unique (Tables 11.1 and 11.4), including the oligochaetes, *Paranais litoralis*, *Tubificoides heterochaetus*, *Tubificoides* sp., Unid. Enchytraeidae, Unid. Naididae, and Unid. Tubificidae; the polychaetes, *Drilonereis* sp., *Eteone foliosa*, *Eteone heteropoda*, *Fabricinuda trilobata*, *Linopherus ambigua*, *Parahesione luteoloa*, *Paranaitis gardineri*, *Polydora cornuta*, *Polydora socialis*, *Scolelepis texana*, and Unid. Syllidae; the insects, *Dicrotendipes* sp., Unid. Ceratopogonidae, Unid. Coleoptera, Unid. Dolichopidae, Unid. Ephemeroptera, and Unid. Hydrophilidae; the crustaceans, *Ameroculodes miltoni*, *Ampithoe valida*, *Ampelisca holmesi*, *Exosphaeroma diminutum*, *Gammarus mucronatus*, *Grandidierella bonnieroides, Hargeria rapax*, *Melita nitida*, *Palaemonetes pugio*, and Unid. Penaidae; the bivalves, *Amygdalum papyrium*, and *Periploma margaritaceum*; and the gastropods, *Bulla striata*, *Epitonium albidum*, *Onobops jacksoni*, *Parvanachis obesa*, and Unid. Nudibranchia. These taxa characterized the intertidal mudflat habitat during the cooler months.

11.3 MONITORING AND RESEARCH NEEDS

- Develop and conduct a macroinfaunal monitoring program which employs both functional metrics and faunistic metrics in conjunction with pelagic and benthic environmental parameters with broad spatial and habitat coverage within the Grand Bay NERR
- Develop, leverage, and implement a multi-investigator/multidisciplinary study of habitat function within the Grand Bay NERR within replicated habitat types throughout the Grand Bay NERR aquatic ecosystem across multiple seasons and years; with macroinfaunal function as a key component.
- Support research aimed at elucidating critical trophic interactions within key habitat types through field experiments involving macroinvertebrates
- Support before/after studies of hurricane effects on macroinfaunal communities and benthic function
- Produce a guidebook on invertebrates of the Grand Bay NERR for the informed public



Rictaxis punctostriatus. *The pink coloration of the mollusc is due to rose bengal used during the sample sorting process to stain the organisms for easy visibility during sample sorting. Photo credit: Jerry McLelland.*

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CHAPTER 12

OYSTERS

Bradley Randall and Christopher A. May

12.1. INTRODUCTION

Fringe intertidal oyster reef at low tide. Photo credit: Chris May.

Oysters (*Crassostrea virginica*) are one of the most important natural resources in Grand Bay National Estuarine Research Reserve (NERR). They serve as ecosystem engineers (Jones et al. 1994) by creating or modifying habitat (i.e., reefs) that is used by other organisms. This ecosystem function changes the abiotic and biotic environment within and around the reefs, thereby increasing both the species diversity and abundance of animals using the reefs for foraging, refugia from predators, and reproduction (Coen and Luckenbach. 2000). A variety of fish and decapods are associated with oyster reefs (Coen et al. 1999, Minello 1999, Lehnert and Allen 2002), and reefs are designated an essential fish habitat by the National Marine Fisheries Service (http://www.nmfs.noaa.gov/habitat/efh/). Oyster reefs also provide shoreline stabilization and erosion control (Meyer et al. 1997) and improve water quality through the filtering capacity of the oysters (Coen and Luckenbach. 2000). In addition, oysters are an economic and recreational resource for humans; not only do humans consume oysters, they also consume the fish and crustaceans that use oyster reefs. Soniat et al. (1992) compiled a bibliography of oyster publications relevant to the Gulf of Mexico.

12.2. OYSTER BEDS AT THE GRAND BAY NERR

Oystering in the area of Grand Bay NERR has been occurring since prehistoric times. Evidence of indigenous people harvesting oysters is supported by several shell middens or mounds in this area (Blitz and Mann 2000). Oysters provided an important renewable food resource for indigenous people, and oyster harvesting in the waters of Grand Bay NERR continued after European settlement. Current use of this resource is primarily recreational (Shellfish Bureau, Mississippi Department of Marine Resources, Unpublished data).

Shell midden on L'Isle Chaude Bayou. Photo credit: Chris May.

The oyster resource of the area has probably declined during historical times because during the middle of the 19th Century the settlement and growing areas were protected by natural spits of land that extended east and west of the current Grande Batture headland (Eleuterius and Criss 1991). However, over the past 150 years wave action and storms have eroded this protective barrier, allowing saltier water from Mississippi Sound into the area. The increased salinity affects the oyster resource in two ways. First, oyster growth is best in moderate salinities (near 15 psu; Stanley and Sellers 1986). Second, the southern oyster drill (*Stramonita haemastoma*) which preys on oysters, becomes more prevalent at high salinities (>15 psu; Stanley and Sellers 1986).

Oysters are present throughout Grand Bay NERR; however they do not occur in large reefs like those found in the western part of the state. Due to the shallow waters and soft sediments, which will not support accumulation of shells, most of the oysters are dispersed in small clumps or patches in the intertidal zones along the bays and bayous (Sanchez-Rubio 2004). Some of the popular areas that may be open to harvest include Graw Point Bay, L'Isle Chaude Bayou, North Rigolets, and Middle Bay. Other oyster resource areas that are closed to harvest are North Bayou, Bangs Lake, the Lake Channel, Crooked Bayou, Bayou Heron, and Bayou Cumbest. Although these latter areas are not open to harvesting, they provide sources for oyster larvae (spat) that contribute to the sustainable populations in areas where harvesting occurs.

12.3. OYSTER MANAGEMENT

In Mississippi, oyster reefs are managed by the Department of Marine Resources (MDMR), which regulates timing and duration of the season, closings due to poor water quality, sack limits, and other harvest activities. In March, 2007, 22 oyster fishermen actively harvested oysters in the Grand Bay NERR. Due to the shallow waters, the traditional methods of harvest have been either small oyster tongs, called nippers, or by hand. The fishermen look for clumps of oysters, collect a clump, and cull or knock off the smaller oysters and empty shells, keeping only the legal size three inch (76 cm) oysters. The fisherman then must check in his catch at the MDMR oyster check station located in nearby Orange Grove to purchase oyster tags. The tags are used to track when and where oysters are harvested. The fees from the tags are then used to help refurbish the oyster reefs by paying for cultch material to be spread in the water to serve as a hard surface upon which new oyster larvae will settle. The oyster beds of Grand Bay NERR support primarily a recreational fishery with each recreational harvester allowed 3 sacks per week. Commercial harvest was limited to 10 sacks per day during the 2007 open season. The total sack harvest for the area ranges from 400 to 500 sacks per year; sacks measure 0.056 m^3 and on average, consist of 3.63 kg of meat.

Harvest is allowed Monday through Saturday from legal sunrise to no later than 2:00 p.m. Traditional harvest season is late September through April. Harvest times, dates, and sack limits are regulated on a seasonal basis.

The waters of Grand Bay NERR are classified as either Conditionally Approved (subject to frequent closings due to rainfall or river discharge) or Restricted (closed). The harvest season in Conditionally Approved areas is closed when water quality declines. Because adult oysters are sessile filter feeders, they cannot move when water quality declines, and therefore, contaminants accumulate in the oyster's flesh. During heavy rainfalls, fecal coliform, a bacterium, from failing human septic systems and wildlife sources in the marsh washes into the open water where it is filtered by the oysters. Following these rainfall events, MDMR closes areas to harvest activities to protect humans from consuming raw and undercooked oysters. The Mississippi Department of Marine Resources monitors fecal coliform in the water column after such rainfall events and opens areas to harvest after coliform levels return to acceptable levels for health and human consumption.

Researchers from The University of Southern Mississippi collect samples to examine the success of restored intertidal oyster reefs. Photo credit: Christina Watters.

Several oyster relays (translocation of live oysters) and shell plants have occurred during the past two decades in waters of the Grand Bay NERR. During 1988-1996, MDMR relayed live oysters from Pascagoula Bay to Grand Bay NERR, usually depositing the oysters into the southern portion of Bangs Lake. These relays consisted of about 224 m^3 (the equivalent of approximately 4000 sacks) of oysters being transported in September each year. In the early 1990s, one load (56 m^3; 1000 sacks) of this material was placed in North Rigolets. In 1996, a load was planted in the southwestern portion of Middle Bay. In 1997, MDMR distributed clam shell in a few spots along Bayou Heron. In 2000, a private contractor planted oyster shell over 16.2 ha (40 ac) of Jose Bay as part of a mitigation project. These projects have had various degrees of success. Due to the shallow water depths of the Grand Bay NERR, the transport of shell on large barges (the method used for reef construction and refurbishment in the western part of the state) is difficult, and the soft sediment does not provide the physical support necessary to bear the weight of the cultch material.

In addition to shell plants, recent research projects have been initiated to better understand the oyster resource at the Grand Bay NERR, improve restoration and management efforts, and assess the impact of anthropogenic stressors on this resource. These projects (and partner institutions) include:

- An intertidal oyster restoration project designed to evaluate (1) the feasibility of small-scale intertidal restoration of oyster beds, and (2) changes in the faunal assemblage and the physical characteristics of oyster reefs over time to determine a trajectory of oyster growth and faunal diversity of constructed reefs compared to natural sites. The restored sites were constructed using mesh bags filled with oyster shell, which has been shown to recruit larval oysters for attachment (Brumbaugh et al. 2006). (The University of Southern Mississippi Department of Coastal Sciences, The Nature Conservancy, Grand Bay NERR)
- Baseline monitoring of reproduction and contaminant levels. Components include improved understanding of the reproductive and developmental biology of eastern oysters in GBNERR, detection and quantification of mercury levels in oyster tissue types, and assessment of the potential of using neurotransmitter (primarily serotonin and dopamine) levels from oyster adductor muscle tissue as biomolecular markers of environmental stress. (University of Mississippi, University of South Alabama)
- An evaluation of the effectiveness of remote sensing of environmental parameters and molecular detection to predict the risk of infection by *Vibrio parahaemolyticus*. (University of Southern Mississippi Department of Coastal Sciences)
- An evaluation of an alternative method to grow oysters in intertidal areas that do not support traditional cultch planting techniques. The project consists of inserting sticks made of various material (bamboo, PVC, cement-coated bamboo, cement-coated PVC) into the sediment of intertidal zones. The sticks serve as a substrate for attachment of oysters; over time, the base of the sticks degrade, the sticks fall over, and the material provides a hard surface for the settlement of additional oyster spat (Toline et al. 2005). (MDMR, Grand Bay NERR)

12.4. MONITORING AND RESEARCH NEEDS:

- Assessment of the use of oyster reefs for erosion control.
- Effects of tonging (oyster harvest) on oyster population parameters and reef ecological function.
- Map the oyster reefs of the Grand Bay NERR.
- Comparison of success/failure of traditional open water cultch plants compared to intertidal cultch plants in Grand Bay NERR.
- Modeling the effects of increased freshwater inflow on oyster populations.
- Development of an oyster management plan for Grand Bay NERR, including coordination with the Shellfish Bureau of MDMR to review and, if necessary, modify harvest sack limits, harvest season, and other management policies and regulations.

Mr. Clyde Brown tonging for oysters. Photo credit: Jennifer Buchanan.

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CHAPTER 13

NEKTON

Mark S. Peterson, Gretchen L. Waggy, and Sara E. LeCroy

13.1 GENERAL OVERVIEW OF NORTHERN GULF MARSH NEKTON

*Darter goby (*Ctenogobius boleosoma*). Photo credit: Gretchen Waggy.*

Northern Gulf of Mexico (Gulf) marshes are productive ecosystems that are dominated by black needlerush (*Juncus roemerianus*) and smooth cord grass (*Spartina alterniflora*); the latter species is typically associated with lower elevation segments of the marsh complex (Stout 1984). These northern Gulf marshes are extremely dynamic in terms of physical-chemical variables (Stout 1984, Wieland 1994) which drive the occurrence and persistence of nekton, many species of which are ecologically and commercially valuable (Subrahmanyam and Drake 1975, Subrahmanyam and Coultas 1980, Peterson and Ross 1991, Rakocinski et al. 1992). To a large extent, the dynamic nature of northern Gulf marsh ecosystems creates a mosaic of habitat types along the coastal landscape and provides an ideal environment for freshwater, estuarine and marine nekton that use it as either transient (nursery grounds) or resident species (Baltz et al. 1993, Rozas and Reed 1993, Minello 1999, Peterson et al. 2000, Jones et al. 2002, Minello et al. 2003). Much of this region of the Gulf has been termed the 'Fertile Crescent' (Gunter 1963, 1967) because of its tremendous fisheries productivity.

13.2. GRAND BAY NERR NEKTON

Knowledge of the nekton associated with the Grand Bay National Estuarine Research Reserve (NERR) site is limited. There are only eight studies that have been conducted at or near the Grand Bay NERR site, with two being of short duration and scope, two with limited spatial extent, two outside the boundary of the Grand Bay NERR, and two others providing appropriate spatial and temporal observations. The

*Silver perch (*Bairdiella chrysoura*). Photo credit: Gretchen Waggy.*

Grand Bay NERR conducted a BioBlitz between 30 April and 1 May 2004 (Mark Woodrey, Personal communication), and Grand Bay NERR personnel collected samples for the Alabama-Mississippi Rapid Assessment Team (AMRAT, Mark Woodrey personal communication) on this site on 30 August 2004. Even during the extensive Gulf of Mexico Estuarine Inventory (GMEI) done in shallow Gulf waters in the late 1960's (Swingle 1971, Christmas 1973), there were only two sites closely associated with the Grand Bay NERR site. One site was located at the western edge of the NERR site boundary (Christmas 1973, site # 68) where trawl and seine data are available. The second site (Swingle 1971, site TS1) was a trawl site located in Grand Bay (in Alabama, east of the NERR site), but there were no specific data presented for that site. Franks et al. (1972) also documented nekton based on collections in Mississippi Sound and deeper offshore waters, but all sites were outside the NERR boundary. Rakocinski et al. (1997) examined littoral fish biodiversity in the major tidal river systems of coastal Mississippi from St. Louis Bay to the Pascagoula River, but no collections were made in the Grand Bay NERR site. Swingle (1971), Franks et al. (1972) and Rakocinski et al. (1997) will not be discussed further as they are outside the Grand Bay NERR boundary. Peterson et al. (2003) documented the occurrence of the federal candidate species saltmarsh topminnow (*Fundulus jenkinsi*) in eastern Mississippi and western Alabama, including the Grand Bay NERR. Finally, Peterson and Rakocinski (2003) conducted a detailed spatial and temporal specific study of nekton within the Grand Bay NERR. Thus, the data presented below is based on these ancillary surveys (BioBlitz and AMRAT), data collected during the Mississippi GMEI (Christmas 1973; Reidel, Personal communication), Peterson et al. (2003), or on as yet unpublished data (Peterson and Rakocinski 2003). Scientific names of fishes follow Nelson et al. 2004.

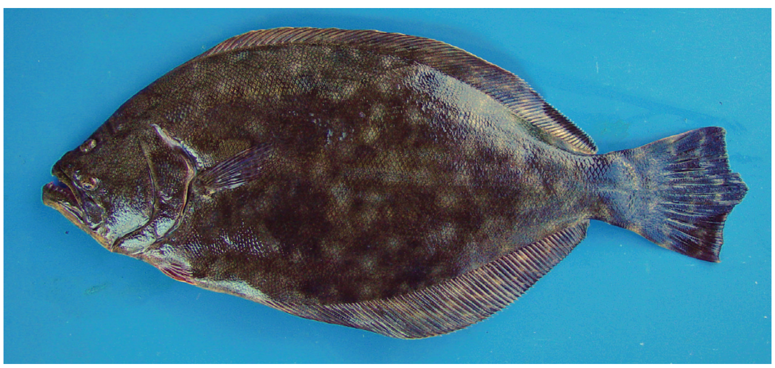
13.2.1 Anecdotal studies

The data gathered during the BioBlitz and AMRAT collection periods totaled 18 fish species, 2 crustaceans and 1 mollusk (Tables 13.1 and 13.2) using minnow traps, 16 ft otter trawls, and a 9-tooth dredge. All species collected were common to the region, and no invasive species were collected. Interestingly, some collections produced freshwater fishes which use the upper regions of the Grand Bay NERR site and are an important component of the ichthyofauna.

*Golden topminnow (*Fundulus chrysotus*). Photo credit: Gretchen Waggy.*

Table 13.1. Nekton collected using 16 ft otter trawls or minnow traps during the Grand Bay NERR BioBlitz conducted from 1500 on 30 April until 1500 on 1 May 2004.

Species	
Lagodon rhomboides	*Fundulus chrysotus*
Micropogonias undulatus	*Fundulus notti*
Bairdiella chrysoura	*Poecilia latipinna*
Leiostomus xanthurus	*Mugil cephalus*
Anchoa mitchilli	*Esox americanus*
Archosargus probatocephalus	*Lepomis gulosus*
Sphoeroides parvus	*Lepomis marginatus*
Chaetodipterus faber	*Farfantepenaeus aztecus*
Syngnathus louisianae	*Farfantepenaeus duorarum*
Aphredoderus sayanus	*Lolliguncula brevis*
Fundulus grandis	



*Southern flounder (*Paralichthyes lethostigma*). Photo credit: Paul Grammer.*

*Atlantic croaker (*Micropogonia undulatus*). Photo credit: Paul Grammer.*

Table 13.2. Nekton (abundance) collected at Grand Bay NERR during the AMRAT project on 30 August 2004. Columns represent location, AMRAT collection number, and gear types used. Organisms captured are presented taxonomically.

	Grand Batture Bar	Bangs Lake	Middle Bay	Mattie Clark Bayou	Jose Bay
Taxa collected	**M-32 (16 ft trawl)**	**M-33 (16 ft trawl)**	**M-34 (16 ft trawl)**	**M-35 (9-tooth dredge)**	**M-36 (9-tooth dredge)**
Cnidaria					
Eudendrium sp.				1 colony	
Hydractinia echinata	1 colony				
Arthropoda					
Balanus sp.				Present	Present
Batea catharinensis					6
Eurypanopeus depressus				3	38
Grandidierella bonnieroides					6
Melita nitida					6
Menippe adina					3
Pagurus pollicaris	1				
Panopeus obesus					1
Mollusca					
Crepidula depressa					1
Ischadium recurvum				18	2
Lolliguncula brevis	1	19	42		
Echinodermata					
Mellita quinquiesperforata	7				
Chordata-Vertebrata					
Anchoa hepsetus	29	3	34		
Anchoa lyolepis	3	1	4		
Anchoa mitchilli		3,533	50		
Bairdiella chrysoura		6	7		
Caranx hippos			1		
Chloroscombrus chrysurus		28	1		
Dorosoma petenense	10	27	4		
Eucinostomus argenteus			3		
Gobiosox strumosus				1	
Harengula jaguana		4			
Lagodon rhomboides	8	2	6		
Leiostomus xanthurus		3	5		
Micropogonias undulatus		5	1		
Opisthonema oglinum	1				
Peprilus alepidotus			1		
Syngnathus louisianae			1		
Synodus foetens			1		

13.2.2 Gulf of Mexico Estuarine Inventory (GMEI)

The 1968-69 data were collected with a single 50 ft seine haul and 16 ft otter trawl per month at site 68, located at the extreme southwest boundary of the NERR site. The available data are summarized by gear type and are comprised of 49 fish species, 16 crustaceans, 1 echinoderm, and 1 mollusk (Table 13.3). Clearly, the two gear types used collected different components of the nekton – shallower versus deeper – which is apparent from this historical data. No invasive species were found at this site in 1968 - 69 (Table 13.3).

Table 13.3. Nekton collected monthly using seines and trawls at site 68 (southwestern edge of NERR) of the GMEI inventory between April 1968 and March 1969. Total catch is ordered from greatest to least abundant (over all months) based on seine data for simplicity.

Species	Total catch (50' seine)	Total catch (16' trawl)
Leiostomus xanthurus	2,255	222
Acetes americanus carolinae	664	0
Palaemonetes pugio	560	0
Palaemonetes vulgaris	245	0
Mugil cephalus	130	1
Anchoa mitchilli	100	12,542
Brevoortia patronus	97	1
Litopenaeus setiferus	82	8
Callinectes sapidus	51	33
Cynoscion arenarius	39	46
Arius felis	37	128
Menticirrhus americanus	24	1
Trachypenaeus similis	21	0
Callinectes similis	14	14
Menidia beryllina	14	0
Bairdiella chrysoura	13	126
Cyprinodon variegatus	11	0
Pagurus pollicaris	8	8
Farfantepenaeus aztecus	7	72
Bagre marinus	5	5
Clibanarius vittatus	5	1
Farfantepenaeus duorarum	5	3
Micropogonias undulatus	4	359
Pagurus longicarpus	4	0
Fundulus majalis	3	0
Symphurus plagiusa	3	0
Larimus fasciatus	2	57
Latreutes parvulus	2	0
Membras martinica	2	0
Monacanthus hispidus	2	0
Mugil curema	2	0
Oligoplites saurus	2	0
Portunus gibbesii	2	1
Trinectes maculatus	2	0

Alosa chrysochloris	1	0
Chaetodipterus faber	1	4
Cynoscion nebulosus	1	1
Elops saurus	1	0
Fundulus jenkinsi	1	0
Hippolyte pleuracantha	1	0
Hypsoblennius hentz	1	0
Libinia dubia	1	1
Poecilia latipinna	1	0
Sphoeroides nephelus	1	1
Strongylura marina	1	0
Syngnathus louisianae	1	1
Xiphopenaeus kroyeri	1	0
Lolliguncula brevis	0	391
Anchoa hepsetus	0	44
Peprilus burti	0	35
Lagodon rhomboides	0	20
Chloroscombrus chrysurus	0	13
Orthopristis chrysoptera	0	12
Harengula jaguana	0	6
Trichiurus lepturus	0	6
Citharichthys spilopterus	0	5
Cynoscion nothus	0	4
Synodus foetens	0	2
Prionotus scitulus	0	2
Prionotus roseus	0	2
Prionotus tribulus	0	2
Portunus gibbesii	0	1
Luidia clathrata	0	1
Dasyatis sabina	0	1
Etropus crossotus	0	1
Chilomycterus schoepfi	0	1
Urophycis floridana	0	1
Urophycis regius	0	1
Peprilus paru	0	1

13.2.3 Status of *Fundulus jenkinsi* (Peterson et al. 2003)

*Saltmarsh topminnow (*Fundulus jenkinsi*). Photo credit: Gretchen Waggy.*

The saltmarsh topminnow, *Fundulus jenkinsi* (Evermann, 1892), occurs sporadically along the northern Gulf and appears to prefer *Spartina* habitat. Throughout its range, it is considered rare or threatened and has been placed on the U.S. Federal Register's List of Candidate Species. To determine the status and habitat characteristics of this species, Peterson et al. (2003) examined collections from 1985 - 86, 1996, 1999 and 2001 from eastern Mississippi and western Alabama. They reported on 868 *F. jenkinsi* collected in 82 locations using 414 seine hauls and 420 Breder traps over 40 dates. Results using all collections indicated *F. jenkinsi* was not as abundant as other fundulids in this area but was more abundant than previously thought. Their work also resulted in the first record for this species from the Pascagoula River drainage. For the Breder trap collections only, a stepwise linear regression indicated that water temperature and salinity explained 39.7 % of the variance in $\log_{10}$ (mean CPUE + 0.5) over the time of their study, and this relationship was significant ($p < 0.001$). The equation was $\log_{10}$ (mean CPUE + 0.5) = 1.623 - 0.0150 (salinity) + 0.77 (depth) - 0.0584 (water temperature). Using bag seine and Breder trap data, this species was most abundant (90.7 % of total) in salinities < 12 psu while being mainly collected in water depths near 0.5 m and water temperatures < 20.0 °C. Peterson et al. (2003) indicate that the use of sampling gear designed to collect resident marsh fishes was imperative and use of other gear types and/or variation in annual rainfall and the subsequent extent and patchiness of low salinity salt marsh area from year to year may explain why this species appears rare or absent in most fish studies of the northern Gulf. Because of its distribution in low-salinity bayou habitats, this small fundulid will probably be continually placed in situations where the habitat will be impacted due to development. Interestingly, this purportedly rare species was not collected in the BioBlitz or the AMRAT events (Tables 13.1 and 13.2), and only one individual was collected in the longer and more detailed 1968 - 69 GMEI efforts (Table 13.3). As noted by Fulling et al. (1999), it is necessary to use the correct gear (Breder traps) to capture this small, intertidal species that is typically not collected with traditional gear types.

13.2.4 Nekton Community Structure Study (Peterson and Rakocinski 2003)

In any coastal ecosystem there are considerable temporal and spatial patterns in nekton distribution and abundance (Subrahmanyam and Coultas 1980, Peterson and Ross 1991) and this, in part, is what makes estuaries so productive. The Grand Bay NERR site illustrates this principle.

Because drop sampling is typically biased

Breder traps used for collecting Fundulus jenkinsi. *Photo credit: Gretchen Waggy.*

Researchers from The University of Southern Mississippi using a drop sampler to collect shallow water estuarine nekton. Photo credit: USM-GCRL Fisheries Ecology Lab.

toward resident or small transient species (Rozas and Minello 1997), pelagic species that are highly aggregated, like *A. mitchilli*, *B. patronus*, and *M. beryllina*, are not as well represented in these collections as are certain resident taxa (Tables 13.4 and 13.5). Nevertheless, these data elucidate clear seasonal and spatial patterns of recruitment into the Grand Bay NERR. For example, young *Bairdiella chrysoura* were more abundant in spring collections than fall and in intertidal emergent vegetated habitats than non-vegetated subtidal habitats. For this species, this pattern was best reflected in Pt. aux Chenes Bay. This general seasonal pattern was also reflected in data on *Callinectes sapidus* megalopae, post-larval *Farfantepenaeus aztecus*, and unidentified gobies; *C. sapidus* megalopae and post-larval *F. aztecus* were more dense in intertidal than subtidal habitats. Moreover, juvenile and adult *C. sapidus*, post-larval *Litopanaeus setiferus*, mysids, *Gobiosoma bosc*, *Ctenogobius boleosoma*, *Palaemonetes pugio*, and *Anchoa mitchilli* were more abundant in fall collections than spring. Mysids, *C. boleosoma*, *P. pugio*, and *A. mitchilli* were not represented disproportionally in any habitat type, whereas juvenile and adult *C. sapidus*, post-larval *L. setiferus*, and the *G. bosc* were denser in intertidal habitats than subtidal. For mysids, this might be due to interactions between season and habitat. Finally, *P. pugio* density did not differ seasonally, but was greater in Middle Bay and Pt. aux Chenes Bay than at other locations, with intertidal densities of this organism greater than subtidal densities. These general patterns are similar to those reported elsewhere in the northern Gulf (Subrahmanyam and Drake 1975, Subrahmanyam and Coultas 1980, Peterson and Ross 1991, Rakocinski et al. 1992, Baltz et al. 1993, Peterson et al. 2000, Jones et al. 2002). One general observation is that for most of the numerically abundant taxa examined, densities were almost always lower in Bayou Cumbest than in the other three locations. This cannot be explained by measured water quality data, as there were no major differences noted during the course of this study except for an elevated salinity in spring compared to fall at the Bayou Heron and Bayou Cumbest locations. In addition, Bayou Cumbest is more visually impacted and appears to receive more residential effluent than the other locations.

In addition to different habitat-use patterns associated with developmental stages of nekton (body size), a portion of the spatial variability in density might be explained by the differences in habitat complexity associated with the sampling sites. For example, *Ruppia maritima* beds were only found during the course of this study in Middle Bay subtidal habitats, and *Gracilaria* sp., *Ulva* sp. and bryozoans were noted in both habitat types in Middle Bay and Pt. aux Chenes Bay in spring, when these taxa tend to be abundant. Structurally complex habitat types like those noted above have been shown to support a greater density and diversity of nekton species worldwide (Perkins-Vissar et al. 1996, Jackson et al. 2001, Pederson and Peterson 2002). Experimental data that support the importance of adjacent habitat types and the linkages between them are from temperate estuarine ecosystems where multiple habitat types (e.g., salt marshes, seagrasses, unvegetated flats) represent habitat heterogeneity at the landscape scale (Irlandi and Crawford 1997). These studies underscore the importance of connectivity among landscape features.

It is clear from an examination of the habitat-specific density data presented in this study that Grand Bay functions as nursery habitat (Beck et al. 2001, Minello et al. 2003) for a number of important species. Density of juveniles is the result of recruitment, mortality, and emigration processes, and thus is an important metric of nursery habitat value (Minello 1999). In particular, densities of *L. setiferus, F. aztecus*, *C. sapidus* (megalopae and juveniles/adults), *Cynoscion nebulosus,* and *Sciaenops ocellatus* were greater in intertidal *S. alterniflora* habitat than in adjacent subtidal habitat, suggesting that these habitats serve a nursery function.

Table 13.4. Listing of abundance and percent contribution of all nekton collected by a 1.0 m^2 drop sampler (n = 10 each location) in the Fall 2001 sampling period by location.

Taxon	Bayou Heron	Middle Bay	Pt. Aux Chenes Bay	Bayou Cumbest	Totals	%
Unidentified Mysidae	3,200	10,843	5,059	1,667	20,769	78.76
Callinectes sapidus megalopae	273	111	936	36	1,356	5.11
Callinectes sapidus	523	204	145	214	1,086	4.14
Palaemonetes pugio	38	146	426	76	686	2.60
Palaemonetes vulgaris	1	257	255	0	513	1.94
Anchoa mitchilli	122	36	224	7	389	1.47
Litopenaeus setiferus	115	43	53	70	281	1.06
Unidentified Gobiidae	2	0	217	15	234	<1
Ctenogobius boleosoma	80	27	40	5	170	<1
Gobiosoma bosc	111	11	22	22	166	<1
Farfantepenaeus aztecus	16	23	33	11	83	<1
Symphurus plagiusa	18	19	26	12	75	<1
Sciaenops ocellatus	1	16	45	0	62	<1
Farfantepenaeus duorarum	25	8	12	7	52	<1
Ctenogobius shufeldti	30	10	1	5	46	1
Microgobius sp.	1	0	38	0	39	<1
Ophiophragmus sp.	0	0	38	0	38	<1
Gobiosoma robustum	13	0	3	17	33	<1
Anchoa sp.	2	8	23	0	33	<1
Microgobius gulosus	20	0	0	11	31	<1
Unidentified Penaeidae	1	0	0	22	23	<1
Palaemonetes sp.	0	18	3	0	21	<1
Callinectes similis	1	9	10	0	20	<1

Alpheus sp.	2	7	9	1	19	<1
Unidentified Xanthidae	10	3	5	1	19	<1
Eucinostomus sp.	0	1	12	0	13	<1
Stellifer lanceolatus	0	0	12	0	12	<1
Farfantepenaeus sp.	0	0	5	5	10	<1
Unidentified Caridea	0	1	9	0	10	<1
Bairdiella chrysoura	0	1	4	3	8	<1
Leiostomus xanthurus	1	0	6	0	7	<1
Menticirrhus americanus	0	5	1	0	6	<1
Macrobrachium sp.	0	0	4	1	5	<1
Myrophis punctatus	1	1	0	2	4	<1
Callinectes sp. megalopae	1	0	0	3	4	<1
Rhithropanopeus harrisii	3	0	0	1	4	<1
Etropus crossotus	0	1	2	0	3	<1
Eurypanopeus depressus	2	0	0	1	3	<1
Menidia beryllina	2	0	0	0	2	<1
Fundulus jenkinsi	0	0	0	2	2	<1
Lagodon rhomboides	0	0	1	1	2	<1
Gobiesox strumosus	0	0	2	0	2	<1
Gobionellus sp.	2	0	0	0	2	<1
Unidentified Atherinidae	2	0	0	0	2	<1
Tozeuma carolinense	0	0	1	0	1	<1
Symphurus civitatus	0	1	0	0	1	<1
Prionotus longispinosus	0	1	0	0	1	<1
Paralichthys lethostigma	0	1	0	0	1	<1
Archosargus probatocephalus	0	1	0	0	1	<1
Menticirrhus sp.	0	1	0	0	1	<1
Pinnixa sp.	0	0	1	0	1	<1
Unidentified Eleotridae	0	1	0	0	1	<1
Unidentified Ophidiidae	0	1	0	0	1	<1

Table 13.5. Listing of abundance and percent contribution of all nekton collected by a 1.0 m^2 drop sampler (n = 10 each location) in the Spring 2002 sampling period by location.

Taxa/Species	Bayou Heron	Middle Bay	Pt. Aux Chenes Bay	Bayou Cumbest	Totals	%
Unidentified Mysidae	4,111	627	62	2,422	7,222	59.16
Palaemonetes pugio	1	1,149	224	31	1,405	11.51
Unidentified Gobiidae	216	1	1	1,030	1,248	10.22
Callinectes sapidus megalopae	67	116	596	94	873	7.15
Callinectes sapidus	43	215	78	78	414	3.39
Farfantepenaeus aztecus	35	43	69	42	189	1.54
Bairdiella chrysoura	3	17	98	11	129	1.06
Palaemonetes vulgaris	0	17	66	1	84	<1
Palaemonetes sp.	2	41	37	4	84	<1
Callinectes similis	5	21	25	3	54	<1
Gobiosoma bosc	13	4	6	28	51	<1
Litopenaeus setiferus	7	27	1	12	47	<1
Unidentified Xanthidae megalopae	2	31	6	2	41	<1
Unidentified Xanthidae	7	28	0	1	36	<1
Anchoa mitchilli	4	5	1	25	35	<1
Microgobius gulosus	12	0	3	12	27	<1
Farfantepenaeus sp.	5	3	8	9	25	<1
Gobiesox strumosus	1	4	14	2	21	<1
Alpheus heterochaelis	4	4	12	0	20	<1
Ctenogobius boleosoma	0	0	6	14	20	<1
Lagodon rhomboides	1	12	3	2	18	<1
Mugil curema	0	18	0	0	18	<1
Uca spp.	0	12	5	0	17	<1
Unidentified Penaeidae	0	8	3	5	16	<1
Menidia beryllina	2	12	2	0	16	<1
Fundulus grandis	1	7	0	0	8	<1
Myrophis punctatus	2	3	1	1	7	<1
Leiostomus xanthurus	2	2	0	2	6	<1
Farfantepenaeus duorarum	0	5	1	0	6	<1
Clibanarius vittatus	0	3	3	0	6	<1
Symphurus plagiusa	0	3	2	0	5	<1
Cyprinodon variegatus	0	5	0	0	5	<1
Citharichthyes spilopterus	0	3	2	0	5	<1
Synodus foetens	2	2	0	1	5	<1
Cynoscion nebulosus	1	0	2	1	4	<1
Microgobius sp.	0	0	0	4	4	<1
Armases cinereus	1	2	0	0	3	<1
Archosargus probatocephalus	0	2	1	0	3	<1

Pinnixa sp.	0	2	1	0	3	<1
Anchoa sp.	2	1	0	0	3	<1
Mugil cephalus	0	2	0	0	2	<1
Alpheus sp.	0	2	0	0	2	<1
Unidentified Brachyura	0	2	0	0	2	< 1
Panopeus spp.	2	1	0	0	2	<1
Eurypanopeus depressus	0	1	0	0	1	1
Ctenogobius shufeldti	1	0	0	0	1	<1
Gobiosoma robustum	1	0	0	0	1	<1
Sesarma reticulatum	1	0	0	0	1	<1
Fundulus jenkinsi	0	0	0	1	1	<1
Cynoscion arenarius	0	1	0	0	1	<1
Orthopristis chryopterus	0	1	0	0	1	<1
Chasmodes saburrae	0	1	0	0	1	<1
Sphoeroides parvus	0	1	0	0	1	<1
Syngnathus floridae	1	0	0	0	1	<1
Limulus polyphemus	0	0	1	0	1	<1
Paralichthys lethostigma	1	0	0	0	1	<1
Hyposblennius spp.	0	1	0	0	1	<1
Unidentified Squillidae	0	0	1	0	1	<1
Unidentified Fundulidae	0	1	0	0	1	<1
Unidentified Sciaenidae	0	1	0	0	1	<1

13.3 SUMMARY

The available literature on nekton of the Grand Bay NERR site is limited, but suggests that the site is diverse and that seasonal patterns reflect those documented from other studies in the northern Gulf. It also suggests that the system has the classic estuarine gradient from freshwater through saltwater, which has been modified by human development in many other estuarine ecosystems in the United States. Additionally, no invasive nekton species have been documented to date in the Grand Bay NERR system, but non-indigenous Nile Tilapia, *Oreochromis niloticus* (Peterson et al. 2004, Peterson et al. 2005) have been documented in nearby Pascagoula River and Simmons Bayou. Additionally, the non-indigenous Giant Malaysian Prawn, *Macrobrachium rosenbergii*, has been documented in Simmons Bayou (Woodley et al. 2002). The lack of any direct connection among these nearby systems will help reduce the possibility that these two highly invasive species will easily migrate to the Grand Bay NERR site through Mississippi Sound.

13.4 MONITORING AND RESEARCH NEEDS

- Evaluate nekton community structure of depositional versus erosional marsh edge habitats
- Quantify trophic relationships of resident and transient fishes that use marsh edge and seagrass habitats

- Quantify the fecundity, spawning season, frequency, and location of resident and transient fishes
- Compare diversity and biomass of nekton using marsh edge versus seagrass habitats
- Compare community structure, diversity, and biomass of nekton in *Juncus* and *Spartina* along a salinity gradient in all three sub-bays of Grand Bay NERR
- Quantify transfer of carbon from upper marsh to lower marsh to offshore habitats via nekton biomass movement using a 'flux by fish stable isotope model'
- Evaluate nursery habitats of resident and transient fishes within the Grand Bay NERR
- Evaluate fisheries productivity

*Frillfin goby (*Bathygobius soporator*). Photo credit: Gretchen Waggy.*

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CHAPTER 14

REPTILES AND AMPHIBIANS

Gabriel J. Langford, Joel A. Borden, C. Smoot Major, and David H. Nelson

14.1. REPTILES AND AMPHIBIANS OF THE MISSISSIPPI GULF COAST

Green Treefrog. Photo credit: Gretchen Waggy.

Although very abundant along the Mississippi Gulf Coast, many amphibians and reptiles are small, secretive animals that may not be readily noticed. Amphibians have a moist glandular skin, and typically deposit eggs in fresh water or very humid environments (like rotting logs). Carnivorous as adults, amphibians usually manifest a larval stage and metamorphosis. Amphibians consist of anurans (frogs and toads) and urodeles (salamanders). Frogs, toads and salamanders of coastal Mississippi are largely adapted to swamps, marshes, ponds and seepages. The vocal frogs and toads gather into breeding choruses where reproduction occurs at certain times of the year. Calls are unique to the species and can be readily recognized. Ponds and freshwater embayments may contain true frogs, treefrogs or toads. True Frogs include the larger pig frogs, bullfrogs, leopard frogs and bronze frogs**.** Treefrogs (having sticky, expanded toe discs) can climb vegetation -- even tall trees -- and breed in ponds (usually during the summer months). They include green treefrogs (*Hyla cinerea*), grey treefrogs (*Hyla chrysoscelis* and *Hyla versicolor*), squirrel treegfrogs (*Hyla squirella*), pine woods treefrogs (*Hyla femoralis*), etc. Toads have a “warty” skin (consisting of poison glands) that makes them distasteful to many mammalian predators. Several species of toads breed during the spring: southern toad (*Bufo terrestris*), Fowler’s toad (*Bufo fowleri*), and oak toad (*Bufo quercicus*). Since toads have short legs, they move somewhat slowly in small hops (and for short distances); thus they are more readily subdued. Salamanders (tailed, non-vocal amphibians) of the Gulf Coast consist of animals that inhabit permanent water (sirens, amphiumas, waterdogs), seepages (dusky; dwarf, and longtail salamanders), and woodlands (slimy, two-lined salamanders, etc.). Elevated deciduous woods that have temporary ponds (occurring farther inland) may be inhabited by a much richer variety of terrestrial woodlands salamanders than are available on the low, moist coastline.

Unlike amphibians, the largely non-vocal reptiles are characterized by scales and claws; they deposit shelled eggs on land or give live birth. Reptiles include turtles, crocodilians, lizards and snakes. The only crocodilian along the Gulf Coast is the American alligator (*Alligator* *mississippiensis*), which generally occurs in most undisturbed bodies of permanent, fresh water. Alligators may constitute the major, noticeable top predator (feeding on fishes, amphibians, reptiles, birds, or mammals). Turtles of coastal Mississippi consist of a rich variety of terrestrial and aquatic forms. Common box turtles (*Terrapene carolina*) are frequently found on land, and a great variety of freshwater turtles such as mud turtles (*Kinosternon*), musk turtles (*Sternotherus*), sliders (*Trachemys*), cooters (*Pseudemys*), snappers (*Chelydra* and *Macroclemys*), etc. occur in ponds, streams and bays. The only species of turtle that usually inhabits brackish water (along the immediate coastline) is the diamondback terrapin (*Malaclemys terrapin*). Lizards are represented by a great variety of anoles (*Anolis* spp.), skinks, fence lizards (*Sceloporus undulatus*) and (legless) glass lizards (*Ophiosaurus* spp.). The arboreal green anole (*Anolis carolinensis*) and the terrestrial ground skink (*Scincella lateralis*) are among the most frequently encountered. Lizards are small, fast-moving carnivores (largely insectivores) that are somewhat difficult to subdue. Because they tend to be larger and conspicuously active, some larger species of snakes are readily noticeable. However, there are a number of small, secretive snakes such as earth snakes, mole snakes, scarlet king snakes (*Lamprotletis triangulum elapsoides*), brown snakes (*Storeria dekayi*), scarlet snakes (*Cemophora coccinea*), etc. that remain hidden within substrates, logs or vegetation. These snakes may not be readily observed, even where abundant. Wetlands are usually inhabited by several species of water snakes (*Nerodia* spp.) (all harmless), cottonmouths (*Agkistrodon piscivorus*) (venomous), crayfish snakes (*Regina regida*), and ribbon snakes (*Thamnophis sauritus*). Although all species of water snakes are harmless, they invariably bite when handled. The only snake characteristic of brackish water is the gulf salt marsh snake (*Nerodia clarkii clarkii*). Although the cottonmouth is the most frequently encountered venomous snake seen along the Gulf Coast, eastern diamondback rattlesnakes (*Crotalus adamanteus*), pygmy rattlesnakes (*Sistrurus miliarius*), and coral snakes (*Micrurus fulvius*) may also occur. A separate assemblage of snakes characterizes the upland, coastal regions to the interior: garter snakes (*Thamnophis* spp.), hognose snakes (*Heterodon* spp.), rat snakes (*Elaphe obsolete*), corn snakes (*Elaphe guttata*), etc. The

American alligator sunning on the bank of a bayou. Photo credit: Sharon Milligan.

beautiful, slender green snake (*Opheodrys aestivus*) is largely arboreal, found on bushes and trees.

14.2. REPTILES AND AMPHIBIANS OF GRAND BAY NERR

With its unique color-changing ability, the green anole can also be brown or grey depending on its mood, temperature, humidity, or health. Photo credit: Gretchen Waggy.

In 2004, we conducted a systematic survey of the amphibians and reptiles of the Grand Bay NERR. The study ("Effects of Prescribed Fire on the Herpetofauna of a Southern Mississippi Pine Savanna") focused on the structures of amphibian and reptile communities in burned (8 mo post-burn) versus unburned sites on the research reserve. The wet pine savannas of Grand Bay constitute a significant, declining type of habitat characteristic of coastal Mississippi and Alabama. Since elevations are very rare, the terrain is extremely flat and wet. These kinds of habitats significantly favor many kinds of amphibians. The preliminary study conducted in 2004 and disclosed a total of 429 specimens (365 amphibians and 64 reptiles). Thus, the overall herpetofauna consisted of 85 % amphibians and 15 % reptiles. There were 14 species of amphibians and 15 species of reptiles encountered (Table 14.1). The four most common species collected (all amphibians) were oak toads (*Bufo quercicus*), southern cricket frogs (*Acris gryllus*), southern leopard frogs (*Rana utricularia*), and pine woods treefrogs (*Hyla femoralis*). These anurans accounted for 89 % of the amphibians and 77 % of all herpetofauna recorded. There were four species of amphibians represented by a single observation. Surprisingly, not a single terrestrial salamander was observed during the study.

Reptiles were far less frequently encountered than were amphibians. Although none were extremely abundant, the two dominant species of reptiles were turtles: eastern mud turtle (*Kinosternon subrubrum*) and the eastern box turtle (*Terrapene carolina carolina*). There were three other species of reptiles represented by a single observation. All organisms that were recorded were expected. Routine collections along the savannas of the southeastern coastal plains generally result in similar species assemblages. The actual numbers of any given species will vary with weather, season and time of day. However, the amphibians and reptiles encountered are representative of this region. A comparison of burned and unburned sites in our recent study shows that a low-intensity, prescribed fire had a positive effect on the herpetofauna (amphibians, Table 14.2). Amphibians are apparently able to exploit

Grey Treefrog Photo credit: Gretchen Waggy.

Gulf Saltmarsh Snake in Salicornia virginica *on a salt panne. Photo credit: Gretchen Waggy.*

newly-burned habitats, even after years of fire suppression have preceded the burn.

Table 14.1. Herpetofauna (abundance) of burned and unburned sites at the Grand Bay NERR, Mississippi.

Species	Common Name	Unburned	Burned	Total
AMPHIBIANS				
Acris gryllus	Southern Cricket Frog	50	63	113
Bufo quercicus	Oak Toad	9	125	134
Bufo fowleri	Fowler's Toad	0	1	1
Bufo terrestris	Southern Toad	1	1	2
Hyla cinerea	Green Treefrog	2	3	5
Hyla femoralis	Pine Woods Treefrog	8	19	27
Hyla squirella	Squirrel Treefrog	1	3	4
Gastrophryne carolinensis	Eastern Narrowmouth Toad	3	2	5
Pseudacris nigrita	Southern Chorus Frog	0	3	3
Rana grylio	Pig Frog	13	2	15
Rana clamitans	Bronze Frog	1	0	1
Rana utricularia	Southern Leopard Frog	2	51	53
Siren intermedia	Lesser Siren	0	1	1
Amphiuma means	Two-toed Amphiuma	0	1	1
TOTAL		90	275	365
REPTILES				
Deirochelys reticularia	Chicken Turtle	1	0	1
Kinosternon subrubrum	Eastern Mud Turtle	2	13	15
Terrapene carolina carolina	Eastern Box Turtle	5	2	7
Trachemys scripta elegans	Red-eared Slider	1	0	1
Agkistrodon piscivorous	Cottonmouth	4	1	5
Coluber constrictor	Black Racer	2	3	5
Lampropeltis getula holbrooki	Speckled Kingsnake	0	3	3
Opheodrys aestivus	Rough Green Snake	0	3	3
Nerodia fasciata	Banded Watersnake	2	0	3
Thamnophis sauritus	Eastern Ribbon Snake	2	0	2
Anolis carolinensis	Green Anole	1	5	6
Eumeces inexpectatus	Southeastern Five-lined Skink	3	0	3
Lygosoma lateralis	Ground Skink	1	4	5
Ophisaurus ventralis	Eastern Glass Lizard	1	4	5
Alligator mississippiensis	American Alligator	0	1	1
TOTAL		25	39	65

Table 14.2. Comparison of herpetofaunal abundance, diversity, and richness between burned and unburned sites.

	Burned	Unburned	$F_{1,4}$	*P*
Total Herpetofauna				
Abundance	13.07 ± 3.72	5.2 ± 0.69	13.03	0.023*
Shannon Index (H′)	0.74 ± 0.41	0.64 ± 0.35	0.11	0.764
Richness	12.67± 6.03	10 ± 7.81	0.22	0.664
Amphibians				
Abundance	11.36 ± 2.91	4.26 ± 1.32	14.82	0.018*
Shannon Index (H′)	0.45 ± 0.26	0.4 ± 0.25	0.06	0.82
Richness	7.67 ± 3.22	4.67 ± 3.06	1.37	0.306
Reptiles				
Abundance	1.33 ± 1.09	0.94 ± 0.64	0.48	0.527
Shannon Index (H′)	0.62 ± 0.28	0.53 ± 0.51	0.07	0.801
Richness	5 ± 3.46	5.33 ± 5.13	0.01	0.93

*Means are significantly different ($P \leq 0.05$)

A short-term study never accurately depicts the complete biodiversity of any area. Long-term studies during different seasons are required to disclose actual community structures. More systematic studies need to be conducted on the Grand Bay NERR. Three additional species of reptiles were observed on the reserve, outside the scope of this study: the Mississippi diamondback terrapin (*Macroclemys terrapin pileata*), the gulf salt marsh snake, and the broad-banded water snake (*Nerodia fasciata confluens*).

14.3. MANAGEMENT RECOMMENDATIONS

Low-intensity, prescribed fire appears to have a positive effect on the herpetofauna within the Grand Bay National Estuarine Research Reserve. Amphibians are able to exploit newly-burned habitats, even after years of fire suppression have preceded the burn. Our management recommendations for the Grand Bay NERR mirror those presented originally in Means and Campbell (1981) and recently reiterated in Means et al. (2004). These include prescribed burns, every 2 or 3 years, during the growing season that mimic wildfires. However, in accord with Schurbon and Fauth (2003), we suggest that the Grand Bay NERR would benefit from leaving small areas unburned, as a refuge and dispersal point for sensitive species (e.g. salamanders) during and after the burn. We stress the importance of burning these refuge areas during the next prescribed burn, to prevent hardwood establishment. Such fire management techniques should allow the herpetofauna to maximize the benefits of the resulting habitat mosaic, while still maintaining the fire-dependent vegetation of the pine savanna ecosystem.

14.4. MONITORING AND RESEARCH NEEDS

Researcher recording shell measurements from a Mississippi diamondback terrapin. Photo credit: Gretchen Waggy

Very little information is available on the amphibian and reptile communities that characterize the Grand Bay NERR; thus, continuing long-term studies need to be conducted. If more land is added to the Reserve in the future, these areas will also need to be studied. Many amphibians and reptiles native to the southeastern coastal plain were probably absent because their habitats do not occur within the present confines of the reserve site: gopher tortoises (*Gopherus polyphemus*), black pine snakes (*Pituophis melanoleucus lodini)*, gopher frogs (*Rana capito*), etc. However, these species may well inhabit other areas nearby. Certain other species of biological interest may occur on the site in significant numbers. Studies need to be conducted to assess the presence/status of organisms of conservation concern, such as the diamondback terrapin, gulf salt marsh snake, flatwoods salamander (*Ambystoma cingulatum*), southeastern five-lined skink, etc. Certainly, there are many other species of amphibians and reptiles that will be discovered upon further study.

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CHAPTER 15

BIRDLIFE OF THE GRAND BAY NERR/NWR AREA

Mark S. Woodrey and Jake Walker

Birds are highly mobile and flexible in their behavior and habitat use. Because of their transitory nature, this paper addresses birds observed on the Grand Bay National Estuarine Research Reserve (NERR), Grand Bay National Wildlife Refuge (NWR) as well as in the vicinity of these areas. When discussing the birds of this area, we typically denote the area as Grand Bay NERR/NWR area or vicinity.

The purpose of this chapter is three-fold. Our first objective is to provide an overview of birdlife of the Grand Bay NERR/NWR area. The second objective is to provide literature citations and references as well as technical data which can be used to develop bird-specific monitoring, research, and/or management projects. Finally, our third objective is to provide general information for the development of education and conservation- oriented programs.

15.1. GENERAL OVERVIEW OF THE BIRDLIFE OF THE NORTHERN GULF OF MEXICO

The birdlife of the Gulf Coast region is highly diverse, likely owing to the diversity of habitats in the area, as well as the interface of the land and the Gulf of Mexico (Lowery and Newman 1954). The high species diversity relates to the use of the area by many different groups of birds including waterfowl, long-legged wading birds (e.g., bitterns, herons, egrets and ibises), hawks, marsh birds (e.g., rails, gallinules and coots), shorebirds (e.g., plovers and sandpipers), hummingbirds, gulls, terns, woodpeckers, flycatchers, vireos, jays, crows, swallows, nuthatches, wrens, kinglets, mimics (e.g., mockingbirds, thrashers, catbirds), warblers, sparrows, cardinals, grosbeaks, and blackbirds.

Many different species of birds, such as (listed from front to rear) Willets, Marbled Godwits, Black Skimmers, and Laughing Gulls, can be viewed on the shorelines of the Grand Bay NERR. Photo credit: Sharon Milligan.

American Bittern in a defensive posture. Photo credit: Gretchen Waggy.

The birdlife of the state of Mississippi is fairly well documented (Turcotte and Watts 1999). In addition to providing 380 species (the number of species documented for Mississippi in 1999) accounts, Turcotte and Watts (1999) provide information on the history of ornithology in the state, discuss wildlife conservation and management in the state, note areas across the state for finding birds, briefly discuss field identification and bird behavior, address migration, and mention organizations, societies, and bird clubs found in Mississippi. Currently, the Mississippi Ornithological Society Checklist includes 400 species documented for the state (Mississippi Ornithological Society 2004).

The three coastal counties in Mississippi, Jackson (eastern-most), Harrison (central), and Hancock (western-most) have long been a focus of ornithologists and bird-watchers. In the first published list of Mississippi birds, Benjamin Wailes (1854) listed 89 species of birds, most of which are typical coastal species. The earliest extensive and intensive study of coastal avifauna in Mississippi was conducted by Thomas Burleigh (1944). Burleigh (1944) studied coastal birds from 1935 to 1943, making and compiling field observations as well as collecting specimens to document the distribution and abundance of birds in this unexplored region. Through his work, he documented 350 species (he also included subspecies) in the three coastal counties. In their treatise of birds and birding on the Mississippi Gulf Coast, Toups and Jackson (1987) provided documentation and accounts for 357 bird species. However, in spite of the relatively recent growth in the popularity of birding and an increase in our understanding of the birdlife of coastal Mississippi, there was no mention of bird species found in the Grand Bay NERR/NWR of southeastern Jackson County until 2004 (Toups et al. 2004). In the publication of "A Guide to Birding Coastal Mississippi and Adjacent Counties", Woodrey (2004) provided a site description highlighting the bird species regularly found at the Grand Bay NERR/NWR.

15.2. BIRDLIFE OF THE GRAND BAY NERR/NWR AREA

The Grand Bay NERR/NWR, located in Southeastern Jackson County, Mississippi contains a diversity of habitats which support numerous and significant populations of pelicans, Osprey (*Pandion haliaetus*), marshbirds, waterfowl, wading birds, shorebirds, and migrant landbirds (Mississippi Department of Marine Resources 1998). In their 1998 assessment of the environmental and biological characteristics of the proposed Grand Bay NERR, Wieland et al. (1998) noted 83 bird species. Based on daily field observations of NERR staff, visiting scientists, and birders as well as specific ornithological studies (see Section 15.2.2), 254 bird species have been observed in and around the Grand Bay NERR/NWR area (Appendix A). This is 65 % of the 387 species documented in the *Birds of the Mississippi Coastal Counties* checklist (Mississippi Coast Audubon Society 2006) for the six southern-most counties in Mississippi. Of the 254 species noted for the reserve/refuge, 43 species (17 %) are known to nest in the vicinity, 55 (22 %) are permanent residents, 94 (37 %) are winter residents, 24 (9 %) are summer residents, and 80 (32 %) are transients, or species that migrate through the area (Appendix A).

15.2.1 Overview of Bird-Habitat Relationships

An appreciation and identification of bird-habitat associations is an important first step in understanding ecological relationships of birds and habitat, identifying potential management issues, and the development of conservation strategies to address birds of concern. Here we provide a brief overview of our current understanding, based on limited systematic inventory and survey data, of broad species-habitat relationships for birds of the Grand Bay NERR/NWR area.

Bays

Common Loon. Photo credit: Sharon Milligan.

We define bay habitats as larger, open water areas typically surrounded on three sides by land. In the Grand Bay NERR/NWR area, the bays typically open into the east Mississippi Sound. The two most prominent bays in the Grand Bay area are Middle Bay and Point Aux Chenes Bay. These areas provide important habitat for large numbers of wintering waterfowl such as Redheads (*Aythya Americana*), Lesser Scaup (*Aythya affinis*), and Buffleheads (*Bucephala albeola*). In addition, these shallow water bodies provide feeding areas for other species such as Common Loons (*Gavia immer*), Brown Pelicans (*Pelecanus occidentalis*), Ospreys, Bald Eagles (*Haliaeetus leucocephalus*), Laughing (*Larus atricilla*) and Bonaparte's Gulls (*Larus philadelphia*), as well as Caspian (*Sterna caspia*), Royal (*Sterna maxima*), and Least Terns (*Sterna antillarum*).

Bayous

Bayous are larger estuarine tidal creeks and channels found throughout the area. The major bayous in the area include Bayou Heron, Crooked Bayou, Bayou Cumbest, and Bang's Bayou. These typically deep-channel waterways provide foraging habitat for many species of birds. During the winter, Hooded (*Lophodytes cucullatus*) and Red-breasted Mergansers (*Mergus serrator*), Pied-billed (*Podilymbus podiceps*), Horned (*Podiceps auritus*) and Eared Grebes (*Podiceps nigricollis*) are commonly seen diving below the surface for food while throughout the year Great Blue (*Ardea herodias*), Little Blue (*Egretta caerulea*), and Tricolored Herons (*Egretta tricolor*) as well as Great (*Ardea alba*) and Snowy Egrets (*Egretta thula*) can be observed foraging in the shallows along the bank. Terns, including Royal, Forster's (*Sterna forsteri*), and Least and Belted Kingfishers (*Ceryle alcyon*) patrol these channels from the air, periodically diving into the water in pursuit of prey.

Mississippi Sound

The Mississippi Sound is a large water body located between mainland Mississippi and the barrier islands about 10 km to the south. This coastal water body is generally variable in salinity and water clarity is low because of sediment loads, making this area ideal for the growth of oyster reefs and the development of marshes (Beck et al. 2002). In addition to supporting large numbers of wintering waterfowl, this area also provides winter habitat for Northern Gannets (*Morus bassanus*) and summer habitat for Magnificent Frigatebirds (*Fregata magnificens*). During the late summer and early fall, as hurricanes approach the northern coast of the Gulf of Mexico, extra-ordinary numbers of frigatebirds can be observed, with over 100 individuals counted the day before hurricane Ivan made landfall in Alabama in September 2004 (Mark Woodrey, Unpublished data).

Black-crowned Night-heron. Photo credit: Sharon Milligan.

Shell Islands/Bars

Shell islands and bars are typically made of common rangia (*Rangia cuneata*) and eastern oyster (*Crassostrea virginica*) shells that accumulated from food-gathering activities of native Americans (Mississippi Department of Marine Resources 1998). The best known example of this habitat is Bang's Island, located near the mouth of Bayou Cumbest. These habitats provide loafing and roosting areas for a variety of birds including American White (*Pelecanus erythrorhynchos*) and Brown Pelicans, shorebirds including Wilson's Plovers (*Charadrius wilsonia*), Spotted Sandpipers (*Actitis macularius*), Whimbrels (*Numenius phaeopus*), Long-billed Curlews (*Numenius americanus*), Ruddy Turnstones (*Arenaria interpres*), foraging American Oystercatchers (*Haematopus palliatus*), and gulls and terns.

Sand Beaches

Sand beaches are predominantly found along the shore of Point Aux Chenes and Grand Batture Island. Coastal birds of conservation interest, in particular Wilson's Plovers, Gull-billed Tern (*Sterna nilotica*) and Least Terns, and Black Skimmers (*Rynchops niger*) commonly use these habitats for nesting. Other species such as Black-bellied (*Pluvialis squatarola*), Semiplamated (*Charadrius semipalmatus*), and Piping Plovers (*Charadrius melodus*), and Sanderlings (*Calidris alba*) are commonly seen feeding and roosting in this habitat.

Pine Savannas

The majority of upland habitat of the Grand Bay NERR/NWR area is wet pine savanna. This fire-adapted community consists of a well-defined herbaceous layer of vegetation with pine trees (*Pinus* spp.) scattered throughout. The fire frequency in this habitat is 2-3 years and is essential for maintaining the herbaceous understory. In addition, frequent fire appears to be related to maintaining a diverse winter grassland bird community. This diverse bird community, although not very species-rich, contains several species of conservation concern. These species include the American Kestrel (*Falco sparverius*), Yellow Rail (*Coturnicops noveboracensis*), American Woodcock (*Scolopax minor*), Sedge Wren (*Cistothorus platensis*), Field Sparrow (*Spizella pusilla*), Grasshopper Sparrow (*Ammodramus savannarum*), Henslow's Sparrow (*Ammodramus henslowii*), Le Conte's Sparrow (*Ammodramus leconteii*), and Lincoln's Sparrow (*Melospiza lincolnii*). In addition, savannas provide nesting habitat for Common Nighthawks (*Chordeiles minor*), Brown-headed Nuthatches (*Sitta pusilla*), Eastern Bluebirds (*Sialia sialis*), Pine Warblers (*Dendroica pinus*), Blue Grosbeaks (*Passerina caerulea*), and Orchard Orioles (*Icterus spurius*).

Freshwater Marshes

Freshwater marshes within Grand Bay NERR/NWR typically occur in isolated depressions interspersed within the more common wet pine savanna habitat or directly adjacent to hydric drains. The largest freshwater marsh in the Grand Bay NERR/NWR area is known as Hawke's Marsh. Bird species commonly found in this habitat include waterfowl such as Wood Duck (*Aix sponsa*), Mallard (*Anas platyrhynchos*), and Blue-winged and Green-winged Teal (*Anas crecca*), waterbirds such as Anhinga (*Anhinga anhinga*), and American Bittern (*Botaurus lentiginosus*), marsh birds such as Virginia Rail (*Rallus limicola*) and Sora (*Porzana carolina*), Wilson's Snipe (*Gallinago delicata*), and Boat-tailed Grackle (*Quiscalus major*).

Bufflehead. Photo credit: Sharon Milligan.

Salt marshes

Salt marshes along the northern coast of the Gulf of Mexico are irregularly flooded habitats dominated by black needlerush (*Juncus roemerianus*), often with a fringe of smooth cordgrass (*Spartina alterniflora*). The salt marshes of the Grand Bay NERR/NWR are largely mesohaline in nature, but often dominated by the saline waters of the Mississippi Sound. Characteristic bird species found in this habitat are nesting Mottled Ducks (*Anas fulvigula*), Least Bitterns (*Ixobrychus exilis*), Clapper Rails (*Rallus longirostris*), Willets (*Catoptrophorus semipalmatus*), Seaside Sparrows (*Ammodramus maritimus*), and Red-winged Blackbirds (*Agelaius phoeniceus*). Species such as Reddish Egret (*Egretta rufescens*) and White Ibis (*Eudocimus albus*) can be found in this habitat year-round whereas Northern Harrier (*Circus cyaneus*), Black Rail (*Laterallus jamaicensis*), Sora, Short-eared Owl (*Asio flammeus*), Tree Swallow (*Tachycineta bicolor*), Marsh Wren (*Cistothorus palustris*), and Nelson's Sharp-tailed Sparrow (*Ammodramus nelsoni*) are strictly winter residents.

Mud/Sand Flats

Mud and sand flats are typically exposed during low tides and can be extensive, given the shallow nature of the Grand Bay NERR/NWR area. Two of the more extensive and regularly exposed areas are Catch-'Em-All Bar located along North Rigolets Bayou and the

Grand Batture Island area. Shorebirds are the most commonly observed birds using this habitat on a regular basis. Species such as American Oystercatcher, Black-bellied Plover, Semipalmated Plover, Greater Yellowlegs (*Tringa melanoleuca*), Willet, Least (*Calidris minutilla*) and Western Sandpiper (*Calidris mauri*), Short-billed Dowitcher (*Limnodromus griseus*), and Dunlin (*Calidris alpina*) are commonly observed at these sites. Less commonly observed, although not necessarily less important, are Marbled Godwits (*Limosa fedoa*), Lesser Yellowlegs (*Tringa flavipes*), Red Knots (*Calidris canutus*), Semipalmated (*Calidris pusilla*), White-rumped (*Calidris fuscicollis*), and Stilt Sandpipers (*Calidris himantopus*), and Long-billed Dowitchers (*Limnodromus scolopaceus*).

Wilson's Plover nest on salt panne. Photo credit: Mark Woodrey

Salt Pannes

Salt pannes are unique, hypersaline, sparsely-vegetated habitats scattered across the NERR with the most extensive areas occurring near Point Aux Chenes. These areas provide habitat for a variety of bird species including herons, egrets, and ibises as well as several species of shorebirds including Black-bellied Plover, American Golden-Plover (*Pluvialis dominica*), Wilson's Plover, Willet, Whimbrel, Long-billed Curlew, shorebirds in the genus *Calidris*, Pectoral Sandpiper (*Calidris melanotos*), and Gull-billed Tern.

Maritime Forests

For the purpose of this discussion, we include both shell midden and slash pine (*Pinus elliottii*) forests in our treatment of this habitat type. Along the northern coast of the Gulf of Mexico, maritime forests are critically important as stopover sites for landbird migrants as they make non-stop flights of 18-24 hours over the Gulf. In the Grand Bay NERR/NWR area, these habitats provide refuge for numerous species of migrant landbirds. Included in this group are raptors such as Cooper's (*Accipiter cooperii*) and Sharp-shinned Hawks (*Accipiter striatus*), Yellow-billed Cuckoos (*Coccyzus americanus*), Ruby-throated Hummingbirds (*Archilochus colubris*), flycatchers such as Western Wood-Pewee (*Contopus sordidulus*), Least (*Empidonax minimus*), Acadian (*Empidonax virescens*), Great Crested (*Myiarchus crinitus*), and Scissor-tailed (*Tyrannus forficatus*), vireos such as White-eyed (*Vireo griseus*), Yellow-throated (*Vireo flavifrons*), Philadelphia (*Vireo philadelphicus*), and Red-eyed (*Vireo olivaceus*), thrushes such as Veery (*Catharus fuscescens*), Gray-cheeked (*Catharus minimus*), Swainson's (*Catharus ustulatus*), and Wood (*Hylocichla mustelina*), warblers such as Blue-winged (*Vermivora pinus*), Tennessee (*Vermivora peregrina*), Magnolia (*Dendroica magnolia*), Black-throated Green (*Dendroica virens*), Black-throated Blue (*Dendroica caerulescens*), Prairie (*Dendroica discolor*), Bay-breasted (*Dendroica castanea*), Cerulean (*Dendroica cerulea*), American Redstart (*Setophaga ruticilla*), Worm-eating (*Helmitheros vermivorum*), Swainson's (*Limnothlypis swainsonii*), Ovenbird (*Seiurus aurocapilla*), Mourning (*Oporornis philadlphia*), Wilson's (*Wilsonia pusilla*), and Canada (*Wilsonia canadensis*), both Scarlet (*Piranga olivacea*) and

Summer Tanagers (*Piranga rubra*), Rose-breasted Grosbeaks (*Pheucticus ludovicianus*), Indigo (*Passerina cyanea*) and Painted Buntings (*Passerina ciris*), and Baltimore Orioles (*Icterus galbula*).

Oak Hammocks
These unique habitats are typically associated with abandoned home sites in the area and are dominated by live oak (*Quercus virginiana*). These small, usually < 3 ha, patches of deciduous forest are often interspersed within larger pine savanna dominated landscapes. Red-tailed Hawk (*Buteo jamaicensis*), White-winged Dove (*Zenaida asiatica*), and several species of owls, including Screech (*Megascops asio*) and Great Horned (*Bubo virginianus*), woodpeckers including Yellow-bellied Sapsucker (*Sphyrapicus varius*), Hairy (*Picoides villosus*), and Pileated (*Dryocopus pileatus*), and both Ruby-crowned (*Regulus satrapa*) and Golden-crowned Kinglets (*Regulus calendula*) use this habitat at various times throughout the year. In addition, many species of migrants can be found using these areas during the spring and fall (see list under Maritime Forests heading above).

15.2.2. Grand Bay NERR Specific Studies

A Clapper Rail after a radio transmitter has been secured to its back to track its movements in the marsh. Photo credit: Gretchen Waggy.

Since the designation of the Grand Bay NERR in 1999, four different bird-related projects have been initiated and/or completed on site. Three of these projects, "Winter Marshbird Ecology", "Winter Ecology of Shorebirds", and "Breeding Ecology of Marshbirds in Coastal Mississippi" are collaborative projects involving NERR staff and scientists from Mississippi State University and the University of Georgia. A fourth project, "Assessing the Value of Coastal Hammocks as Stopover Habitat for Passerine Migrants" is being conducted by a Graduate Research Fellow at the University of Southern Mississippi, in collaboration with scientists from Mississippi State University and the Grand Bay NERR.

Winter Marshbird Ecology
Little is known about wintering marsh bird communities along the northern coast of the Gulf of Mexico. Thus, in December 2003, the staff at the Grand Bay NERR, along with university colleagues, initiated a study to

characterize winter marsh bird communities and to collect data as baseline information for future research opportunities. To document the abundance, distribution and habitat associations of wintering marsh birds, we conducted weekly line-transect surveys along 15-17 randomly selected transects ranging from 200 to 500 meters in length. Surveys were conducted for three winters (December 2003-February 2004, December 2004-Marsh 2005, and January-March 2006) in the Grand Bay NERR/NWR area (Ogle and Rodriguez 2004, Ogle and Leach 2005, Walker 2006).

Sixteen species of winter marsh birds were detected during the surveys, with Marsh Wren, Nelson's Sharp-tailed Sparrow, and Seaside Sparrow being the most commonly detected species (Figure 15.1). Although currently preliminary, there appears to be a positive relationship between vegetation diversity and species diversity. Sparrow densities were low in homogeneous stands of black needlerush whereas Marsh Wrens were common across all habitat types. Marsh Wren relative density estimates decreased significantly during the study but both sparrow species were consistently common across the three years. Species-specific habitat associations for each species remained consistent across years. This study suggests that species-specific annual variation in site-specific abundance may be a feature of winter Gulf Coast marsh bird communities.

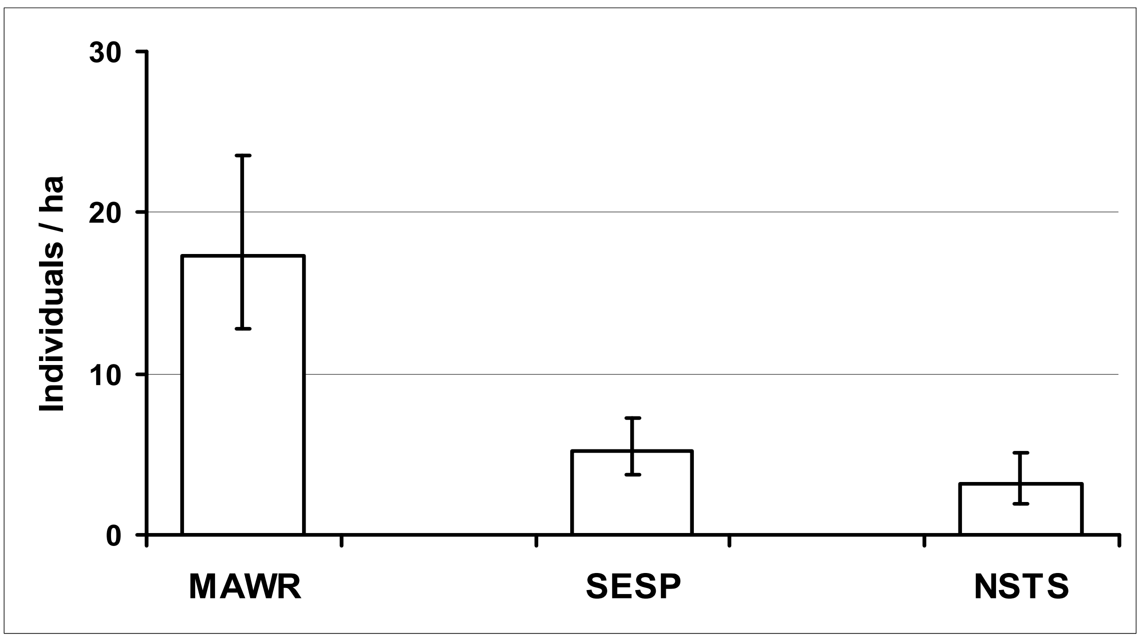

Figure 15.1. Mean (+ Standard Error) densities of wintering Marsh Wrens (MAWR), Seaside Sparrows (SESP), and Nelson's Sharp-tailed Sparrows (NSTS) at the Grand Bay National Estuarine Research Reserve and Grand Bay National Wildlife Refuge, Jackson County, Mississippi, 2004-2006.

Winter Ecology of Shorebirds

A primary goal of the NERR program is to determine the abundance and distribution (both spatial and temporal) of organisms using the particular site. Toward this end, we, along with colleagues from Mississsippi State University and the University of Georgia, initiated a study to quantify shorebird species presence and abundance on the reserve, focusing on one primary location, a large tidal sand flat located on Grand Batture Island (Ogle and Rodriguez 2004, Ogle and Leach 2005, Walker 2006). To better understand the population dynamics and feeding ecology of shorebirds using the area, we conducted bi-weekly surveys during the winters (December-March) of 2004, 2005, and 2006. During these surveys, which were conducted within two hours of low tide, we identified and counted all birds, categorized their activity as feeding, resting, or other (preening, bathing, etc.), and noted the microhabitat where the individuals were located (i.e., water, sand, mud).

In order of decreasing abundance, Dunlin, peeps (*Calidris* spp.), Western Sandpiper, dowitchers (*Limnodromus* spp.), and Black-bellied Plover were the five most commonly counted species (Table 15.1, Walker 2006). In general, the percentage of birds observed feeding was higher for smaller species than larger ones. Only Dunlin and dowitchers were observed preening regularly, but still not a commonly observed behavior. Black-bellied Plovers, dowitchers, and Dunlin were noted to be resting during more than 30 % of all observations. Semipalmated Plovers, Sanderlings, and Western Sandpipers were observed on mud the majority of the time. Dunlin and peeps were typically observed feeding in the mud and shallow water areas (<5 cm), whereas the dowitchers generally fed further from shore in deeper water areas (>10 cm).

Table 15.1. Mean number of individuals observed during winter shorebird surveys at the Grand Bay National Estuarine Research Reserve and Grand Bay National Wildlife Refuge, Jackson County, Mississippi, 2004-2006.

Species	2003 -'04	2004 -'05	2006
American Oystercatcher	1.4	0.4	1.7
Black-bellied Plover	7.9	3.6	7.9
Dowitcher sp.	23.0	12.4	52.6
Dunlin	201.2	110.4	354.3
Greater Yellowlegs			1.7
Killdeer	0.2		
Least Sandpiper			0.7
Peep	28.5	21.3	57.0
Piping Plover			0.3
Red Knot	1.2		0.39
Ruddy Turnstone	1.9	1.6	1.1
Sanderling	8.6	11.2	1.9
Semipalmated Plover	12.0	3.3	5.4
Western Sandpiper			56.3
Willet	2.6	0.4	1.3
Wilson's Plover			1.4
Yellowlegs sp.	0.1	0.7	1.7

In summary, the Grand Batture tidal flat is used by shorebirds in several ways (Walker 2006). During low tides when surveys were conducted, shorebirds primarily used the sand flats as a feeding area. During higher tides the larger species were observed roosting on two exposed sand islands in the middle of the tidal flat, or on adjacent islands. Smaller species often continued to forage along the edge of the water, regardless of water height.

Breeding Ecology of Marshbirds in Coastal Mississippi

In the spring of 2005, researchers from the University of Georgia, in conjunction with scientists from the NERR and Mississippi State University, initiated the first extensive marsh bird monitoring and research project for the Mississippi Gulf Coast (Woodrey et al. 2007). Despite the rapid loss of tidal marsh along the Gulf Coast of the United States, little is known about the marsh birds that inhabit this ecosystem. Specifically, how these species may be responding to loss of habitat and stochastic events such as tropical storms and hurricanes remains largely unknown. To address these issues, Woodrey and colleagues conducted call-broadcast surveys for marsh birds during the spring/summers (April-August) of 2005-2007. In addition, they used GIS to identify factors that influence the distribution and abundance of Least Bitterns, Clapper Rails, Common Moorhens (*Gallinula chloropus*), Marsh Wrens, Seaside Sparrows, Red-winged Blackbirds, and Boat-tailed Grackles in Mississippi's tidal marshes.

A flock of White Pelicans on the Grand Batture Islands. This species of pelican over-winters in the Reserve. Photo credit: Gretchen Waggy.

Preliminary results from the analysis of call-broadcast survey data indicate that Clapper Rails appear to be more common (Figure 15.2) and Least Bitterns less common in salt marshes experiencing greater salinity regimes. Further, an examination of macrohabitat variables in relation to the density of marsh birds at survey points suggests that the density of Common Moorhens, Boat-tailed Grackles and Red-winged Blackbirds may be positively related to the linear distance of a survey point to marsh-upland interface while the density of Seaside Sparrows showed a negative relationship. Estimates of home range size for Clapper Rails during 2006, as determined using radio-telemetry, were similar to estimates derived from call-broadcast surveys. In addition, radio-telemetry revealed that in the tidal systems of coastal Mississippi Clapper Rails undergo little intra-seasonal movement, a fidelity that may continue through the post-breeding period. Comparison of density estimates for Clapper Rails as derived from surveys conducted during the summer of 2005 and 2006 suggest that site-specific population size for this species may have increased slightly in the wake of Hurricane Katrina. For many marsh birds such as the Clapper Rail, periodic stochastic events such as hurricanes and tropical storms could afford an ecological release leading to an increase in prey availability, habitat rejuvenation, and reduced predation. Collectively, the results of this study demonstrate the importance of landscape metrics (e.g. emergent marsh patch size and availability), vegetation composition, and tidal regimes to marsh bird distribution and abundance. Understanding these interspecific relationships are critical to the development of effective marsh bird conservation planning and implementation, successful coastal marsh restoration efforts, and the overall conservation of coastal salt marsh communities along the Gulf of Mexico.

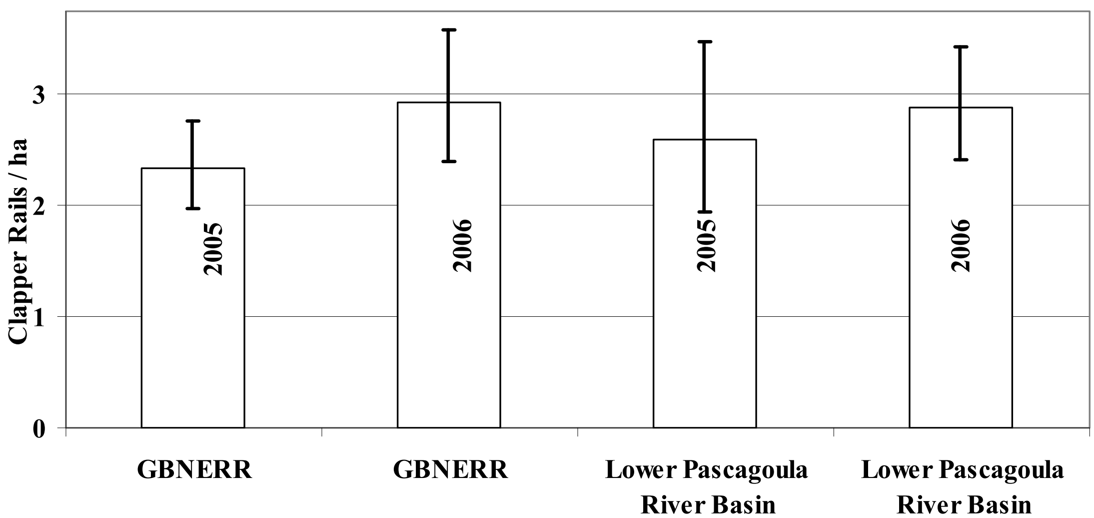

Figure 15.2. Mean (± Standard Error) density of Clapper Rails nesting at the Grand Bay National Estuarine Research Reserve and Lower Pascagoula Marshes Coastal Preserve, Jackson County, Mississippi, 2005-2006.

Assessing the Value of Coastal Hammocks as Stopover Habitat for Passerine Migrant

To better understand the factors which influence the use of critical stopover habitats along Coastal Mississippi, scientists from the University of Southern Mississippi, Mississippi State University, and the Grand Bay NERR used a combination of mist-netting and line-transect surveys to evaluate the effects of patch size on use by landbird migrants, determine species-specific patterns of habitat selection, and resources use by migrants (Hughes et al. 2006). During September and October 2006, Hughes and colleagues banded 1,796 birds of 71 different species, averaging 0.45 birds per net hour. The five species she captured most often were in descending order: Myrtle Warbler (*Dendroica coronata*), Gray Catbird (*Dumetella carolinensis*), Common Yellowthroat (*Geothlypis trichas*), Swamp Sparrow (*Melospiza georgiana*), and Ruby-crowned Kinglet.

In addition to mist-netting, this project generated a variety of other data to better understand the relationships between migrants their use of habitats at the reserve. For example, the field crew conducted daily surveys along line transects located on six different islands, detecting a total of 5,651 individuals of 132 species. Further, the crew collected blood samples from Common Yellowthroats and Gray Catbirds for plasma metabolite analysis. Plasma metabolite analysis will provide data on β-hydroxybutyrate and triglyceride concentrations, surrogate measures for mass change within the few hours prior to bleeding. The quantification of these metabolite levels represents an efficient method for assessing mass change that does not require recapturing an individual bird, a problem that has traditionally hindered many studies of bird migration.

15.2.3. Conservation of the Birdlife of the Grand Bay NERR/NWR

Black-necked Stilts foraging along the marsh edge on a sand spit. Photo credit: Gretchen Waggy.

Birds and the conservation of habitats they use have played increasingly prominent roles in the planning and implementation of on-the-ground conservation activities of government and non-government agencies in the past two decades. The development of the North American Bird Conservation Initiative (NABCI; North American Bird Conservation Initiative 2007a) in 1999 has been instrumental in fostering an increased focus on the conservation of birds and their habitats. The geographic basis for implementing their vision of "…populations and habitats of North America's birds that are protected, restored, and enhanced through coordinated efforts at international, national, regional, state, and local levels, guided by sound science and effective management" are ecological regions for bird conservation research, or Bird Conservation Regions (BCRs; North American Bird Conservation Initiative 2007a). The Grand Bay NERR/NWR area falls within the boundaries of the Southeastern Coastal Plain, or BCR 27 (North American Bird Conservation Initiative 2007b). Priority landbirds, which occur in the Grand Bay NERR/NWR area, for this BCR include Swallow-tailed Kites, Swainson's Warblers, Bachman's Sparrows, and Painted Buntings. Coastal intertidal habitats within this BCR provide critical areas for American Oystercatchers, important wintering and spring migration areas for Short-billed Dowitchers and Dunlin whereas coastal areas within this region provide important nesting and foraging habitats for large numbers of herons, egrets, ibis, terns, and other waterbird species. The coastal bays within this BCR winter large number of waterfowl, including Redheads and Lesser Scaup in the Grand Bay NERR/NWR vicinity.

Given the lack of funds and personnel for coastal zone management activities, the Grand Bay NERR/NWR staff should take advantage of the various partnerships available through NABCI. The best mechanism for taking advantage of this developing partnership and leveraging funding and activities is through Joint Ventures (JVs). Joint Ventures are self-directed partnerships of agencies, organizations, universities, corporations, and/or individuals that have formally accepted the responsibility of implementing national or international bird conservation plans within a specific geographic area or for a specific taxonomic group, and have received general acceptance in the bird conservation community for such responsibility (U.S. Fish and Wildlife Service 2007a). Two JVs, The Gulf Coast and East Gulf Coastal Plain overlap the Grand Bay NERR/NWR area. Integration of NERR/NWR monitoring, research, stewardship, and education activities into these two JVs could leverage existing funds as well as provide other types of support to bird–related activities at the NERR/NWR.

Sixty-seven (26 %) of the 254 bird species noted in the Grand Bay NERR/NWR vicinity are listed at some level as being of conservation interest (Table 15.2). Only three species are designated by the U.S, Fish and Wildlife Service as federally endangered or threatened (U.S. Fish and wildlife Service 2007b). In addition, the U.S. Fish and Wildlife Service created their list of "Birds of Conservation Concern", which is to be used to develop research, monitoring, and management initiatives (U.S. Fish and Wildlife Service 2002). The goal of this effort, by focusing attention on species of highest priority, is to "…promote greater study and protection of the habitats and ecological communities upon which these species depend, thereby ensuring the future of healthy avian populations and communities." Similarly, the Mississippi Comprehensive Wildlife Conservation Strategy (Mississippi Museum of Natural Science 2005) lists species in greatest need of conservation action at the state level. Given the availability of these prioritized lists and the limited resources available for conducting avian research, monitoring, and conservation, it is imperative that future bird-related efforts in the Grand Bay NERR/NWR area focus attention on species and/or groups of species found on these lists.

Table 15.2. Birds of conservation interest found in the vicinity of the Grand Bay National Estuarine Research Reserve and National Wildlife Refuge (Notes: [1]Species are listed in taxonomic order [see Appendix A]; [2]Source – U.S. Fish and Wildlife Service 2007b; [3]Source – U.S. Fish and Wildlife Service 2007b; [4]Source – U.S. Fish and Wildlife Service 2002; [5]Source – Mississippi Museum of Natural Science 2005).

Common Name[1]	Federal Status: Endangered[2]	Federal Status: Threatened[3]	Bird of Conservation Concern[4]	Species of Greatest Conservation Need[5]
Mottled Duck				X
Lesser Scaup				X
Northern Bobwhite				X
American White Pelican				X
Brown Pelican	X			X
Anhinga				X
American Bittern				X

Least Bittern				X
Snowy Egret				X
Little Blue Heron			X	X
Tricolored Heron				X
Reddish Egret			X	X
Black-crowned Night-Heron				X
Yellow-crowned Night-Heron				X
White Ibis				X
Wood Stork				X
Osprey				X
Swallow-tailed Kite			X	X
Bald Eagle		X		X
Peregrine Falcon			X	
Yellow Rail			X	X
Black Rail			X	X
Wilson’s Plover			X	X
Piping Plover	X	X		X
American Oystercatcher			X	X
Whimbrel			X	
Marbled Godwit			X	X
Red Knot			X	X
Semipalmated Sandpiper			X	
Western Sandpiper				X
Dunlin				X
Stilt Sandpiper			X	
Short-billed Dowitcher			X	
American Woodcock				X
Gull-billed Tern			X	X
Royal Tern				X
Sandwich Tern				X
Common Tern			X	
Least Tern			X	X
Black Tern			X	
Black Skimmer			X	X
Common Ground-Dove			X	X
Common Barn Owl				X
Short-eared Owl				X

Chuck-will's-widow	X	X
Red-headed Woodpecker		X
Loggerhead Shrike		X
Brown-headed Nuthatch	X	X
Wood Thrush	X	X
Northern Parula	X	
Black-throated Green Warbler	X	
Prairie Warbler	X	X
Cerulean Warbler	X	X
Prothonotary Warbler		X
Worm-eating Warbler		X
Swainson's Warbler	X	X
Louisiana Waterthrush		X
Kentucky Warbler		X
Scarlet Tanager		X
Bachman's Sparrow	X	X
Grasshopper Sparrow		X
Henslow's Sparrow	X	X
Le Conte's Sparrow	X	X
Nelson's Sharp-tailed Sparrow	X	X
Seaside Sparrow	X	X
Painted Bunting	X	X
Orchard Oriole	X	

15.3. MONITORING AND RESEARCH NEEDS

Mist nets set up on a coastal hammock to capture passerine migrants. Photo credit: Mark Woodrey.

Avian-specific monitoring and research needs are numerous and varied because of the lack of bird studies focusing on the Grand Bay NERR/NWR area. However, these projects fall into several broad categories including (1) inventory and survey efforts, (2) monitoring programs, (3) ecological studies, and (4) management/conservation-oriented projects. We recommend an initial focus on inventory and survey efforts focused on species groups, or guilds, such as wading birds and terrestrial breeding birds, which have not been addressed to date. In addition, we suggest that monitoring programs be established or continued for groups of interest in the area; groups such as wading birds, shore birds, marsh birds, and bird communities of pine savanna habitats (given the near-term focus on restoring these habitats to a more natural, open condition). Priority ecological studies include impacts of natural disturbance on bird communities, effects of pine savanna restoration activities on bird communities, ecology and movements of shorebirds in the area, distribution of waterfowl in relation to submerged aquatic vegetation, ecology of marsh birds in the area, and the potential impacts of mercury on the ecology of birds in the area.

Below is a general list of bird-related projects developed by the NERR staff. These projects outline general non-prioritized areas of interest and interested parties are encouraged to contact NERR staff to discuss these project ideas in greater detail:

- Study bird usage of area by season, e.g., wintering sparrows
- Conduct studies to understand bird community changes with restoration of wet pine savanna habitats
- Determine mercury (Hg) levels in different bird communities/guilds using various habitats within the NERR/NWR and evaluate the potential impacts
- Develop and conduct a survey/inventory of upland forest (i.e., pine savanna) breeding birds
- Develop and conduct a survey/inventory of wading bird use of the NERR/NWR area
- Conduct studies to understand the population dynamics, movements, and habitat use of shorebird communities in the NERR/NWR area
- Conduct studies to evaluate and understand the impacts of natural disturbance (e.g., fire, hurricanes) on bird communities
- Conduct studies to determine the factors relating to wading bird distributions of the NERR/NWR area
- Conduct studies to determine the distribution of wintering waterfowl in relation to submerged aquatic vegetation beds

- Conduct a survey/inventory of year-round bird use of freshwater marshes
- Conduct a survey/inventory of waterfowl to better understand population levels and evaluate the hunting pressure on this group of birds
- Establish and conduct an International Shorebird Survey Program at Grand Battures, the Chevron-Texaco Refinery, Point Aux Chenes salt pannes, Catch-'Em-All bar and Bang's Island
- Establish nest-box programs to supplement natural cavity loss from hurricane Katrina; focus could be on cavity nesting species such as Barn Owls, Eastern Screech Owls, Eastern Bluebirds, etc.
- Use/Establish a nest-box trail program for species such as Eastern Bluebirds for public education programs focused on bird banding, monitoring, etc.
- Develop a spatially explicit Bird Atlas (map of the breeding and wintering distribution and abundance of species), and link to vegetation types
- Establish and conduct a monitoring program for beach-nesting bird species

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Appendix 15. A. A summary of the 254 species of birds observed at the Grand Bay National Estuarine Research Reserve (NERR) and National Wildlife Refuge (NWR) area. Species are listed in taxonomic order according to the American Ornithologists' Union *Check-list of North American Birds*7th ed. (1998), including changes made in the 42nd, 43rd, 44th, 45th, 46th, and 47th supplements to the checklist (2000-2006). An * following the common name indicates a species known to nest at the Grand Bay NERR. Abbreviations used in the table are defined as follows:

Seasons	Sp-	Spring (Mar-May)		
	Su-	Summer (June-August)		
	F-	Fall (September-November)		
	W-	Winter (December-February)		
Seasonal Abunance	C-	Common (more than 10 individuals per day; almost certain to be seen or heard)		
	LC-	Less Common (1-10 individuals per day; may be overlooked)		
	O-	Occasional (several records; occasionally seen or heard, but most often missed)		
	R-	Rare (few records; not expected to be seen or heard)		
Residency Status	P-	Permanent Resident (present year round)		
	W-	Winter Resident (species that occur in the winter and migrate north for the summer)		
	S-	Summer Resident (species that occur in the summer and migrate south for the winter)		
	T-	Transient (species that migrate through the Grand Bay NERR, but do not stay for long)		
Habitat Types-	BA-	Bays	FM-	Freshwater Marshes
	BY-	Bayous	SM-	Salt marshes
	MS-	Mississippi Sound	MD-	Mud/Sand Flats
	SI-	Shell Islands/Bars	SP-	Salt Pannes
	SB-	Sand Beaches	MF-	Maritime Forests
	PS-	Pine Savannahs	OH-	Oak Hammocks
	FO-	Fly-over		

		Seasonal Abundance				Residency	Habitat
Common Name	**Scientific Name**	**Sp**	**Su**	**F**	**W**	**Status**	**Type**
Greater White-fronted Goose	*Anser albifrons*			O		T	FO
Snow Goose	*Chen caerulescens*			O		T	FO
Canada Goose	*Branta canadensis*			R		T	FO
Wood Duck	*Aix sponsa*	LC	LC	LC	LC	P	FM
Gadwall	*Anas strepera*	O			LC	W	BA, BY
Mallard	*Anas platyrhynchos*	O		O	LC	W	FM
Mottled Duck*	*Anas fulvigula*	C	C	C	C	P	FM,SM,BY
Blue-winged Teal	*Anas discors*	LC		LC	O	T	FM,BA,BY
Northern Shoveler	*Anas clypeata*	O		O	R	W	BA,BY
Green-winged Teal	*Anas crecca*	O		O	LC	W	FM
Canvasback	*Aythya valisineria*				R	W	BA
Redhead	*Aythya americana*	O		O	C	W	BA,MS
Ring-necked Duck	*Aythya collaris*				R	W	BA
Greater Scaup	*Aythya marila*	R		R	O	W	BA,BY,MS
Lesser Scaup	*Aythya affinis*	LC		O	C	W	BA,MS
White-winged Scoter	*Melanitta fusca*				R	W	BA
Bufflehead	*Bucephala albeola*	LC			C	W	BA,MS
Common Goldeneye	*Bucephala clangula*	O			O	W	BA
Hooded Merganser	*Lophodytes cucullatus*	LC			C	W	BA,BY,FM
Red-breasted Merganser	*Mergus serrator*	C			C	W	BA,BY
Ruddy Duck	*Oxyura jamaicensis*				R	W	BY,SM
Wild Turkey	*Meleagris gallopavo*	R	R	R	R	P	MF,OH,PS
Northern Bobwhite	*Colinus virginianus*	LC	LC	R	R	P	PS
Common Loon	*Gavia immer*	LC	R	O	C	W	BA,BY
Pied-billed Grebe	*Podilymbus podiceps*	LC		LC	LC	W	BY,FM

Horned Grebe	*Podiceps auritus*	C			C	W	BA,BY
Eared Grebe	*Podiceps nigricollis*	O			LC	W	BA,BY
Northern Gannet	*Morus bassanus*	LC		LC	C	W	MS,BA
American White Pelican	*Pelecanus erythrorhynchos*	C	R	C	C	W	BA,BY,SI
Brown Pelican	*Pelecanus occidentalis*	C	C	C	C	P	BA,BY,SI
Double-crested Cormorant	*Phalacrocorax auritus*	C		C	C	W	BA,BY
Anhinga	*Anhinga anhinga*	O	O	O	R	P	FM
Magnificent Frigatebird	*Fregata magnificens*	O	O	O		T	MS,BA
American Bittern	*Botaurus lentiginosus*	O		O	O	W	FM,SM
Least Bittern*	*Ixobrychus exilis*	LC	LC			S	SM
Great Blue Heron*	*Ardea herodias*	C	C	C	C	P	FM,SM,BY,MF
Great Egret	*Ardea alba*	C	C	C	C	P	FM,SM,BY,MF
Snowy Egret	*Egretta thula*	C	C	C	C	P	SM,BY
Little Blue Heron	*Egretta caerulea*	LC	LC	LC	O	P	SM,BY
Tricolored Heron	*Egretta tricolor*	C	C	C	C	P	SM,BY
Reddish Egret	*Egretta rufescens*	LC	O	LC	LC	P	SM,BA, MD
Cattle Egret	*Bubulcus ibis*	LC	LC			S	SM
Green Heron	*Butorides virescens*	LC	LC			S	FM,SM
Black-crowned Night-Heron	*Nycticorax nycticorax*	O	LC	LC	O	P	SM, MF
Yellow-crowned Night-Heron	*Nyctanassa violacea*		C	C		S	SM, MF
White Ibis	*Eudocimus albus*	LC	C	LC	O	P	SM
Roseate Spoonbill	*Platalea ajaja*		R	R		T	SM
Wood Stork	*Mycteria americana*		R	R		T	SM
Black Vulture	*Coragyps atratus*	O	O	O	O	P	FO
Turkey Vulture	*Cathartes aura*	LC		O	LC	P	FO
Osprey*	*Pandion haliaetus*	C	C	C	C	P	BA,BY,SM,FM,PS
Swallow-tailed Kite	*Elanoides forficatus*	R	R			T	FO
Mississippi Kite	*Ictinia mississippiensis*	R		R		T	FO

Bald Eagle*	*Haliaeetus leucocephalus*	LC		LC	LC	W	BA,BY,MF
Northern Harrier	*Circus cyaneus*	LC		LC	C	W	SM
Sharp-shinned Hawk	*Accipiter striatus*	R		R	R	W	PS,OH,MF
Cooper's Hawk	*Accipiter cooperii*	O		O	O	W	PS,OH,MF
Red-shouldered Hawk	*Buteo lineatus*	LC	O	LC	LC	P	PS,OH,MF
Broad-winged Hawk	*Buteo platypterus*	O		O		T	FO
Red-tailed Hawk	*Buteo jamaicensis*	LC	O	LC	LC	P	PS,OH,MF,SM
American Kestrel	*Falco sparverius*	O		O	LC	W	PS,SM
Merlin	*Falco columbarius*	R			R	W	BA
Peregrine Falcon	*Falco peregrinus*				LC	W	BA,SI
Yellow Rail	*Coturnicops noveboracensis*	R		R	R	W	PS,FM,SM
Black Rail	*Laterallus jamaicensis*	R		R	R	W	SM
Clapper Rail*	*Rallus longirostris*	C	C	C	C	P	SM
Virginia Rail	*Rallus limicola*	R		R	R	W	SM,FM
Sora	*Porzana carolina*	LC		LC	R	W	SM,FM
American Coot	*Fulica americana*	O		O	O	W	BA,BY
Sandhill Crane	*Grus canadensis*			R		T	PS
Black-bellied Plover	*Pluvialis squatarola*	C	R	C	C	W	SB,SP,SI,MD
American Golden-Plover	*Pluvialis dominica*	O				T	SP
Wilson's Plover*	*Charadrius wilsonia*	LC	LC			S	SB,SP,SI
Semipalmated Plover	*Charadrius semipalmatus*	C	R	C	C	W	SB,SP,SI,MD
Piping Plover	*Charadrius melodus*				R	W	SB
Killdeer	*Charadrius vociferus*	LC	R	LC	LC	P	FM,SM,MD
American Oystercatcher*	*Haematopus palliatus*	LC	O	LC	LC	P	SB,SI,MD
Black-necked Stilt	*Himantopus mexicanus*		O	LC	R	S	SI
American Avocet	*Recurvirostra americana*			O	R	T	SI
Greater Yellowlegs	*Tringa melanoleuca*	C		C	C	W	FM,SM,MD
Lesser Yellowlegs	*Tringa flavipes*	LC		LC	LC	W	FM,SM,MD

Willet*	*Catoptrophorus semipalmatus*	C	C	C	C	P	SM,SP,MD
Spotted Sandpiper	*Actitis macularius*	O		O		T	SI
Whimbrel	*Numenius phaeopus*	LC	O			T	SP,SI
Long-billed Curlew	*Numenius americanus*	O		O		T	SP,SI
Marbled Godwit	*Limosa fedoa*	O		O	O	W	SI,MD
Ruddy Turnstone	*Arenaria interpres*	LC		LC	LC	W	SI,MD
Red Knot	*Calidris canutus*	R		R		T	MD
Sanderling	*Calidris alba*	LC		LC	LC	W	SB,MD
Semipalmated Sandpiper	*Calidris pusilla*	C		C		T	MD,SP
Western Sandpiper	*Calidris mauri*	C		C	C	W	MD,SP
Least Sandpiper	*Calidris minutilla*	C		C	C	W	MD,SP,SM
Baird's Sandpiper	*Calidris bairdii*			R		T	SP
White-rumped Sandpiper	*Calidris fuscicollis*	R				T	MD
Pectoral Sandpiper	*Calidris melanotos*	LC		LC		T	SP,MD
Dunlin	*Calidris alpina*	C	R	C	C	W	MD,SI,SP
Stilt Sandpiper	*Calidris himantopus*			R		T	MD,SI
Short-billed Dowitcher	*Limnodromus griseus*	C		C	C	W	MD,SM
Long-billed Dowitcher	*Limnodromus scolopaceus*	LC		LC	LC	W	MD,FM,SM
Wilson's Snipe	*Gallinago delicata*	LC		LC	LC	W	SM,FM,PS
American Woodcock	*Scolopax minor*	R			R	W	FM,PS
Laughing Gull	*Larus atricilla*	C	LC	C	C	P	SI,BA,BY,MD
Bonaparte's Gull	*Larus philadelphia*				LC	W	BA,MS,MD
Ring-billed Gull	*Larus delawarensis*	C	O	LC	C	W	BA,BY,SI,MD
Herring Gull	*Larus argentatus*	LC		O	LC	W	BA,MS,SI,MD
Gull-billed Tern*	*Sterna nilotica*	LC	LC			S	SB,SP,SM
Caspian Tern	*Sterna caspia*	LC	O	LC	O	P	BA,SI,SB
Royal Tern	*Sterna maxima*	C	LC	C	C	P	BA,BY,SI,MD
Sandwich Tern	*Sterna sandvicensis*	LC	LC	LC		S	BA,SB

Common Tern*	*Sterna hirundo*	O	O			S	BA,SB
Forster's Tern	*Sterna forsteri*	C	LC	C	C	P	BA,BY,SB,SI,MD
Least Tern	*Sterna antillarum*	C	C	LC		S	BA,BY,SB
Black Tern	*Chlidonias niger*		LC	LC		T	BA,SB
Black Skimmer*	*Rynchops niger*	C	C	C	O	P	BA,SB
Rock Pigeon	*Columba livia*	R			R	T	FO
Eurasian Collared-Dove	*Streptopelia decaocto*	R		R	R	T	FO
White-winged Dove	*Zenaida asiatica*			R		T	MF
Mourning Dove*	*Zenaida macroura*	LC	LC	LC	LC	P	PS,OH,MF
Common Ground-Dove	*Columbina passerina*				R	T	
Yellow-billed Cuckoo	*Coccyzus americanus*	LC		LC		T	OH,MF
Common Barn Owl	*Tyto alba*	R	R	R	R	P	PS,SM,FM
Eastern Screech-Owl	*Megascops asio*	R	R	R	R	P	OH,MF
Great Horned Owl	*Bubo virginianus*	R	R	R	R	P	OH,MF,PS
Barred Owl	*Strix varia*	R	R	R	R	P	OH,MF
Short-eared Owl	*Asio flammeus*				R	W	SM
Common Nighthawk*	*Chordeiles minor*	C	C			S	PS
Chuck-will's-widow	*Caprimulgus carolinensis*	R		R		T	PS,OH
Chimney Swift	*Chaetura pelagica*	C	C	C		S	FO
Ruby-throated Hummingbird	*Archilochus colubris*	LC	LC	LC		S	OH,MF,PS
Belted Kingfisher	*Ceryle alcyon*	LC		LC	LC	W	BY,FM
Red-headed Woodpecker*	*Melanerpes erythrocephalus*	LC	LC	R	R	P	PS
Red-bellied Woodpecker*	*Melanerpes carolinus*	LC	LC	LC	LC	P	PS,OH,MF
Yellow-bellied Sapsucker	*Sphyrapicus varius*	LC		LC	LC	W	OH,MF
Downy Woodpecker	*Picoides pubescens*	O		O	O	W	OH,MF
Hairy Woodpecker	*Picoides villosus*	R		R	R	W	OH,MF
Northern Flicker*	*Colaptes auratus*	LC		LC	LC	W	OH,MF,PS
Pileated Woodpecker*	*Dryocopus pileatus*	LC		LC	LC	W	OH,MF

Olive-sided Flycatcher	*Contopus cooperi*			R		T	PS
Western Wood-Pewee	*Contopus sordidulus*			R		T	MF
Eastern Wood-Pewee	*Contopus virens*	O		O		T	OH,MF
Least Flycatcher	*Empidonax minimus*			O		T	OH,MF
Acadian Flycatcher	*Empidonax virescens*			O		T	OH,MF
Eastern Phoebe	*Sayornis phoebe*	LC			LC	W	OH,MF,PS
Great Crested Flycatcher*	*Myiarchus crinitus*	LC	LC	LC		S	OH,MF
Eastern Kingbird*	*Tyrannus tyrannus*	LC	LC	LC		S	OH,MF,PS
Scissor-tailed Flycatcher	*Tyrannus forficatus*			R		T	MF
Loggerhead Shrike	*Lanius ludovicianus*	O	O	O	O	P	PS
White-eyed Vireo	*Vireo griseus*	LC	O	LC	O	P	OH,MF,PS
Yellow-throated Vireo	*Vireo flavifrons*	O		O		T	OH,MF
Philadelphia Vireo	*Vireo philadelphicus*			R		T	OH,MF
Blue-headed Vireo	*Vireo solitarius*	LC			O	W	OH,MF,PS
Red-eyed Vireo	*Vireo olivaceus*	LC		LC		T	OH,MF, PS
Blue Jay*	*Cyanocitta cristata*	LC	LC	LC	LC	P	OH,MF,PS
American Crow	*Corvus brachyrhynchos*	LC	LC	LC	LC	P	FO
Fish Crow	*Corvus ossifragus*	LC	LC	LC	O	P	FO
Horned Lark	*Eremophila alpestris*				R	W	
Purple Martin	*Progne subis*	C	C			S	FO
Tree Swallow	*Tachycineta bicolor*	C		C	C	W	FM,SM
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	LC	O	LC		S	FO
Bank Swallow	*Riparia riparia*	O	C	O		T	FO
Cliff Swallow*	*Petrochelidon pyrrhonota*		C	O		T	FO
Barn Swallow*	*Hirundo rustica*	C	LC	C		S	FO
Carolina Chickadee	*Poecile carolinensis*	LC	LC	LC	LC	P	OH,MF,PS
Tufted Titmouse	*Baeolophus bicolor*	LC	LC	LC	LC	P	OH,MF,PS
Brown-headed Nuthatch*	*Sitta pusilla*	LC	LC	LC	LC	P	PS

Brown Creeper	*Certhia americana*			O	O	W	OH,MF
Carolina Wren*	*Thryothorus ludovicianus*	C	C	C	C	P	OH,MF,PS
House Wren	*Troglodytes aedon*	LC		LC	LC	W	OH,MF,PS
Winter Wren	*Troglodytes troglodytes*				R	W	PS
Sedge Wren	*Cistothorus platensis*	LC		LC	C	W	PS,FM,SM
Marsh Wren	*Cistothorus palustris*	LC		LC	C	W	SM
Golden-crowned Kinglet	*Regulus satrapa*	LC			LC	W	OH,MF,PS
Ruby-crowned Kinglet	*Regulus calendula*	C			C	W	OH,MF,PS
Blue-gray Gnatcatcher	*Polioptila caerulea*	LC	O	LC	O	P	OH,MF
Eastern Bluebird*	*Sialia sialis*	C	C	C	C	P	PS
Veery	*Catharus fuscescens*	R				T	OH,MF
Gray-cheeked Thrush	*Catharus minimus*	R				T	OH,MF
Swainson's Thrush	*Catharus ustulatus*	O		O		T	OH,MF
Hermit Thrush	*Catharus guttatus*	O		O	C	W	OH,MF,PS
Wood Thrush	*Hylocichla mustelina*	LC		LC		T	OH,MF
American Robin	*Turdus migratorius*				C	W	OH,MF,PS
Gray Catbird	*Dumetella carolinensis*	O		O	LC	W	OH,MF,PS
Northern Mockingbird*	*Mimus polyglottos*	LC	LC	LC	LC	P	OH,MF,PS
Brown Thrasher*	*Toxostoma rufum*	LC	LC	LC	LC	P	OH,MF,PS
European Starling	*Sturnus vulgaris*	R		R	R	T	FO
Cedar Waxwing	*Bombycilla cedrorum*	LC			C	W	OH,MF,PS
Blue-winged Warbler	*Vermivora pinus*	O				T	OH,MF
Tennessee Warbler	*Vermivora peregrina*	O		LC		T	OH,MF
Orange-crowned Warbler	*Vermivora celata*				LC	W	OH,MF,PS
Nashville Warbler	*Vermivora ruficapilla*			R		T	OH,MF
Northern Parula	*Parula americana*	LC		LC		T	OH,MF
Yellow Warbler	*Dendroica petechia*	O		LC		T	OH,MF
Chestnut-sided Warbler	*Dendroica pensylvanica*			O		T	OH,MF

Magnolia Warbler	*Dendroica magnolia*	O		LC		T	OH,MF
Cape May Warbler	*Dendroica tigrina*			R		T	OH,MF
Black-throated Blue Warbler	*Dendroica caerulescens*			R		T	OH,MF
Yellow-rumped Warbler	*Dendroica coronata*	LC		LC	C	W	OH,MF,PS
Black-throated Green Warbler	*Dendroica virens*	O		LC		T	OH,MF
Blackburnian Warbler	*Dendroica fusca*	O		LC		T	OH,MF
Yellow-throated Warbler	*Dendroica dominica*			O		T	OH,MF
Pine Warbler*	*Dendroica pinus*	C	C	C	C	P	PS,MF
Prairie Warbler	*Dendroica discolor*	O		LC		T	PS,MF
Palm Warbler	*Dendroica palmarum*	LC		LC	C	W	PS,MF
Bay-breasted Warbler	*Dendroica castanea*	O		O		T	OH,MF
Cerulean Warbler	*Dendroica cerulea*	O		O		T	OH,MF
Black-and-white Warbler	*Mniotilta varia*	LC		LC		T	OH,MF
American Redstart	*Setophaga ruticilla*	LC		LC		T	OH,MF
Prothonotary Warbler	*Protonotaria citrea*	LC		LC		T	OH,MF,FM
Worm-eating Warbler	*Helmitheros vermivorum*	O		O		T	OH,MF
Swainson's Warbler	*Limnothlypis swainsonii*	O		O		T	OH,MF
Ovenbird	*Seiurus aurocapilla*	O				T	OH,MF
Northern Waterthrush	*Seiurus noveboracensis*	O		O		T	OH,MF
Louisiana Waterthrush	*Seiurus motacilla*	O		O		T	OH,MF
Kentucky Warbler	*Oporornis formosus*			O		T	OH,MF
Mourning Warbler	*Oporornis philadlphia*			R		T	OH,MF
Common Yellowthroat*	*Geothlypis trichas*	LC	LC	LC	O	P	MF,FM,SM,PS
Hooded Warbler	*Wilsonia citrina*	LC		LC		T	OH,MF
Wilson's Warbler	*Wilsonia pusilla*			O		T	OH,MF
Canada Warbler	*Wilsonia canadensis*			O		T	OH,MF
Yellow-breasted Chat*	*Icteria virens*	LC	LC	LC		S	PS,MF
Summer Tanager	*Piranga rubra*	LC	O	LC		S	OH,MF

Scarlet Tanager	*Piranga olivacea*	O		O		T	OH,MF
Eastern Towhee*	*Pipilo erythrophthalmus*	LC	O	LC	LC	P	OH,MF,PS
Bachman's Sparrow	*Aimophila aestivalis*	R	R	R	R	P	PS
Chipping Sparrow	*Spizella passerina*				O	W	PS
Field Sparrow	*Spizella pusilla*			O		T	PS
Savannah Sparrow	*Passerculus sandwichensis*	LC			LC	W	PS,SB,SM,SP
Grasshopper Sparrow	*Ammodramus savannarum*				R	W	PS
Henslow's Sparrow	*Ammodramus henslowii*	LC			LC	W	PS
Le Conte's Sparrow	*Ammodramus leconteii*				O	W	PS
Nelson's Sharp-tailed Sparrow	*Ammodramus nelsoni*	LC		LC	LC	W	SM
Seaside Sparrow*	*Ammodramus maritimus*	C	C	C	C	P	SM
Fox Sparrow	*Passerella iliaca*				R	W	PS
Song Sparrow	*Melospiza melodia*	LC		LC	C	W	PS,MF
Lincoln's Sparrow	*Melospiza lincolnii*	R		R	R	W	PS
Swamp Sparrow	*Melospiza georgiana*	C		C	C	W	PS,FM,SM
White-throated Sparrow	*Zonotrichia albicollis*	C		C	C	W	PS,OH,MF
White-crowned Sparrow	*Zonotrichia leucophrys*				R	W	PS
Dark-eyed Junco	*Junco hyemalis*				R	W	PS
Northern Cardinal*	*Cardinalis cardinalis*	LC	C	LC	LC	P	OH,MF,PS
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	O				T	OH,MF
Blue Grosbeak*	*Passerina caerulea*	LC	LC	LC		S	PS,MF
Indigo Bunting*	*Passerina cyanea*	LC	LC	LC		S	OH,MF,PS
Painted Bunting	*Passerina ciris*	O				T	OH,MF
Dickcissel	*Spiza americana*			O		T	MF
Red-winged Blackbird*	*Agelaius phoeniceus*	C	C	C	C	P	FM,SM
Eastern Meadowlark	*Sturnella magna*	LC		LC	LC	W	PS,SM
Brewer's Blackbird	*Euphagus cyanocephalus*				O	W	FO
Common Grackle	*Quiscalus quiscula*	LC	LC		O	S	MF

Boat-tailed Grackle	*Quiscalus major*	O	O	O	O	P	SM,FM
Brown-headed Cowbird	*Molothrus ater*	O				T	PS,MF
Orchard Oriole*	*Icterus spurius*	LC	LC			S	OH,MF,PS
Baltimore Oriole	*Icterus galbula*	O		O		T	OH,MF
House Finch	*Carpodacus mexicanus*			O		P	PS
American Goldfinch	*Carduelis tristis*	LC		LC	LC	W	PS

CHAPTER 16

MAMMALS

Christopher A. May

16.1. INTRODUCTION

Knowledge of the ecology of mammalian species along the Gulf Coast varies; relatively little information is available on the ecology of most species. However, many of the species found on the coast have been studied extensively in other parts of the United States because of the species' importance as game, furbearer, or nuisance animals. Thus, most studies of the better known species have been conducted with the intent of improving the management of game and furbearers or improving the control of invasive and nuisance animals. Some studies have been the result of increasing awareness and directives to protect threatened and endangered species. Little is known of the many small mammals, especially bats, rodents, and shrews (i.e., species without recognized economic or social value), some of which are common along the Gulf Coast.

A raccoon trying to gain an easy meal near a fringe oyster reef at low tide. Photo credit: Jennifer Buchanan.

16.2. MAMMALS OF GRAND BAY NERR

Seminole Bat captured by researchers from The University of Southern Mississippi using mist nets. Photo credit: Austin Trousdale.

Very few mammalian studies or organized scientific collections have occurred at Grand Bay National Estuarine Research Reserve (NERR). The Grand Bay NERR mammal list (Table 16.1) was compiled from several sources. Mammalian surveys, species records, and distribution maps for the State of Mississippi (Crain and Cliburn 1965, Ward 1965, Wolfe 1971, Jones and Carter 1989, Shropshire 1998) and the eastern United States (Whitaker and Hamilton 1998) served as general guides. The Grand Bay NERR Management Plan (Mississippi Department of Marine Resources 1998) provided the only published list of mammals known to occur on the Grand Bay NERR site; however, this reference is best considered gray literature. Field observations made by the staff of Grand Bay NERR and other individuals also provided information on known occurrences. For species without documented occurrences on the Reserve, inclusion in the list was based on species abundance throughout southeastern Mississippi and southwestern Alabama, the presence of suitable habitat on the reserve, and published range maps. Marine mammals were limited to dolphins and manatee because the shallow waters north of the barrier islands restrict access by larger cetaceans.

Table 16.1. Species list of mammals known or expected to occur on Grand Bay National Estuarine Research Reserve (NERR), Mississippi. Species shown in bold have been observed at the site since NERR designation in 1999. [a] Introduced species.

Common name	Scientific name	Management status in Mississippi
Virginia opossum	*Didelphis virginiana*	Predatory animal
southern short-tailed shrew	*Blarina carolinensis*	
least shrew	*Cryptotis parva*	
southeastern shrew	*Sorex longirostris*	
eastern mole	*Scalopus aquaticus*	
big brown bat	*Eptesicus fuscus*	
red bat	*Lasiurus borealis*	
hoary bat	*Lasiurus cinereus*	Protected
northern yellow bat	*Lasiurus intermedius*	Protected
Seminole bat	*Lasiurus seminolus*	
southeastern myotis	*Myotis austroriparius*	Protected
little brown bat	*Myotis lucifugus*	Protected
evening bat	*Nycticeius humeralis*	
eastern pipistrel	*Pipistrellus subflavus*	
Rafinesque's big-eared bat	*Plecotus rafinesquii*	Protected
Brazilian free-tailed bat	*Tadarida brasiliensis*	
nine-banded armadillo	*Dasypus novemcinctus*	
swamp rabbit	*Sylvilagus aquaticus*	Game
eastern cottontail	*Sylvilagus floridanus*	Game
eastern gray squirrel	*Sciurus carolinensis*	Game
fox squirrel	*Sciurus niger*	Game
southern flying squirrel	*Glaucomys volans*	
North American beaver	*Castor canadensis*	Predatory animal
eastern woodrat	*Neotoma floridana*	
golden mouse	*Ochrotomys nuttalli*	
muskrat	*Ondatra zibethicus*	Furbearer
marsh rice rat	*Oryzomys palustris*	
cotton mouse	*Peromyscus gossypinus*	
fulvous harvest mouse	*Reithrodontomys fulvescens*	

eastern harvest mouse	*Reithrodontomys humulis*	
hispid cotton rat	*Sigmodon hispidus*	
Norway rat[a]	*Rattus norvegicus*	
roof rat[a]	*Rattus rattus*	
house mouse[a]	*Mus musculus*	
nutria[a]	*Myocastor coypus*	Furbearer
domestic dog[a]	*Canis familiaris*	
coyote	*Canis latrans*	Predatory animal
gray fox	*Urocyon cinereoargenteus*	Furbearer, Predatory animal
red fox	*Vulpes vulpes*	Furbearer, Predatory animal
American black bear	*Ursus americanus*	Protected
raccoon	*Procyon lotor*	Furbearer, Predatory animal
North American river otter	*Lontra canadensis*	Furbearer
striped skunk	*Mephitis mephitis*	Furbearer
eastern spotted skunk	*Spilogale putorius*	Furbearer
long-tailed weasel	*Mustela frenata*	Furbearer
American mink	*Mustela vison*	Furbearer
domestic cat[a]	*Felis catus*	
bobcat	*Lynx rufus*	Furbearer, Predatory animal
Atlantic spotted dolphin	*Stenella frontalis*	
spinner dolphin	*Stenella longirostris*	
Atlantic bottlenose dolphin	*Tursiops truncates*	
West Indian manatee	*Trichechus manatus*	*Protected*
wild pig[a]	*Sus scrofa*	Game
white-tailed deer	*Odocoileus virginianus*	Game

*A mouse (*Peromyscus *sp.) foraging for food. Photo credit: Chris May.*

Grand Bay NERR consists of three broad physical or vegetation environments: open water that is tidally influenced, salt marsh, and forests and savannas. Dolphins are commonly seen in the open water of the Reserve. West Indian manatees (*Trichechus manatus*) are rare visitors to the site. Manatees were reported in Bayou Heron during October 2003, and Jones and Carter (1989) mentioned other reports in Jackson County. River otters (*Lontra canadensis*) and nutria (*Myocastor coypus*) are seen occasionally along the bayous. Bats are commonly seen flying over the brackish water of the bayous from spring through fall, though it is not known which species are using these areas.

Characteristic species of the salt marsh include the marsh rice rat (*Oryzomys palustris*), raccoon (*Procyon lotor*), river otter, white-tailed deer (*Odocoileus virginianus*), nutria, muskrat (*Ondatra zibethicus*), and mesopredators (i.e., canids and some mustelids). The tracks of white-tailed deer and raccoon are seen often on the salt pannes of the Reserve.

A researcher, using a Sherman Live Trap, captured this elusive marsh rice rat on a salt panne. Photo credit: Gretchen Waggy.

The forest and savanna vegetation types support the highest diversity of mammals. This environment includes areas dominated by pine (*Pinus* spp.) trees as well as shell middens, maritime forest, cypress (*Taxodium* spp.) wetlands, and oak (*Quercus* spp.) forest. The most common species based on sightings of animals or their sign are bats, nine-banded armadillo (*Dasypus novemcinctus*), eastern gray squirrel (*Sciurus carolinensis*), gray fox (*Urocyon cinereoargenteus*), raccoon, and white-tailed deer. During the fall of 2003 several sightings of a black bear (*Ursus americanus*) were reported from the area near the Oak Grove Birding Trail and the upper reaches of Bayou Heron. Many small mammals are certainly common in the forest and savanna vegetation types, though they are not often seen.

The expected mammals of Grand Bay NERR include seven species introduced from outside North America (Table 16.1). At least three mammalian species (red wolf [*Canis rufus*], mountain lion [*Felis concolor*], and bison [*Bison bison*]) have been extirpated since European settlement.

16.3. MONITORING AND RESEARCH NEEDS

- Baseline mammal surveys, especially for bats, shrews, and rodents.
- Mammal use of special habitats (salt pannes, slash pine savanna islands, salt marsh).
- Effects of fire on mammals of marsh and savanna environments.
- Data on size, condition, and ecology of white-tailed deer in the marsh environment.
- Bat use of bayous and marsh for foraging.
- Movement of mammals (population dynamics and genetic transfer) between island habitats (shell middens, slash pine islands) and mainland.
- Impact of mesopredators on the ecology of marsh inhabitants. Raccoon, foxes, bobcat, and mustelids have been released from the hunting pressures of traditional top predators (mountain lion, red wolf). All these species are generalists in habitat use and diet, and most are adept at locating bird nests. What impact do they have on the productivity of nesting marsh birds and small mammals?

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CHAPTER 17

MONITORING AND RESEARCH NEEDS FOR THE GRAND BAY NERR

Mark S. Woodrey

17.1. INTRODUCTION

A Grand Bay NERR staff member collecting a sediment core from inside a throw trap while sampling for nekton. Photo credit: Mark Woodrey.

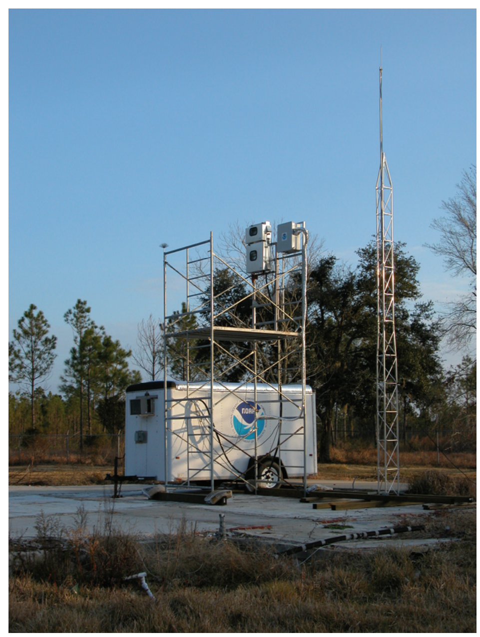
The Grand Bay National Estuarine Research Reserve (NERR) provides an excellent opportunity for scientists interested in studying coastal ecosystems. In addition to being one of the most, if not the most, pristine estuaries along the northern coast of the Gulf of Mexico, designation as a NERR site provides a variety of benefits to researchers. These benefits include regular and systematically collected monitoring data (e.g., water quality, meteorological, nutrient data, status and distribution of submerged-aquatic vegetation and emergent vegetation, land use/land cover data) acquired through the System-Wide Monitoring Program (SWMP); the availability of the research fellowships through the NERRS Graduate Research Fellowship Program; access to boats, ATVs, and other field equipment; and availability of modest laboratory and dormitory facilities on and near the site, respectively.

The Grand Bay NERR staff have cultivated professional relationships with a variety of academic institutions, government researchers, and non-government organizations. While these relationships are active, strong, and growing, the reserve staff is making a concerted and focused effort to broaden the exposure of the site through attendance at professional meetings, making presentations at international, national, regional, and local professional society meetings, conferences, and workshops. In addition, research staff are currently preparing a broad-based, Grand Bay NERR-focused presentation specifically targeting local and regional university seminar programs to provide and encourage local academic scientists to conduct research at the reserve, thus helping the staff to address the many and varied monitoring and research needs identified in this ecological characterization.

Currently, many valued, high-level partners are actively engaged in monitoring and research activities at the Grand Bay NERR. Academic scientists engaged in monitoring and research activities come from a variety of institutions including: The University of Southern Mississippi (both the Main Campus and Gulf Coast Research Laboratory), Dauphin Island Sea Lab, University of South Alabama, Louisiana State University, Southern Illinois University at Carbondale, Mississippi State University, The University of Mississippi, University of Georgia, University of Nebraska, University of South Carolina, University of New Orleans, Jackson State University, and Florida A&M University. The NERR also has a strong relationship with federal government scientists and programs, including the U.S. Geological Survey - Biological Resources Division, the National Wetlands Center, and Mississippi Water Science Center, the U.S. Army Corp of Engineers, the National Oceanic and Atmospheric Administration – Estuarine Reserves Division, Air Resources Laboratory, Coastal Services Center, National Coastal Data Development Center, National Aeronautics and Space Administration and state government agencies including the Mississippi Department of Environmental Quality, Mississippi Department of Wildlife, Fisheries and Parks – Museum of Natural Science, and the Mississippi Department of Marine Resources.

17.2. MONITORING AND RESEARCH IN THE NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

The National Estuarine Research Reserve System (NERRS) identified four high priority science and training needs for coastal managers: (1) Land Use and Population Growth, (2) Habitat Loss and Alteration, Water Quality Degradation, and (4) Changes in Biological Communities (National Oceanic and Atmospheric Administration 2005). These topics are locally and nationally important and appropriate to the mission of the NERRS. Increasing our understanding of these topics will improve the reserve system's ability to protect and restore coastal watersheds and estuaries and empower individuals to make informed decisions regarding coastal management. The goals, objectives, and strategies laid out in the 2005-2010 NERRS Strategic Plan (National Oceanic and Atmospheric Administration 2005) provides a framework, which emphasizes the role of monitoring and research, to address these priority science and training needs.



Atmosphric Mercurey Monitoring Station located on the Reserve. Photo credit: Jake Walker.

The individual National Estuarine Research Reserves, established for long-term research, monitoring, education, and stewardship, provide excellent opportunities for the study of coastal ecosystems. This system of reserves currently protects more than 1.3 million acres of coastal habitat including estuarine lands and water which serve as living laboratories for scientists, educators, and students (National Oceanic and Atmospheric Administration 2006a). Currently, five priority research areas have been identified with input from a variety of sources including reserve staff and managers, the NERRS Strategic Plan, and national documents outlining national coastal research needs and priorities. The priority research areas focus on:

- Habitat and Ecosystem Coastal Processes
- Anthropogenic Influences on Estuaries
- Habitat Conservation and Restoration
- Species Management
- Social Science and Economics

The five priority research areas listed above will be addressed using key reserve research goals, objectives and strategies outlined in the NERRS 2006-2011 Research and Monitoring Plan (National Oceanic and Atmospheric Administration 2006a). Four goals were set forward in the Monitoring and Research Plan to not only address thefive research priority areas but also to meet the strategic goals outlined by the NERRS. The four research goals include:

Goal 1: Biological, chemical, physical, and ecological conditions of reserves are characterized and monitored to describe reference conditions and to quantify change.

Goal 2: Scientists conduct research at reserves that is relevant to coastal management needs and increases the basic understanding of estuarine processes.

Goal 3: Scientists, educators, and coastal managers have access to NERRS datasets, science products and results.

Goal 4: The scientific, coastal management, and education communities, as well as the general public, use data, products, tools, and techniques generated at the NERRS.

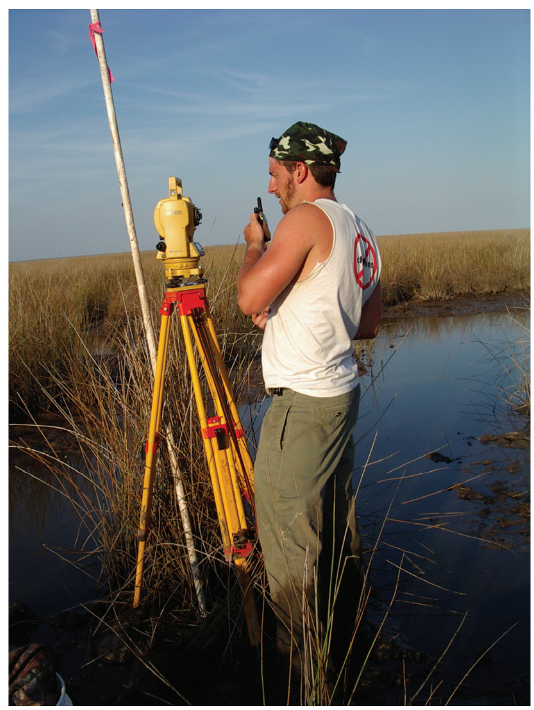
Grand Bay NERR's Research Coordinator holding a Clapper Rail which is a very secretive marsh bird. Photo credit: Scott Rush.

The monitoring and research needs identified in Section 17.4 of this ecological characterization are consistent with and are directly applicable to the goals of the NERRS Research and Monitoring Plan, particularly with respect to Goals 1 and 2. Thus, future research efforts addressing the monitoring and research needs or the Grand Bay NERR will contribute not only to our understanding of issues at the local level, but these projects will have regional and national significance as well.

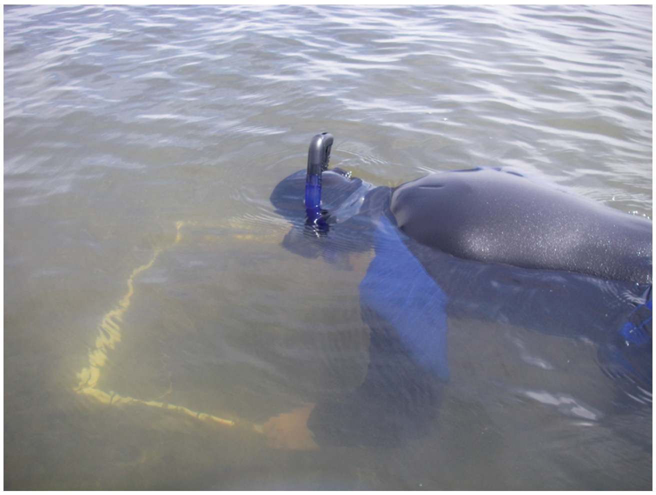
Two current NERRS programs, the System-Wide Monitoring Program (SWMP) and the Graduate Research Fellowship (GRF) program, provide critical data in our understanding of the ecology of each reserve as well as addressing the system as a whole (Owen and White 2005, National Oceanic and Atmospheric Administration 2006a). In addition, these programs are important sources of data which are used to develop management strategies for the conservation of critical coastal resources, they provide baseline data and supplement research and monitoring efforts outside the local reserve, and they support data synthesis efforts (e.g., Wenner et al. 2001, Sanger et al. 2002, Kennish and Finkl 2004).

The NERRS System-Wide Monitoring Program, developed in 1995, provides the framework for collecting quantitative data to assess short-term variability and long-term change in estuarine conditions (Owen and White 2005, National Oceanic and Atmospheric Administration 2006a). A key element of SWMP is the system-wide use of a set of consistent standard operating procedures that ensure the long-term collection of data that is comparable both temporally and spatially. This program utilizes a phased monitoring approach that focuses on three different ecosystem characteristics (National Oceanic and Atmospheric Administration 2002, 2006a, Owen and White 2005):

1. Phase 1 – Abiotic Parameters, including atmospheric conditions and water quality (nutrients, salinity, contaminants, etc.);
2. Phase 2 – Biological Monitoring, including biodiversity, habitat and population characteristics; and
3. Phase 3 – Watershed and Land Use Classifications, including changes in human uses and land cover types.


A researcher surveying in a vegetation transect to track long term trends of sea level rise. Photo credit: Mark Woodrey.

Currently, water quality data (i.e., conductivity, salinity, temperature, pH, dissolved oxygen, turbidity, and water level)) are being collected at 15 minute intervals via data loggers continuously deployed at a minimum of four water quality stations at each reserve. In addition, each reserve also collects monthly nutrient data (e.g., nitrate, nitrite, ammonia, and ortho-phosphate, and chlorophyll-*a* concentrations) from the water column at each of the four water quality sampling locations. In addition, diel sampling (12 samples per a 25 hour time period) for nutrients and chlorophyll-*a* occurs at a minimum of one site each month. At least one weather station per reserve records meteorological measurements, including local temperature, wind speed and direction, relative humidity, barometric pressure, rainfall, and Photosynthetic Active Radiation, at 15 minute intervals. Finally, reserve staff are working to integrate the phase-one SWMP data collection network into the backbone of the United States' Integrated Ocaen Observing System (IOOS) with near-real-time telemetry for timely data dissemination (National Estuarine Research Reserve 2004, 2006a, Owen and White 2005). Phase 2, or Biological Monitoring, was initiated in 2004, with biomonitoring demonstration projects at 16 reserves. These projects focused on developing baseline data for submerged and emergent vegetation distribution for use in land change use research, tracking changes in the health and distribution of these communities with long-term changes in water quality and quantity, and quantifying changes in estuarine habitat types (Owen and White 2005, National Oceanic and Atmospheric Administration 2006a). As with Phase 1, rigorous protocols were established to ensure compatibility across the reserve system, while retaining local flexibility as appropriate for individual reserves (Moore and Bulthius 2003). The Watershed and Land Use Classifications (Phase 3 of SWMP) portion has also been initiated with a recent effort to development a common classification system to assist reserves in consistent, and this nationally comparable, habitat and watershed mapping and inventory efforts (Kutcher et al. 2005). Several reserves are now piloting this "NERRS Classification Scheme" to assess its applicability to the reserve system (Owen and White 2005).



Grand Bay NERR's Stewardship Coordinator monitoring seagrass beds in Middle Bay. Photo credit: Christina Watters.

The Graduate Research Fellowship program, a second NERRS program, provides graduate students with opportunities to conduct research of local and national significance to promote the conservation of coastal ecosystems. The five focus areas for the GRF program are (1) eutrophication, effects of non-point source pollution and/or nutrient dynamics; (2) habitat conservation and/or restoration; (3) biodiversity and/or the effects of invasive species; (4) mechanisms for sustaining resources within estuarine ecosystems; and (5) economic, sociological, and/or anthropological research applicable to estuarine ecosystem management Created in 1997, this program has funded more than 160 fellows from 56 universities across the country (National Oceanic and Atmospheric Administration 2006a). At Grand Bay, eight students have been funded through the GRF program since 2000 and their work has made substantial contributions to our understanding of the ecology of the NERR. Fellows conduct their research within a NERR and gain hands-on experience by participating in their host reserve's research and monitoring program (National Oceanic and Atmospheric Administration 2006b).

17.3. GRAND BAY NERR RESEARCH GOALS AND OBJECTIVES

In 2003, the Grand Bay NERR staff and their partners completed work on a strategic plan for the reserve. Among the elements outlined in this strategic plan were issues relating to the development of the research program. The goals and objectives for a successful research program serve as a framework for the development of an efficient, long-term research program at the Grand Bay NERR. The strategic goal for the research program at the reserve is to "*Establish conditions for a successful research program including: monitoring program, site characterization, Research Advisory Committee, and research cooperatives*" (Grand Bay NERR 2003). Seven objectives were developed by the planning team to help meet the goal for a successful research program:

- Develop a PowerPoint presentation to promote research opportunities (e.g., presentations to local, regional, etc. universities, government agencies, etc.)
- Implement various monitoring programs
- Support site characterization surveys and inventories
- Develop cooperative agreements with various research institutions
- Develop an informational packet for visiting scientists
- Develop a Research Advisory Committee with diverse areas of expertise and utilize their knowledge and skills
- Develop research cooperatives with interested organizations and agencies

Creating a compilation of research and monitoring needs as identified by contributors to this ecological characterization will provide guidance for future research efforts at the Grand Bay NERR/NWR. In particular, addressing the monitoring and research needs as outlined in this document relate to several of the objectives for the Grand Bay NERR's research program. These include the implementation of monitoring programs, conducting status surveys and inventories, and this compilation of potential projects will be a key element in the informational packet for scientists.

17.4. SUMMARY OF RESEARCH AND MONITORING NEEDS

A review of the research and monitoring needs in this document demonstrates the variety and breadth of issues which have been identified for the Grand Bay NERR/NWR. These needs are numerous because of the lack of studies focused on the Grand Bay NERR/NWR. In spite of the diversity of topics noted in each chapter, these projects fall into several broad categories including (1) inventory and survey efforts, (2) monitoring programs, (3) ecological studies, and (4) management/conservation-oriented projects. The objective of creating this categorized list of projects is to provide a framework and some organization to this assortment of ideas which should allow interested individuals to identify projects that are of interest to them while at the same time ensuring information gaps for the Grand Bay NERR/NWR are addressed. It should be noted that the list of projects is not prioritized but rather the projects are listed in the order in which they appear in this document. In addition to the needs identified in each chapter by contributors, additional research needs were

Researchers using a seine net to examine the fish communities of the Grand Bay NERR. Photo credit: Gretchen Waggy gleaned from two documents including Stout (1984) and Greening (2005). Further, we directly contacted other collaborators not involved with the preparation of this document to solicit monitoring and research needs from them.

17.4.1. Inventory and Survey Projects

- Acquire data on shoreline geometry and bathymetry (*Hydrology*)
- Investigate the archaeology and vegetation of shell middens (*Historical Land and Water Use*)
- Further characterize habitats especially the high marsh, pine flatwoods/savanna, wet coastal prairie, and freshwater marshes (*Habitat Types/Ecological Communities*)
- Conduct additional surveys for confirmation of plant and animal species of conservation concern (*Habitat Types/Ecological Communities*)
- Complete more detailed classification of Grand Bay NERR using high resolution aerial photography (*Habitat Types/Ecological Communities*)
- Map bottom texture of subtidal areas (*Habitat Types/Ecological Communities*)
- Conduct additional survey work would improve the accuracy of habitat type maps and help to locate additional areas of rare communities (slash pine with wiregrass) (*Habitat Types/Ecological Communities*)
- Conduct inventories of vegetation, including phenology and genetic studies (*Vegetation*)
- Collect and analyze hyperspectral imagery for biological and historical reference (*Vegetation*)
- Conduct a quantitative inventory and survey of plants found on the Native American shell middens (*Vegetation*)
- Characterize substrate types of the Grand Bay NERR and determine the composition of the invertebrates found in the core samples (*Macroinfauna*)
- Develop a detailed GIS data layers/map of the oysters resources, both sub-tidal and inter-tidal, of the reserve (*Oysters*)
- Conduct status assessments/surveys for the presence/absence of organisms of conservation concern, such as the diamondback terrapin, gulf salt marsh snake, flatwoods salamander, southeastern five-lined skink, etc. (*Reptiles/Amphibians*)
- Develop and conduct a survey/inventory of upland forest (i.e., pine savanna) breeding birds (*Birds*)
- Develop and conduct a survey/inventory of wading bird use of the NERR/NWR area (*Birds*)
- Conduct a survey/inventory of year-round bird use of freshwater marshes (*Birds*)
- Conduct a survey/inventory of waterfowl to better understand population levels and evaluate the hunting pressure on this group of birds (*Birds*)
- Develop a spatially explicit Bird Atlas (map of the breeding and wintering distribution and abundance of species, and link to vegetation types (*Birds*)
- Conduct baseline mammal surveys, especially for bats, shrews, and rodents (*Mammals*)
- Determine mammal use of special habitats (salt pannes, slash pine savanna islands, salt marsh) (*Mammals*)
- Measure mercury content in dated sediment cores at various locations within the NERR/NWR

- Measure the mercury methylation rate in surficial sediments at various locations within the NERR/NWR
- Measure the water column concentrations of inorganic, methylmercury, and particulate mercury at various locations within the NERR/NWR

17.4.2. Monitoring Programs

Grand Bay NERR staff member collecting flooding frequency data on the many salt pannes located with in the Reserve's boundary. Photo credit: Gretchen Waggy.

- Collect baseline data on the existing conditions of conservation targets across the reserve site and correlate with hydrologic data (*Hydrology*)
- Develop a status report based upon a well conceived and executed baseline water quality study for the Grand Bay NERR/NWR area (*Historical Water Quality*)
- Conduct a baseline study as an integral part of a bioassessment program directed to current bioassessment/biocriteria goals of the U.S. Environmental Protection Agency (*Historical Water Quality*)
- Collect baseline contaminant data, including hydrocarbons, pesticides, and heavy metals, to be able to evaluate changes and assess future inputs (*Pollution Impacts*)
- Monitor widgeon grass (*Ruppia maritima*) beds (*Habitat Types/Ecological Communities*)
- Develop and conduct a macroinfaunal monitoring program which employs both functional metrics and faunistic metrics in conjunction with pelagic and benthic environmental parameters with broad spatial and habitat coverage within the Grand Bay NERR (*Macroinfauna*)
- Monitor populations of diamondback terrapin (*Reptiles/Amphibians*)
- Establish and conduct an International Shorebird Survey Program at Grand Battures, the Chevron-Texaco Refinery, Point Aux Chenes salt pannes, Catch-'Em-All bar and Bang's Island (*Birds*)
- Establish and conduct a monitoring program for beach-nesting bird species (*Birds*)
- Develop a monitoring program to collect measurements of speciated ambient concentrations of mercury in the ambient air at the newly established monitoring site at the NERR/NWR
- Measure concentrations and/or wet deposition at other sites within or near the NERR/NWR to investigate spatial variations

17.4.3. Ecological Studies

A successful prescribed burn in a wet pine savanna. Photo credit: Mark Woodrey.

- Identify threats to the natural hydrology of the area – specifically test the hypothesis that overall discharge to the areas seepage bogs is decreasing due to upland groundwater withdrawals (*Hydrology*)
- Determine the extent of hydrologic alterations from excessive groundwater withdrawals by compiling existing data on the extent of private, agricultural, and recreational water withdrawals and collect better data on industrial withdrawals (*Hydrology*)
- Determine the extent of hydrologic alterations from excessive groundwater withdrawals by developing a water budget for groundwater at the reserve by quantifying the sources and sinks such as recharge, evapotranspiration, stream flow, and withdrawals, for groundwater (*Hydrology*)
- Determine the extent of hydrologic alterations from excessive groundwater withdrawals by defining the hydrogeology of the system, such as aquifer hydraulic parameters, stratigraphy, potentiometric surface, etc (*Hydrology*)
- Determine the extent of hydrologic alterations from development by determining how impervious surface changes the overall recharge rate of the NERR/NWR (*Hydrology*)
- Explore the hydrologic alterations associated with rural development such as the impacts of failed septic systems (*Hydrology*)
- Study the interplay between fore, sea level rise, and hurricane return intervals (*Hydrology*)
- Determine the rate of sea level rise in the Grand Bay NERR/NWR area (*Hydrology*)
- Conduct extensive archaeological excavations to gain a better understanding of pre-historic Native American and early European settlement communities (*Historical Land and Water Use*)
- Evaluate and examine possible dominant nitrogen (N) sources (overland runoff, groundwater seepage, and atmospheric deposition) to characterize the nitrogen species and their contributions to the ecosystem nitrogen (N) budget (*Water Quality*)
- Characterize the stable isotopes of carbon (C) and nitrogen (N) at sources and in the water column to provide information on biogeochemical cycling within system (*Water Quality*)
- Couple stable isotope source characterization with temporal water column dynamics to provide insight into which sources fuel biological production throughout the year (*Water Quality*)

- Characterize the particulate organic matter (POM) pool to better understand biogeochemical aspects of the Nero's nutrient and carbon budgets (*Water Quality*)
- Determine the organic carbon loads in the NERR sediments; carbon fractions such as total organic carbon, dissolved organic carbon, dissolved inorganic carbon and sediment carbonates are important variables to understand and to use to predict the toxicant fate and bioavailability of contaminants (*Pollution Impacts*)
- Compare soil characteristics of the salt marsh zones, especially interstitial soil salinity, with vegetation composition (*Habitat Types/Ecological Communities*)
- Study the mud shore community and its importance to ecology of the tidal marshes (*Habitat Types/Ecological Communities*)
- Determine effects of burning on tidal marshes (*Vegetation*)
- Develop, leverage, and implement a multi-investigator/multidisciplinary study of habitat function within the Grand Bay NERR within replicated habitat types throughout the Grand Bay NERR aquatic ecosystem across multiple seasons and years; with macroinfaunal function as a key component (*Macroinfauna*)
- Support research aimed at elucidating critical trophic interactions within key habitat types through field experiments involving macroinvertebrates (*Macroinfauna*)
- Support before/after studies of hurricane effects on macroinfaunal communities and function (*Macroinfauna*)
- Evaluate nekton community structure of depositional versus erosional marsh edge habitats (*Nekton*)
- Quantify trophic relationships of resident and transient fishes that use marsh edge and seagrass habitats (*Nekton*)
- Quantify the fecundity, spawning season, frequency, and location of resident and transient fishes (*Nekton*)
- Compare diversity and biomass of nekton using marsh edge versus seagrass habitats (*Nekton*)
- Compare community structure, diversity, and biomass of nekton in *Juncus* and *Spartina* along a salinity gradient in all three sub-bays of Grand Bay NERR (*Nekton*)
- Quantify transfer of carbon from upper marsh to lower marsh to offshore habitats via nekton biomass movement using a 'flux by fish stable isotope model' (*Nekton*)
- Evaluate nursery habitats of resident and transient fishes within the Grand Bay NERR (*Nekton*)
- Evaluate fisheries productivity (*Nekton*)
- Conduct population studies of crustaceans (*Nekton*)
- Conduct long-term studies of amphibian and reptile communities characteristic of the Grand Bay NERR (*Reptiles/Amphibians*)
- Study bird usage of area by season, i.e. wintering sparrows (*Birds*)
- Determine mercury (Hg) levels in different birds communities/guilds using various habitats within the NERR/NWR and evaluate potential impacts (*Birds*)
- Conduct studies to understand the population dynamics, movements, and habitat use of shorebird communities in the NERR/NWR area (*Birds*)
- Conduct studies to evaluate and understand the impacts of natural disturbance (e.g., fire, hurricanes) on bird communities (*Birds*)

- Conduct studies to determine the factors relating to wading bird distributions of the NERR/NWR area (*Birds*)
- Conduct studies to determine the distribution of wintering waterfowl in relation to submerged aquatic vegetation beds (*Birds*)
- Determine the effects of fire on mammals of marsh and savanna environments (*Mammals*)
- Determine bat use of bayous and marsh for foraging (*Mammals*)
- Investigate the movement of mammals (population dynamics and genetic transfer) between island habitats (shell middens, slash pine islands) and mainland (*Mammals*)
- Determine the impact of mesopredators on the ecology of marsh inhabitants. Raccoon, foxes, bobcat, and mustelids have been released from the hunting pressures of traditional top predators (mountain lion, red wolf). All these species are generalists in habitat use and diet, and most are adept at locating bird nests. What impact do they have on the productivity of nesting marsh birds and small mammals? (*Mammals*)
- Conduct studies to determine mercury (Hg) levels in different types of fish within the reserve
- Analyze structure of aquatic food web within the NERR and determine relative levels of mercury at different trophic positions
- Evaluate atmospheric fate and transport models (e.g., HYSPLIT-Hg) using atmospheric measurements at the NERR/NWR
- Estimate spatial and temporal variations of atmospheric mercury concentrations and deposition at the NERR/NWR using one or more atmospheric mercury fate and transport models

17.4.4. Management/Conservation/Socio-Economic-oriented Projects

- Determine the extent of hydrologic alterations from development by determining the minimum water quality needed to protect the viability of conservation targets such as pine savanna matrix, seepage bogs and freshwater wetlands, coastal marshes, and independent streams (*Hydrology*)
- Determine the extent of hydrologic alterations from development by developing a projected land use model, building on existing land use and project growth data for Jackson County, Mississippi (*Hydrology*)
- Map the extent and distribution of various land use/land cover categories for the East Mississippi Sound Estuarine Drainage Area Watershed (*Hydrology*)
- Determine the difference in recharge rates for pine savannas versus more closed type forest types that result from fire suppression (*Hydrology*)
- Re-establish the natural hydrology of wet pine savanna and pine flatwood habitat types by (1) filling ditches that were historically created to drain water from land to be used for agricultural and livestock purposes, (2) minimizing the impacts of fire breaks, and (3) rehabilitating dirt roads and ATV trails that are not used for resource management or research (*Hydrology*)
- Develop shoreline protection structures and evaluate techniques that provide beneficial ecosystem processes and habitat

- Develop a plan to identify and monitor reference sites on Grand Bay NERR that could be used by researchers and natural resource managers to gauge the success of restoration projects throughout the Southeast
- Conduct more extensive interviews with descendants of early inhabitants to fill current knowledge gaps (*Historical Land and Water Use*)
- Conduct a review and summarize the archival land records and other pertinent documents (*Historical Land and Water Use*)
- Determine the danger of abandoned crab pots to mortality of non-target species, remove pots when located (*Habitat Types/Ecological Communities*)
- Restore and maintain wet pine savanna/pine flatwood habitat types through fire management and tree thinning (*Vegetation*)
- Conduct projects to control invasive species, particularly cogon grass (*Imperata cylindrical)* and Chinese tallow tree (*Triadica sebifera*) in wet pine savanna, pine flatwoods, and freshwater wetlands (*Vegetation*)
- Establish a seed bank for restoration purposes (*Vegetation*)
- Restore the submerged aquatic vegetation beds (Ruppia maritima) that were present in Bayou Cumbest prior to hurricane Katrina (*Vegetation*)
- Produce a guidebook on invertebrates of the Grand Bay NERR for the informed public (*Macroinfauna*)
- Assess the utility of oyster reefs for erosion control (*Oysters*)
- Evaluate the effects of tonging (oyster harvest) on oyster population parameters and reef ecological function (*Oysters*)
- Compare the success/failure of traditional open water cultch plants compared to intertidal cultch plants in Grand Bay NERR (*Oysters*)
- Model the effects of increased freshwater inflow on oyster populations (*Oysters*)
- Develop an oyster management plan for Grand Bay NERR, including coordination with the Shellfish Bureau of MDMR to review and, if necessary, modify harvest sack limits, harvest season, and other management policies and regulations (*Oysters*)
- Document bird community changes with restoration of wet pine savanna habitats (*Birds*)
- Establish nest-box programs to supplement natural cavity loss from hurricane Katrina; focus could be on cavity nesting species such as Barn Owls, Eastern Screech Owls, Eastern Bluebirds, etc. (*Birds*)
- Use/Establish a nest-box trail program for species such as Eastern Bluebirds for public education programs focused on bird banding, monitoring, etc. (*Birds*)
- Collect/gather data on size, condition, and ecology of white-tailed deer in the marsh environment (*Mammals*)
- Determine the effects of fire on tidal marshes (*Vegetation*)
- Conduct a Visitor Use study to determine who is using the reserve and what activities they are engaged in when visiting the reserve
- Conduct an economic evaluation/impact study of the users groups of the reserve
- Conduct multi-media modeling of mercury in the air, water, sediments, biota within the NERR/NWR
- Evaluate the risk to human and wildlife populations due to consumption of mercury-containing organisms

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