The Ecology of the Sapelo Island National Estuarine Research Reserve

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Introduction

by Buddy Sullivan

In 1972, Congress passed the Coastal Zone Management Act (CZMA). In the CZMA, and its subsequent reauthorizations, Congress officially recognizes that resources of the coastal zone are of national significance and are rapidly disappearing. The CZMA also recognizes the interrelationships between uplands and tidelands. The "coastal zone" was defined in the Act as including all uplands "to the extent necessary to control shorelands." The CZMA established as a national goal "to preserve, protect, develop and, where possible, to restore and enhance the resources of the nation's coastal zone for this and succeeding generations."

Section 315 of the CZMA of 1972, as amended, establishes the National Estuarine Research Reserve System. Under the system, healthy estuarine ecosystems which typify different regions of the U.S. are designated and managed as sites for long-term research, and used as a base for estuarine education and interpretive programs. The system also provides a framework through which research results and techniques for estuarine education and interpretation can be shared throughout the region and across the nation.

As stated in the Coastal Zone Management Act, the National Estuarine Research Reserve System provides for "the establishment and management, through Federal-state cooperation, of a national system of Estuarine Research Reserves representative of the various regions and ecological types in the United States. Estuarine Research Reserves are established to provide opportunities for long-term research, education and interpretation."

Prior to the establishment of the NERR system, scientific understanding of estuarine processes was increasing slowly and without national coordination. There was no ready mechanism for the detection and measurement of local, regional or national trends in estuarine conditions. Resource managers, governments and the public did not always have access to information about the significance and ecology of their estuaries, could not assess the full impact of past activities, and could not readily anticipate the damaging effects of proposed management and development policies. NERR System research and education can help fill those gaps in knowledge and guide estuarine management for sustained support of commercial and recreational fisheries, tourism and other activities.

NERRS sites serve as laboratories and classrooms where the effects of both natural and human activity can be monitored and studied. There are currently 22 Estuarine Research Reserves comprising 445,000 acres in 17 states and Puerto Rico. Through careful management of these resources, generations of scientists, fishermen, naturalists and others will come to experience the beauty to be found where rivers return to the sea.

The Sapelo Island National Estuarine Research Reserve lies in the midst of an estuary where the currents of Doboy Sound and the Duplin River meet. The Reserve comprises 6,110 acres and encompasses ecologies typical of the Carolinian biogeographic region and incorporates a coastline characterized by expanses of tidal salt marshes protected by a chain of barrier islands. The SINERR contains about 2,200 acres of upland forest dominated by stands of southern live oak hardwoods, pine (longleaf and loblolly), white-tailed deer, wild turkey and numerous other forms of wildlife. Two-thirds of the Reserve is comprised of expansive belts of salt marsh, which host a wealth of inhabitants. Members of this diverse salt marsh community feed and reproduce in the marshes and along the exposed river and creek banks at low tide. The Reserve also includes large areas of beach and dune communities fronting the Atlantic Ocean, as well as a network of oak, cedar and palm upland hammocks scattered through the marsh and beach areas.

The Reserve annually receives funds from the National Oceanic and Atmospheric Administration (NOAA), supplemented by matching state funds to conduct various educational and scientific monitoring programs. Part of the monitoring program has entailed the preparation of this ecological site characterization profile. This project began in late 1994 with a contract between the Georgia Department of Natural Resources, which manages the Reserve, and the University of Georgia Marine Institute. The UGMI, with funding provided by the Reserve's annual operations grant award from NOAA, has prepared this document based, in part, on the forty-five years of scientific research its resident faculty members have conducted on Sapelo Island, primarily within the boundaries of the Estuarine Research Reserve. This ecological profile contains a diverse range of material, including:

1. The story of human activity on Sapelo Island, current use and ownership of the island and the regional setting of the SINERR, including the commercial and recreational utilization of Georgia estuarine areas;
2. The geological and hydrological characterization of the SINERR, to include the development of lagoonal marshes, tidal conditions, hydrology of the Duplin River, geomorphology of the Duplin River, influence of the Altamaha River and upland runoff, and beach morphology and the sand-sharing system;
3. Ecological habitats of the Reserve, including (a) aquatic, Duplin River and Doboy Sound; and (b) intertidal, mudflats and mudbanks, intertidal creeks, vegetated salt marsh and high marsh, beaches and sand dunes, forested uplands, vegetation patterns and shoreline changes through time utilizing Geographic Information System (GIS) and historical maps and photos to document changes;
4. Chemical characterization of aquatic and marsh habitats, including water column (carbon, nitrogen, phosphorous and silica nutrients), marsh sediments and biota;
5. Primary productivity (water column and salt marsh);
6. Secondary productivity, including the Duplin River (zooplankton, crabs and fish) and salt marsh (fiddler crabs, snails and tidal migratory organisms);
7. Organic matter;

8. Detritus foodweb and outwelling (hypotheses and paradigms about SINERR marshes), including early mass balance studies and models, the salt marsh as a nursery, coupling of marsh to nearshore and riverine influences on marsh and nearshore.
9. The future of the SINERR: management and recommendations.

The Ecological Profile of Sapelo Island is a document to be read and understood by the concerned citizen, by monitoring groups and management agency personnel, and by scientists studying this and similar estuarine systems. Much of the material referenced is necessarily very technical, but the Profile itself should give a useful overview of the ecology of the Sapelo Island National Estuarine Research Reserve to anyone with the interest to read it.

The Sapelo Island National Estuarine Research Reserve and Sapelo Island

The Sapelo Island National Estuarine Research Reserve was established in December 1976 in the Duplin River watershed of McIntosh County, Georgia, on the western side of Sapelo Island (Fig. 1). Sapelo Island and its surrounding marshes have been the focus of ecological and geological research since the early 1950s; archaeological research has been conducted on the uplands of Sapelo Island since the late 1800s. In 1981 *The Ecology of a Salt Marsh* (Pomeroy and Wiegert, 1981) was published, synthesizing much of the research that had been done in the SINERR and describing quite thoroughly our understanding of the ecology of the marsh as it stood at that time. This profile presents an update of *The Ecology of a Salt Marsh*, reviewing research that has been completed since that book was written, and adding some supplemental information that was not included. Some of the material contained in *The Ecology of a Salt Marsh* is included here for the sake of clarity. For further information on research that has been done in the SINERR and elsewhere on Sapelo Island, the reader may consult the original publications on which this review is based. Scientific publications reporting results of research conducted on Sapelo Island are collected by the University of Georgia Marine Institute and published periodically in their Collected Reprints series. A list of selected papers from the Collected Reprints series can be found in Appendix 8.

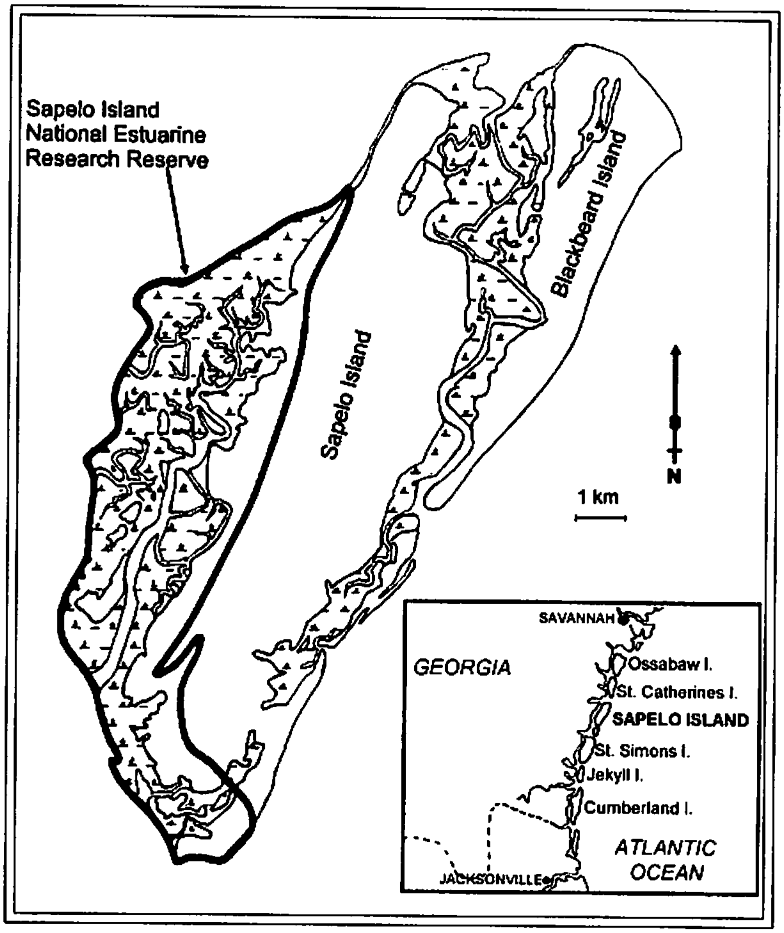


Figure 1. Location of Sapelo Island and SINERR.

REGIONAL SETTING OF SINERR

Climate

Sapelo Island has a subtropical climate with short, mild winters and long, hot, humid summers (Fig. 2a and 2b). The ocean has a moderating effect on temperatures, with

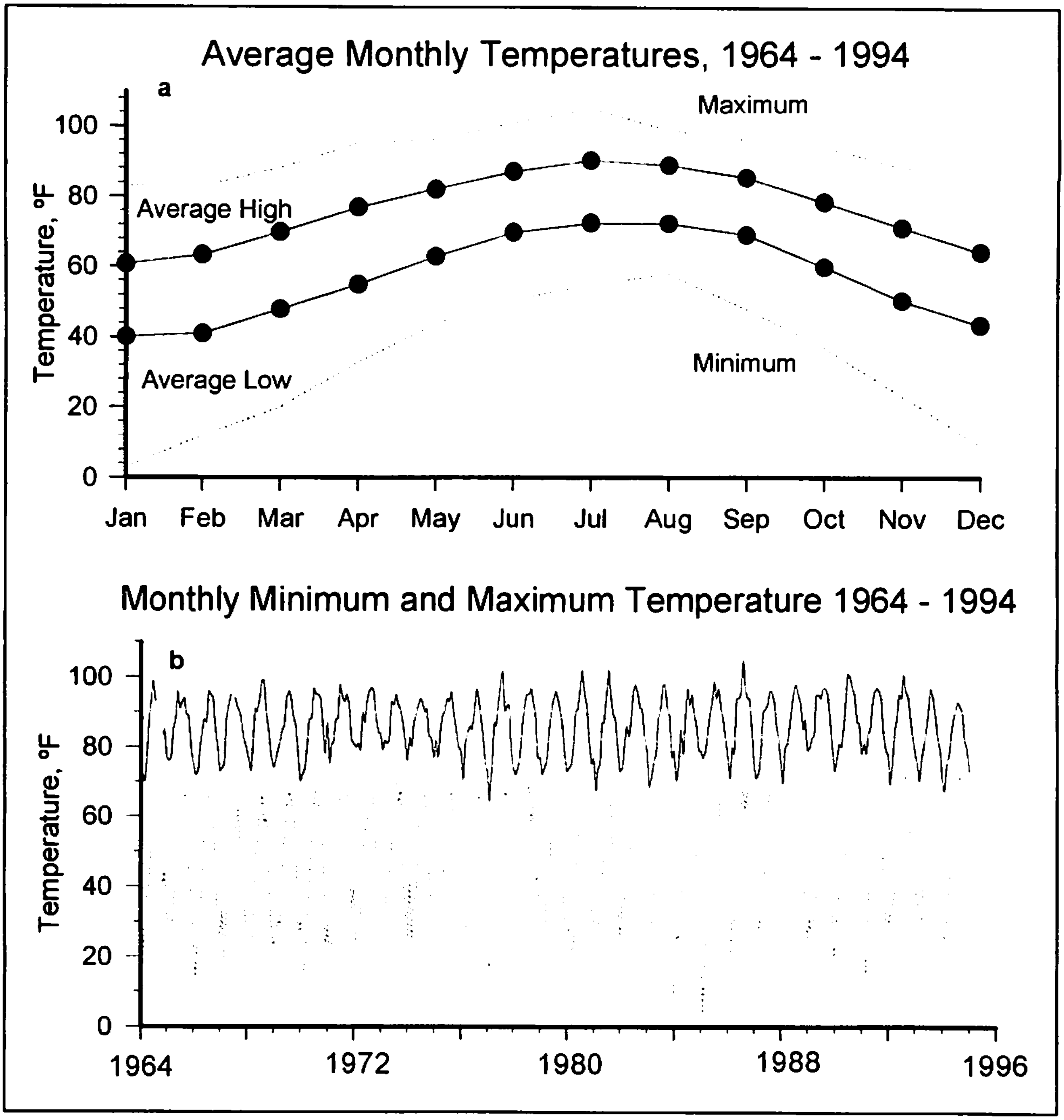


Figure 2. Temperatures at Sapelo Island, 1964 - 1994. Measured at the National Weather Service station at the University of Georgia Marine Institute.

Sapelo Island generally reporting lower maxima and higher minima than are reported from inland areas. Rainfall is heaviest during the summer months (Fig. 3a), when short, intense afternoon thunderstorms are common, and heavy rains associated with hurricanes and tropical storms often impact the area. Total annual rainfall over the 30 year record averaged 51.3 inches, with a minimum of 32.3 and a maximum of 66.9 inches (Fig. 3b). Although there are cycles of wet and dry years (Fig. 3b), it is unusual to have a month

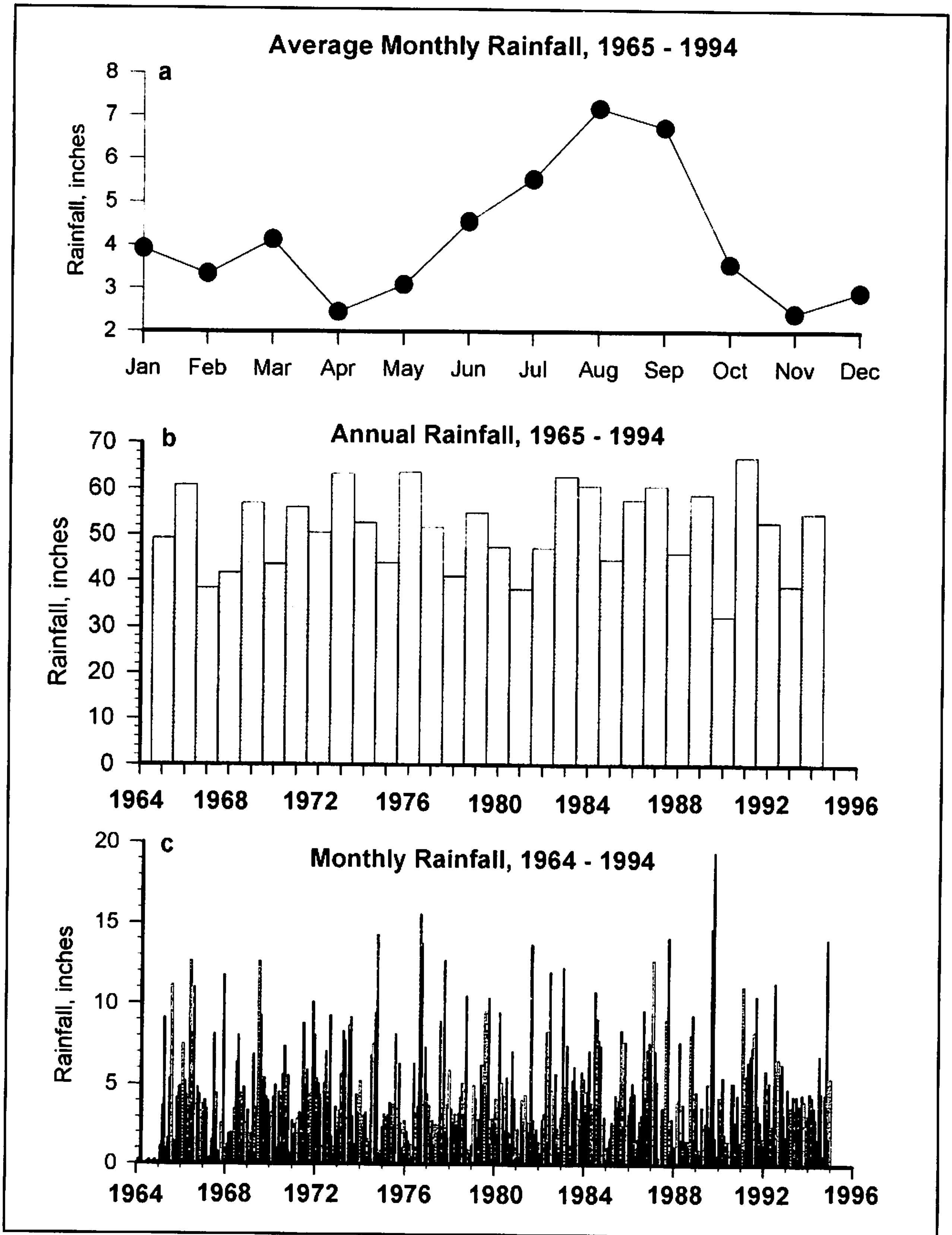


Figure 3. Rainfall at Sapelo Island, measured at the National Weather Service station at the University of Georgia Marine Institute.

go by with no rain; totally dry months occurred only 3 times during the 30 year period (Fig. 3c). On average, there is less than one month a year when rainfall is less than one inch.

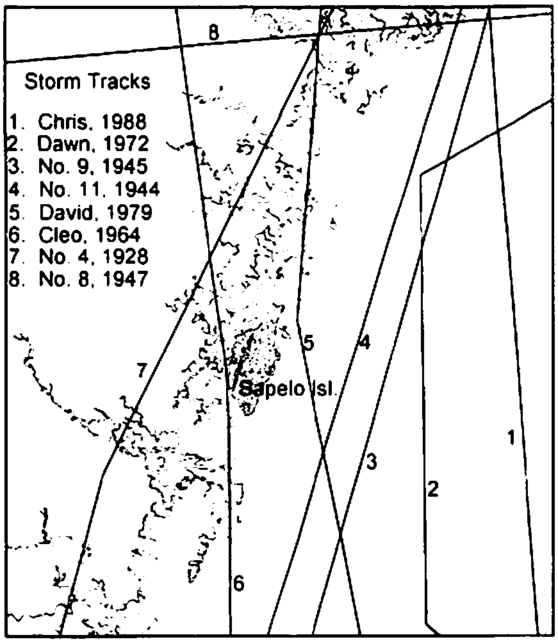


Figure 4. Storm tracks of hurricanes within 50 miles of Sapelo.

Sapelo Island has not suffered severe damage from a hurricane since the late nineteenth century, but has been brushed by several which have caused moderate wind damage and erosion. A database of hurricanes which have hit the U.S. since 1900 contains only 8 storms which passed within 50 miles of Sapelo (Fig. 4). Winter storms (northeasters) have typically caused more beach erosion than hurricanes and tropical storms in recent years.

HISTORY OF HUMAN ACTIVITY ON SAPELO ISLAND

The following account is a brief overview of the history of Sapelo, with emphasis on activities that have some bearing on the ecological conditions on Sapelo today. Sapelo Island has been occupied, protected and managed by its private and, in recent years, public owners for over 200 years. We know little about ways in which native Americans, the earliest occupants of Sapelo Island, might have altered or managed the environment. We do know that beginning with settlement by Europeans and continuing to the present, major changes have been made in the vegetation and topography of the island.

Prehistoric Indians

The earliest inhabitants of Sapelo Island were prehistoric Indians. Shell middens, mounds, and pottery fragments provide ample evidence of their presence from 4000 BP up through the influx of Europeans during the eighteenth century, when they were known as the Guale. Artifacts excavated from the Shell Ring, on the northwestern side of the island between Chocolate and High Point (Fig. 5), have been carbon-dated to 4120 " 200 BP (Simpkins, 1975). Excavations at Kenan Field, within the Reserve, and Bourbon Field, on the northeastern side of the island, have shown that villages were located at these two sites (Crook, 1978). The village at Kenan Field covered at least 60 hectares, and artifacts recovered there have been carbon-dated to AD 1155 " 75 (Crook, 1980).

In general, the sites of Indian habitation occur on Pleistocene sand ridges with elevations of 2 to 5 meters (McMichael, 1977). The vegetation at these sites is described as Maritime Live Oak Forest (Johnson *et al.*, 1974), dominated by live oak (*Quercus virginiana*)

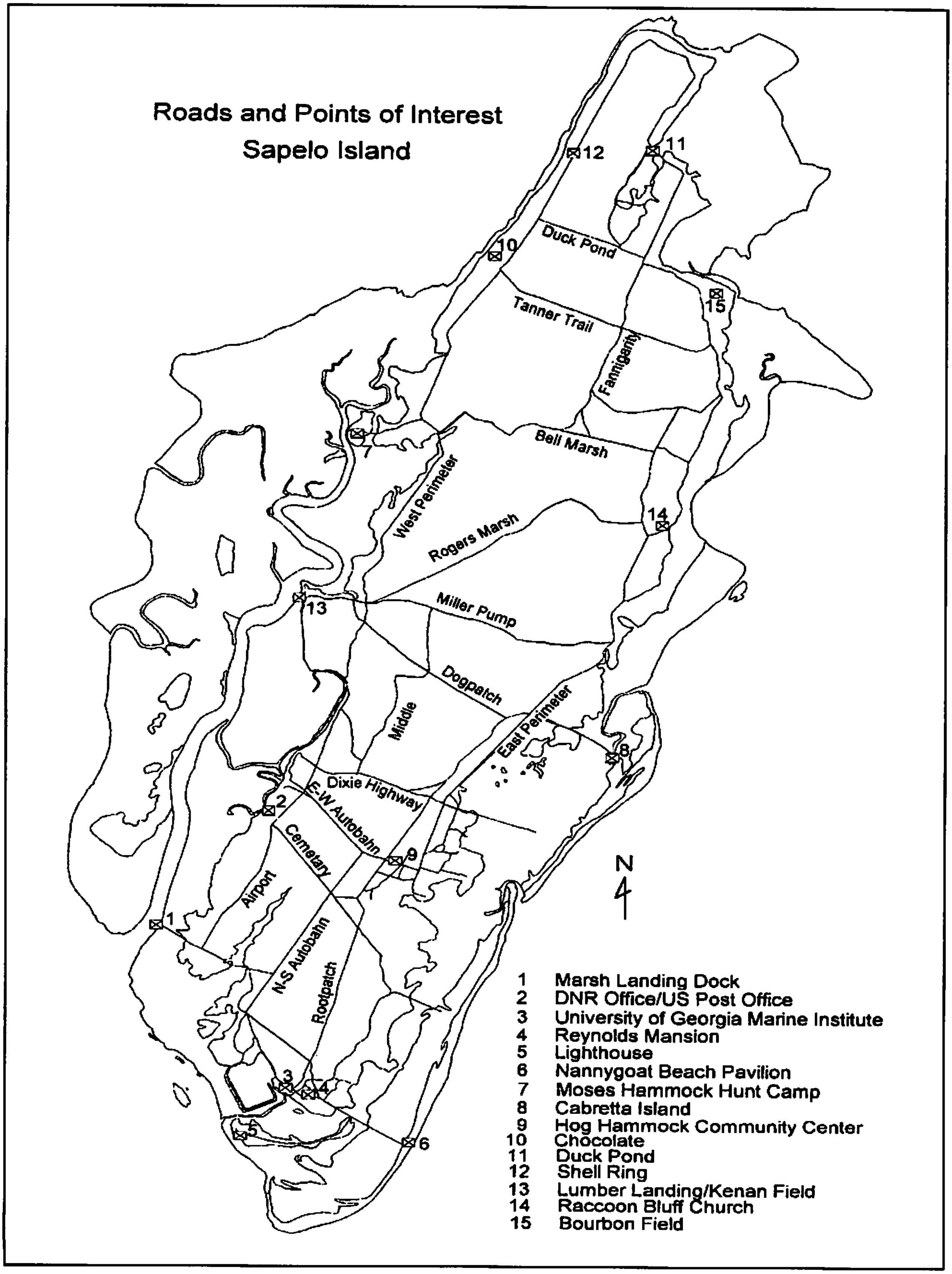


Figure 5. Some points of interest on Sapelo Island.

and Laurel oak (*Q. laurifolia*). Other significant species found in these areas are *Magnolia* spp., pine (*Pinus* spp.), grape (*Vitus* spp.), *Smilax*, red cedar (*Juniperus silicicola*), holly (*Ilex opaca*), mulberry (*Morus rubra*), yaupon (*Ilex vomitoria*), redbay (*Persea borbonia*), sweetbay (*Magnolia virginiana*), hickory (*Carya* spp.), cabbage palm (*Sabal palmetto*), wax myrtle (*Myrica cerifera*), gallberry (*Ilex glabra*), saw palmetto (*Serenoa repens*), and blueberry (*Vaccinium* spp.). All of these species are present on Sapelo today.

In addition to being located at relatively high elevations, sites are usually adjacent to salt marsh rather than at inland sites, and often occur where tidal creeks closely approach the upland (McMichael, 1977). Archaeological evidence indicates that the Indians had a varied diet consisting of nuts; berries, and numerous animals that could be found in and near the marsh and tidal creeks (Crook, 1978, 1980). Excavations of middens at Kenan Field and the Shell Ring produced identifiable remains of mammals such as white-tailed deer (*Odocoileus virginianus*), raccoon (*Procyon lotor*) and rabbit (*Sylvilagus* sp.); reptiles such as diamond-backed terrapin (*Malaclemys terrapin*), aquatic turtles (*Chrysemys* spp.), box turtle (*Terrapene carolina*), chicken turtle (*Deirochelys reticularia*), mud turtle *Kinosternon subrubrum*) and various snakes; and fish such as gar (*Lepisosteus* sp.), Gafftopsail (*Bagre marinus*) and sea catfish (*Arius felis*), red (*Sciaenops ocellata*) and black drum (*Pogonias cromis*), spotted sea trout (*Cynoscion nebulosus*), Atlantic croaker (*Micropogonias undulatus*), sheepshead (*Archosargus probatocephalus*), mullet (*Mugil* spp.) and herring or shad (*Clupediae*) (Crook, 1980). By far the most numerous remains were the shells of various mollusks, such as Eastern oyster (*Crassostrea virginica*), Southern quahog (*Mercenaria campechiensis*), periwinkles (family *Littorinidae*), knobbed whelk (*Busycon carica*), channeled whelk (*B. canaliculatum*) and olive (family *Oliviadae*). Whelks were not only useful as food; *Busycon* shells were used extensively as tools such as hammers, picks, hoes and pounders (Simpkins, 1975). The remains of many small fish in refuse middens at the village sites led Crook (1980) to the conclusion that impoundments were used to trap fish in tidal creeks.

Early Spanish, French and English

During the 17th century Spain established missions in what is now coastal Georgia as part of their effort to convert the native Indians to Christianity and to guard their sea routes to Mexico. One of the missions on the coast was named San JosJ de Z<pala, from which the name Sapelo is derived. Although archaeological surveys on Sapelo have located a number of sites where fragments of their pottery attest to the influence of the Spanish in the area, no architectural remains of a Spanish mission have yet been identified on Sapelo (Larson, 1980). Spanish presence in the area declined during the latter part of the 17th century, and by the time that Georgia was established as a British colony in 1733 the coast was occupied by the Creek Indians.

Mary Musgrove, a niece of the Creek chief who served as interpreter for James Oglethorpe, claimed ownership of three of the Georgia barrier islands, St. Catherines, Ossabaw and Sapelo. Her claim was disputed by Colonial authorities, but was eventually validated in part when Governor Henry Ellis granted ownership of St. Catherines to her and her husband, and turned over to her the proceeds of the sale of Ossabaw and Sapelo in payment for her services as interpreter and for goods she had provided to the colonists. In 1760 Grey Elliot, the purchaser of the islands, was awarded a grant to the islands by King George II. Sapelo was later sold to Patrick Mackay, who was the first to undertake large-scale cultivation on the island. Over the next 40 years, ownership of the island passed through several hands, including a group of Frenchmen who established plantations at several locations on the island. One of these was at Chocolate, on the western side of the island, which was also probably the location of an Indian settlement in earlier years (Sullivan, 1990). Although some crops were cultivated, cattle seemed to be the major interest of these early plantations.

The French syndicate failed, and ownership of most of the island eventually passed to Thomas Spalding. Chocolate was bought by the Marquis de Montalet, who had been a planter in Santo Domingo prior to coming to Georgia. After his death, Chocolate was sold to Edward Swarbreck, a Danish mariner, who built many of the tabby buildings whose remains can be seen there today. His successor, Dr. George Rogers, who bought Chocolate around 1827, built many of the "newer looking" buildings that occupy the field there. These three men, but most importantly Thomas Spalding, had a tremendous influence on Sapelo as we know it today.

Thomas Spalding

In 1802 Thomas Spalding purchased 4000 acres on the south end of Sapelo; he eventually became the owner of all but a small portion of the island. He had learned how to run a successful plantation from his father and was a leader and innovator in the cultivation and processing of sugar and in the cultivation of Sea Island long-staple cotton. Spalding was a proponent of crop rotation and diversification rather than dependence on one crop, experimenting with indigo, silk, olives and oranges; he also was an authority on the cultivation of rice. Spalding wrote extensively for agricultural journals of the day and shared his views on agriculture through an extensive correspondence. He was a promoter of tabby construction, using it in his home, the South End House, a sugar cane mill and several other buildings on Sapelo (Coulter, 1940; O'Grady, 1980; Sullivan, 1990). The present-day Reynolds Mansion was built on the foundations of Spalding's South End House, incorporating some of the original exterior tabby walls (Sullivan, 1990). The first Sapelo Lighthouse was built on the southern end of the island during the Spalding era (Sullivan, 1990).

During Spalding's tenure, much of the land on Sapelo was cleared for cultivation or pasture. John D. Legare, editor of the *Southern Agriculturist* reported after a tour of the south end of Sapelo "...the spectator who visits the island for the first time is struck with the peculiar appearance presented him, instead of meeting with a thick growth of trees, such as is common on all sea-islands on our coast, he suddenly finds himself in a prairie, extending to the north almost as far as can be seen..." (1832, as quoted in Sullivan, 1990). A network of ditches and canals, still evident today, were dug to drain the swampy interior of the island. Thus whatever natural climax forest existed on Sapelo Island largely disappeared during the 1800s, both from upland areas and from the inland swamps. Originally these ditches and canals directed water into the intertidal salt marshes around the island;

today, with artesian wells no longer flowing the canals only fill during periods of heavy, extended rainfall or at times of high spring tides when salt water flows into the canals from the marsh.

Spalding introduced many new plant species to Sapelo, testing for the practicality of using them in cultivation. The few that still reproduce on the island, such as bermuda grass (*Cynodon dactylon*), cherokee rose (*Rosa laevigata*) and mulberry (*Morus* spp.) are quite abundant. Other non-native species, probably introduced by Spalding, are *Paspalum notatum, Populus alba, Maclura pomifera, Nymphaea mexicana, Cinnamomum camphora, Wisteria sinensis, Kummerowa striata, Citrus aurantinum, and Mentha X piperita* (Duncan, 1982).

Thomas Spalding died in 1851 and a long period began during which ownership of Sapelo passed through many hands, many of them descendants of Thomas Spalding. During the Civil War the island was abandoned by owners and was occupied by only a few former slaves. Union troops blockading the southern coast frequently visited Sapelo to hunt and enjoy a change of surroundings. After the war the barrier islands were set aside as reservations for former slaves, and black communities were established at several sites on Sapelo Island. One of them, Hog Hammock, is still an active community. Much of the island was eventually returned to the Spalding family by the Federal government (Sullivan, 1990). During the next forty years, various tracts of land changed hands and several attempts to reestablish profitable agricultural operations failed. By the early 1900s many of the cultivated fields had reverted to forest, serving as habitat for birds and wild game. The south end of the island was developed as a hunting preserve by the Sapelo Island Company, a syndicate of investors from Macon, GA. They partially restored Spalding's South End House for use as a hunting lodge.

Howard Coffin

Howard Coffin of Detroit, developer of the Hudson motor car, first came to Sapelo to hunt in 1911. A year later he purchased much of the island from the Sapelo Island Company and the five families who owned most of the land. He set out to restore the island's agriculture and many of its buildings, including the South End House. The agricultural restorations included clearing of the drainage canals, cultivation of a variety of crops including long staple Sea Island cotton, clearing of pastures for beef and dairy cattle, and building and repair of roads to facilitate access to all parts of the island. With his cousin Alfred W. Jones as manager of Sapelo, Coffin built the dock at Marsh Landing (Fig. 6), the duck pond at the north end of the island and other freshwater ponds, established an oyster and shrimp cannery on Barn Creek, established an oyster farming project in the waters between Sapelo and Little St. Simons, and built a saw mill to provide lumber for buildings and boats. He built a marine railway on South End Creek so that his many boats could be repaired and serviced on the island and built the greenhouse which still stands, though in disrepair, near the South End House. He also had a keen interest in hunting, and raised ring-necked pheasant and turkeys which he and his guests would hunt, aided by dogs from the Sapelo kennels. He introduced the Chachalaca (*Ortalis vetula*) to Sapelo as a game bird; native to Central America, the birds adapted well to the environment on the island. They were well established on the island as recently as the late 1970s, but are now seen only occasionally. Coffin also planted the many oleanders which line the road from Marsh Landing.

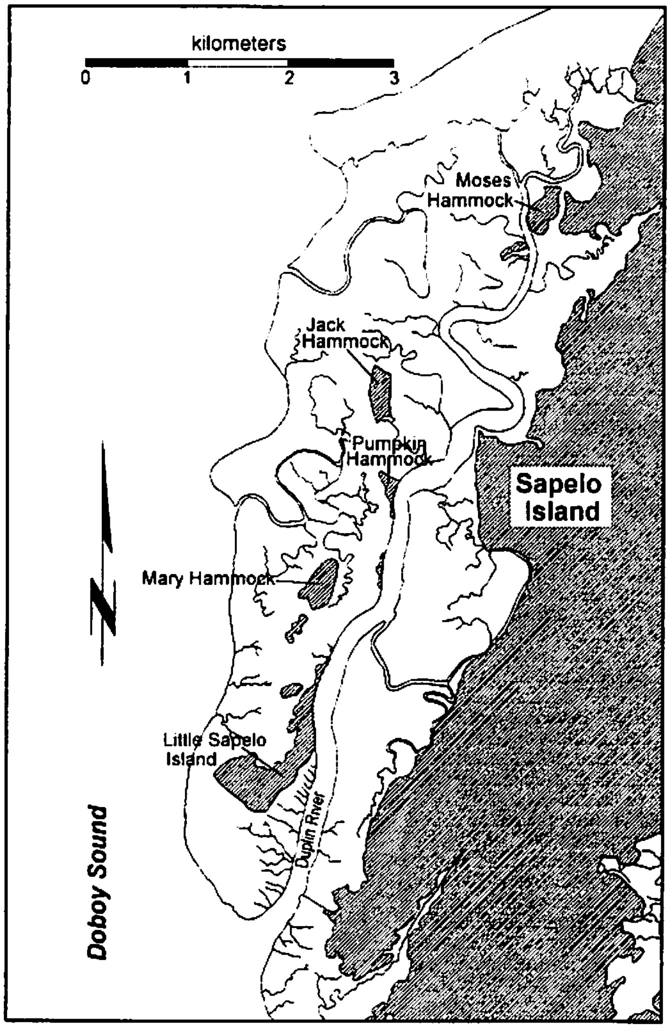


Figure 6. The Duplin River Watershed.

Although much of his time, energy and financial resources were focused on restoring all aspects of the Sapelo Plantation, Coffin's influence and interest extended to other parts of coastal Georgia, most notably St. Simons and Sea Island. He purchased Sea Island, then known as Long Island (Sullivan, 1990), in 1926 and began work to establish an exclusive resort on the island with the Cloister Hotel as its centerpiece. After the stock market crash of 1929, financial pressures forced Coffin to sell Sapelo Island in order to continue the development of Sea Island.

R. J. Reynolds

Richard J. Reynolds, Jr., heir to a tobacco fortune, purchased Sapelo from Howard Coffin in 1934. In many ways, he continued the work done by Coffin, maintaining and enlarging the dairy herd, continuing cultivation of crops in fields on the south end of the island, and trying to make the Sapelo Plantation a self-supporting enterprise. He redesigned and rebuilt most of the buildings in the quadrangle complex that now houses the University of Georgia Marine Institute, remodeled the interior of South End House (the Reynolds Mansion), refurbished buildings at Long Tabby to be used as a camp for underprivileged boys, and for several years opened the Big House and the apartments in the quadrangle complex to vacationers as an exclusive resort.

During the late 1930s and early 1940s, Reynolds attempted to consolidate the land holdings of blacks on the island into one community at Hog Hammock by purchasing their land at Raccoon Bluff, Shell Hammock and other locations or swapping it for land at Hog Hammock. Because of the island's isolation, many among its black population depended on Sapelo's owner for employment, and complied with his wishes even though it meant giving up land that had been theirs for generations. Although some individuals continued to claim ownership of parcels of land elsewhere, by the time of his death in 1964, Reynolds claimed ownership of all of Sapelo Island except for some 434 acres at Hog Hammock.

Prompted by his lifelong interest in the sea, in the early 1950s Reynolds invited Eugene Odum and Donald Scott, faculty at the University of Georgia, to prepare a proposal for the use of Sapelo and its surrounding marshes for basic research on the productivity of coastal waters and marshes, which led to the establishment of the Sapelo Island Research Foundation, and of the University of Georgia Marine Institute in 1953. From a modest beginning, the Marine Institute undertook much of the early research on salt marsh ecosystems, describing the biology, hydrology and geology of the waters and marshes around Sapelo Island.

In 1969, his widow, Annemarie Reynolds, sold the northern half of Sapelo Island to the State of Georgia to be administered by the Georgia Department of Natural Resources (DNR) as the R. J. Reynolds Wildlife Refuge. With the exception of the land in Hog Hammock and the land surrounding the lighthouse, the rest of the island came under the ownership of the Sapelo Island Research Foundation. In 1975, the state of Georgia nominated the Duplin River Estuary (Fig. 6) as a national estuarine sanctuary; after approval of the proposal by the U.S. Department of Commerce, the National Oceanic and Atmospheric Administration (NOAA) provided funds for management of the sanctuary and for the purchase of the privately owned land within the sanctuary. In 1976, the state matched the federal funds and completed the purchase of the south end of Sapelo Island from the Foundation, establishing the Sapelo Island National Estuarine Sanctuary, now known as the Sapelo Island National Estuarine Research Reserve (SINERR).

CURRENT USE AND OWNERSHIP OF SAPELO ISLAND

The Department of Natural Resources

The State of Georgia currently owns all but 175.7 hectares of Sapelo Island's 6477.8 ha; the Department of Natural Resources (DNR) is charged with management of the island. They operate the ferry, which makes 3 round trips per day between Sapelo and the mainland, transport fuel to the island in a fuel barge, sell gasoline to island residents, operate a barge which transports vehicles, other large objects and equipment to and from the island, transport garbage off the island to the McIntosh County landfill, maintain roads, and provide a law enforcement presence on the island. In addition to providing transportation to island residents, employees of DNR and the University of Georgia and visitors, the ferry carries mail to and from the island and transports school children during the school year. There are four distinct DNR administrative units on the island, each with different management objectives.

SINERR

The SINERR occupies 2390.74 ha, slightly more than one-third of the area of Sapelo Island. It contains the Duplin River watershed, primarily intertidal salt marsh with some small upland tracts (Fig. 7), and the upland maritime forest, marsh, dune and beach areas of the southern end of the island, and a light house built in 1820. DNR has plans to restore the lighthouse to working condition using private funds.

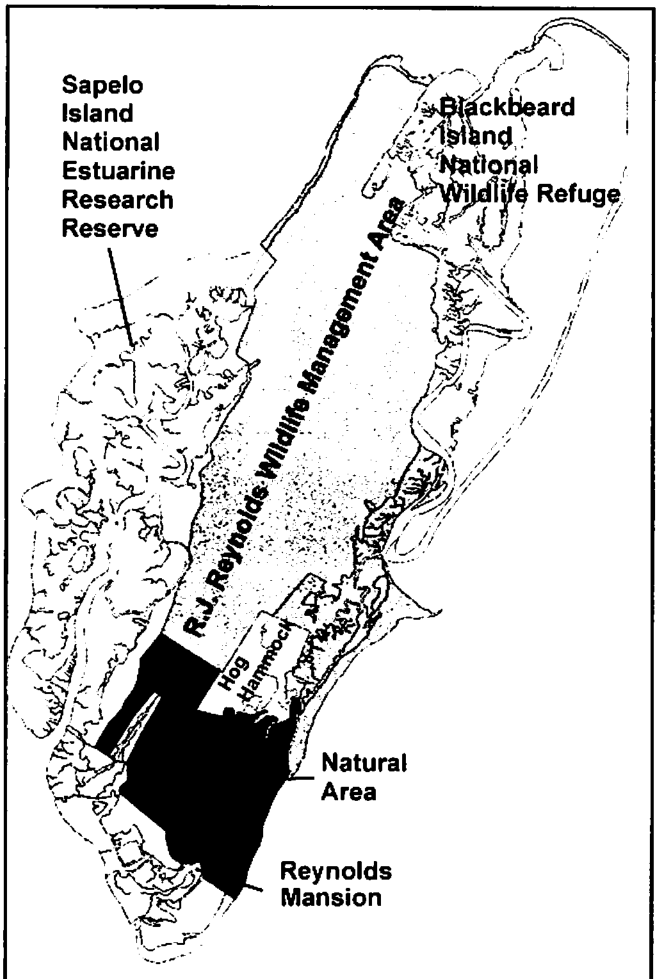


Figure 7. Administrative units on Sapelo Island.

The University of Georgia leases approximately 637.65 ha within the SINERR and the Sapelo Island Natural Area (see below), on which are located the Marine Institute, residences of faculty and staff, administrative offices and other facilities related to the research and educational activities of the Marine Institute.

The DNR's management goals for the land in the SINERR include:

a. maintaining the integrity of the SINERR for research and educational programs,
b. protecting its lands and waters from stress and alteration,
c. promoting increased public access for nature interpretation and low intensity recreation, and
d. promoting and encouraging improved scientific understanding of estuarine ecosystems (Georgia Department of Natural Resources, 1990).

The SINERR is managed by DNR, but is administered by the National Oceanic and Atmospheric Administration, which provides funds for operations, education and monitoring.

Public access to Sapelo Island is coordinated by SINERR personnel, who conduct tours which visit a tidal salt marsh and creek, the Marine Institute, ruins of a sugar mill built prior to the Civil war, the Hog Hammock Community, the Reynolds Mansion and Nannygoat Beach. In addition to public day tours, special group tours and tours for school field trips are available. In all 200-300 tours are conducted by SINERR staff each year. The Reserve personnel also conduct outreach programs, publish a newsletter about activities in the SINERR, and promote public awareness of the Reserve and the environmental and ecological aspects of Sapelo Island and the other Georgia barrier islands.

The waters and marshes of the SINERR are used by the research faculty of the University of Georgia Marine Institute and other scientists for a variety of projects. Scientific publications by the research faculty and visiting scientists are collected and reprinted by the University of Georgia Marine Institute (currently, 21 volumes have been produced). With funding from SINERR, NOAA and the University of Georgia, the Marine Institute conducts a meteorological and hydrological monitoring program which provides continuously recorded data on parameters such as wind speed and direction, sunlight, rainfall, barometric pressure, relative humidity, air and water temperature, salinity, conductivity and pH of tidal waters and tide heights at 3 locations in the SINERR. The monitoring stations (Fig. 8) are located in the upper and lower water masses of the Duplin River (see below for explanation of water masses) and in a tidal branch of the Duplin which runs adjacent to the SINERR uplands.

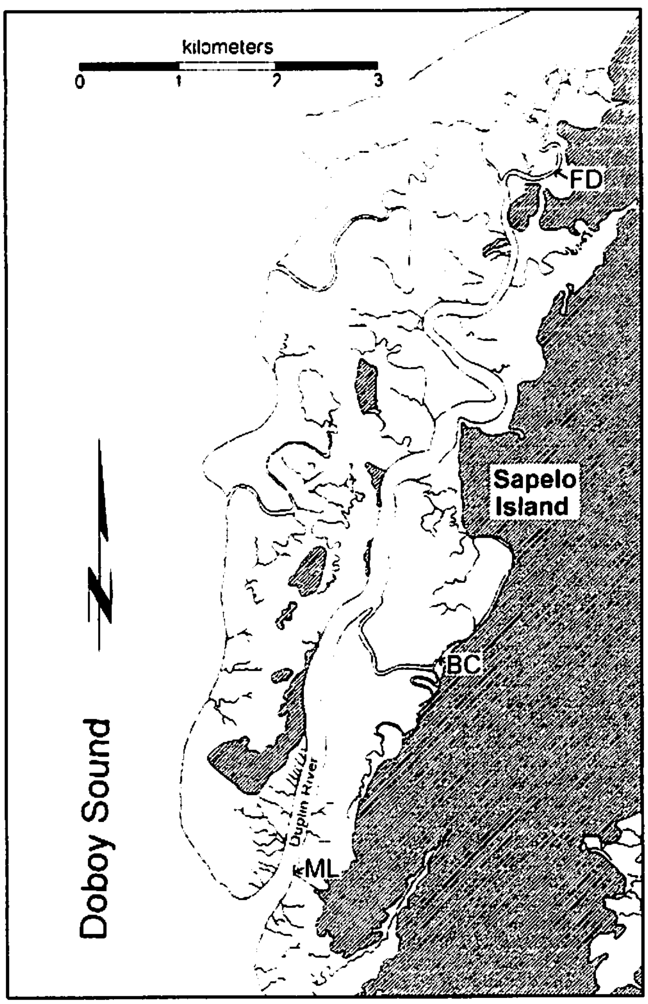


Figure 8. Location of monitoring stations. ML - Marsh Landing; BC - Barn Creek; FD - Flume Dock.

R. J. Reynolds Wildlife Management Area

The R. J. Reynolds Wildlife Management Area occupies approximately 2805 ha on the northern end of Sapelo Island. It was purchased in 1969 with funds from the State of Georgia and with Pittman-Robertson funds from the U.S. Department of Interior. The area is managed for all game and non-game species with the objective of maintaining healthy communities of flora and fauna and to provide for public use of the area through hunting, fishing and camping. Management techniques in use in the RJR WMA are selective timber harvesting, prescribed burning and creation of wildlife openings. The primary large game species are turkey and deer, with DNR sponsoring several managed hunts each year.

The Sapelo Island Natural Area

The Sapelo Island Natural Area occupies 1106 ha of marsh, upland, dunes and beach on the southern end of Sapelo outside the Duplin River watershed, and includes an interpretive trail which begins in an upland area near the Reynolds Mansion and proceeds across intertidal marsh, dunes and inter-dune areas to Nannygoat beach. The Natural Area is managed by DNR to provide outdoor recreational opportunities to the general public and for public education about barrier island and dune ecosystems.

The Reynolds Mansion

The Reynolds Mansion, which is physically within the boundaries of the Reserve, is operated and maintained by the Lodge Authority of DNR. It serves as a conference and meeting facility for groups of up to 30 persons, providing lodging, meals and transportation. Educational programs about Sapelo and the SINERR conducted by Reserve personnel are available to each group.

The University of Georgia Marine Institute

The University of Georgia Marine Institute was established in 1953 to serve as a research facility for resident and campus-based faculty and students. Its original objective was to study the productivity of the nearby coastal waters and marshes, and in the years since its establishment the Marine Institute has compiled an extensive database on salt marsh-estuarine ecology. Most of the research has dealt with the functional ecology of salt marsh ecosystems, although there has been extensive related research on the geology of barrier islands and adjacent estuarine environments, the biochemistry of bioluminescence and taxonomy. The ecological research has dealt with several general topics: estuarine hydrography; the detritus food chain; primary productivity; nutrient cycling; energy and carbon flow phenomena; microbial ecology; outwelling of materials and nutrients to the nearshore; utilization of the intertidal marsh by various organisms for refuge, feeding and reproduction; effects of interactions among marsh macrofauna on community and population structure; and the role of fungi in decomposition of organic matter in the marsh. Much of this research has taken place within the SINERR, and forms the basis for this ecological profile. Marine Institute faculty receive funding for their research from the University of Georgia, the Sapelo Island Foundation and a number of federal agencies including National Science Foundation, National Oceanic and Atmospheric Administration (NOAA) Sea Grant and National Estuarine Research Reserve Programs, and the Environmental Protection Agency.

The Hog Hammock Community

The Hog Hammock Community is a privately owned tract occupying 175.7 ha of upland in the south central area of Sapelo Island. Many of its residents are descendants of slaves owned by Thomas Spalding prior to the Civil War, although in recent years a number of "outsiders" have bought or built homes in the community. As has been the case throughout its history, the island's primary landowner is also its primary employer. Many residents of Hog Hammock work for the University of Georgia Marine Institute or for DNR, although others commute daily to the mainland to work. Recently a number of businesses have sprung up in the community to serve the needs of the growing number of tourists and vacationers who visit Sapelo by offering accommodations, transportation and local crafts. The preservation and revitalization of the community and its culture is one of the central concerns of everyone associated with Sapelo Island. The SINERR has indirectly played a role in the development of the new businesses by increasing public awareness of Sapelo Island and the Hog Hammock community through its tours and public outreach.

POPULATION AND DEVELOPMENT OF NEARBY COASTAL AREAS

McIntosh County is one of the smallest and poorest of Georgia's counties. A high proportion of property in the county is owned by state or federal government, and much of the rest is owned by paper companies for cultivation of pine trees. There is little industry or agriculture in the county, and Darien is the largest center of population. Population density in McIntosh County, Georgia, location of Sapelo Island, is 20.32 people per square mile, the lowest in coastal Georgia (Hodler *et al.*, 1994) and its rate of population growth is also low, with a 17.31 percent change in the period 1970-1990, compared to over 100 percent growth during the same period for Camden and Bryan counties and 200% growth for Liberty County (Hodler *et al.*, 1994). Nevertheless, marshfront property in McIntosh County is increasingly attractive to builders and prospective homeowners, and growth rate will no doubt show a larger increase at the time of the next census. Recreational use of the coastal areas of Georgia is increasing, and with that increase the demand on the recreational resources of SINERR can be expected to increase as well.

Because of its distance from the mainland and from major population and industrial areas, water quality in the SINERR has thus far been little affected by the changing conditions in mainland coastal Georgia. The strong tidal currents result in flushing of channels and sounds; mixing of upland runoff with estuarine water dilutes and distributes nutrients and pollutants throughout the nearshore and estuarine zone. The spatial and temporal variability in nutrient distribution and water movement makes the detection of small changes in nutrient and pollutant concentrations almost impossible. The long-term cumulative effects of these small, unmeasurable changes is yet to be determined, but at present they have not been detected in the SINERR.

Geological and Hydrological Characterization of SINERR

GEOLOGICAL SETTING

Sapelo Island and Georgia's other barrier islands are remnants of Pleistocene barriers formed approximately 110,000 to 25,000 years ago, fronted by active Holocene beach ridges formed during the last 4000 - 5000 years (Howard and Frey, 1985). The latest Pleistocene (late Sangamon) beach deposits form the core of most of the modern barrier islands. Following a major drop in sea level during the Wisconsin glaciation, Holocene sea level rise has resulted in reworking of Pleistocene sediments and deposition of a veneer of sediments along the shoreline in the form of the Silver Bluff barrier island deposits which form the core of Sapelo Island (Hoyt *et al.*, 1964; Hails and Hoyt, 1969). The Georgia barrier islands, including the Duplin River watershed, are located in the most recent of a series of six Pleistocene shoreline complexes that increase in age and elevation westward from the present-day coast (Hails and Hoyt, 1968).

The broad expanse of salt marshes and tidal drainages which form most of the SINERR is classed as a salt marsh estuary, as opposed to riverine marsh estuaries which have rivers at their heads, such as the Altamaha (Howard and Frey, 1985). The Duplin River tidal salt marsh sediments consist mainly of reworked Pleistocene muds, eroded and redeposited by the tidal currents. The marshes of the SINERR are in approximate dynamic equilibrium with sea level at present, with deposition being balanced by erosion and sea level change (Letzsch, 1983). Measurement of deposition and erosion at various marsh sites over a 7 year period revealed a mean deposition rate of 0.2 cm/yr (Letzsch, 1983). Erosion and meandering of tidal creek banks is caused by tidal action, slumping and bioturbation (Letzsch and Frey, 1980). Erosion varies greatly from one location to another, but changes in the position of major channels are rare (Letzsch, 1983).

TIDAL CONDITIONS

Tides along the Georgia coast have an average amplitude of 2.4 m and a spring tide range of 3.4 m. The hydraulic energy resulting from the rise and fall of the tides is a major factor in many of the ecological processes active in the marshes (Schelske and Odum, 1961). Most tidal streams are contained within steep banks and natural levees which create a pattern of marsh flooding in which water moves along progressively smaller channels which eventually dissipate in headwaters on the marsh surface. Tidal water flows directly across levees only on the highest spring tides. Motile aquatic organisms follow this same pattern when moving onto and off of the marshes during high tide, although the rising and falling tides make the steep banks and levees available as feeding and refuge sites to them and to those organisms which do not move out of the creeks. In spite of the large tidal amplitude, there are still extensive areas of marsh which are flooded only at spring tide and even more extensive areas which, although flooded daily, are submerged for very short periods of time. Thus the tidal regime maintains a diversity of habitats in the intertidal area.

Tidal currents in the main channel are very strong. It is an ebb-dominated system, as are all of the tidal streams in this region. Friction between the marsh surface and tidal water retards flow out of the marsh on ebb tide, steepening the hydraulic gradient in the channels and increasing ebb tide current speeds when the water finally clears the marsh surface. (Zarillo, 1979).

HYDROLOGY OF THE DUPLIN RIVER

The Duplin River (Fig. 6) is a river in name only. It receives no freshwater input at its head, and is more correctly described as a large tidal creek or embayment. Prior to the 1970's there was a noticeable input of fresh artesian groundwater in the upper Duplin (Kjerfve, 1973), but increased industrial withdrawals along the Georgia coast lowered the water table and ended the flow of artesian water. Now its only freshwater inputs are rainfall, runoff and groundwater discharge from the surrounding uplands.

The Duplin has three tidal prisms along its 12.5 km length, the first ending in the area of Pumpkin Hammock, the second extending to Moses Hammock, and the third encompassing the creeks and marshes of the Upper Duplin River (Fig. 6). Strong tidal currents and the lack of freshwater input at the head of the river keep the water column within each tidal prism well-mixed, but result in little net advective transport. Thus the waters of the upper tidal excursion are in effect hydrologically isolated from the waters of the lower reaches of the river and Doboy Sound.

Transport of materials is diffusive except under the relatively rare circumstances of very heavy rainfall occurring at low tide, which can create a lens of freshwater in the upper water mass or even completely replace it (Imberger *et al.*, 1983). The volume of the upper water mass is such that on most tides it is moved completely out of the river and creek channels onto the marsh surface at high tide. On high spring or storm tides water may flow between the upper Duplin River system and the Mud River/Sapelo Sound system to the north. Seasonally, during periods of high discharge from the Altamaha River into Doboy Sound, there can be inputs of lower salinity water at the mouth of the Duplin River.

Some of the earliest research in the SINERR by Ragotzkie and Bryson (1955) and Ragotzkie and Pomeroy (1957) established the importance of water circulation in the ecology of the estuary. The work of Imberger *et al.* (1983) confirmed those early results and extended our understanding of the fluxes of dissolved and particulate materials in relation to the hydrography of the Duplin River. Their approach emphasized the importance of ordering the time scales of the dominant fluxes of materials and then choosing appropriate time and spatial scales of resolution for a sampling program. They separated the effects of water motion and mixing from the variability of a biological component, and thus were able to interpret the variability of the residual. For example, rapidly recycled constituents such as ammonium had a very patchy distribution that was independent of water motion, while more refractory or abundant compounds such as silicate, which was produced in large amounts by the marsh, was exported from the Duplin by longitudinal mixing. The work of Chalmers *et al.* (1985), confirming earlier findings of Sottile (1974), showed that dissolved organic carbon (DOC) has both a refractory and a labile component, with the refractory component being present throughout the year at concentrations of 3 - 5 mg C/l. Chalmers *et al.* (1985) also found that there were concentration gradients of both DOC and particulate organic carbon (POC) throughout the year, with higher concentrations in the Upper Duplin decreasing towards the mouth of the river.

GEOMORPHOLOGY OF THE DUPLIN RIVER WATERSHED

The geomorphology of the Duplin River watershed (variation in elevation, drainage pattern and drainage density) is a result of an interaction of tidal currents, sea level fluctuations, biological activity and sedimentation that has been taking place for thousands of years. Superficially, the marshes of SINERR appear uniform, but there is in fact a great deal of heterogeneity present. Although variations in elevation over much of the marsh surface are in the centimeter range and are not represented on topographic maps of the area, the small variations that do occur produce gradients in physical and chemical conditions in marsh sediments that affect plant growth and zonation. Figure 9 depicts an idealized cross-section through a Georgia salt marsh.

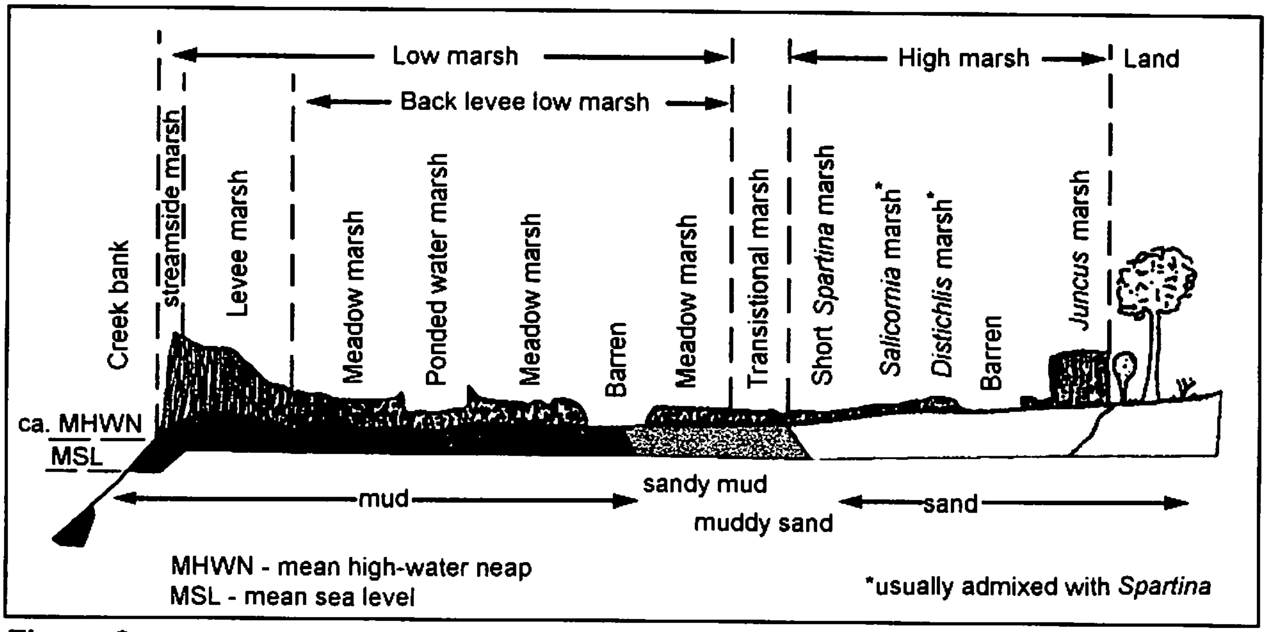


Figure 9. Idealized cross-section of an intertidal salt marsh, based on Frey and Basan (1985).

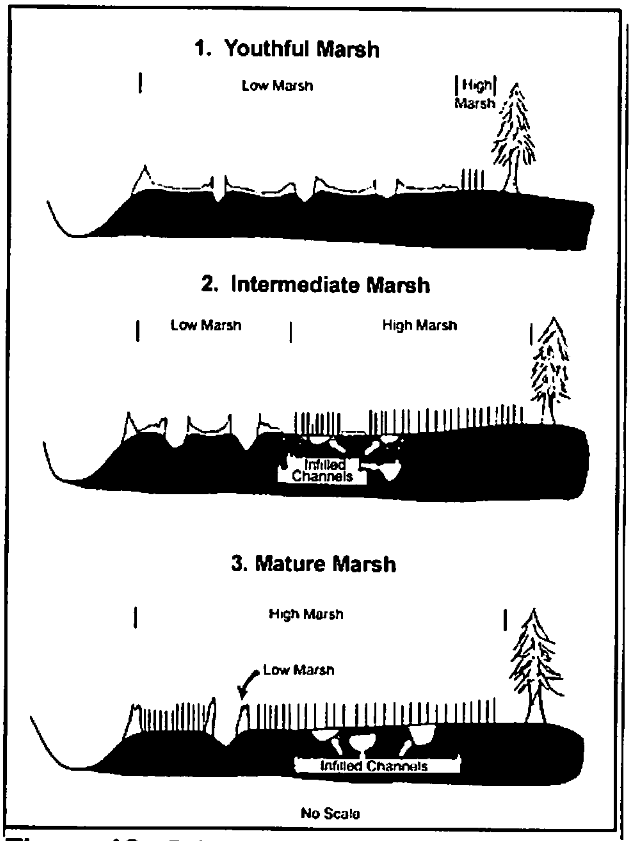


Figure 10. Schematic diagram of the three stages of marsh maturation. 1) Youthful, with high drainage density and high proportion of low marsh; 2) Intemediate; 3) Mature, with low drainage density and high proportion of high marsh. (After Frey and Basan, 1985.)

The centuries-long process of marsh maturation (Frey and Basan, 1985) has produced a succession of stages of marsh development, ranging from youthful marshes intersected by many deep, interconnecting creeks and channels such as those present in the Upper Duplin watershed to geologically mature, stable marshes higher in elevation with fewer, shallower channels (Fig. 10). The youthful marshes, by virtue of their lower elevation and higher density of drainage channels, have a higher proportion of "tall *Spartina alterniflora*" than the mature marshes.

Hypothetically, end-member marshes in a geological evolutionary sequence are those in which the entire area is covered either by high marsh with little aquatic area or low marsh with substantially more aquatic area. However, the coast of Georgia has not been geologically stable long enough to achieve such simple structure (Frey and Basan, 1985). The Duplin River water shed includes

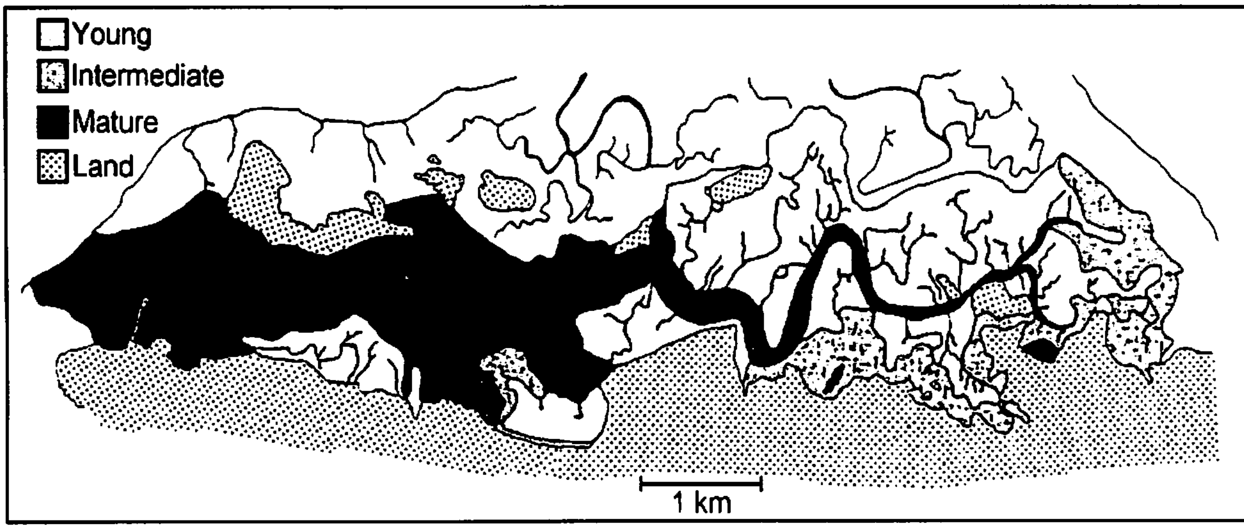


Figure 11. Distribution of the three major physiographic regions of the Duplin River tidal salt marshes. (From Wadsworth, 1980.)

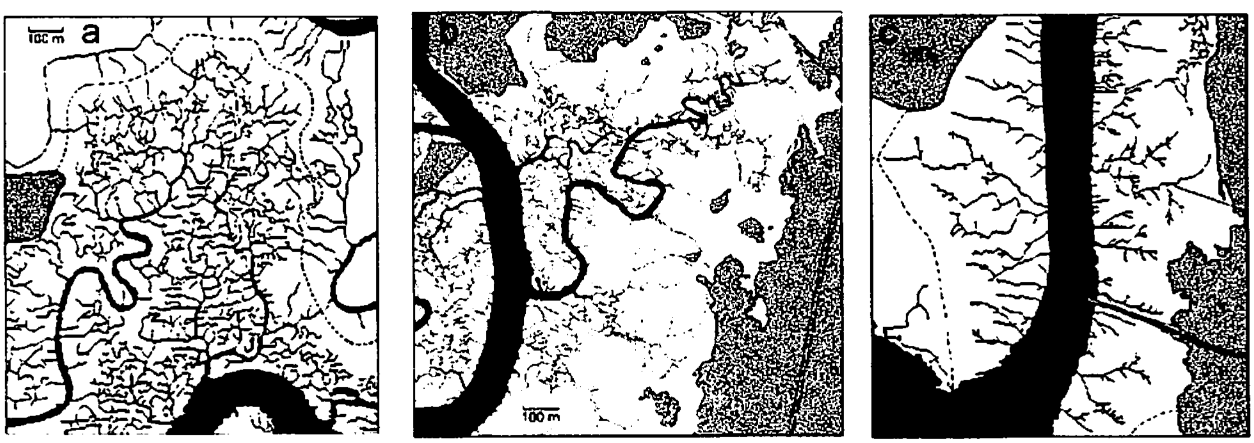


Figure 12. Patterns of drainage density in the three physiographic regions of the Duplin River salt marshes: a) high drainage density, young marsh; b) intermediate drainage density and age; c) low drainage density, mature marsh. (From Wadsworth, 1980.)

marshes at three stages of maturation (Fig. 10), corresponding closely with the three major physiographic provinces (Fig. 11) as established from patterns of drainage networks and drainage density (Fig. 12) (Wadsworth, 1980). The sequence of marsh maturation described by Frey and Basan (1985) is characterized by a progressive filling of the marsh-lagoon, the net effect of which is a gradual increase in elevation and diminution of tidal effect in more mature marsh areas. Marshes at the three stages of maturation portrayed in Fig. 10 differ markedly in rates of surficial sedimentation, slope, frequency, topography, headward erosion and network extension, sediment permeability and response to storm events (Wadsworth, 1980; Frey and Basan, 1985).

The effect of these major geomorphic differences on utilization of the intertidal marsh by aquatic organisms has been studied in the SINERR by Kneib (1991), whose findings are discussed later in this profile, but many questions remain as to the effect of geomorphic heterogeneity on fundamental ecosystem processes such as gross and net ecosystem production and net ecosystem exchange of materials.

BEACH MORPHOMETRY AND THE SAND-SHARING SYSTEM

On the eastern side of the SINERR is Nannygoat Beach, a broad, gently sloping beach with low wave energy which is a result of the energy-dampening effect of the broad, shallow Continental Shelf present along the Georgia coast. Wave heights average 0.8 - 1.25 m (Henry, 1989). Lateral troughs and bars, or runnels and ridges, which retain water at low tide are commonly present on the beach, formed by breaking waves (Greaves, 1966; Hoyt, 1962). The troughs often have ripples of a variety of shapes determined by the water flows which formed them. Two kinds commonly seen are oscillation ripples, with sharp crests and relatively wide troughs; and current ripples formed by water running out of runnels, with broad, gentle slopes on the upstream side and steep slopes on the downstream side (Hoyt and Henry, 1963).

Above the high tide line, dunes develop when wind-blown sand builds up behind small obstacles such as wrack, culms of dead *S. alterniflora* washed out of the marshes and sounds and deposited on the beach. Fig. 13 depicts a schematic cross-section through a Georgia barrier island, and shows the relationship of the shifting dunes nearest the beachfront, the stable dunes and the maritime forest and salt marsh which they protect from the direct force of breaking waves. Once an obstacle has begun to capture sand, the dune continues to grow unless high tides or storm tides wash it away. Salt-tolerant foredune plants quickly begin to colonize the new dune, and their roots are important factors in its stabilization. Sea oats, *Uniola paniculata,* is the most important of these plants because of the depth of penetration and lateral spreading of its root systems (Wagner, 1964). Dunes along the Georgia coast often get as high as 3 - 4 m. Even when they have been well-vegetated with sea oats and other species they remain fragile and easily damaged by natural forces as well as by man.

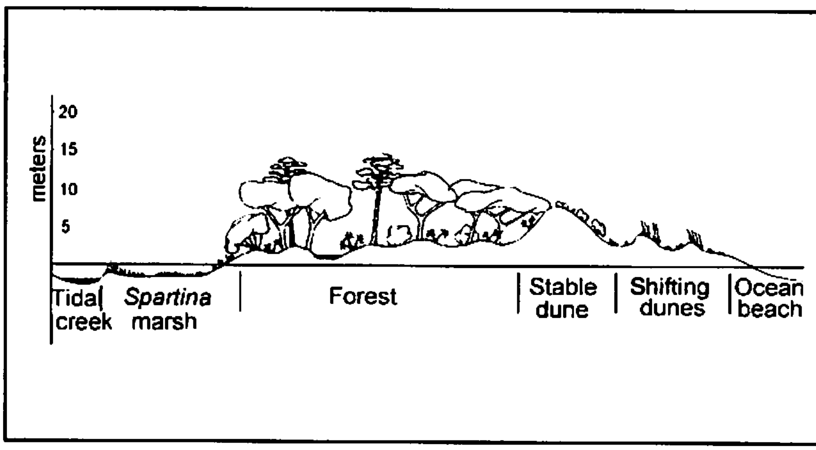


Figure 13. Idealized cross-section of Sapelo Island.

The prevailing longshore current is from north to south (Hoyt *et al.*, 1964; Greaves, 1966; Frey and Howard, 1969), although strong tidal currents sweeping out of the mouth of Doboy Sound often dominate the longshore current locally. An aerial view of the south end of Nannygoat Beach reveals the long-term result of the north-to-south currents, beach and marsh-building on the south end of coastal barrier islands (Fig. 14).

Figure 14. The black line shows the approximate location of the 1953 shoreline in relation to the 1989 shoreline in the photograph. Note the ridged appearance of the added dunes and vegetation, typical of Holocene development.

The beach, dunes and offshore sandbars form a dynamic sand-sharing system driven by tides, longshore currents and wave energy. Sapelo Island is one of the few places on the East Coast of the U.S. where the sand-sharing system operates with minimal interference from human activity. After a long period of accretion, Nannygoat Beach has recently experienced several years of erosion, losing 10 meters or more of dunes. This cycle of erosion and accretion is constantly active, with sand eroded from one area of beach by storm waves being deposited in offshore sandbars and gradually being washed back onto the beach to be trapped and held by dune vegetation. As evidenced by the accretion on the south end of Sapelo during the past 45 years (Fig. 14), some of the sand is transported southward by the prevailing currents.

Fortunately, beach erosion on Sapelo is only a minor problem even when it does occur since there are no major structures near the beach. The boardwalk and pavilion at Nannygoat Beach, built by the Department of Natural Resources to protect the dunes from trampling by tourists and other visitors, have been threatened by the recent erosion, but the prospect of their loss will not result in expensive and sometimes counter-productive protective measures such as those seen on nearby Georgia coastal islands (Henry, 1989). Erosion of Sapelo beaches can be a more serious problem for animals that use the beaches as nesting areas, such as the Atlantic loggerhead turtle (*Caretta caretta*), and shorebirds such as the American Oystercatcher (*Haematopus palliatus*), Wilson's Plover (*Charadrius wilsonia*), Gull-billed tern (*Sterna nilotica*), Least Tern (*Sterna antillarum*) and Black Skimmer (*Rynchops niger*). Each of these species depends on access to stable beach areas near but above high tide to lay their eggs. One cause of nesting failure is higher than normal tides which submerge or wash away birds' eggs (Corbat, 1990) or erode the area where loggerhead turtles have nested.

Ecological Studies in the SINERR

AQUATIC HABITAT

The aquatic habitat of the SINERR includes the water that remains in tidal creeks and the Duplin River throughout the tidal cycle and the water which covers the marsh at high tide. At low tide this water resides in the Duplin and in the larger tidal channels which do not drain completely. Approximately 80% of the Duplin River watershed is intertidal marsh and mud flat, and the remaining 20% is permanently submerged. Many ecologically important species reside permanently in the subtidal areas of the Duplin River system, while others migrate on and off the marsh surface with the tide. All of the organisms which move onto the marsh surface at high tide try to leave with the receding tide, but some very small individuals may be able to survive until the next flood tide by taking refuge in small puddles of standing water which form in depressions, or even in fiddler crab burrows. Many species spend only part of their life cycle in estuary-marsh areas such as the Duplin.

The aquatic environment is highly variable with fluctuations in water height, salinity, temperature and many other factors which affect biological processes occurring on time scales from hours to months. Figure 15 illustrates that variability in water temperature, salinity and pH at the Marine Institute's Flume Dock hydrological monitoring station within the SINERR. Water temperature (Fig. 15a) follows the expected seasonal trend, with coldest temperatures occurring in January and the warmest in mid-summer. Salinity varies in response to local rainfall, evaporation during hot summer months and river discharge. During periods of high flow in the Altamaha River, or of high discharge from Georgia's other rivers emptying into the Atlantic Ocean, low salinity water can be introduced to Doboy Sound from the Altamaha via the North River and Back River or from the Atlantic Ocean, and some low salinity water can enter the Duplin River on flood tide. Conversely, when river discharge is low and nearshore salinities are high, saltier water can be introduced to the system by flood tides. Thus the pattern of variation in salinity (Fig. 15b) is more variable than that for temperature; pH, which is affected by even more factors than salinity, shows even more variability (Fig. 15c). These graphs depict monthly averages, which hide much of the short-term variability that organisms living in the Duplin River experience.

Other important abiotic components of the aquatic system are less easily measured. Particulate and dissolved materials are carried by tidal currents on and off the marsh and are constantly being redistributed within the estuary. Distributions of these materials, which range from dissolved nutrients such as ammonium, phosphate and nitrate to small

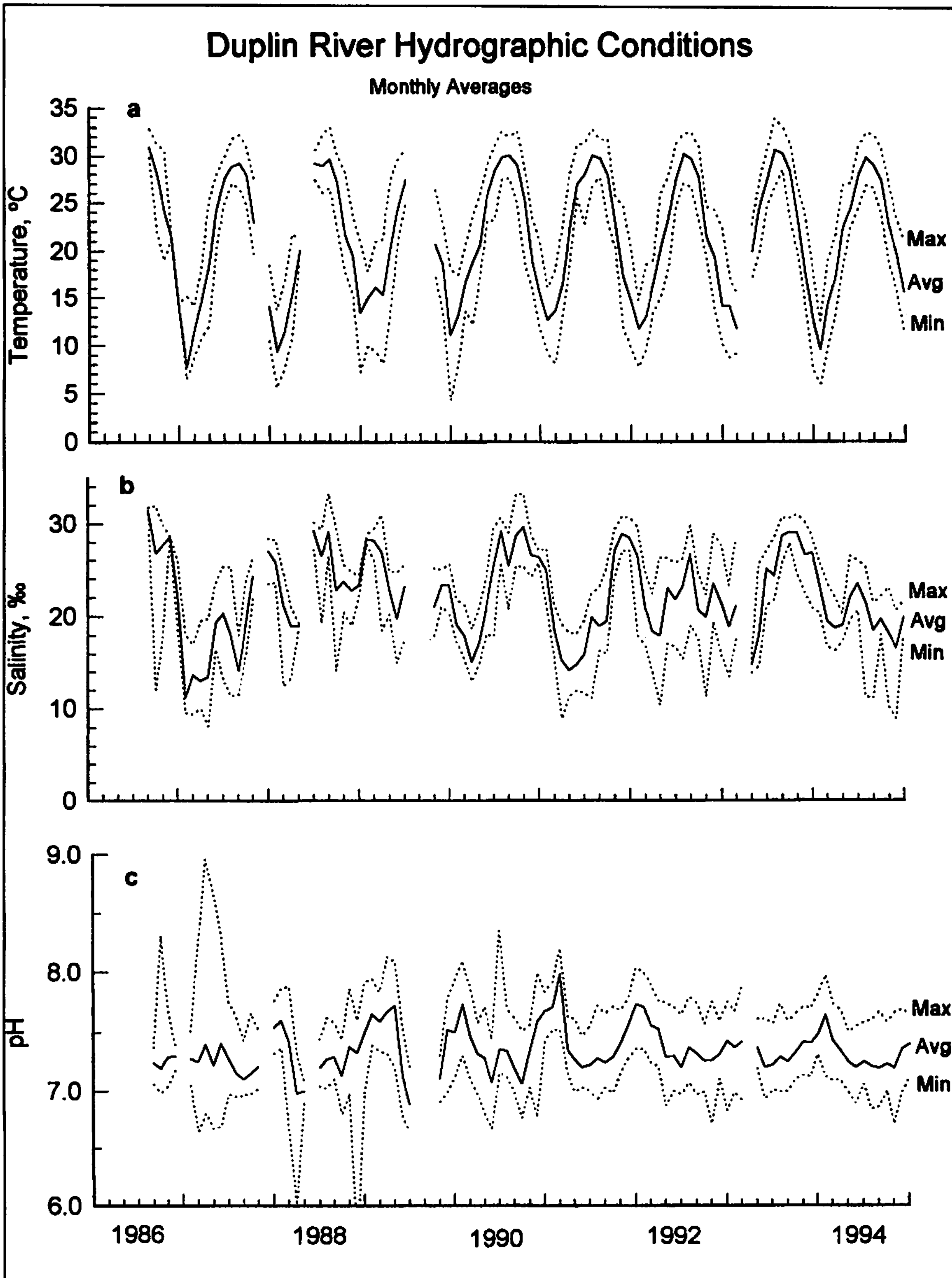


Figure 15. Temperature, salinity and pH in the Duplin River for 1986 -1994.

particles of dead plant material and to large floating rafts of dead plant stems (wrack), are controlled by hydrology and biological activity and, in the case of floating wrack, wind. Dissolved compounds and particulate matter entrained in the water column move with the tidal currents, but net transport is largely a function of diffusive gradients (Imberger *et al.*, 1983; Chalmers *et al.*, 1985).

INTERTIDAL HABITAT

The intertidal habitats of the SINERR consist of unvegetated creek banks and mud flats in the Duplin River and adjacent tidal creeks, including small tidal creeks that drain completely at low tide and the vegetated marsh surface, which contains several distinct zones (Fig. 9). As discussed in the section on geomorphology, the plant zonation is controlled by a combination of interacting factors including elevation and hydrology (Chalmers, 1982; Wiegert *et al.*, 1983). Although the marsh surface is covered by water less than half of each tidal cycle, there is a perched water table which maintains the sediments of all but the highest intertidal elevations in a near waterlogged condition. Near creek channels the hydraulic head created by difference in the level of the water table and water level in the channel results in a slow seepage of interstitial water through the creekbanks into the channels. At a distance from the creeks, however, there is little subsurface water movement except that due to water loss near the surface via evaporation and transpiration. That water is replenished by the subsequent flood tide, but the difference in water exchange near creeks and at a distance from them results in large and constant differences in redox potential, salinity, sulfide concentration and plant productivity (Chalmers, 1982; King *et al.*, 1982; Wiegert *et al.*, 1983). Table 1 shows a comparison of plant, soil, and microbial attributes of low and high *S. alterniflora* zones in Sapelo Island marshes.

The different growth forms of *S. alterniflora*, tall on creekbanks and levees grading into an intermediate height behind the levees and to the short form in areas farthest from creeks, collectively have a rate of annual production that rivals that of any natural ecosystem. In spite of decades of research, the cause of the different growth forms remains unclear. Wiegert *et al.* (1983) found that increasing subsurface drainage in areas with the intermediate growth form could increase height of culms and double production in one growing season. They attributed this increase in growth to removal of end-products of anaerobic decomposition such as sulfide and increased availability of nutrients. The agent of these changes was increased flushing of the sediments with tidal water. Bradley and Dunn (1989) showed that in hydroponic culture sulfide could indeed inhibit growth of *S. alterniflora* at concentrations commonly found in high marsh sediments. They also found evidence that sulfide concentration could be an agent in determining zonation of species in the marsh.

The bare mud banks of the creeks and larger drainage channels also support a flora which has relatively high rates of primary production, even though it is overshadowed by the production of marsh grass in ecosystem budgets (Pomeroy, 1959). The diatoms that form a golden sheen on the surface of the mud when they are not covered by water migrate down into the mud when the tide comes in (Williams, 1963). They live in a nutrient-rich environment due to water seeping through the creek banks (Agosta, 1985), but

Table 1. Comparison of High Marsh (SS) and Low Marsh (TS) at Sapelo Island. A plus sign (+) indicates location where higher value is found. An equal sign (=) indicates that values are the same in each location.

ATTRIBUTE	TS	SS	REFERENCE
Spartina alterniflora			
Height	+		Pomeroy *et al.*, 1981
Biomass	+		Pomeroy *et al.*, 1981
Aerial production	+		Pomeroy *et al.*, 1981
% N	+		Pomeroy *et al.*, 1981
Root penetration depth	+		Pomeroy *et al.*, 1981
Belowground production	=	=	Pomeroy *et al.*, 1981
Stem density (stems/m^2)		+	Pomeroy *et al.*, 1981
Soil			
Water flow	+		Nestler, 1977
CO_2 evolved (soil)	+		Christian *et al.*, 1981
Eh	+		Giblin & Howarth, 1984
pH	+		Giblin & Howarth, 1984
SO_4^{2-} concentration	+		Oshrain, 1977
Dissolved iron (>7cm)	+		King *et al.*, 1982
Dissolved iron (surface)		+	King *et al.*, 1982
Mn-reduced (surface)	+		Spratt and Hodson, 1994
Mn-soluble	+		Spratt and Hodson, 1994
Mn-reduced (>10cm)	=	=	Spratt and Hodson, 1994
NH_4^+, NO_2^-, NO_3^-	=	=	Chalmers, 1977
Volatile H_2S		+	Oshrain, 1977
Salinity		+	Christian *et al.*, 1981
Dissolved organic carbon		+	Sottile, 1974
Macroorganic matter		+	Gallagher and Plumley, 1979
Microbial			
Benthic algal production	+		Pomeroy *et al.*, 1981
Adenylate energy charge	+		Wiebe and Bancroft, 1975
Fermentation	+		Christian and Wiebe, 1978
Sulfate reduction rate	+		Skyring *et al.*, 1979
Nitrogen fixation rate	+		Ubben and Hanson, 1980
Mn oxidation rate	+		Spratt *et al.*, 1994
ATP (>10 cm depth)	+		Christian *et al.*, 1975
ATP (top 5-10 cm)		+	Christian *et al.*, 1975
Denitrification		+	Sherr and Payne, 1978
CH_4 evolution		+	King and Wiebe, 1978

are heavily grazed by snails (*Ilyanassa obsoleta*) and fiddler crabs (*Uca pugnax)* when they are on the surface photosynthesizing (Pace *et al.*, 1979).

Feeding behavior of fiddler crabs, particularly of the sand fiddler, *Uca pugilator*, was studied extensively by Robertson and his colleagues (Robertson *et al.*, 1980, 1981; Robertson and Newell, 1982a, 1982b) to determine the factors controlling foraging behavior, the efficiency of extraction of food from the substrate and the feeding stimulants which cue their feeding. They found that the pattern of foraging exhibited by the sand fiddler is partially in response to gradients in the food resource, and that the crabs are forced to forage at a distance from their burrows, which serve as a refuge from predation, because of reduction in food density by previous grazing. Paradoxically, Robertson *et al.* (1980) found that sand fiddlers leave behind a significant portion of the food available near their burrows as a consequence of harvesting less than half of the available substrate. Once harvested, food is extracted from the substrate at a high level of efficiency. The favored foods of sand fiddlers are diatoms and blue-green algae (Robertson *et al.*, 1981). Robertson and Newell (1982b) showed that differences in mouth parts cannot totally explain the separation in the distribution of the three species of *Uca* present in the SINERR: *Uca pugilator*, which is found on sandy beaches with low wave activity, bare creekbanks having sand content of 10%-70%, and sandy areas of salt marshes dominated by species of *Salicornia* and *Distichlis*; *U. pugnax*, which is found in the muddy, regularly flooded intertidal marsh as well as in the *Salicornia—Distichlis* marshes; and *U. minax*, which is found primarily in the higher elevation short *Spartina* marshes.

Throughout the intertidal marsh, benthic invertebrates, bacteria and algae live in close association with the marsh vegetation, grazing on it, decomposing it, using it as refuge or a substrate for attachment, and serving as a food resource for other marsh residents and for animals which migrate onto the marsh with the tide. Distribution, life history characteristics and energetics of various populations of marsh invertebrates have been the subject of various studies through the years (Teal, 1958, 1959a, 1959b, 1962; Odum and Smalley, 1959; Smalley, 1960; Kuenzler, 1961a, 1961b; Wolf *et al.*, 1975, Montague, 1982; Kneib and Parker, 1991; Covi and Kneib, 1995). In recent years Kneib has focused a great deal of effort on determining what species of nekton utilize vegetated intertidal habitat (Kneib, 1991), how distributions of marsh infauna are affected by predation by foraging nekton (Kneib, 1992) and how geomorphology, spatial scale and physical structure of the marsh affect interactions between nekton and prey species (Kneib, 1994; Lee and Kneib, 1994).

Natant organisms must balance the benefits of swimming onto the flooded marsh to forage with the dangers of being stranded in the marsh by the receding tide. Kneib and Wagner (1994) found that less than a third of the species of fishes, shrimps and swimming crabs which inhabit the SINERR estuary (21species out of over 75) actually used the intertidal marsh surface during the summer months. Individuals of only four species comprised 95% of all individuals collected. Year-round sampling collected only an additional 12 species using the marsh surface during high tide (Kneib, 1991). Abundance and species richness was greatest in the low intertidal (25 m from the nearest creek), with fewer individuals being found in the high intertidal (90 m from a creek) (Kneib and Wagner, 1994). Variations in stages of the tide when various species were most abundant on the marsh suggested that larger species such as white shrimp, *Penaeus setiferus*, leave the marsh earlier in the ebb tide than some of the smaller species, which may be more tolerant of stranding in the marsh. At low tide smaller individuals are abundant in shallow water adjacent to vegetated marsh, but move only a short distance into the marsh at high tide (Kneib and Wagner, 1994), while larger individuals move further into the marsh to forage on the more abundant prey species available at higher elevations (Kneib, 1992, 1995). Mayer (1985) found that juvenile white shrimp, *Penaeus setiferus*, fed extensively on marsh benthic invertebrates such as the polychaete *Nereis succinea*, ostracods, tanaids and dipteran larvae, especially on night-time high tides. Kneib and Wagner (1994) also found that white shrimp were more abundant on the marsh at night.

Behavior in some cases affects what prey species a predator in the intertidal marsh will consume. Kneib and Weeks (1990) found that although the mud crab, *Eurytium limosm*, would readily eat young killifish (*Fundulus heteroclitus*) in laboratory feeding experiments, crabs collected in the marsh did not have killifish remains in their cardiac stomachs, indicating that they were not feeding on killifish in the field. The explanation for this apparent failure to utilize an abundant intertidal prey species is that the mud crab feeds primarily at high tide when young killifish are dispersed in the water column and less vulnerable to benthic predators than during laboratory studies.

Gradients in abiotic and biotic factors produced by tidal flooding can influence distribution of marsh organisms. At lower elevations and on levees adjacent to creeks, the marsh surface and vegetation generally remains damp even during low tide due to the duration of tidal inundation that those areas experience. Organisms such as the amphipod *Uhlorchestia spartinophila* which favor moist conditions are most abundant on the levees (Covi and Kneib, 1995). The structural characteristics of the *Spartina alterniflora* growing there also provide refuge from submergence and predators during high tide. *U. spartinophila* was also abundant at the other end of the tidal gradient, possibly due to lower pressure from predators at that elevation (Covi and Kneib, 1995). Size and abundance of other prey species, such as the marsh periwinkle, *Littoraria irrorata*, can be affected by intertidal migratory behavior of predators. Schindler *et al.* (1994) used the incidence of shell-scarring, evidence of a non-lethal attack by a blue crabs, to estimate intensity in predation of crabs on the snails. They hypothesized that distance from the marsh edge, vegetation density and duration of tidal inundation would affect the ability of crabs to forage in the marsh and the length of time available to them to forage, and predicted lower rates of predation by crabs on snails with increasing intertidal elevation.

Studies of utilization of intertidal marsh by blue crabs, *Callinectes sapidus,* have been conducted by Arnold and Kneib (1983) and Fitz and Wiegert (1991). Although there were some differences in the conclusions of the two studies with respect to frequency with which larger crabs move onto the marsh surface, both agreed that smaller individuals are more frequently found to move onto the marsh during high tide and feed there on invertebrate species such as non-portunid crabs, shrimp and similar crustaceans, gastropods and annelids. Fitz and Wiegert (1991) found that guts of crabs collected on the marsh were fuller at or after high tide than before high tide, confirming that they are feeding while on the marsh during high tide. Mayer (1985) found that juvenile white shrimp (*Penaeus setiferus*) also had near-empty guts at low tide but full guts when captured on the marsh during high tide. These findings support the hypothesis of Chalmers *et al.* (1985) that nekton which migrate onto the marsh surface to feed and then return to the tidal channels of the estuary when the tide recedes can serve as a significant mechanism for redistribution of organic matter within the ecosystem, specifically removing organic carbon from the marsh and releasing it in the water column where it is more likely to be exported from the estuary to the sounds and nearshore waters.

At the highest elevations of the marsh interstitial salinities can become quite high due to infrequent inundation and evaporation except in areas adjacent to uplands, where groundwater seepage and runoff may alleviate osmotic stress for plants living there. Areas near the uplands often have a fringing band of *Juncus roemerianus*, which also can often be seen as large dark patches in the midst of an expanse of *S. alterniflora*. Often these patches are perched on old beds of the marsh mussel, *Geukensia demissa*. Although clearly able to tolerate inundation with salt water, *J. roemerianus* appears also to occur where it has more freshwater and infrequent inundation, in contrast to the succulent species found in the high marsh such as *Salicornia virginica* and *Sarcocornia perennis*, which are often found fringing salt pans or invading bare areas of marsh with relatively high elevation. Factors influencing zonation of these and other high marsh plants such as *Batis maritima*, *Baccharis angustifolia*, and *Borrichia frutescens* are poorly understood and have received little attention from researchers on Sapelo Island until recently. Dr. Steven Pennings has begun investigating the effects of salinity, competition, shading and other factors on zonation of high marsh plant species.

UPLAND HABITAT

The upland areas of SINERR include hammocks dominated by mature live oak, areas of mixed species maritime forest with an overstory of live oak and other species of oak interspersed with pine, areas dominated by pine which were planted during the R.J. Reynolds era, abandoned clearings in various stages of succession and areas of palmetto, pine and shrubs. Management practices in the upland areas include harvesting of pines to thin mature stands and controlled burning to control underbrush. The effect of these management techniques on the marshes adjacent to the uplands has not been studied. Although the impacts are indirect, the marshes adjacent to the SINERR uplands are affected by runoff and groundwater seepage. These effects would be most important in areas where there is a pronounced elevation difference between marsh and upland, as along much of the eastern edge of the Duplin River watershed.

Several freshwater ponds are found on Sapelo Island, although only a few occur within the SINERR. Almost any area with fresh or brackish water also has a resident population of alligators. The pond near the Marine Institute and the Reynolds Mansion has numerous small and a few large alligators which can be seen floating on the surface among the duckweed and emergent vegetation or on the banks of the small islands in the pond. The alligators frequently move between freshwater areas and the salt marsh during the summer, particularly at night. The upland and dune areas of the island are also populated by Eastern diamondback rattlesnakes (*Crotalus adamanteus*), while the cottonmouth moccasin (*Agkistrodon piscivorus)* is sometimes found near wet areas. Appendix 5 contains a list of reptiles and amphibians which can be found on Sapelo.

Numerous species of birds can be found in the various habitats of the SINERR and elsewhere on Sapelo Island (Appendix 6). The brown pelican (*Pelecanus occidentalis*), herring gulls (*Larus argentatus*), laughing gulls (*L. atricilla*) with their distinctive black heads, ring-billed gulls (*L. delawarensis*), and double-crested cormorants (*Phalacrocorax auritus*) are among the many birds one might see on the ferry ride to and from the island. Willets (*Catoptrophorus semipalmatus*), American oystercatchers (*Haematopus palliatus*) and sanderlings (*Calidris alba*) are among the many species that frequent the beaches; black skimmers (*Rynchops niger*) can often be seen skimming the surface of tidal sloughs and near the water line at low tide. Numerous heron species and egrets can be seen hunting for food along creek banks, in the marsh and in freshwater areas, with clapper rails (*Rallus longirostis*) being heard more often than they are seen. It is not uncommon to see a flock of white ibis (*Eudocimus albus*) in the marsh, or an occasional wood stork (*Mycteria americana*), with a distinctive black edge on the underside of their wings visible when they fly. Various hawk species, black and turkey vultures (*Coragyps atratus* and *Cathartes aura*, respectively), ospreys (*Pandion haliatus*) and, occasionally, bald eagles (*Haliaeetus leucocephalus*) can be observed in the SINERR. Black-crowned night herons (*Nycticorax nycticorax*) and American coots (*Fulica americana*) frequent the pond across from the Marine Institute. During the summer, the painted bunting (*Passerina ciris*) is a spectacular sight as it flits among the shrubs and trees lining the road to the beach and elsewhere.

Several mammal species can be seen in the SINERR and elsewhere on the island (Appendix 7). Those most commonly seen are white-tailed deer (*Odocoileus virginianus virginianus*), raccoons (*Procyon lotor solutus*) and opossums (*Didelphis marsupialis*). Sightings of feral hogs are unfortunately becoming more common, as their population grows from the few that were introduced to the island in the early 1990s. Armadillos (*Dasypus novemcinctus*) also began being sighted on the island during the 1990s. Feral cattle, remnants of a herd once belonging to R.J. Reynolds, inhabit the north end of the island, and occasionally are seen on the south end. They are reclusive and cautious, so that sightings are uncommon although signs of their presence, tracks and fecal matter, are more common sights.

BEACH AND DUNES

The beach and dune area with its salt-spray community of plants is one of the least studied habitats in the SINERR. This area has a distinct zonation of plants with a gradient of vegetation from the active dunes with their salt tolerant plant species to the back dune area which is more protected from salt spray and wind. The combined effects of high temperatures, high light intensities, high evaporation, salt spray and wind severely limit the diversity of plants growing in the active dune area. Duncan (1982) recognized four zones in the open dune area, with the most fragile and ephemeral being that at the high tide level and on overwash areas of the beach. Here beach hogwort (*Croton punctatus*), salt wort (*Salsola kali*) and sea-purslane (*Sesuvium portulacastrum*) are among the species that can be found. On the active dunes sea oats, railroad vine (*Ipomoea pes-caprae)*, beach sand-spur (*Cenchrus tribuloides*), beach pennywort (*Hydrocotyle bonariensis*), Spanish bayonet (*Yucca* spp.) and seashore elder (*Iva imbricata*) are found, along with some of the high tide plants. Older, less active dunes are also more protected from wind and salt spray, and become vegetated by a greater variety of plants, including shrubs and small trees. Wax myrtle (*Myrica cerifera*), prickly pear (*Opuntia humifusa*), yaupon (*Ilex vomitoria*), buckthorn (*Bumelia tenax*), Southern red cedar (*Juniperus silicicola*), hercules club (*Zanthoxylum clava-herculis*) and sand live-oak (*Quercus geminata*). The interdune areas are vegetated by many of the species found on older dunes with many additional grasses and shrub species (Duncan, 1982). In recent years, the Chinese tallow tree (*Sapium sebiferum* Roxb.) has begun invading this area (Fred Hay, DNR, personal communication). There are also a number of small ponds in the interdune area. Between the Reynolds mansion and Nannygoat beach, just east of Dean Creek, is a ridge of high wooded dunes covered by many old and beautiful cedars, oaks and pines along with many of the same species found in the younger dune areas.

Although the beach itself appears nearly devoid of life, there are many species that live there or are dependent on its availability for feeding or nesting. At lower levels of the beach, where the surface sand remains damp throughout low tide, there are often large patches of diatoms which give the surface a golden sheen, similar to diatoms found on exposed mud banks in the intertidal areas of the Duplin River, and during summer and fall the lower beach is often covered by a layer of green which is a flagellated euglenoid alga which migrates up and down in the sand in much the same fashion as the marsh diatoms. The factors controlling their vertical migration and the contribution that their photosynthesis and growth make to the nearshore ecosystem has not been adequately studied.

At low tide it is common to see many small holes in the sand surrounded by a ring of small, brown, cylindrical pellets. The hole is the burrow of the ghost shrimp, *Callianassa major*, and the pellets are fecal matter which has been deposited on the surface by the animal in the burrow. Frankenberg *et al.* (1967) investigated the rate of production of *C. major* fecal pellets and their potential significance as food for animals on the beach and in nearshore waters. The fecal pellets contain bacteria and undigested algal cells and cell fragments, along with clay particles, and could provide a neatly packaged source of organic carbon for deposit feeding animals. Frankenberg *et al.* (1967) found that blue crabs (*Callinectes sapidus*) and pagurid crabs (*Pagurus* spp.) readily ingest *C. major* fecal pellets, suggesting that the fecal pellets may be an important food resource for subtidal species.

One permanent resident of the beach is the ghost crab, *Ocypode quadratus*. Research by Robertson and Pfeiffer (1982) on feeding behavior of these semi-terrestrial crabs revealed that in addition to nocturnal predatory foraging, *O. quadratus* engages in deposit feeding during daylight hours, using its minor chelae to transport substrate to the buccal cavity and then to remove feeding pellets, aggregations of uningested substratum. Their behavior is similar to that of the sand fiddler crab, *Uca pugilator*, which can also be found on some sheltered areas of beach and in sandy substrate high marsh habitats. Both *O. quadratus* and *U. pugilator* are highly efficient at removing algae from sand particles (Robertson and Pfeiffer, 1982; Robertson *et al.*, 1980). Deposit feeding by ghost crabs was restricted to areas with visibly dense patches of diatoms.

Sea birds nest in some areas of the SINERR beaches, but Corbat (1990) found that the number and success rate of nests on Sapelo and in Georgia in general is lower than that found in nesting areas in adjacent states. This may be due to a shortage of suitable habitat. Nesting shorebirds prefer nesting on a sparsely vegetated wide berm above the high tide line, and although Georgia's beaches are wide and gently sloping, there are not many flat areas above the high tide level. Most of the nests that were observed on Sapelo failed to produce hatchlings. Many were disrupted by raccoons and ghost crabs, and others were inundated by an unusually high tide or were abandoned for unknown reasons (Corbat, 1990). It appeared that there were occasionally good nesting years when hatching rates were somewhat higher, but in any case, shorebird nesting in the SINERR is an activity which is highly sensitive to disturbance from natural events, and one that needs to be protected from human intrusion as much as possible.

Loggerhead turtle nesting in the SINERR is another risky and often unsuccessful activity. DNR has been monitoring nesting activity and success rate since 1987, and the number of nests laid during that time ranged from 24 in 1993 to 79 in 1995 (personal communication, Brad Winn, Georgia DNR). The average number of nests per year during the 10-year monitoring period is 50, with an average of 120 eggs/nest. Hatching success has ranged from 0 to 90%, with the main causes of mortality being predation on the eggs by raccoons and ghost crabs; erosion because of storms, unusually high tides or poor site selection by the female turtle; and drowning of the nest by an unusually high water table after periods of heavy rain (personal communication, Brad Winn, Georgia DNR). Interestingly, one of the earliest publications from the Marine Institute concerned mortality of loggerhead turtle eggs due to excessive rainfall (Ragotzkie, 1956).

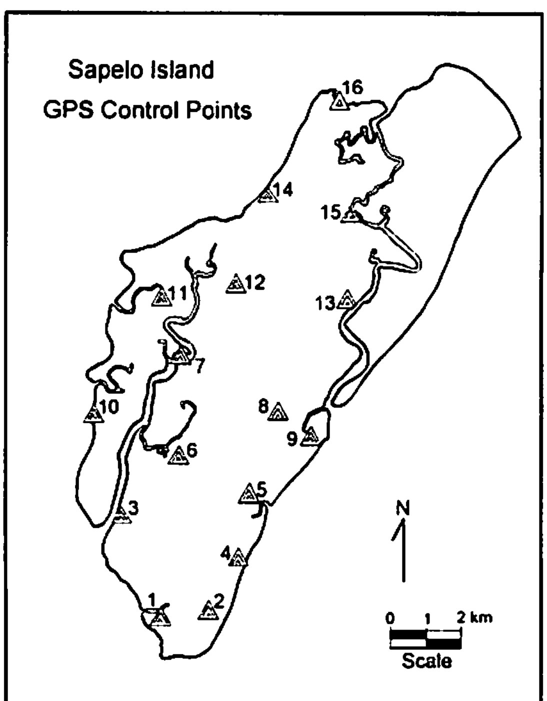


Figure 16. Network of GPS Control Points.

LAND USE, HABITAT AND SHORELINE CHANGE ON SAPELO ISLAND

In 1991, with funding from a NOAA Research Reserve grant, the Center for Remote Sensing and Mapping Science and the Marine Institute of the University of Georgia constructed an integrated resource database for the SINERR to be used for research and educational activities promoting marshland preservation. The original database contained information on topography, planimetry, vegetation, land use and land forms based on photographs

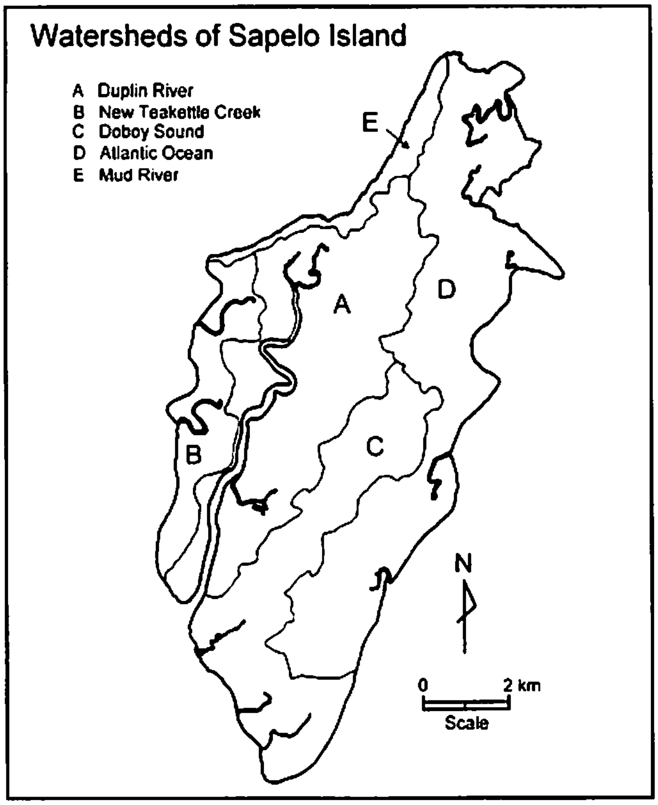


Figure 17. Boundaries of 5 watersheds on Sapelo Island with the water bodies they drain

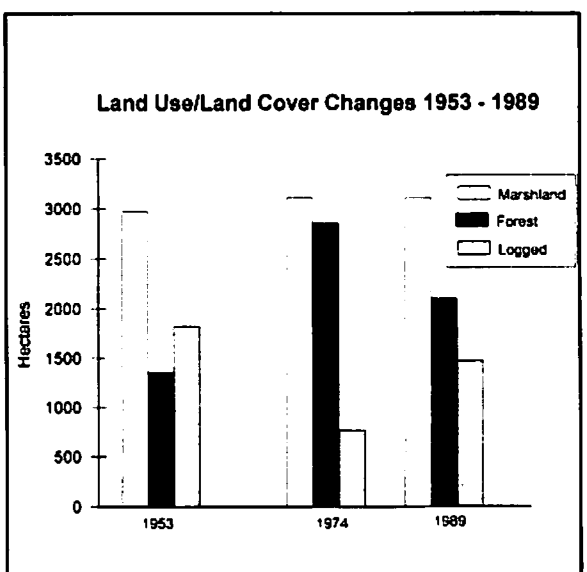


Figure 18. Some results of land cover/ land use change analysis of Sapelo Island, 1953 - 1989. (From Welch *et al.*, 1992.)

recorded in 1989. Global Positioning System (GPS) surveys, photogrammetric aerotriangulation and compilation procedures, computer-aided image analyses and air photo interpretation were used to compile the database. A network of 16 GPS control points was established (Fig. 16) and a topographic map with a contour interval 1 m were produced from spot heights measured using 1:16,000-scale film transparencies and a stereo-plotter (Welch *et al.*, 1991).

Subsequent work added drainage basin boundaries (Fig. 17), soils information from the McIntosh County Soils map (Fig. 19) and vegetation and land-use data sets derived from photointerpretation of aerial photographs recorded in 1953 and 1974 (Fig. 20b and 20c) were added to that from 1989 (Fig. 20d). Outlines of polygons of the various land use and vegetation classes were digitized and annotated with attribute information using Arc/ Info. Then comparisons of land-use/land-cover were made for the time intervals 1953 - 1974, 1953 - 1989, and 1974 - 1989 (Welch *et al.*, 1992).

Two of the most striking changes were the increase in forested areas during the 36 year interval from 1953 to 1989, most likely due to changes in ownership and management of land in what is now the R. J. Reynolds Wildlife Management Area, and the changes in the area which had been recently logged. During the period 1953 - 1974 there was a large decrease in the logged area (Fig. 18), reflecting a change in management goals during the period that the island was shifting from private to public ownership. During the period from 1974 - 1989, how-ever, logged areas nearly doubled, clearly showing the effect of the return to thinning of the pine forests on the island.

Since the database was created, a GIS laboratory has been established at the Marine Institute so that the database is now maintained and updated on the island. Color infrared aerial photographs were taken of the island in 1992, 1993 and 1994, making it possible for researchers to assess short-term changes in vegetation, land use and shorelines.

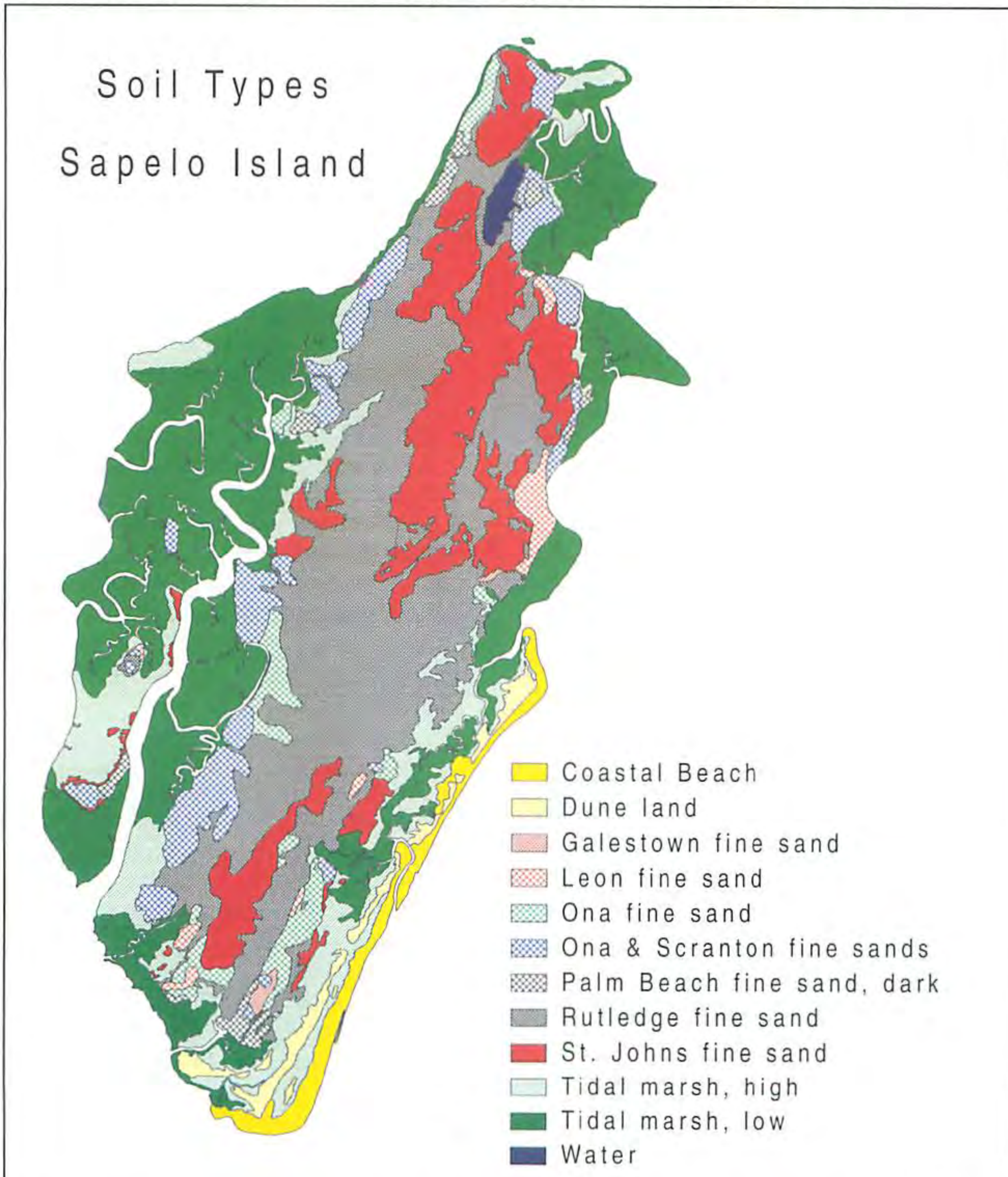


Figure 19. Soil types of Sapelo Island. From McIntosh County, Georgia Soil Survey, 1959. United States Department of Agriculture, Soil Conservation Service.

Land Use/Cover Changes for the SINERR and Sapelo Island

1953 and 1989

LEGEND

Open Water and Marsh Species

- WATER
- SA
- SP
- SA, JUN, IVA, BOR, BAC, SAL
- JUN, IVA, BAC
- SALTPAN, SAL
- INLAND MARSH

Upland Vegetation Types

- O
- P
- P, O
- O, P
- P, O, CUT
- O, P, CUT
- LO, P, SAW, RC
- P, RC, MYR, DUNES
- SAW, LO, RC

Land Uses and Landforms

- CLEARING
- RESIDENTIAL
- SHELLS/WRACK/MUD
- BEACH
- SHRUBS/DUNES

SA - **Smooth Cordgrass,** *Spartina alterniflora*
SP - **Saltmeadow Cordgrass,** *Spartina patens*
JUN - **Black Needlerush,** *Juncus roemerianus*
IVA - **Marsh Elder,** *Iva frutescens*
SAL - **Glasswort,** *Salicornia* spp.
BAC - **Groundsel Bush,** *Baccharis halimifolia*
BOR - **Sea Ox-Eye,** *Borrichia frutescens*
RC - **Red Cedar,** *Juniperus virginiana*
O - **Oak,** *Quercus* spp.
P - **Pine,** *Pinus* spp.
LO - **Live Oak,** *Quercus virginiana*
SAW - **Saw Palmetto,** *Serenoa repens, and*
Cabbage Palmetto, *Sabal palmetto*
MYR - **Wax Myrtle,** *Myrica cerifera*

Figure 20a. Legend. Land use/cover for the SINERR and Sapelo Island, 1953 to 1989 based on aerial photographs and generated using the ARC/INFO geographic information system by the Center for Remote Sensing and Mapping Science, Department of Geography, The University of Georgia.

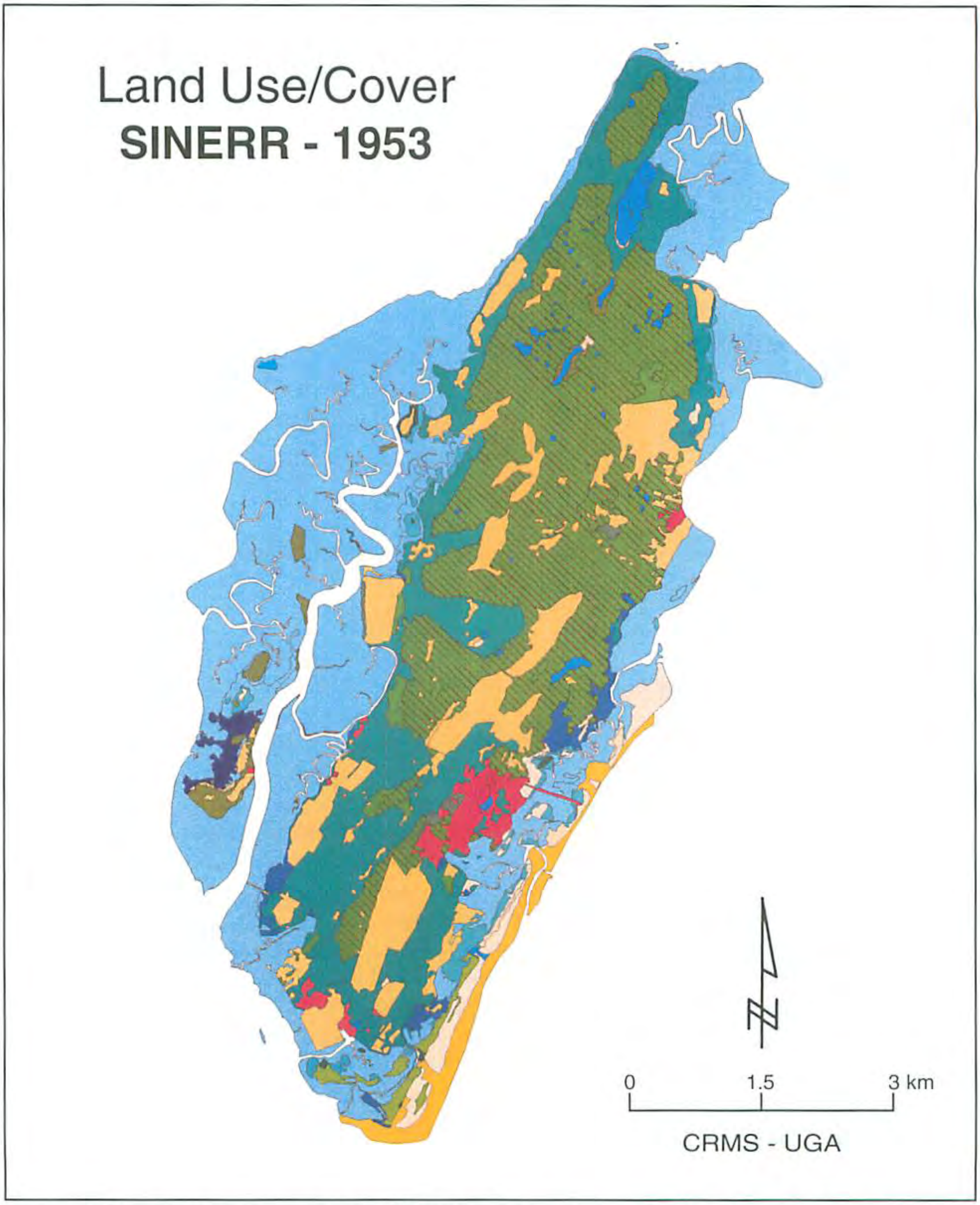


Figure 20b. Land use/cover for the SINERR and Sapelo Island, 1953 based on aerial photographs and generated using the ARC/INFO geographic information system by the Center for Remote Sensing and Mapping Science, Department of Geography, The University of Georgia. See Fig. 20a for legend.

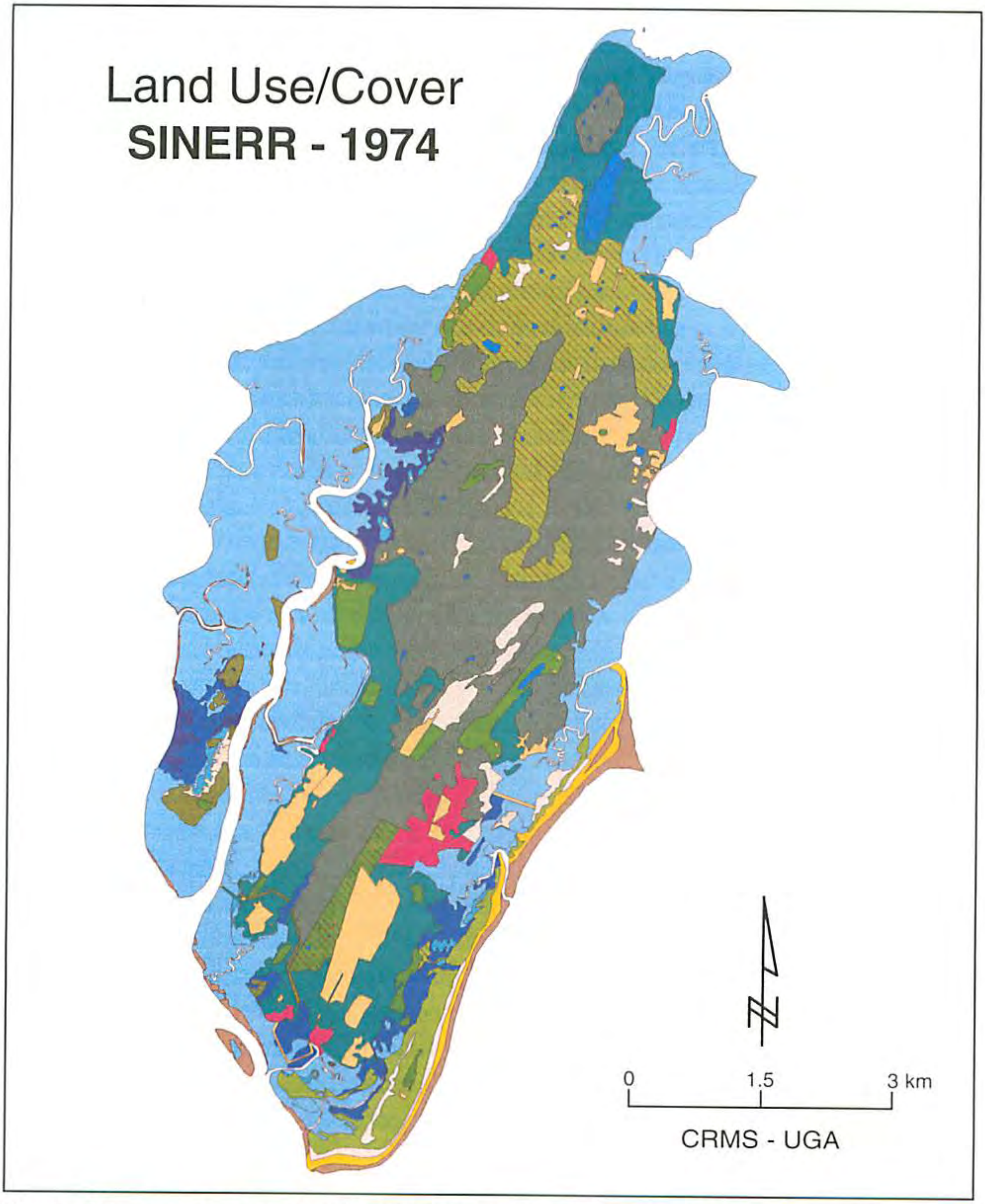


Figure 20c. Land use/cover for the SINERR and Sapelo Island, 1974 based on aerial photographs and generated using the ARC/INFO geographic information system by the Center for Remote Sensing and Mapping Science, Department of Geography, The University of Georgia. See Fig. 20a for legend.

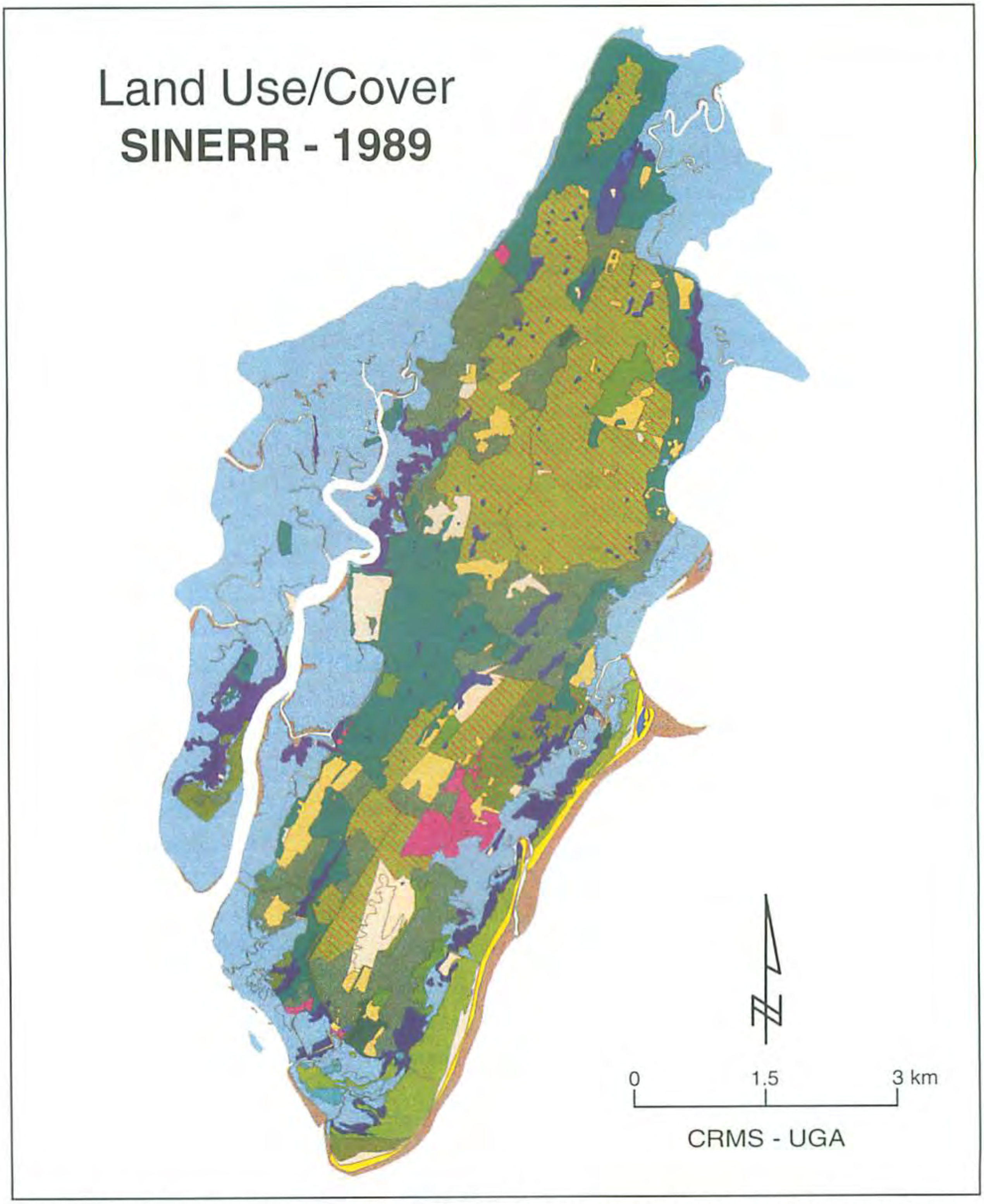


Figure 20d. Land use/cover for the SINERR and Sapelo Island, 1989 based on aerial photographs and generated using the ARC/INFO geographic information system by the Center for Remote Sensing and Mapping Science, Department of Geography, The University of Georgia. See Fig. 20a for legend.

PRIMARY PRODUCTION

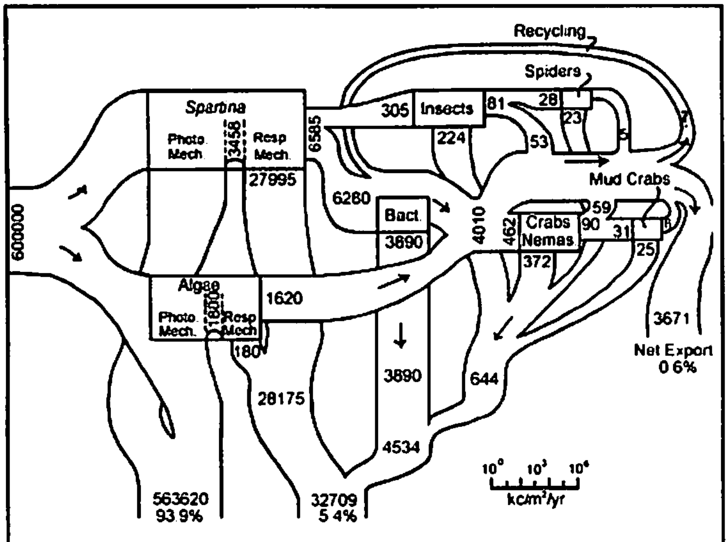
Primary production in the water column and in the marsh have been studied intensively in the SINERR. Annual primary production by phytoplankton in the Duplin River has been estimated to be in the range of 250 - 375 g C/m^2 (Ragotzkie, 1959; Pomeroy and Wiegert, 1981). Rates of photosynthesis in the highly turbid waters of the Duplin River are generally light limited. While standing stocks of nutrients are often low, rapid biological and physicochemical processes maintain a continuous supply of nitrogen and phosphorus large enough for phytoplankton growth (Pomeroy *et al.*, 1972; Haines, 1979a). Whitney *et al.* (Pomeroy and Wiegert, 1981) found that the highest rates of phytoplankton photosynthesis occurred in the water over the marsh on spring high tide.

Benthic and epiphytic algae make a significant contribution to primary productivity in the Duplin River watershed, with net productivity of epibenthic algal assemblages of approximately 190 g C m^{-2} yr^{-1} (Pomeroy and Wiegert, 1981; Whitney and Darley, 1983), nearly 25% of the aerial productivity of *S. alterniflora* (Gallagher *et al.*, 1980). The highest rates of production occur on exposed bare creekbank. Algal biomass and productivity in the marsh is both light and nitrogen limited and heavily grazed by fiddler crabs (Darley *et al.*, 1981; Whitney and Darley, 1983).

The most obvious, and most studied, primary producer in the Duplin River ecosystem is *S. alterniflora*. That research is extensively reviewed in Pomeroy and Wiegert (1981). Early work focused on aerial production, but subsequent research by Gallagher and Plumley (1979) showed that rates of belowground production could equal the aboveground in short *Spartina*, and that although aerial production of tall *Spartina* is 2.5 times that of short, belowground production is roughly the same in both areas, 770 g C m^{-2} yr^{-1}. Net aerial production of *Juncus roemerianus* is intermediate between that of tall and short *Spartina* (Gallagher *et al.*, 1980), but when belowground production is considered, it is nearly as productive as tall *Spartina*. Because it occupies only a small portion of the whole watershed, however, its overall contribution to marsh production is small. Likewise, some of the other minor marsh plant species have high rates of net productivity (Linthurst and Reimold, 1978) but make only a small contribution to the total marsh production.

DECOMPOSITION

Decomposition and utilization of *S. alterniflora* has also been the subject of a great deal of research in the SINERR. Early studies of the marsh found that only 5% of the aboveground biomass was lost each year to grazing insects, and little appeared to be degraded on the marsh surface, although it was not building up on or in the sediments. Standing dead *Spartina* disappeared from the marsh, and some pieces and particles were observed in tidal creeks draining the marsh. Furthermore, Ragotzkie (1959) had found that the aquatic portion of the estuary was heterotrophic during most of the year and had postulated that the aquatic system was subsidized by inputs of organic matter from the marsh.



Energy flow diagram for a Georgia salt marsh (Teal, 1962)

Figure 21. Teal's energy flow diagram of the salt marsh. Numbers are kcal m^{-2} yr^{-1}. (From Teal, 1962.)

Teal (1962) synthesized these data and other information on the energetics and food web of salt marsh organisms into a model of energy flow in a salt marsh ecosystem (Fig. 21) that estimated that roughly half of the net production by *Spartina* is exported from the marsh into adjacent creeks and bays by the tide. This model used calories as a bookkeeping unit, tracking transfers of energy between components of the salt marsh food web, with sunlight furnishing 600,000 kcal m^{-2} yr^{-1}, of which 563,620 kcal m^{-2} yr^{-1} (93.9%) is lost during photosynthesis. Table 2 summarizes the information in Teal's energy-flow diagram.

Table 2. Summary of salt marsh energetics (from Teal, 1962).

	kcal m^{-2} yr^{-1}	
Input as sunlight	600,000	
Loss in photosynthesis	563,620	93.9% of total energy input
Gross production	36,380	6.1% of total energy input
Producer respiration	28,175	77% of gross production
Net production	8,205	
Bacterial respiration	3,890	47% of net production
1° consumer respiration	596	7% of net production
2° consumer respiration	48	0.6% of net production
Total energy dissipation by consumers	4,534	55% of net production
Export	3,671	45% of net production

During the same period of time when Teal was collecting the information that led to his energy flow diagram (Teal, 1962), research was being conducted on microbial decomposition of marsh grass and the importance of the decomposing material (detritus) to estuarine food webs by Burkholder (1956), Burkholder and Bornside (1957) at Sapelo and by Darnell (1961, 1967) elsewhere. Their work together with that of Teal (1962) led to the concept of the detrital food chain in the marsh and estuary which was supported by the 45% of *S. alterniflora* production which was washed out of the marsh by the tide. The prevailing view was that this export of excess marsh production supported extensive "nursery grounds" for a number of commercial and sport fish and shellfish (Setzler, 1977). Several studies were conducted at the Marine Institute on aspects of the detrital food chain, primarily on detritus as a substrate for microbes which are in turn food for detritivores such as mullet (*Mugil cephalus*) (Odum, 1968; Bunker, 1979) and the marsh periwinkle (*Nassarius obsoletus*, now *Ilyanassa obsoleta*) (Wetzel, 1975, 1976; Christian and Wetzel, 1978).

The observations of an extensive detrital foodweb and the excess marsh production were integrated by Odum (1968) into his "outwelling" concept in which he postulated that net primary productivity of marsh-macrophyte dominated estuaries greatly exceeded local degradation and storage of carbon, and that the excess was exported by the tides to the adjacent ocean where it was finally degraded and incorporated into the coastal detrital food web. By the late 1970's, however, the concept of outwelling as well as that of the vast detritus food web was seriously called into question by investigators looking for firm evidence to support those views, which established the importance of intertidal marshes to the entire coastal ecosystem.

Haines (1976b, 1976c, 1977, 1979b) and Haines and Montague (1979) presented evidence based on $^{13}C/^{12}C$ ratios (^{13}C) that while most organisms resident in the marsh were feeding on *Spartina*, *Spartina*-derived detritus and the microorganisms living on the detritus, organisms which reside in the creeks and waterways of the estuary were feeding on microalgae and phytoplankton. Also, in 1980 Nixon (1980) published a paper reviewing the concrete evidence for outwelling and export of organic matter from marshes and estuaries. His conclusion was that although the outwelling concept was consistent with the available evidence, it was based on limited information, and that in fact there were virtually no quantitative data to support it. Likewise, Wiegert (1980) concluded that although like Teal (1962) he and his colleagues could not identify mechanisms for consumption or degradation of more than 55% of the net production of the Duplin River watershed ecosystem, neither could they find evidence that it was being exported from the system. Nevertheless, the question of the fate of the excess marsh production remained.

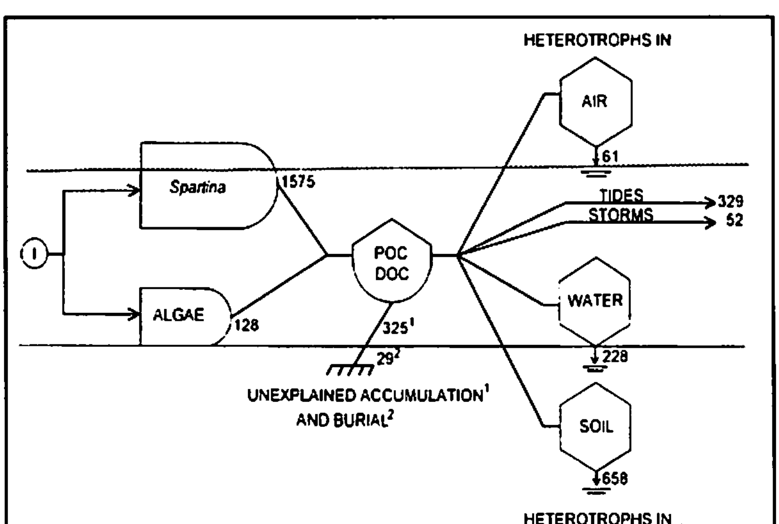


Figure 22. Conceptual model summarizing net carbon balance in a Georgia salt marsh. Numbers are g C $m^{-2} yr^{-1}$ (Data from Chalmers *et al.*, 1985.)

Chalmers *et al.* (1985) looked closely at three possible explanations for the "missing" carbon (Fig. 22). They examined the possibility that **1)** a significant portion of the excess production might be leaving the marsh and estuary as large, floating rafts of wrack, which are often deposited high in the marsh, on the beach or piled up against obstructions such as docks in impressively large quantities; **2)** that seasonal concentrations of DOC and POC in the Duplin River had been underestimated, leading to low estimates of diffusive tidal transport and storm transport (Imberger *et al.*, 1983); **3)** that tidally-mediated fluxes of carbon onto and off of the marsh and storm-driven erosion of carbon from the marsh surface had been underestimated.

They found, however, that the previous estimates of diffusive transport of DOC and POC were too high, so that less carbon was being exported via the Duplin River than previously thought, and that contrary to expectations almost all tidal exchanges within the marsh result in deposition, not export, of carbon (Fig. 22) (Chalmers *et al.*, 1985). Rainfall on the exposed marsh surface was found to subsequently remove most of this deposited carbon, suggesting a mechanism for keeping POC in the thin aerobic surface layer of the marsh where it is most available to detritivores and aerobic microbes (Fig. 23). Finally, they found that although visually impressive, the total standing stock of wrack in the Duplin River system is only a small fraction of the annual production of *S. alterniflora*, and thus its export is a negligible term in the carbon balance equation (Chalmers *et al.*, 1985).

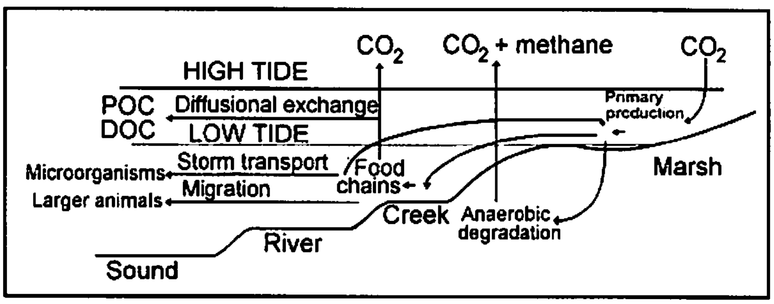


Figure 23. Diagrammatic representation of pathways of carbon relocation within the marsh. (From Chalmers *et al.*, 1985.)

Recent studies by Newell and his colleagues on the decomposition of standing dead *S. alterniflora* and the dynamics of its associated microflora have suggested a whole new means of accounting for the "missing" salt marsh carbon. Their work has necessitated a complete reassessment of most of the decomposition literature, since they clearly demonstrate the artificiality of conditions in classic litterbag experiments in which plant material is often cut or ground into small particles and deposited in bags on the marsh surface and weighed and analyzed at intervals to assess loss of material and conversion of chemical constituents. Unlike trees and many other plants which abscise dead leaves, grasses, including *S. alterniflora*, retain their senescent leaves, which begin to decay in the canopy. Environmental conditions in the canopy are significantly different than those present on the marsh surface, and the decomposer communities are well-adapted to exploit those differences (see Newell (1993b) for an extensive review of *Spartina* decomposition.)

Newell *et al.* (1985, 1989) found high rates of microbial respiration and loss of mass from standing, decaying leaves of *S. alterniflora* that were similar to those for detached litter on the sediment surface (Newell and Fallon, 1989). Also, significant rates of microbial nitrogen fixation can occur within standing, decaying leaves (Newell *et al.*, 1992). The early stages of decomposition of the standing dead or decaying *Spartina* are accomplished by ascomycetous fungi, and fungal mass can compose more than 90% of the microbial standing crop associated with the naturally decaying leaves (Newell, 1992, 1993a, 1994). In addition to the food resource that this fungal mass represents for shredder snails (*Littoraria irrorata*) and other consumers (Bärlocher *et al.*, 1989; Kemp *et al.*, 1990; Newell and Bärlocher, 1993), decomposition of *Spartina* on the marsh surface could go a long way to explaining the difficulty other investigators have had in measuring direct export of *Spartina* detritus. A large portion of the "missing" carbon may be blown off as CO_2 by the microbial community associated with the standing decaying leaves.

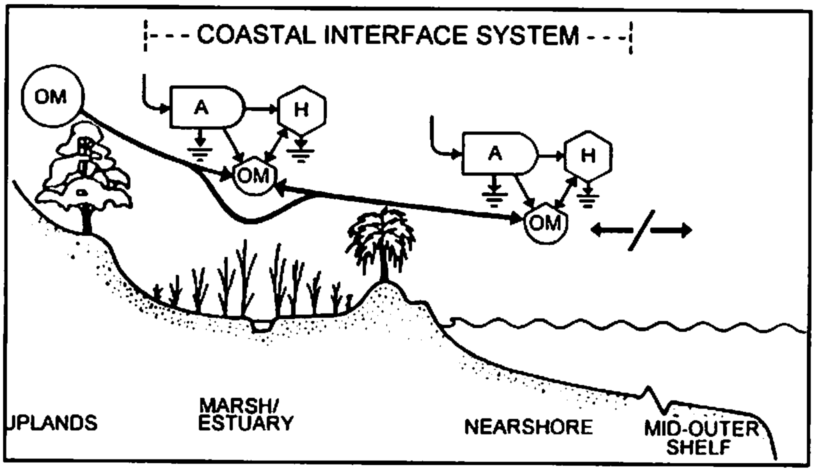


Figure 24. A conceptual model of the coastal interface system. A = autotroph, H = heterotroph, OM = organic matter. (From Hopkinson and Hoffman, 1984.)

Taking another approach to solving the problem, Hopkinson and Hoffman (1984) and Hopkinson (1985) applied the mass balance approach to the entire coastal interface system (Fig. 24). Considering flows between estuarine subsystems, the whole estuarine system, and the nearshore, they concluded that the near-shore system required an input of approximately 210 g C m^{-2} yr^{-1} in addition to local primary production to sustain the high rate of community respiration (Fig. 25). The annual ratio of primary production to community respiration averaged 0.72 in the nearshore region, clearly indicating that the nearshore was dependent on allochthonous carbon inputs from either terrigenous or marsh/estuarine sources, or both.

The question of the fate of the excess organic production of the marsh and the source of the necessary subsidy of the nearshore system remains unanswered. As Smith (1984) and Hopkinson (1989) point out, an ecosystem cannot indefinitely maintain excess net ecosystem production without receiving inputs of nutrients or eventually depleting stored resources. Thus in addition to the question of what happens to the excess production of the marsh/estuary, we must identify the source or sources of new nutrients for the system. Riverine input is the most likely source for our coastal marshes, and evidence of riverine influence on the Duplin River needs to be examined. Also, the potential impact of changes in nutrient loading from riverine watersheds on coastal ecosystems and fisheries needs to be studied.

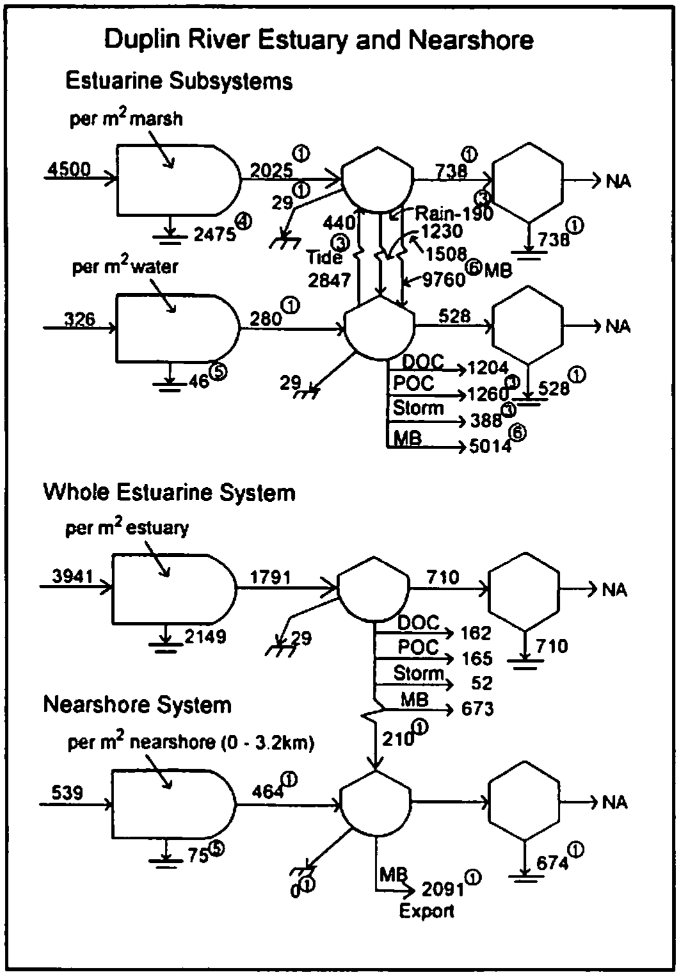


Figure 25. Conceptual models of carbon flow in the Georgia Duplin River estuary and nearshore ecosystems. Estuarine subsystems are the salt marsh proper (top) and adjacent tidal creeks and rivers. The whole estuarine system consists of both salt marsh and tidal creeks and rivers. The nearshore is the area out to 3.2 km from shore. Numbers are g C m^{-2} yr^{-1}.

Notes: **1)** Hopkinson and Hoffman, 1984; **2)** Pomeroy and Wiegert, 1981; **3)** Chalmers *et al.*, 1985; **4)** assuming 55% of gross production; **5)** assuming 14% of gross production; **6)** mass balance; **7)** discontinuous lines portray scalar differences for donor and recipient systems areas. (From Hopkinson, 1988.)

CHEMICAL STUDIES IN THE SINERR
by James J. Alberts

INORGANIC CHEMICALS

Atmospheric Inputs

Chemical studies of atmospheric compounds have been relatively few. A 1975-76 study of rainfall on Sapelo Island showed that average pH of rain was 5.6, which is close to the dissociation constant of carbonic acid, and that dissolved organic nitrogen comprised about 22% of the total dissolved nitrogen in rain (Haines, 1976a). Total nitrogen inputs from rain were calculated to be approximately 0.3 g N/m^2 per annum, which represents a minor source of nitrogen to the salt marshes relative to riverine and nitrogen fixation sources.

Studies of atmospheric sulfur species conducted in 1989-90 showed that dimethylsulphide (DMS) resulting from numerous biological processes in the marsh was the predominant biogenic sulfur species in the atmosphere over Sapelo. However, frequently continental air masses advecting over Sapelo brought high levels of industrially derived sulfur species to the island (Berresheim, 1993).

Major Elements, Trace Metals and Organometallics

Several studies have been conducted of the major element and trace metal contents primarily of sediments and biota in the SINERR. Almost no analyses of the water column or suspended particulate matter exist. Furthermore, the studies which have been conducted are relatively isolated with no overall synthesis or attempts to systematically determine seasonal or long-term trends.

Bulk sediment elemental data have been reported for eleven metals (Al, Cd, Cr, Cu, Fe, Hg, Mn, Mo, Ni, V and Zn) in the SINERR and these values have been compared to the sediments collected at sites that were exposed to higher industrial activity (Alberts *et al.*, 1990). Only Cr, Cu, Hg, V and Zn were higher in the industrial/port sites by a factor of less than ten relative to the SINERR sediments, while all remaining metals had similar concentrations in all sediments. Concentrations of metals in interstitial waters were often below detection limits in the SINERR sediments (Alberts *et al.*, 1987). A sediment core taken in the SINERR and dated by radiochemical techniques indicate that metal fluxes to the SINERR have decreased by a factor of 0.5-0.8 fold over the past few centuries and that Ni is the strongest anthropogenic signal in the core (Alexander and Wenner, 1995). These latter results are opposite to data for the ACE Basin NERR site.

Most elemental analyses of biota are for Spartina alterniflora. However, elemental analyses of the calcareous skeletal material of the intertidal *Crassostrea virginica* and *Balanus eburneus* (Pilkey and Harriss, 1966) and major cation contents of *Sporobolus virginicus* (Gallagher, 1979) have been reported. Comparison of elemental concentrations of *S. alterniflora* from nonpolluted sites within the SINERR and those of more industrialized sites indicate little variation in elemental concentrations, with only Hg showing elevated levels (Newell *et al.*, 1982). The elemental distributions also indicate that *S. alterniflora* apparently does not assimilate Al and Fe, but does take up Cu and Hg and controls the internal concentrations of these elements in its tissues (Alberts *et al.*, 1990). *S. alterniflora* also assimilates inorganic tin through its roots and rhizomes, translocates it to the leaves and methylates the Sn to the trimethyl form (Weber and Alberts, 1990). These studies indicate that *S. alterniflora* apparently has mechanisms that actively control the concentrations of elements in its tissues and that senescence and death lead to loss of these mechanisms and elemental concentrations of the remaining tissue that resemble those of the sediments on which the plants had been growing (Alberts *et al.*, 1995). The studies need to be extended to conclusively demonstrate the nature of these mechanisms so that they may be employed in remediation of impacted marsh sites.

Elemental Redox Cycles

The sediments of the salt marshes in the SINERR are extremely reducing below the relatively thin surface oxidized layer. Although oxidizing conditions can be detected to relatively great depths in the sediments as a result of oxygen diffusion into tunnels and burrows that occurs in the sediments, the oxygen is consumed rapidly and the oxidized layers are measured in thicknesses of millimeters. Due to these highly reducing conditions and the large area of oxidized/reduced chemical interfaces, cycling of easily oxidized/reduced elements among their oxidation states is wide spread.

Iron and Manganese Cycling

Iron and manganese redox cycling in Sapelo Island sediments are closely linked to the redox cycling of sulfur and anaerobic respiration reactions in the sediments. The dynamics of these cycles have been discussed in several papers (Pomeroy and Wiegert, 1981 and papers cited therein; Howarth and Giblin, 1983; Giblin and Howarth, 1984; Howarth and Merkel, 1984; Howarth and Marino, 1984; Fallon, 1987).

Porewaters of these sediments tend to have higher dissolved Fe and Mn concentrations and lower sulfide concentrations at sites with lower pH. Sedimentary solid phases of iron and manganese are sulfide minerals, while dissolved concentrations of Fe(II) and Mn(II) appear to be undersaturated with respect to carbonates, but the importance of phosphates in this environment is unclear (Giblin and Howarth, 1984).

Manganese (II) is effectively oxidized to Mn(IV) in surface sediments of the SINERR as a result of microbial processes with the formation of manganese oxides (Spratt *et al.*, 1994). The rates of this oxidation were shown to be a function of both temperature and pH and were much higher for creek bank sediments than for high marsh sediments (2.31 ± 0.28 and 0.45 ± 0.14 nmol mg dwt^{-1} h^{-1}, respectively). These rates were also higher than values reported in other estuarine and water column studies, and from sediments of a mangrove estuary (Spratt and Hodson, 1994).

ORGANIC MATTER

Occurrence

A significant portion of the naturally occurring organic matter in the SINERR results from the primary production of *S. alterniflora* and macroalgae, and their subsequent decay and decomposition. The process of decomposition leads to two potential types of organic matter, dissolved (DOC) and particulate (POC). The importance of these two forms of organic matter have been studied in great detail in the salt marsh estuaries, as they represent a substantial source of energy to the biotic community (Pomeroy and Wiegert, 1981). The biological processes affecting the decomposition and transformation of macrophytes to these available organic pools are discussed in this report. Below, we will summarize the chemical alterations that occur during these processes and some of the ramifications of those changes to the ecosystem.

Plants and POC

At first approximation, the formation of particulate organic matter in the estuary was thought to be primarily the decomposition of *S. alterniflora* (Odum and de la Cruz, 1967). However subsequent studies of the $^{13}C/^{12}C$ ratios of seston, sediments and biota of the salt marshes have demonstrated that it is a complex process in which microflora appear to be the primary herbivores of plants (Haines, 1976b,c; 1977; Haines and Hanson, 1979; Haines and Montague, 1979; Sherr, 1982).

The reasons that *S. alterniflora* is not heavily grazed by macroinvertebrates are not clear, though it has been demonstrated that for one major consumer, the periwinkle snail *Littoraria irrorata* (Say), the high phenolic and low protein content of standing plants relative to dead plants may be the reason for the snails preference for the latter (Bärlocher and Newell, 1994). While further studies are needed to determine if other chemical deterrents in the leaves of aboveground *S. alterniflora* plants are responsible for the lack of grazing, studies to date have shown that cellulose, hemicellulose and lignin constitute a significant fraction of the plant biomass (>75%) and that these components are lost at varying rates with time of decomposition (Benner *et al.*, 1987).

Polysaccharides

The carbohydrate signature of standing, undecayed plants has been determined (Wicks *et al.*, 1991) along with those of standing dead plants and some of the major plant components (Alberts *et al.*, 1992). In addition, carbohydrates and proteins in the roots and rhizomes have been shown to cycle with season in the marsh with sugar and starch contents of the roots being relatively low compared to rhizomes throughout the year (Gallagher *et al.*, 1984).

As much as 60% of the primary production of the *S. alterniflora* is lost while the plants are standing in the marsh (Newell and Fallon, 1989; Newell *et al.*, 1989). Only a small fraction of the *S. alterniflora* biomass appears to be lost through leaching into surrounding waters, but this material is efficiently assimilated into microbial biomass (Gallagher *et al.*, 1976). Similarly, carbohydrates are lost from the plants to the surrounding environment (Pakulski, 1986) and free amino acids appear to be released from marine zooplankton and invertebrates (Johannes and Webb, 1965, 1970; Webb and Johannes, 1967). While the potential exists for the uptake of these materials by salt marsh organisms (Darley *et al.*, 1979), the importance of these additions of organic matter to the estuarine foodweb is still poorly defined (Johannes *et al.*, 1969).

LIGNIN

Approximately 75% of the total biomass of *S. alterniflora* is lignocellulose (Maccubbin and Hodson, 1980). Using marsh sediment microflora and ^{14}C-radiolabelled substrates of both ^{14}C-(cellulose)- and ^{14}C-(lignin)- lignocellulose, it was shown that the cellulosic moiety of the labeled lignocellulose initially is decomposed approximately 3 times faster than the lignetic moiety (Hodson *et al.*, 1984). Furthermore, those authors demonstrated that the rates of decomposition of both moieties were not linear with time, but rather were best fit with an exponentially decreasing rate curve with no fixed "half-life". The apparent cause of this decrease in decomposition rate was the increased refractory nature of the remaining lignocellulose, as more easily attacked components of the biopolymer were decomposed first.

After 576 hr. of incubation under oxic conditions, 30% of the polysaccharide component and between 12 - 18% of the lignetic component of *S. alterniflora* lignocellulose was mineralized by salt marsh sedimentary microflora (Benner *et al.*, 1984a). Under anaerobic conditions, the same consortium of salt marsh sedimentary microflora degraded 30% of the polysaccharide component and 16.9% of the lignin component of *S. alterniflora* lignocellulose in 246 days (Benner *et al.*, 1984b). This biodegradation of lignocellulose under anaerobic conditions was further demonstrated in litterbags, over an 18 month period, with a loss of 55% of the organic carbon in belowground tissue biomass and a significant alteration of the phenolic moieties of lignin (Benner *et al.*, 1991). While the rates of decomposition are much slower in the anaerobic system, the demonstration of anaerobic biodegradation of lignocellulose, has important implications for the cycling of carbon from these biopolymers in the biosphere.

The biodegradation of the cellulosic and lignetic components of lignocellulose are also affected by pH and temperature. Over a pH range of 4-8 the biodegradation of the lignetic component of lignocellulose is only minimally affected, while the biodegradation of the cellulosic component is increased several fold with increasing pH (Benner *et al.*, 1985). Rates of mineralization of lignocellulose from *S. alterniflora* in salt marsh sediments increased eightfold between winter and summer. Therefore, under the hydrologic conditions of Sapelo Island (high rates of water movement due to flushing by semidiurnal tides), the temporal lag between deposition of plant material in the fall and winter and microbial degradation the following spring and summer is a potential mechanism for substantial advective redistribution of lignocellulosic detritus away from sites of production (Benner *et al.*, 1986a). However, the lignin phenolic structure of organic matter from estuarine sediments near Sapelo Island, while containing vascular plant material, indicate that *S. alterniflora* may not be its primary source (Whelan *et al.*, 1986).

Bacteria are the predominant decomposers of lignocellulosic carbon in the salt marsh sediments, with little biodegradation of these biopolymers by the fungal consortium present (Benner *et al.*, 1984c; Benner *et al.*, 1986b). However, *S. alterniflora* plants undergo a significant period of senescence during which the leaves of the plants remain standing upright in the marsh. During this period, significant loss of organic matter and lignin occurs in the plants (Newell and Fallon, 1989; Newell *et al.*, 1989). Up to 25% of the total lignin mass loss of tagged standing plants occurred in 146 days, with >90% of that occurring early in the degradation history (Haddad *et al.*, 1992). Using radiolabelled lignocellulose from *S. alterniflora*, 3.3% of the lignin moiety was mineralized and 22% of the polysaccharides were mineralized in 45 days by the ascomycete *Phaeosphaeria spartinicola* (Bergbauer and Newell, 1992). Transmission electron microscopy studies have shown that the fungi *P. spartinicola* caused both thinning of the lignocellulosic-rich secondary walls of fiber cells from cell lumina outwards, and digestion extending from hyphae within longitudinal cavities in the secondary wall types. Three other fungal species were also shown to cause either one or the other type of soft rot (Newell *et al.*, 1996). Thus, considerable evidence exists to demonstrate two distinctive mechanisms of biodegradation of the lignocellulosic biopolymers which are promulgated by different microbial consortia and occur at different spatial and temporal points in the plant's life history.

During microbial degradation of lignocellulose, soluble decomposition products are released into the environment. Bergbauer and Newell (1992) report 2.7% of the lignin moiety and 4% of the polysaccharide component of their radiolabelled lignocellulose to be released as dissolved organic carbon (DOC) by the ascomycete *P. spartinicola*, and lignocellulose-derived DOC was produced in laboratory microcosm experiments at rates of 0.7 - 1.0% of the particulate lignocellulose per day (Moran and Hodson, 1989). While much of this dissolved material is mineralized by microbes, the more recalcitrant compounds may play a role in formation of humic substances. In 6 month decomposition studies, DOC accounted for 50 - 60% of the total degradation products of the lignetic component of lignocellulose, while it only accounted for 20 - 30% of the cellulosic products (Moran and Hodson, 1990). However, 34% of the DOC accumulating during the degradation of *S. alterniflora* from southeastern coastal wetlands is humic matter by definition, with lignin being the primary source of 66% of the total dissolved humic substances (Moran and Hodson, 1994). Thus, vascular plants appear to be contributing yet another highly recalcitrant organic pool to the salt marsh environment.

HUMIC SUBSTANCES

Occurrence

In riverine systems of the southeastern United States, the dissolved organic matter is dominated by naturally occurring mixtures of organic compounds that are derived from plants. These mixtures are called humic substances and have been extensively studied for many years both for their contribution to the cycling of essential nutrients, and their ability to interact with numerous potentially toxic organic and inorganic chemicals (Schnitzer and Khan, 1972; Gjessing, 1976; Aiken *et al.*, 1985). Humic substances also occur in the sediments and plants of the marshes. Base extractions of the *S. alterniflora* plants, both living and standing dead, and the sediments underlying these plants have yielded 0.56, 1.09 and 2.17 g dry wt of humic substances/100 g dry wt of source material, respectively (Filip *et al.*, 1988).

Living and dead plant material obtained from the SINERR, when exposed to long-term (10 month) incubations in the presence of sterile seawater, or fungi, bacteria or mixed cultures of organisms indigenous to the SINERR, released humic substances into the seawater under both biotic and abiotic conditions (Filip and Alberts, 1988). While the amount of humic matter released from abiotic control experiments was low relative to the amount of humic matter found in the plant material prior to treatment, both mixed culture treatments and particularly a culture of epiphytic organisms were able to release significant amounts of the plant humic matter (41.1% and 22.0% of the living and dead plant material, respectively, in the case of the epiphytes). In addition to the release of humic material from plant material, both epiphytic organisms and fungi were capable of humifying living and dead plant material as well as plant extracts (Filip and Alberts, 1993; Alberts and Filip, 1994), which may account for some of the 34% of the dissolved organic matter released from degrading salt marsh grass that were isolated as humic matter (Moran and Hodson, 1994).

Utilization

Salt marsh related microflora are also capable of utilizing humic substances under aerobic and semi-anaerobic conditions, both as the sole sources of C and N and as supplemental sources of nutrients (Filip and Alberts, 1994). The average utilization of humic acids under aerobic and semi-anaerobic conditions followed the order of humic acids from dead *S. alterniflora* < humic acids from sediments < humic acids from fresh *S. alterniflora*. These authors go on to demonstrate that the chemical alterations of the humic substances observed during these incubations were consistent with the processes of sedimentary diagenetic alteration observed in the literature (Alberts and Filip, 1994). Moran and Hodson (1994) found that 24% of the salt-marsh derived humic substances were utilized by marine bacteria in a 7-week period, which was a significantly faster turnover rate than previously noted for humic materials from freshwater environments. Both groups of authors attribute the more rapid turnover of "newer" humic matter to the presence of labile components which have been decomposed from "older" material.

Chemical Characterization

Fulvic and humic acids isolated from living and dead *S. alterniflora* and the surficial sediments underlying them (Alberts *et al.*, 1988) have been studied by numerous spectrochemical and wet chemical techniques. Summarization of those studies are beyond the scope of this text, but may be found in the literature cited below:

Spectrochemical Characteristics

1. Ultraviolet-Visible Spectroscopy: Alberts *et al.*, 1988; Alberts *et al.*, 1992;
2. Fluorescence Spectroscopy: Alberts *et al.*, 1988;
3. Fourier Transform Infrared Spectroscopy (FTIR): Filip *et al.*, 1988; Filip and Alberts, 1988, 1989, 1994;
4. Carbon-13 Nuclear Magnetic Resonance Spectroscopy (^{13}C-NMR): Alberts *et al.*, 1991; Filip *et al.*, 1988; Filip *et al.*, 1991;
5. Electron Paramagnetic Resonance Spectroscopy (EPR): Filip *et al.*, 1988; Cheshire *et al.*, 1977.

Chemical Characteristics

1. Elemental Analyses: Filip and Alberts, 1988, 1989; Alberts *et al.*, 1989;
2. Elemental Atomic Ratios: Filip and Alberts, 1988, 1989; Alberts *et al.*, 1992;

3. Lignin, Carbohydrate and Amino Acid Contents: Alberts *et al.*, 1992.

CHEMICAL REACTIONS

Inorganic Reactions

Humic substances are known to strongly bind with Cu^{2+} (Stevenson, 1982; Alberts and Geisy, 1983; Rashid, 1985). The humic and fulvic acids isolated from the plants and sediments of the salt marshes have copper binding capacities (CuBC as g atm Cu^{2+} mg^{-1} humic matter) ranging from 0.12 to 0.27 and 0.06 to 0.23, respectively.

The CuBC values for the salt marsh humic substances do not follow any trend respective to condition of source material, fulvic versus humic acid, nor to total acidities of the humic substances. This latter point is consistent with EPR studies indicating the presence of Cu^{2+}-porphyrin complexing in humic acids from living plants (Filip *et al.*, 1988), as well as several other EPR studies that indicate that copper may be bound to nitrogen-containing structures in the humic substances.

This latter hypothesis is given some support by the positive relationship demonstrated between CuBC and N:C ratio of the salt marsh humic substances (Alberts *et al.*, 1989) and the fact that solvent extraction of the source materials to remove pigments and lipids before extraction of the humic substances does not change the CuBC of either the humic or fulvic acids (Alberts and Filip, 1989).

Organic Reactions

Besides oxygen and nitrogen containing functional groups that can interact with inorganic elements, humic substances are relatively large molecules which contain considerable aliphatic and aromatic organic carbon groups. These groups can interact with other organic molecules, particularly hydrophobic compounds such as polycyclic aromatic hydrocarbons (PAH), through electrostatic or van der Waals interactions to form organic-organic complexes.

The binding constant (K_{oc}) of three PAH compounds was determined with estuarine sedimentary fulvic and humic acids (Alberts *et al.*, 1994). All three PAH compounds bind very strongly to all the humic substances. The K_{oc} values are in general agreement with data for organic colloids from other estuaries (Wijayaratne and Means, 1984a, 1984b). The log K_{oc} values of the fulvic acids are lower than those of the humic acids, which is consistent with the fact that fulvic acids tend to be smaller more soluble molecules and therefore, would be expected to have smaller hydrophobic surfaces available for binding with other hydrophobic organic molecules.

Flux Calculations

It has been estimated that the standing crop of *S. alterniflora* in the Georgia salt marshes represent 65.5 g C m^{-2} yr^{-1} as fulvic acids and 14.5 g C m^{-2} yr^{-1} as humic acids (Alberts *et al.*, 1988). The values are 216% and 56%, respectively, of the amount C that is sedimented as humic substances in the surficial marsh sediments per annum. Since there is approximately 373,400 m^2 of salt marsh in Georgia (Alexander *et al.*, 1986), it is possible to estimate the annual production and sedimentation of carbon and nitrogen in Georgia's salt marshes.

From our earlier flux estimates of carbon and nitrogen as humic substances entering the estuaries from riverine transport, we can calculate that 13.5% and 7% of the humic substance carbon and nitrogen produced by plants is brought to the estuaries by river flow. Summing these to the plant production and comparing to the sedimentation of these elements as humic and fulvic acids, we estimate that 54.5 thousand tons of carbon, or 39% of the annual input of humic substance carbon, can not be accounted for by sedimentation. Since we know that fulvic acids are produced in the *S. alterniflora* plants in a 200% excess, it is reasonable that the excess carbon produced is either respired by organisms in the marsh or lost to the ocean in the form of soluble fulvic acids.

It is estimated that marshes provide 55% of the terrestrially derived DOC and 38% of the humic carbon input into the coastal ocean of the southeastern U.S. (Moran and Hodson, 1994). However, there is a net 18% deficiency of nitrogen that is sedimented relative to estimated annual inputs. Thus, it seems unlikely that the 54.5 thousand tons of carbon has been exported as fulvic acids, but rather a significant portion of this material must be lost from the system by respiration.

MISCELLANEOUS ANTHROPOGENIC CHEMICALS

Sewage Sludge, Dredge Spoil and Pulp Mill Effluents

Application of sewage sludge to short form *S. alterniflora* plots resulted in a 1/3 to 1/2 increase in plant biomass relative to controls, with little effect on dead biomass, stem density or propagation of new shoots (Haines, 1979c). Furthermore, after 20 months, approximately half of the sludge nitrogen remained in the sediments. It was later shown that sewage sludge had an inhibitory effect on salt marsh denitrifying bacteria (Sherr and Payne, 1981).

An assay technique for the uptake and translocation of contaminants from dredge spoil material to marsh plants showed that neither chlorinated pesticides nor polychlorinated biphenyls appeared to be taken up or translocated by *Distichlis spicata*, *Salicornia virginica*, *S. alterniflora*, or *S. patens*. Although, some problems with experimental conditions may have influenced the results. However, in the case of dredge material with high heavy metal contents, the authors found, "The uptake and translocation question in the heavy metal case tested became inconsequential because all of the plant species that were planted have now died." (Gallagher and Wolf, 1980).

Heterotrophic microbial activity is extremely sensitive to and inhibited by Kraft mill effluents. This finding indicates that detritus based, microbial foodwebs are potentially at higher risk from these materials than the foodwebs whose organic carbon inputs are controlled by photosynthetic processes (Maccubbin *et al.*, 1983).

Pesticides, Herbicides and Polycyclic Aromatic Hydrocarbons

The pesticide toxaphene was shown to be absorbed from anaerobic salt marsh soils through below-ground plant tissue and translocated in both directions from the point of uptake (Gallagher *et al.*, 1979). Highest concentrations of the toxaphene were located in the below-ground plant tissues. In another study (Gallagher and Wolf, 1980), toxaphene injected into marsh sediments were accumulated and translocated by *S. alterniflora* plants to above-ground tissue. Following cessation of the injections, concentrations of toxaphene in living above-ground plant tissue decreased from 43 to 7 ppm, but dead plant material increased to 110 ppm. The dead plant material began to lose toxaphene, perhaps through dilution with newer, less contaminated material and decay and fragmentation, until toxaphene was undetectable after 7 months.

Concern that the increased use of organic arsenical herbicides such as monosodium methanearsonate (MSMA) in the 1970's might eventually impact the salt marsh ecosystem led to several field experiments to test the hypothesis. Applications of MSMA in levels significantly above those expected from tidal flooding led to no measurable detrimental effects and only direct foliar application in massive amounts (90,000 ppm or 30 applications of 10,000 ppm) led to significant damage (Edwards and Davis, 1974; 1975).

The potentially carcinogenic and mutagenic polycyclic aromatic hydrocarbons (PAH) are hydrophobic, naturally occurring organic compounds that are found widely in the environment. Studies have shown that PAH compounds bind strongly to naturally occurring humic and fulvic acids which are found in the SINERR (Alberts *et al.*, 1989; 1994); thus making them either more or less available to estuarine organisms. One of these compounds, benzo(a)pyrene, is a known cancer agent and has been shown to dissolve in the dietary fat of the killifish, *Fundulus heteroclitus* (Vetter *et al.*, 1985). The latter study indicates that this association may be a partial explanation of the observed link between high fat diets and some cancers.

RESEARCH NEEDS

A large majority of the chemical research conducted in the SINERR has involved the production, decomposition, transport and chemical reactions of naturally occurring organic matter. These studies were the natural outgrowth of a major focus of research at the Marine Institute, which is the understanding of the processes controlling foodwebs and energy flow of the salt marsh. While considerable work has been undertaken in this area, further studies involving organic matter in this environment are still required:

What is the fate of DOC generated from particle decomposition?

What are the physical and chemical reactions that newly formed DOC undergo?

How does organic matter react with anthropogenic organic and inorganic compounds and do these reactions increase or decrease the bioavailability and toxicity of the materials?

What types of natural products are produced in the salt marsh and do they act as stimulants or deterrents to plant/animal interactions?

While the natural organic matter of the system has been studied, though hardly exhaustively, the studies of inorganic chemicals are even less advanced. Basic biological and geochemical questions still exists such as:

What are the elemental and trace metal distributions in various biota and how do they change temporally and spatially?

What mechanisms are active in biota to control the uptake and toxicity of inorganic elements?

What are the atmospheric exchanges in the marsh, both as gaseous losses and elemental sources?

What are the distributions of and geochemical process affecting inorganic elements in water and sediment?

Are inorganic elemental inputs to the marsh increasing, decreasing or remaining unchanged over time scales representative of man's activities on land?

The research activities in the SINERR have been dominated by biological and geological studies. There is a definite need for numerous chemical studies to supplement the knowledge already gained and to advance our understanding of the chemical mechanisms which are important.

Research and Monitoring Goals

RESEARCH

SINERR personnel, in consultation with the SINERR advisory committee, have identified several goals for research and management in the Reserve. They include:

1. Assess the cultural resources with the SINERR, including sites of archaeological interest and of historic significance, with the objective of documenting and protecting them.

2. Increase knowledge and understanding of the basic processes involving water movement, water mixing, and natural variation in water parameters within the SINERR. objectives include measuring the relative contributions of upland and groundwater runoff, freshwater exchanges with mainland rivers and the ocean; estimating effects of climate change on hydrological processes; determining the effects of manmade and natural disturbances.

3. Increase knowledge and understanding of sediment transport and transformation in the SINERR, including current and historical trends in accretion and erosion and the effects of human activities and management practices on these processes.

4. Increase knowledge and understanding of the natural variability of nutrient and other chemical inputs into the salt marsh, including the effects of watershed management practices on nutrient flows, and the effects of nonpoint source inputs of nutrients, metals, organics, bacteria and biochemical oxygen demand on water and sediment quality.

5. Improve knowledge and understanding of the life cycles of important species which depend upon salt marsh estuaries, and quantify the importance of the salt marsh and adjacent upland areas. Objectives include determining the importance of the marsh to estuarine and coastal fisheries through direct food-web and habitat interactions, biotic resources and dynamics of fisheries and recruitment in the SINERR, the extent of coupling between primary and secondary production and the effect of abiotic processes on that coupling, and the effects of upland management practices and other human activities on marine and non-marine wildlife species in the upland/marine transitional zone.

6. Evaluate the effects of management decisions on the health and stability of the SINERR's ecosystem, including the effects of forest management and vessel traffic in the Duplin River.

7. Establish a comprehensive database of baseline and research data which allows rapid, user-friendly access to research and monitoring information gathered within the SINERR. Establish a database for archaeological findings.

MONITORING

One function of the NERR system is to provide benchmark information on estuarine ecosystems to researchers, coastal communities and ecosystem managers. The monitoring program in the SINERR is designed to provide that information. Its mission is to improve the ability of resource managers to detect, quantify and predict both short- and long-term changes in the health and viability of estuarine ecosystems. Trend monitoring of hydrological and meteorological parameters is conducted in the SINERR by the University of Georgia Marine Institute under contract to DNR, continuing a program begun by UGMI in 1986. As discussed earlier in this profile, data are collected at three sites within the Duplin River watershed. Summary reports are published quarterly; data is available on request to UGMI.

DNR's Environmental Protection Division (EPD) monitored a number of water column, sediment and tissue accumulation parameters in the Duplin River estuary from 1985 through 1994. The parameters measured included dissolved oxygen, pH, conductance, chlorophyll, 5-day biological oxygen demand, coliform bacteria concentrations, water color and alkalinity, nitrogen, phosphorus, organic compounds and metals. They hope to reimplement the program in the near future. DNR's Coastal Resources Division has monitored several of these same parameters at monthly intervals at seven locations in the Duplin River since 1984. In addition, NOAA has established a mussel-watch station near the mouth of the Duplin River, analyzing tissue samples from oysters for a wide variety of contaminants.

The Future of SINERR: Management Questions and Research Needs

Throughout this document we have pointed out research needs and questions that remain unresolved. In addition to those we have identified, there are many other important and useful research projects that investigators can and will formulate. These may be related to questions of basic research which have no obvious immediate application to management issues, but as we have seen in the past, issues and needs change and hypotheses and paradigms that seem to explain the observations we make are not necessarily correct. Thus just because a subject has received attention in the past or does not seem pertinent to today's problems should not exclude it from eligibility for funding and support.

Beyond the research questions identified in the previous sections, there are major issues facing managers of Sapelo Island and the Research Reserve which need to be addressed. A high priority must be to objectively and scientifically determine the carrying capacity of Sapelo Island. There are factors to be considered beyond the most obvious ones, because of the logistics involved in transporting people and materials to and from the island. In addition to questions of how many vehicles the Marsh Landing parking area can accommodate and how the increasingly cramped parking situation can be resolved without sacrificing the integrity of the marshes near the dock, we must determine how many people and how much freight can reasonably be carried by the ferry. The often competing interests of island residents and visitors, who bring welcome revenue to small businesses on the island, must be balanced. In the push to accommodate the general public, the legitimate requirements of island residents should not be ignored.

The question of waste disposal is a critical one. It may be possible to decrease, or at least minimize, the expense of barging solid waste off the island by engaging in some form of recycling, composting or compaction of the garbage before it is loaded onto the barge. In addition to solid wastes, the question of capacity of the island's soils to absorb septic effluents must be examined. In areas where septic tanks are concentrated, is there evidence of effects of increased nutrient loading to the marshes? What are the alternatives to septic tanks for this environment?

What are the effects of increased boat traffic in the Duplin River and its associated tidal creeks? Should there be limits on traffic to control noise or wake?

The island has recently seen the introduction by some means of at least 2 species of animal not found here in the recent past, the armadillo and feral pigs. Both create substantial disturbance of the ground as they root for food, and the habitat destruction by feral pigs is well known. At least in the case of the pigs, DNR is making an effort to limit the population. Should eradication of these animals be advocated and pursued? What should be done about invasions of exotic plant species not already established on Sapelo, such as the Chinese tallow tree? Should efforts be made to eradicate them or to control their distribution?

Although it is a sensitive issue that has been raised several times already, the use of management practices like controlled burning and timber harvesting within the SINERR should not be ignored. The effects of those practices on adjacent marshes of the SINERR has never been studied. Detection of effects is probably not possible within the time-frame of the usual one to three year funding cycle that most research programs support, and could be taken on as an aspect of the monitoring program of the Reserve scientific staff. Atmospheric inputs during burn cycles, direct runoff to the marshes and groundwater seepage are the most likely pathways that should be evaluated, although populations of infauna and vegetation near the upland transition zone should not be neglected.

Finally, what are the long-term prospects for the integrity of the water supply for Sapelo Island? Already some Georgia coastal areas are experiencing problems with intrusion of salt water into groundwater wells.

The increasing numbers of visitors to Sapelo put additional demands on all of the natural resources and the infrastructure of the island. The question of how many of these demands can be met without destroying the very resource that makes the island increasingly attractive to visitors is not unique to the Sapelo Island National Estuarine Research Reserve, and is not an easily answered one, but it is one that should be seriously addressed with the best available information and not just the opinions and desires of policymakers, residents and visitors. The commitment of all parties to formulating an integrated management plan for the entire island is a promising beginning.

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Appendix 1. Vegetation of Sapelo Island[1]

PTERIDOPHYTA

OSMUNDACEAE		
Osmunda cinnamomea L.	Cinnamon fern	C[2]
Osmunda regalis L. var. *spectabilis* (Willd.) Gray	Royal fern	I
POLYPODIACEAE		
Polypodium polypodioides (L.) Watt.	Resurrection fern	C
DENNSTAEDTACEAE		
Pteridium aquilinum (L.) Kuhn var. *pseudocaudatum*	Bracken fern	C
ASPLENIACEAE		
Asplenium platyneuron (L.) Oakes ex. D.C. Eaton	Spleenwort	C
Thelypteris kunthii (Deav.) Morton	Southern shield fern	I
Thelypteris palustris Schott var. *haleana* Fern.	Marsh fern	I
BLECHNACEAE		
Woodwardia areolata (L.) Moore	Netted chain fern	C
Woodwardia virginica (L.) J. Sm.	Virginia chain fern	R
SALVINIACEAE		
Salvinia minima Baker	Salvinia	R
AZOLLACEAE		
Azolla caroliniana Willd.	Mosquito fern	R

SPERMATOPHYTA

PINACEAE		
Pinus elliottii Engelm.	Slash pine	TC
Pinus palustris Mill.	Longleaf pine	TC
Pinus serotina Dougl.	Pond pine	TC
Pinus taeda L.	Loblolly pine	TC
TAXODIACEAE		
Taxodium ascendens Brongn.	Pond cypress	TI
CUPRESSACEAE		
Juniperus silicicola (Small) Bailey	Southern red cedar	TC
TYPHACEAE		
Typha domingensis Pers.	Southern cattail	C
POTAMOGETONACEAE		
Potamogeton nodosus Poir.	Pondweed	R
P. illinoensis Morong.	Pondweed/fishweed	R
Ruppia maritima L.	Widgeon grass	I
NAJADACEAE		
Najas guadalupensis (Spreng.) Magnus	Southern naiad	I
SCHEUCHZERIACEAE		
Triglochin striata R. & P.	Arrow-grass	R
ALISMATACEAE		
Sagittaria graminea Michx. var. *chapmanii* J. G. Sm.	Narrow-leaved Sagittaria	I
S. lancifolia L.	Lance-leaved Sagittaria	I
S. subulata (L.) Buch.		I
HYDROCHARITACEAE		
Vallisneria americana Michx.	American wild celery	R
Limnobium spongia (Bosc) Steud.	Frog's bit	R

POACEAE

Tripsacum dactyloides (L.) L.	Gamma grass	R
Erianthus coarctatus Fern.	Plume grass	I
E. giganteus (Walt.) Muhl.	Giant plume grass	C
Coelorachis rugosa (Nutt.) Nash		R
Andropogon glomeratus (Walt.) B.S.P.	Bushy broomsedge	C
A. longiberbis Hack.	Sand broomsedge	I
A. ternarius Michx.	Splitbeard	C
A. virginicus L. var. *virginicus*	Virginia Broomsedge	C
A. virginicus L. var. *glaucopsis* (Ell.) Hitchc.	Virginia Broomsedge	I
Schizachyrium stoloniferum Nash	Bluestem	I
Sorghastrum elliottii (Mohr) Nash	Elliot's woodgrass	C
S. secundum (Ell.) Nash	Indian grass	I
Sorghum halepense (L.) Pers.	Johnson grass	C
Paspalum boscianum Flugge	Bullgrass	I
P. difforme LeConte		I
P. dilatatum Poir.	Dallis grass	C
P. dissectum (L.) L.	Bullgrass	I
P. distichum L.	Knotgrass	C
P. floridanum Michx. var. *floridanum*	Tall Paspalum	I
P. giganteum Baldw. ex Vasey		I
P. laeve Hichx. var. *laeve*	Field paspalum	I
P. laeve Michx. var. *pilosum* Schribn.		R
P. notatum Flugge var. *saurae* Parodi	Bahia grass	C
P. praecox Walt.		I
P. setaceum Michx. var. *ciliatifolium* (Michx.) Vasey	Fringe-leaved paspalum	C
P. setaceum Michx. var. *longipedunculatum* (LeConte) Wood		I
P. setaceum Michx. var. *supinum* (Bosc ex Poir.) Fern.		I
P. urvillei Steud.	Vasey grass	C
P. vaginatum Sw.	Seashore paspalum	C
Axonopus affinis Chase	Common carpet grass	C
A. furcatus (Flugge) Hitchc.	Big carpet grass	C
Eriochloa michauxii (Poir.) Hitchc.	Longleaf cup grass	R
Panicum amarum Ell. var. *amarum*	Seaside panicum	I
P. dichotomiflorum Michx.	Fall panic grass	I
P. rhizomatum Hitchc. & Chase	Flat-stemmed panic grass	C
P. rigidulum Bosc. ex Nees		C
P. verrucosum Muhl.	Warty panic grass	C
P. virgatum L. var. *virgatum*	Switchgrass	C
Dichanthelium aciculare (Desv. ex Poir.) Gould & Clark		C
D. acuminatum (Sw.) Gould & Clark var. *acuminatum*	Wooly panic grass	C
D. acuminatum (Sw.) Gould & Clark var. *implicatum* (Schribn.) Gould & Clark		R
D. commutatum (Schult.) Gould		C
D. consanguineum (Kunth) Gould & Clark		I
D. dichotomum (L.) Gould var. *ensifolium* (Bald. ex Ell.) Gould & Clark		C
D. laxiflorum (Lam.) Gould		C
D. leucoblepharis (Trin.) Gould & Clark var. *leucoblepharis*		I
D. oligosanthes (Schult.) Gould var. *oligosanthes*		C
D. ovale (Ell.) Gould & Clark var. *ovale*		I
D. sabulorum (Lam.) Gould & Clark var. *patulum* (Scribn. & Merr.) Gould & Clark		C
D. sabulorum (Lam.) Gould & Clark var. *thinium* (Hitchc. & Chase) Gould & Clark		

D. scabriusculum (Ell.) Gould & Clark		C
D. scoparium (Lam.) Gould	Velvet panic grass	I
Sacciolepis striata (L.) Nash	Baggy knees	C
Echinochloa walteri (Pursh) Heller	Salt marsh millet	C
Digitaria sanguinalis (L.) Scop.	Hairy crab grass	C
D. serotina (Walt.) Michx.	Blanket crab grass	I
D. villosa (Walt.) Pers.		C
Oplismenus hirtellus (L.) Beauv. ssp. *setarius* (Lam.) Mez ex Ekman	Woodgrass	R
Setaria corrugata (Ell.) Schult.	Bristlegrass	C
S. geniculata (Lam.} Beauv.	Knotroot bristlegrass	C
S. macrosperma (Scribn. & Merr.) K. Schum.	Foxtail grass	R
S. magna Griseb.	Giant foxtail grass	I
Cenchrus echinatus L.	Southern sandspur	C
C. incertus M. A. Curtis	Coastal sandspur	C
C. tribuloides L.	Dune sandspur	C
Stenotaphrum secundatum (Walt.) Kuntze	St. Augustine grass	C
Luziola fluitans (Michx.) Terrel & H. Robins.	Water grass	R
Phalaris caroliniana Walt.	Canary grass	R
Anthoxanthum odoratum L.		C
Aristida lanosa Muhl. ex Ell.	Three awn grass	I
A. purpurascens Poir.	Arrowfeather three awn grass	C
A. spiciformis Ell.	Bottlebrush three awn grass	I
A. virgata Trin.	Trinius three awn	C
Stipa avenacea L.	Black seed needle grass	C
Muhlenbergia filipes M. A. Curtis	Pink muhly, sweet grass	C
Sporobolus clandestinus (Biehler} Hitchc.	Hidden dropseed	C
S. indicus (L.) R. Br.	Smut grass	C
S. virginicus (L.) Kunth	Dropseed	C
Polypogon maritimus Willd.	Mediterranean polypogon	C
Agrostis scabra Willd.		I
Sphenopholis obtusata (Michx.) Scribn. var. *obtusata*	Prairie wedgescale	C
Cynodon dactylon (L.) Pers.	Bermuda grass	C
Spartina alterniflora Loisel.	Smooth cordgrass	C
S. bakeri Merr.	Bunch cordgrass	C
S. cynosuroides (L.) Roth	Giant cordgrass	R
S. patens (Ait.) Muhl.	Saltmeadow cordgrass	C
Eustachys petraea (Sw.) Desv.	Finger grass	C
Eleusine indica (L.) Gaertn.	Goosegrass	C
Tridens flavus (L.) Hitchc. var. *flavus*	Purple top	C
Triplasis purpurea (Walt.) Chapm.	Purple sandgrass	C
Eragrostis elliottii S. Wats.	Love grass	C
E. refracta (Hubl.) Scribn	.Coastal love grass	I
Melica mutica Walt.	Twoflower melic	C
Uniola paniculata L.	Sea oats	C
Chasmanthiu laxum (L.) Yates	Spike grass	C
C. sessiliflorum (Poir.) Yates	Spangle grass	C
Distichlis spicata (L.) Greene	Salt grass	C
Poa annus L.	Annual bluegrass	C
Vulpia octoflora (Walt.) Rydb.	Annual fescue	C
Elymus virginicus L.	Wild rye grass	I
Arundinaria gigantea (Walt.) Muhl. ssp. *tecta* (Walt.) McClure	Cane	SR
CYPERACEAE		
Cyperus brevifolius (Rottb.) Endl. ex Hassk.	One-headed flatsedge	C

C. filicinus Vahl	Umbrella sedge	C
C. globulosus Aubl.	Flatsedge nutgrass	C
C. haspan L.	Flatsedge	C
C. odoratus L.	Flatsedge	I
C. ovularis (Michx.) Torr.		I
C. polystachyos Rottb. var. *texensis* (Torr.) Fern.	Sedge	C
C. pseudovegetus Steud.		I
C. retrorsus Chapm. var. *retrorsus*	Flatsedge	C
C. rotundus L.	Sedge	C
Fuirena breviseta (Cov.) Cov.		C
Scirpus americanus Pers.	Swordgrass	C
S. tabernaemontanii K. C. Gmel.	Soft-stem bulrush	I
Eleocharis albida Torr.	Spikerush	C
E. flavescens (Poir.) Urban var. *flavescens*	Spikerush	C
E. parvula (R. & S.) Link ex Buff. & Fingerh.	Dwarf spikerush	R
E. tricostata Torr.		I
E. tuberculosa (Michx.) R. & S.	Spikerush	R
Fimbristylis autumnalis (L.) R. & S.		I
F. caroliniana (Lam.) Fern.	Water ash	C
F. castanea (Michx.) Vahl	Fimbristylis	C
Bulbostylis barbata (Rottb.) Clarke	Water grass	I
B. stenophylla (Ell.) Clarke		I
Dichromena colorata (L.) Hitchc.	Star-rush	I
Rhynchospora caduca Ell.		R
R. cephalantha Gray var. *cephalantha*		R
R. corniculata (Lam.) Gray	Horned beaked rush	C
R. fascicularis (Michx.) Vahl. var. *fascicularis*		C
R. filifolia Gray		I
R. plumosa Ell.	Plumed beak rush	I
R. rariflora (Michx.) Ell.		I
Scleria ciliata Michx. var. *glabra* (Chapm.) Fairey	Nut rush	R
S. reticularis Michx. var. *reticularis*		I
S. triglomerata Michx.	Nut rush	C
Carex cherokeensis Schwein.	Sedge	C
C. glaucescens Ell.		I
C. longii Mack.		I
C. verrucosa Muhl.		R
C. walteriana Bailey	Walter's sedge	I
ARECACEAE		
Sabal minor (Jacq.) Pers.	Dwarf palmetto	SC
S. palmetto (Walt.) Lodd ex Schult. & Schult.	Cabbage Palmetto	TI
Serenoa repens (Bartr.) Small	Saw palmetto	TC
LEMNACEAE		
Spirodela polyrhiza (L.) Schleid.	Big duckweed	R
Lemna aequinoctialis Welwitsch	Duckweed	I
Lemna obscura (Austin) Daubs		I
Lemna valdiviana Phil.	Duckweed	C
Wolffia columbiana Karst	Water-meal	I
Wolfiella gladiata (Hegehm.) Hegehm.	Eastern wolfiella	R
XYRIDACEAE		
Xyris caroliniana Walt.	Yellow-eyed grass	I
ERIOCAULACEAE		
Eriocaulon compressum Lam.	Pipewort	R
E. decangulare L.	Pipewort	R

BROMELIACEAE		
Tillandsia usneoides (L.) L.	Spanish moss	C
COMMELINACEAE		
Commelina erecta L. var. *angustifolia* (Michx.) Fern.	Dayflower	C
C. benghalensis L.		R
Tradescantia ohiensis Raf. var. *ohiensis*	Spiderwort	C
PONTEDERIACEAE		
Pontederia cordata L.	Pickerelweed	C
JUNCACEAE		
Juncus effusus L. var. *solutus* Fern. & Wieg.	Soft rush	C
J. marginatus Rostk.	Rush	C
J. megacephalus M. A. Curtis		C
J. polycephalus Michx.	Flat-leaved rush	R
J. repens Michx.	Creeping rush	I
J. roemerianus Scheele	Black needlerush	C
J. scirpoides Lam.	Needlepod rush	I
J. tenuis Willd	Path rush	C
LILIACEAE		
Nothoscordum bivalve (L.) Britt.	False garlic	I
Yucca — See AGAVACEAE		
Asparagus officinalis L.		R
Smilax — See SMILACEAE		
AMARYLLIDACEAE		
Hypoxis juncea Sm.	Yellow star grass	R
AGAVACEAE		
Yucca aloifolia L.	Spanish bayonet	TI
Y. flaccida Haw.	Bear-grass	SI
Y. gloriosa L.	Mound-lily yucca	TI
SMILACACEAE		
Smilax auriculata Walt.	Dune greenbrier	SC
S. bona-nox L.	Fringed greenbrier	SI
S. glauca Walt.	Sawbrier	SC
S. laurifolia L.	Bamboo-vine	SC
S. pumila Walt.	Sarsaparilla-vine	SC
IRIDACEAE		
Iris virginica L.	Blue flag	I
Sisyrinchium albidum Raf.	Blue-eyed grass	I
CANNACEAE		
Canna flaccida Salisb.	Golden canna lily	R
ORCHIDACEAE		
Platanthera cristata (Michx.) Lindl.		R
Habenaria quinqueseta (Miebx.) A. A. Eaton		R
Spiranthes praecox (Walt.) Wats.	Green-leaved ladies' tresses	I
S. tuberosa Raf.	Autumn ladies' tresses	I
S. vernalis Engelm. & Gray	Spring ladies' tresses	I
Zeuxine strateumatica (L.) Schltr.		R
Corallorhiza wisteriana Conrad	Spring coral root	R
Hexalectris spicata (Walt.) Barnh.	Crested coral root	R
Pteroglossaspis ecristata (Fern.) Rolfe		R
SAURURACEAE		
Saururus cernuus L.	Lizard's tail	C
SALICACEAE		
Populus alba L.	White or silver poplar	TR
Salix caroliniana Michx.	Swamp willow	TC

MYRICACEAE		
Myrica cerifera L.	Wax myrtle	TC
JUGLANDACEAE		
Carya glabra (Mill.) Sweet	Pignut hickory	TI
C. illinoensis (Wang.) K. Koch	Pecan	TR
C. ovalis (Wang.) Sarg.	Sweet pignut hickory	TR
BETULACEAE		
Betula nigra L.	River birch	TR
FAGACEAE		
Castanea pumila (L.) Mill. var. *ashei* Sudw.	Chinquapin	TR
Quercus chapmanii Sarg.	Chapman oak	TR
Q. geminata Small	Sand live oak	TC
Q. hemispherica Bartr.	Laurel oak	TC
Q. myrtifolia Willd.	Myrtle oak	TR
Q. nigra L.	Water oak	TI
Q. stellata Wang.	Post oak	TR
Q. virginiana Mill.	Live oak	TC
ULMACEAE		
Celtis laevigata Willd.	Hackberry	TI
MORACEAE		
Morus rubra L. T	Red mulberry	TI
Maclura pomifera (Raf. ex Sarg.) Schneid.	Osage orange	TR
Cudrania tricuspidata (Carr.) Bur. ex Lavallee		TR
URTICACEAE		
Boehmeria cylindrica (L.) Sw.	False nettle	C
Parietaria floridana Nutt.	Pellitory	C
LORANTHACEAE		
Phoradendron serotinum (Raf.) M.C. Jonst.	Mistletoe	SC
POLYGONACEAE		
Rumex hastatulus Baldw. ex Ell.	Wild sorrel	C
Polygonum glaucum Nutt.	Seaside knotweed	R
P. hydropiperoides Michx. var. *hydropiperoides*	Water pepper	C
P. punctatum L. var. *confertiflorum* (Meisn.) Fassett	Water smartweed	I
P. scandens L. var. *cristatum* (Engelm. & Gray) Gl.	Climbing false buckwheat	C
CHENOPODIACEAE		
Chenopodium album L.	Lamb's quarters	C
C. ambrosioides L.	Wormseed; Mexican tea	C
Atriplex pentandra (Jacq.) Standl.		C
Salicornia bigelovii Torrey	Glasswort	C
S. europaea L.	Glasswort	I
S. virginica L.	Perennial glasswort	C
Suaeda linearis (Ell.) Moq.	Sea-blite	C
Salsola kali L.	Russian thistle	C
AMARANTHACEAE		
Amaranthus gracilis Desf.		I
A. spinosus L.		C
Froelichia floridana (Nutt.) Moq.	Cottonweed	R
Iresine rhizomatosa Standl.	Bloodleaf	I
NYCTAGINACEAE		
Boerhavia erecta L.	Erect spiderling	R
BATACEAE		
Batis maritima L.	Saltwort	SC
PHYTOLACCACEAE		
Phytolacca rigida Small	Pokeweed	C

MOLLUGINACEAE		
Mollugo verticillata L.	Carpetweed/Indian chickweed	C
AIZOACEAE		
Sesuvium maritimum (Walt.) B.S.P.	Sea purslane	I
S. portulacastrum L.	Sea purslane	I
PORTULACACEAE		
Portulaca oleracea L.	Common purslane	I
P. pilosa L.	Hairy portulaca	I
CARYOPHYLLACEAE		
Stellaria media (L.) Vill.	Common chickweed	C
Cerastium glomeratum Thuill.	Mouse-ear chickweed	C
Sagina decumbens (Ell.) T. & G. ssp. *decumbens*	Birdseye	C
Arenaria lanuginosa (Michx.) Rohrb. Ssp. *lanuginosa*	Perennial sandwort	I
A. serphyllifolia L.	Thymeleaf sandwort	C
Paronychia baldwinii (T. & G.) Chapm. ssp. *baldwinii*		C
P. fastigiata (Raf.) Fern.		I
Silene antirrhina L.Sleepy catchfly		I
NYMPHAEACEAE		
Nymphaea mexicana Zucc.	Banana waterlily	I
N. odorata Ait. var. *odorata*	White waterlily	C
N. odorata Ait. X *N. mexicana* Zucc.	Waterlily	R
CERATOPHYLLACEAE		
Ceratophyllum demersum L.	Coontail	R
MENISPERMACEAE		
Cocculus carolinus DC.		SC
MAGNOLIACEAE		
Magnolia grandiflora L.	Soutern magnolia/Bullbay	TC
M. virginiana L.	Sweetbay	TI
ANNONACEAE		
Asimina parviflora (Michx.) Dunal	Pawpaw	TR
LAURACEAE		
Cinnamomus camphora (L.) Presl	Camphor tree	TI
Persea borbonia (L.) Spreng. var. *borbonia*	Redbay	TC
P. palustris (Raf.) Sarg.	Swampbay	TC
Sassafras albidum (Nutt.) Nees	Sassafras	TI
PAPAVERACEAE		
Argemone albiflora Hornem.	Prickly poppy	I
BRASSICACEAE		
Lepidium virginicum L.	Peppergrass/pepperwort	C
Coronopus didymus (L.) Sm.	Wart-cress/carpet-cress	I
Cakile edentula (Bigel.) Hook. spp. *harperi* (Small) Rodman	Sea rocket	C
Cardamine debilis D. Don	Bitter cress	I
C. pensylvanica Muhl. ex Willd.	Spring cress	I
Capsella brusa-pastoris (L.) Medic.	Shepherd's purse	I
Descurainia pinnata (Walt.) Britt. ssp. *pinnata*	Tansey mustard	C
DROSERACEAE		
Drosera brevifolia Pursh	Sundew	C
D. capillaris Poir.	Sundew	R
SAXIFRAGACEAE		
Itea virginica L.	Virginia willow	SI
HAMMELIDACEAE		
Liquidambar styraciflua L.	Sweet gum	TI
Hamamelis virginiana L.	Witch-hazel	TR

ROSACEAE		
Aronia arbutifolia (L.) Pers.	Red Chokeberry	SI
Rubus betulifolius Small	Blackberry	SI
Rubus trivialis Michx.	Dewberry	SI
Rosa laevigata Michx.	Cherokee rose	SI
Prunus angustifolia Marsh.	Chicksaw plum	TR
P. serotina Ehrh. var. *serotina*	Black cherry	TC
FABACEAE		
Cassia aspera Muhl. ex Ell.	Partridge-pea	C
C. fascilulata Michx. var. *fasciculata*	Partridge-pea	C
C. nictitans L.	Partridge-pea	I
C. obtusifolia L.	Coffee-weed/Sickle-pod	I
Crotalaria brevidens Benth.		R
C. rotundifolia (Walt.) Poir. var. *vulgaris* Windler	Rabbit-bells	I
Medicago arabica (L.) Huds.	Spotted medick	C
M. lupulina L.	Black medick	I
M. polymorpha L.	Bur-clover/Medick	I
Melilotus indica (L.) All.	Sour clover	I
Trifolium carolinianum Michx.	Clover	C
T. repens L.	White clover	I
Indigofera caroliniana Mill.	Carolina indigo	I
Amorpha glabra Desf. ex Poir.	Mountain indigo	SR
Wisteria sinensis (Sims) Sweet	Wisteria	SR
Sesbania macrocarpa Muhl.	Sesbania	I
S. vesicaria (Jacq.) Ell.	Bladder-pod	C
Daubentonia punicea (Cav.) DC.	Rattle-bush	SR
Aeschynomene indica L.	Joint-vetch	I
A. viscidula Michx.	Littleleaf tickclover	R
Desmodium ciliare (Muhl. ex Willd.) DC.	Panicled tickclover	C
D. paniculatum (L.) DC. var. *paniculatum*	Beggar-ticks	C
Lespedeza hirta (L.) Hornem. ssp. *hirta*	Lespedeza	C
Kummerowa striata (Thunb.) Schindl.		I
Vicia acutifolia Ell.	Sand vetch	C
Clitoria mariana L.	Butterfly-pea	I
Centrosema virginianum (L.) Benth.	Climbing butterfly-pea	C
Erythrina herbacea L.	Cardinal spear/Coral bean	SR
Apios americana Medic.	American potato bean	R
Galactia elliottii Nutt.	Elliots's milk-pea	C
G. volubilis (L.) Britt.	Milk-pea	C
Rhynchosia difformis (Ell.) DC.	Least rhynchosia	I
R. minima (L.) DC.	Climbing rhynchosia	I
Strophostyles helvola (L.) Ell.	Wild bean	C
S. umbellata (Muhl. ex Willd.) Britt.	Pink wild bean	I
GERANIACEAE		
Geranium carolinianum L.	Carolina cranesbill	C
OXALIDACEAE		
Oxalis corymbosa DC.	Wood-sorrel	I
O. dillenii Jacq. ssp. *dillenii*		I
O. dillenii Jacq. ssp. *filipes* (Small) Eiten		C
LINACEAE		
Linum medium (Planch.) Britt. var. *texanum* (Planch.) Fern.	Wild flax	C
RUTACEAE		
Zanthoxylum clava-herculis L.	Hercules-club	TC
Citrus aurantinum L.	Sour orange	TR

MELIACEAE		
Melia azedarach L.	Chinaberry	TR
POLYGALACEAE		
Polygala cymosa Walt.	Polygala	R
P. incarnata L.	Slender polygala	I
P. lutea L.	Candyweed	R
EUPHORBIACEAE		
Croton glandulosus L. var. *septentrionalis* Muell.-Arg.	Croton	C
C. punctatus Jacq.		C
Acalypha gracilens Gray ssp. *gracilens*	Three-seeded mercury	C
A. ostraeifolia Ridd.		I
Tragia urens L.	Noseburn	I
Cnidoscolus stimulosus (Michx.) Engels. & Gray	Bull-nettle	C
Euphorbia cyathophora Murr.		I
Chamaesyce bombensis (Jacq.) Dug.	Seaside spurge	I
C. hirta (L.) Millsp.	Hairy spurge	I
C. nutans (Lag.) Small	Eyebane/Wartweed	C
C. ophthalmica (Pers.) Burch		I
C. polygonifolia (L.) Small	Seaside spurge	C
CALLITRICHACEAE		
Callitriche peploides Nutt.		I
ANACARDIACEAE		
Rhus copallina L.	Winged sumac	TI
Toxicodendron radicans (L.) Kuntze var. *radicans*	Poison ivy	SC
CYRILLACEAE		
Cyrilla racemiflora L.	Summer titi	TR
AQUIFOLIACEAE		
Ilex ambigua (Michx.) Torr.	Carolina holly	SR
I. cassine L.	Dahoon holly	TR
I. glabra (L.) Gray	Inkberry/Bitter gallberry	SC
I. opaca Ait.	American holly	TC
I. vomitoria Ait.	Yaupon	TC
ACERACEAE		
Acer rubrum L. var. *rubrum*	Red maple	TI
A. rubrum L. var. *trilobum* (T. & G.) K. Koch		TI
HIPPOCASTANACEAE		
Aesculus pavia L.	Red buckeye	TR
SAPINDACEAE		
Sapindus marginatus Willd.	Florida soapberry	TR
RHAMNACEAE		
Berchemia scandens (Hill) K. Koch	Rattan-vine/Supple jack	SI
Sageretia minutifolia (Michx.) Trel.	Buckthorn	SR
Rhamnus caroliniana Walt.	Carolina buckthorn	TR
VITACEAE		
Vitis aestivalis Michx.	Summer grape/Pigeon grape	SI
V. rotundifolia Michx.	Muscadine/Scuppernong	SC
V. vulpina L.		SC
Parthenocissus quinquefolia (L.) Planch.	Virginia-creeper/Woodbine	SC
Ampelopsis arborea (L.) Koehne	Pepper-vine	SC
MALVACEAE		
Abutilon theophrasti Medic.	Velvet-leaf/Butter-print	R
Modiola caroliniana (L.) G. Don	Carolina modiola	I
Sida rhombifolia L.	Sida	C
Hibiscus grandiflorus Michx.	Great rose-mallow	R
H. moscheutos L.	Swamp rose-mallow	I

Kosteletzkya virginica (L.) Presl ex Gray	Seashore mallow	R
STERCULIACEAE		
Melochia corchorifolia L.	Chocolate-weed	I
CLUSIACEAE		
Hypericum cistifolium Lam.		R
H. crux-andreae (L.) Crantz		SR
H. gentianoides (L.) B.S.P.	Pineweed/Orange-grass	C
H. hypericoides (L.) Crantz ssp. *hypericoides*		SC
H. mutilum L.	Hypericum	C
H. myrtifolium Lam.	Myrtle leaf St. John's wort	SR
H. tetrapetalum Lam.		SR
Triadenum virginicum (L.) Raf.	Marsh St. John's wort	I
CISTACEAE		
Helianthemum corymbosum Michx.	Sunrose	SI
H. georgianum Chapm.	Sunrose	R
Lechea pulchella Raf. var. *pulchella*	Pinweed	I
L. villosa Ell.	Hairy pinweed	C
VIOLACEAE		
Viola lanceolata L. ssp. *vittata* (Greene) Russell	Lance-leaved violet	R
V. floridana Brainerd		R
PASSIFLORACEAE		
Passiflora incarnata L.	Passion-flower	R
P. lutea L.	Passion-flower	R
CACTACEAE		
Opuntia ficus-indica (L.) Mill.	Indian-fig/Prickly-pear	SI
O. humifusa (Raf.) Raf. var. *humifusa*	Eastern prickly-pear	SI
O. pusilla (Haw.) Haw.	Devil-joint	SI
O. stricta (Haw.) Haw. var. *stricta*	Southern prickly-pear	SI
LYTHRACEAE		
Ammannia latifolia L.		I
Decodon verticillatus (L.) Ell.	Water-willow/Swamp loosestrife	SR
MELASTOMACEAE		
Rhexia cubensis Griseb.	Meadow-beauty	I
R. nashii Small	Meadow-beauty	I
R. virginica L.	Common meadow-beauty	I
ONAGRACEAE		
Ludwigia leptocarpa (Nutt.) Hara		I
L. linearis Walt.	Narrow-leaved ludwigi	C
L. uruguayensis (Comb.) Hara	Seed-box/Primrose-willow	I
L. maritima Harper	Slender seed-box	C
L. palustris (L.) Ell.	Trailing Ludwigia	C
L. repens Forst.	Water purslane/Marsh purslane	I
L. suffruticosa Walt.		C
Oenothera humifusa Nutt.	Dunes evening primrose	C
O. laciniata Hill	Cut-leaved Oenothera	C
O. speciosa Nutt.	Showy evening primrose	C
Gaura angustifolia Michx.	Gaura	C
HALORAGIDACEAE		
Myriophyllum pinnatum (Walt.) B.S.P.	Water milfoil	I
Proserpinaca pectinata Lam.	Mermaid-weed	C
ARALIACEAE		
Aralia spinosa L.	Hercules-club/ Devil's walking stick	TC
APIACEAE		
Hydrocotyle bonariensis Comm. ex Lam.	Seaside pennywort	C

H. umbellata L.	Marsh pennywort	I
H. verticillata Thunb. var. *verticellata*	Pennywort	I
Centella asiatica (L.) Urban	Chinaman's shield	C
Sanicula canadensis L.	Canada snakeroot	I
Chaerophyllum tainturieri Hook.	Wild chervil	C
Cicuta mexicana Coult. & Rose	Water-hemlock	C
Ptilimnium capillacem (Michx.) Raf.Mock	Bishop's-weed	C
Foeniculum vulgare Mill.	Common fennel	R
Oxypolis filiformis (Walt.) Britt.	Leafless cowbane	R
NYSSACEAE		
Nyssa biflora Walt.	Swamp blackgum	TC
CORNACEAE		
Cornus asperifolia Michx.	Stiff-cornel dogwood	TI
ERICACEAE		
Monotropa uniflora L.	Indian-pipe	R
Kalmia hirsuta Walt.	Hairy wicky	SI
Lyonia fruticosa (Michx.) G. S. Torrey	Stagger-bush	SI
L. ferruginea (Walt.) Nutt	Stagger-bush	SC
L. lucida (Lam.) R. Koch	Fetterbush	SC
Gaylussacia dumosa (Andr.) T. & S.	Dwarf Huckleberry	SI
G. frondosa (L.) T. & G. ex Torr. var. *tomentosa* Gray	Dangleberry	SI
Vaccinium arboreum Marsh.	Sparkleberry/Tree blueberry	TC
V. corymbosum L.	Highbush blueberry	SC
V. myrsinites Lam.	Evergreen blueberry	SC
V. stamineum L. var. *stamineum*	Deerberry	SC
PRIMULACEAE		
Samolus valerandi L. ssp. *parviflorus* (Raf.) Hulten	Water pimpernel	C
Anagallis minima (L.) Krause		I
PLUMBAGINACEAE		
Limonium carolinianum (Walt.) Britt.	Sea-lavender/Marsh rosemary	C
SAPOTACEAE		
Bumelia tenax (L.) Willd.	Southern buckthorn	TC
EBENACEAE		
Diospyros virginiana L.	Persimmon	TC
SYMPLOCACEAE		
Symplocos tinctoria (L.) L'Her.	Sweetleaf/Horsesugar	TI
OLEACEAE		
Fraxinus profunda (Bush) Bush	Pumpkin ash	TR
Osmanthus americanus (L.) Benth. & Hook. f. ex Gray	Devilwood/Wild-olive	TI
Forestiera segregata (Jacq.) Krug & Urban var. *segregata*	Florida privet	TR
LOGANIACEAE		
Gelsemium sempervirens (L.) St.-Hil.	Yellow jasmine	SI
Cynoctonum mitreola (L.) Britt.	Miterwort	I
Polypremum procumbens L.	Polypremum	C
GENTIANACEAE		
Sabatia stellaris Pursh	Common marsh-pink	C
Bartonia verna (Michx.) Muhl.	Vernal bartonia	R
APOCYNACEAE		
Apocynus cannabinum L.	Indian hemp	I
ASCLEPIADACEAE		
Asclepias lanceolata Walt.	Red milkweed	R
A. pedicellata Walt.	Milkweed	R
Cynanchun angustifolium Pers.	Sand-vine	C

Matelea carolinensis (Jacq.) Woods.	Spiny-pod	R
M. gonocarpos (Walt.) Shinners	Angle-pod	I
CONVOLVULACEAE		
Cuscuta pentagona Engeln.	Dodder	R
Dichondra carolinensis Michx.	Pony-foot	C
Ipomoea pandurata (L.) Mey.	Wild potato-vine	I
I. pes-caprae (L.) R. Br.	Railroad-vine	C
I. quamoclit L.		I
I. sagittata Poir.	Arrow-leaf morning-glory	C
I. stolonifera (Cyr.) Poir.	Fiddleleaf Morning-glory	C
I. trichocarpa Ell.	Coastal morning-glory	I
POLEMONIACEAE		
Phlox drummondii Hook.	Annual phlox	C
BORAGINACEAE		
Heliotropium curassavicum L.	Marsh heliotrope	C
VERBENACEAE		
Verbena officinalis L.	Vervain	I
V. scabra Vahl	Vervain	C
Lantana camara L. var. *camara*	Shrub-verbena/Lantana	SR
L. montevidensis (Spreng.) Briq.	Trailing lantana	SR
Phyla nodiflora (L.) Greene	Frog-fruits	C
Callicarpa americana L. var. *americana*	Beautyberry/French-mulberry	SC
Clerodendron indicum (L.) Kuntze	India tubeflower	R
LAMIACEAE		
Teucrium canadense L. var. *hypoleucum* Griseb.	Germander/Wood-sage	C
Trichostema dichotomum L.	Blue-curls	C
Scutellaria integrifolia L.	Northern skullcap	I
Lamium amplexicaule L.	Henbit	C
Salvia coccinea Juss. ex J. Murr	Scarlet sage	I
S. lyrata L.	Lyre-leaved sage	C
Monarda punctata L.	Horse mint	I
Mentha X *piperita* L. nm. *piperita*		R
Hyptis alata (Raf.) Shinners	Bitter mint	I
SOLONACEAE		
Physalis angulata L.	Cutleaf ground-cherry	I
P. pubescens L. var. *pubescens*	Downy ground-cherry	I
P. viscosa L. ssp. *maritima* (H. A. Curtis) Waterfall	Sand ground-cherry	C
Solanum carolinense L. var. *carolinense*	Horse-nettle/Bull-nettle	C
S. americanum Mill.	Black nightshade	I
S. sisymbriifolium Lam.	Spiny nightshade	I
S. pseudogracile Heiser	Black nightshade	C
SCROPHULARIACEAE		
Verbascum thapsus L.	Wooly mullein/Flannel-plant	I
Linaria canadensis (L.) Dum.-Cours.	Toadflax	C
Gratiola pilosa Michx.	Hairy gratiola	I
G. ramosa Walt.		I
Bacopa caroliniana (Walt.) Robins.	Blue water-hyssop	I
B. monnieri (L.) Penn.	Smooth water-hyssop	C
Micranthemum umbrosum (Walt.) Blake	Micranthemum	I
Veronica peregrina L. var. *xalapensis* (H.B.K.) Penn.	Purslane/Speedwell	I
Agalinis purpurea (L.) Penn.	Gerardia	C
Buchnera americana L.	Blue-hearts	I
BIGNONIACEAE		
Bignonia capreolata L.	Cross-vine	SI
Campsis radicans (L.) Seem. ex Bureau	Trumpet-creeper/Cow-itch	SI

LENTIBULARIACEAE		
Pinguicula pumila Michx.	Dwarf bitterroot	I
Utricularia gibba L.	Bladderwort	I
U. inflata Walt.	Floating bladderwort	R
U. subulata L.	Wiry bladderwort	C
ACANTHACEAE		
Ruellia caroliniensis (J. F. Gmel.) Steud. ssp. *caroliniensis* var. *caroliniensis*	Carolina Ruellia	I
PLANTAGINACEAE		
Plantago virginica L.	Hoary plantain	C
RUBIACEAE		
Hedyotis procumbens (Walt. ex J. F. Gmel.) Fosb.	Trailing bluet	C
H. uniflora (L.) Lam.	Oldenlandia	C
Cephalanthus occidentalis L.	Buttonbush	TC
Richardia scabra L.	Mexican clover	I
Diodia teres Walt.	Rough buttonweed	C
D. virginia L.	Buttonweed	C
Galium aparine L.	Bedstraw/Catchweed	I
G. hispidulum Michx.	Purple galium	C
G. pilosum Ait. var. *laevicaule* Weath. & Blake		I
G. tinctorium L.	Dye bedstraw	I
CAPRIFOLIACEAE		
Sambucus simpsonii Rehd.	Common elderberry	SC
Lonicera japonica Thunb.	Japanese honeysuckle	SI
L. sempervirens L.	Coral honeysuckle	SI
CUCURBITACEAE		
Melothria pendula L. var. *pendula*	Creeping cucumber	R
CAMPANULACEAE		
Triodanis perfoliata (L.) Nieuw. var. *perfoliata*	Venus' looking-glass	I
T. perfoliata (L.) Nieuw. var. *biflora* (R. & P.) Bradley		I
Lobelia glandulosa Walt.	Purple lobelia	I
ASTERACEAE		
Elephantopus nudatus Gray	Elephant's-foot	I
E. tomentosus L.	Elephant's-foot	C
Eupatorium anomalum Nash	Narrow-leaved Eupatorium	I
E. aromaticum L.	Coastal white snakeroot	I
E. capillifolium (Lam.) Small	Dog-fennel	C
E. leptophyllum DC.	Dog-fennel	I
E. recurvans Small		C
E. rotundifolium L. var. *rotundifolium*	Broad-leaved eupatorium	C
E. serotinum Michx.	Late eupatorium	I
Mikania scandens (L.) Willd.	Climbing hempweed	C
Liatris graminifolia (Walt.) Willd. var. *graminifolia*	Blazing-star	R
Carphephorus odoratissimus (J. F. Gmel.) Herb.	Deer-tongue/Vanilla-plant	I
C. paniculatus (J. F. G el.) Herb.		I
Heterotheca subaxillaris (Lam.) Britt. & Busby	Camphorweed	C
Pityopsis graminifolia (Michx.) Nutt. var. *microcephala* (Small) Semple in ed.	Grass-leaved golden aster	C
Solidago odora Ait. var. *chapmannii* (T. & G.) Cronq.	Sweet goldenrod	C
S. sempervirens L. var. *mexicana* (L.) Fern.	Seaside goldenrod	C
Euthamia tenuifolia (Pursh) Nutt.	Flat-topped goldenrod	C
Aster dumosus L.	Many-flowered aster	C
A. reticulatus Pursh		I
A. subulatus Michx. var. *subulatus*	Annual saltmarsh aster	I
A. tenuifolius L.	Perennial saltmarsh aster	I

Erigeron quercifolius Lam.	Oak-leaf erigeron	C
E. vernus (L.) T. & G.	Robin's plantain	I
Conyza bonariensis (L.) Cronq.	Hairy fleabane	I
C. canadensis (L.) Cronq. var. *pusilla* (Nutt.) Cronq.	Horseweed	C
Baccharis angustifolia Michx.	False-willow	SC
B. glomeruliflora Pers.	Groundsel tree	SR
B. halimifolia L.	Silverling/Groundsel tree	TC
Pluchea odorata (L.) Cass. var. *odorata*	Marsh fleabane	I
P. rosea Godfrey	Stinkweed	I
Pterocaulon pycnostachyum (Michx.) Ell.	Blackroot	I
Gnaphalium obtusifolium L. var. *obtusifolium*	Rabbit-tobacco/Everlasting	I
G. purpureum L. var. *purpureum*	Purple cudweed	C
Polymnia uvedalia L.	Bearsfoot	I
Iva annua L.	Annual marsh elder	R
I. frutescens L.	Marsh elder	SC
I. imbricata Walt.	Seashore-elder	SC
Ambrosia artemisiifolia L. var. *artemisiifolia*	Common ragweed	C
Xanthium strumarium L. var. *strumarium*	Cocklebur	I
Eclipta prostrata (L.) L.	Eclipta	I
Borrichia frutescens (L.) DC.	Sea ox-eye	SC
Helianthus angustifolius L.	Narrow-leaved sunflower	I
Melanthera nivea (L.) Small	Melanthera	I
Verbesina occidentalis (L.) Walt.	Crown-beard/Wingstem	C
V. virginica L. var. *virginica*	Tickweed	C
Coreopsis lanceolata L.	Coreopsis	R
Bidens bipinnata L.	Spanish-needles	I
B. laevis (L.) B.S.P.	Wild-goldenglow/Bur-marigold	I
Helenium amarum (Raf.) Rock	Bitterweed	C
Gaillardia pulchella Foug.	Gaillardia/Fire-wheel	C
Erechtites hieracifolia (L.) Raf. ex DC.	Fireweed	C
Cirsium horridulum Michx.	Yellow-thistle	C
C. nuttallii DC.	Thistle	I
Krigia virginica (L.) Willd.	Dwarf-dandelion	C
Sonchus asper (L.) Hill	Prickly sow-thistle	I
S. oleraceus L.	Common sow-thistle	I
Lactuca graminifolia Michx.	Wild lettuce	I
Pyrrhopappus georgianus Shinners	False dandelion	C
Youngia japonica (L.) DC.		R
Hieracium gronovii L.	Leafy hawkweed	I
H. megacephalon Nash	Hawkweed	R

[1] From Duncan, 1982; Duncan and Duncan, 1987, 1988.

[2] Unless identified as tree (T) or shrub (S), listed species are herbaceous. Abundance is indicated as common (C), infrequent (I) or rare (R).

Appendix 2. Selected List of Invertebrates (Excluding Insects and Arachnids) in Tidal Salt Marshes of the Southeastern Atlantic Coast[1]

Phylum Cnidaria
Class Anthozoa
  Order Actiniaria
    Family Edwardsiidae
      Nematosella vectensis
      Heteromastus filiformis
Phylum Rhynchocoela
Class Anopla
  Order Paleonemertea
    Family Carinomidae
      Carinoma tremaphoras
  Order Heteronemertea
    Family Lineidae
      Lineus socialis
Class Enopla
  Order Hoplonemertea
    Family Amphiporidae
      Amphiporus ochraceus
Phylum Annelida
Class Oligochaeta
  Order Tubificida
    Family Enchytraeidae
      Enchytraeus spp.
    Family Naididae
      Paranais frici
    Family Tubificidae
      Monopylephorus evertus
      Tubificoides brownae
Class Polychaeta
  Subclass Errantia
  Order Eunicida
    Family Arabellidae
      Drilonereis magna
    Family Lumbrineridae
      Lumbrineris tenuis
    Family Onuphidae
      Diopatra cuprea
  Order Phyllodocida
    Family Glyceridae
      Glycera americana
    Family Nereidae
      Laenonereis culveri
      Namalycastis abiuma
      Neanthes succinea
    Family Phyllodocidae

Subclass Sedentaria
Order Capitellida
Family Capitellidae
Capitella capitata
Family Maldanidae
Branchioasychis americana
Order Orbiniida
Family Orbiniidae
Haploscoloplos robustus
Scoloplos fragilis
Order Sabellida
Family Sabellidae
Manayunkia aestuarina
Order Spionida
Family Spionidae
Streblospio benedicti
Order Terebellida
Family Ampharetidae
Hobsonia florida
Family Pectinariidae
Cistenides gouldii
Family Terebellidae
Amphitrite ornata
Phylum Mollusca
Class Gastropoda
Subclass Prosobranchia
Order Archaeogastropoda
Family Neritidae
Neritina usnea
Order Mesogastropoda
Family Assimineidae
Assiminea succinea
Family Hydrobiidae
Hydrobia spp.
Littoridinops tenuipes
Onobops jacksoni
Family Littorinidae
Littorina irrorata
Family Potamididae
Cerithidea costata
C. scalariformis
Order Neogastropoda
Family Nassariidae
Ilyanassa obsoleta
Subclass Pulmonata
Order Basommatophora
Family Ellobiidae
Decracia floridana
Melampus bidentatus

Class Bivalvia

Subclass Pteriomorphia

Order Mytiloida

Family Mytilidae

Amygdalum papyrium

Geukensia demissa

Iscahdium recurvum

Family Ostreidae

Crassostrea virginica

Subclass Heterodonta

Order Veneroida

Family Corbiculidae

Polymesoda caroliniana

Family Cyrenoididae

Cyrenoida floridana

Family Mactridae

Mulinia lateralis

Family Solecurtidae

Tagelus plebeius

Family Venendae

Gemma gemma

Phylum Arthropoda

Subphylum Crustacea

Class Cirripedia

Order Thoracica

Family Chthamalidae

Chthamalus fragilis

Class Malacostraca

Order Decapoda

Suborder Pleocyemata

Infraorder Caridea

Family Alpheidae

Alpheus heterochaelis

Family Palaemonidae

Palaemonetes pugio

P. vulgaris

Infraorder Brachyura

Family Grapsidae

Sesarma cinerium

S. reticulatum

Family Ocypodidae

Uca minax

U. pugilator

U. pugnax

Family Pinnotheridae

Pinnixia chaetopterana

Family Portunidae

Callinectes sapidus

Family Xanthidae

Eurypanopeus depressus
Eurytium limosum
Panopeus obesus
Rithropanopeus harrisii

Superorder Peracarida

Order Tanaidacea

Family Paratanaidae

Hargeria rapax

Order Isopoda

Family Anthuridae

Cyathura polita

Family Bopyridae

Probopyrus pandalicolaon
P. pugio

Family Idoteidae

Edotea montosa

Family Munnidae

Munna reynoldsi

Family Sphaeromidae

Cassidinidea ovalis

Order Mysidacea

Neomysis americana

Order Amphipoda

Family Aoridae

Grandidierella bonnieroides

Family Gammaridae

Cammarus mucronatus
C. palustris

Family Hyalidae

Parhyale hawaiensis

Family Melitidae

Melita nitida

Family Talitridae

Orchestia grillus
O. platensis
O. uhleri

[1] From Wiegert and Freeman, 1990.

Appendix 3. Selected List of Insect and Arachnid Families in Tidal Salt Marshes of the Southeastern Atlantic Coast [1]

Class Arachnida
- Order Pseudoscorpionida
  - Family Cheliferae
- Order Araneae
  - Family Dictynidae
  - Family Gnaphosidae
  - Family Clubionidae
  - Family Thomisidae
  - Family Salticidae
  - Family Pisauridae
  - Family Lycosidae
  - Family Theridiidae
  - Family Araneidae
  - Family Tetragnathidae
  - Family Micryphantidae
- Order Acarina
  - Family Trombidiidae

Class Insecta
Subclass Apterygota
- Order Collembola
  - Family Isotomidae
  - Family Entomobryidae
  - Family Sminthuridae
  - Family Exopterygota

Subclass Terygota
- Order Odonata
  - Family Aeschnidae
  - Family Libellulidae
  - Family Agrionidae
- Order Dermaptera
  - Family Forficulidae
- Order Orthoptera
  - Family Mantidae
  - Family Gryllidae
  - Family Tetrigidae
  - Family Acrididae
  - Family Tettigoniidae
- Order Hemiptera
  - Family Scutellaridae
  - Family Corimelaenidae
  - Family Pentatomidae
  - Family Coreidae
  - Family Neididae
  - Family Lygaeidae
  - Family Reduviidae

Family Nabidae
Family Miridae
Family Hydrometridae
Family Mesoveliidae
Family Gerridae
Family Saldidae
Family Belostomatidae
Family Corixidae
Order Homoptera
Family Cicadidae
Family Membracidae
Family Cercopidae
Family Cicadellidae
Family Cixiidae
Family Derbidae
Family Acanaloniidae
Family Dictyopharidae
Family Issidae
Family Delphacidae
Family Aphidae
Family Pysyllidae
Family Pseudococcidae
Family Diaspididae
Order Thysanoptera
Family Thripidae
Family Phloeothripidae
Endopterygota
Order Neuroptera
Family Mantispidae
Family Myrmeleonidae
Order Coleoptera
Family Cicindellidae
Family Dytiscidae
Family Gyrinidae
Family Hydrophyllidae
Family Staphylinidae
Family Scarabaeidae
Family Eucinetidae
Family Buprestidae
Family Elateridae
Family Cantharidae
Family Lampyridae
Family Cleridae
Family Melyridae
Family Mordellidae
Family Oedemeridae
Family Languriidae
Family Coccinellidae
Family Orthoperidae
Family Chrysomelidae

Family Phalacridae
Family Anthribidae
Family Curculionidae
Order Lepidoptera
Family Pyralidae
Family Noctuidae
Family Lycaenidae
Family Hesperiidae
Order Diptera
Family Tipulidae
Family Culicidae
Family Ceratopogonidae
Family Chironomidae
Family Sciaridae
Family Tabanidae
Family Asilidae
Family Empididae
Family Dolichopodidae
Family Phoridae
Family Pipunculidae
Family Conopidae
Family Otitidae
Family Platystomatidae
Family Tephritidae
Family Sciomyzidae
Family Ephydridae
Family Chamaemyiidae
Family Chloropidae
Family Anthomyiidae
Family Muscidae
Family Callophoridae
Family Sarcophagidae
Order Hymenoptera
Family Braconidae
Family Ichneumonidae
Family Eulophidae
Family Encyrtidae
Family Eupelmidae
Family Pteromalidae
Family Eurytomidae
Family Chalicididae
Family Elasmidae
Family Cynipidae
Family Scelionidae
Family Formicidae
Family Chrysididae
Family Tiphiidae
Family Multillidae
Family Vespidae
Family Pompilidae

Family Sphecidae
Family Halictidae
Family Apidae

[1] From Wiegert and Freeman, 1990.

Appendix 4. Selected List of Fish Found in Estuarine Waters Near Sapelo Island [1]

Subphylum Vertebrata
Superclass Pisces
Class Elasmobranchiomorphi
Order Lamniformes
- Family Carcharhinidae
  - *Carcharhinus acronotus* (Poey)—Blacknose shark
  - *Carcharhinus isodon* (Valenciennes)—Finetooth shark
  - *Carcharhinus limbatus* (Valenciennes)—Blacktip shark
  - *Carcharhinus plumbeus* (Nardo)—Sandbar shark
  - *Galeocerdo cuvier* (Peron and Lesueur)—Tiger shark
  - *Negaprion brevirostris* (Poey)—Lemon shark
- Family Sphyrnidae
  - *Sphyrna lewini* (Griffith and Smith)—Scalloped hammerhead shark

Order Rajiformes
- Family Rajidae
  - *Raja eglanteria* Bosc—Clearnose skate
- Family Dasyatidae
  - *Dasyatis americana* (Hildebrand and Schroeder)--southern stingray
  - *Dasyatis sabina* (Lesueur)—Atlantic stingray
  - *Gymnura micrura* (Schneider)—Smooth butterflly ray

Class Osteichthyes

Order Acipenseriformes
- Family Acipenseridae
  - *Acipenser oxyrhyncus* Mitchill—Atlantic sturgeon

Order Lepisosteiformes
- Family Lepisosteidae
  - *Lepisosteus osseus* (Linnaeus)—Longnose gar

Order Elopiformes
- Family Elopidae
  - *Elops saurus* Linnaeus--ladyfish
  - *Megalops atlanticus* Valenciennes—Tarpon

Order Anguilliformes
- Family Anguillidae
  - *Anguilla rostrata* (Lesueur)—American eel
- Family Ophichthidae
  - *Myrophis punctatus* Lütken--speckled worm eel

Order Clupeiformes
- Family Clupeidae
  - *Brevoortia smithi* Hildebrand--yellowfin menhaden
  - *Brevoortia tyrannus* (Latrobe)—Atlantic menhaden
  - *Dorosoma cepedianum* (Lesueur)—gizzard shad
  - *Dorosoma petenense* (Günther)—threadfin shad
  - *Harengula jaguana* Poey--scaled sardine
  - *Opisthonema oglinum* (Lesueur)—Atlantic thread herring
- Family Engraulidae

Anchoa hepsetus (Linnaeus)—striped anchovy
Anchoa mitchilli (Valenciennes)—bay anchovy
Order Siluriformes
Family Ariidae
Bagre marinus (Mitchill)—Gafftopsail catfish
Arius felis (Linnaeus)—hardhead catfish
Order Gadiformes
Family Gadidae
Urophycis floridana (Bean and Dresel)—Southern hake
Urophycis regia (Walbaum)—Spotted hake
Family Ophidiidae
Ophidion marginatum (DeKay)—striped cusk-eel
Order Batrachoidiformes
Family Batrachoididae
Opsanus tau (Linnaeus)—oyster toadfish
Order Atheriniformes
Family Belonidae
Strongylura marina (Walbaum)—Atlantic needlefish
Family Cyprinodontidae
Cyprinodon variegatus Lacepède--sheepshead minnow
Fundulus confluentus Goode and Bean--marsh killifish
Fundulus diaphanus (Lesueur)--banded killifish
Fundulus heteroclitus (Linnaeus)—mummichog
Fundulus luciae (Baird)—spotfin killifish
Fundulus majalis (Walbaum)--striped killifish
Lucania parva (Baird and Girard)—rainwater killifish
Family Poeciliidae
Gambusia affinis (Baird and Girard)—western mosquitofish
Heterandria formosa Agassiz—Least killisfish
Poecilia latipinna (Lesueur)—sailfin molly
Family Atherinidae
Membras martinica (Valenciennes)—rough silverside
Menidia beryllina (Cope)—inland silverside
Menidia menidia (Linnaeus)—Atlantic silverside
Order Gasterosteiformes
Family Syngnathidae
Syngnathus fuscus Storer—Northern pipefish
Syngnathus louisianae Günther--chain pipefish
Order Scorpaeniformes
Family Scorpaenidae
Scorpaena plumieri Bloch--spotted scorpionfish
Family Triglidae
Prionotus evolans (Linnaeus)—striped searobin
Prionotus tribulus Cuvier--bighead searobin
Order Perciformes
Family Centropomidae
Centropomus undecimalis (Bloch)—common snook
Family Serranidae
Centropristis philadelphica (Linnaeus)—Rock sea bass

Centropristis striata (Linnaeus)—black sea bass
Diplectrum formosum (Linnaeus)—Sand perch
Mycteroperca microlepis (Goode and Bean)—gag
Family Pomatomidae
Pomatomus saltatrix (Linnaeus)—bluefish
Family Carangidae
Caranx crusos (Mitchill)—Blue runner
Caranx hippos (Linnaeus)—Crevalle jack
Caranx latus Agassiz--horse-eye jack
Chloroscombrus chrysurus (Linnaeus)—Atlantic bumper
Oligoplites saurus (Schneider)—leatherjacket
Selene vomer (Linnaeus)—lookdown
Trachinotus carolinus (Linnaeus)—Florida pompano
Trachinotus falcatus (Linnaeus)—permit
Trachinotus goodei Jordan and Evermann—Palometa
Family Lutjanidae
Lutjanus griseus (Linnaeus)—gray snapper
Lutjanus synagris (Linnaeus)—lane snapper
Family Gerreidae
Diapterus auratus Ranzani--Irish pompano
Diapterus plumieri (Cuvier)—striped mojarra
Eucinostomus argenteus Baird and Girard--spotfin mojarra
Family Haemulidae
Orthopristis chrysoptera (Linnaeus)--pigfish
Family Sparidae
Archosargus probatocephalus (Walbaum)--sheepshead
Lagodon rhomboides (Linnaeus)—pinfish
Stenotomus chrysops (Linnaeus)—scup
Family Sciaenidae
Bairdiella chrysoura (Lacepède)—silver perch
Cynoscion nebulosus (Cuvier)—spotted seatrout
Cynoscion nothus (Holbrook)—silver seatrout
Cynoscion regalis (Bloch and Schneider)—weakfish
Larimus fasciatus Holdbrook--banded drum
Leiostomus xanthurus Lacepède--spot
Menticirrhus littoralis (Holbrook)—gulf kingfish
Menticirrhus saxatilis (Bloch and Schneider)--northern kingfish
Micropogonias undulatus (Linnaeus)--Atlantic croaker
Pogonias cromis (Linnaeus)—black drum
Sciaenops ocellatus (Linnaeus)—red drum
Stellifer lanceolatus (Holbrook)—star drum
Family Mugilidae
Mugil cephalus Linnaeus--striped mullet
Mugil curema Valenciennes--white mullet
Family Ephippidae
Chaetodipterus faber (Broussonet)—Atlantic spadefish
Family Uranoscopidae
Astroscopus y-graecum (Cuvier)—southern stargazer
Family Blenniidae

Chasmodes bosquianus (Lacepède)—striped blenny
Hypsoblennius hentz (Lesueur)—feather blenny
Hypsoblennius ionthas (Jordan and Gilbert)—freckled blenny
Family Eleotridae
Dormitator maculatus (Bloch)—fat sleeper
Family Gobiidae
Gobionellus boleosoma (Jordan and Gilbert)—darter goby
Gobionellus oceanicus (Girard)—highfin goby
Gobiosoma bosc (Lecepède)—naked goby
Gobiosoma ginsburgi Hildebrand and Schroeder--seaboard goby
Family Stromateidae
Peprilus alepidotus (Linnaeus)—harvestfish
Peprilus triacanthus (Peck)—butterfish
Order Pleuronectiformes
Family Bothidae
Ancylopsetta quadrocellata Gill--ocellated flounder
Citharichthys spilopterus Gunther--bay whiff
Etropus crossotus Jordan and Gilbert--fringed flounder
Etropus rimosus Goode and Bean--gray flounder
Paralichthys albigutta Jordan and Gilbert--Gulf flounder
Paralichthys dentatus (Linnaeus)—summer flounder
Paralichthys lethostigma Jordan and Gilbert--southern flounder
Scophthalmus aquosus (Mitchill)—windowpane
Family Soleidae
Symphurus plagiusa (Linnaeus)—blackcheek tonguefish
Trinectes maculatus (Bloch and Schneider)—hogchoker
Order Tetraodontiformes
Family Balistidae
Aluterus schoepfi (Walbaum)—orange filefish
Monacanthus hispidus (Linnaeus)—planehead filefish
Family Tetraodontidae
Chilomycterus schoepfi (Walbaum)—striped burrfish

[1] From Dahlberg, 1975.

Appendix 5. Reptiles and Amphibians Known or Likely to Occur on Sapelo Island [1]

Order Caudata: Salamanders

Family Ambystomatidae: Mole Salamanders

Ambystoma cingulatum—Flatwoods salamander
Ambystoma opacum—Marbled salamander
Ambystoma talpoideum—Mole salamander
Ambystoma tigrinum tigrinum—Eastern tiger salamander

Family Amphiumidae: Amphiumas

Amphiuma means—Two-toed amphiuma

Family Plethodontidae: Woodland Salamanders

Desmognathus auriculatus—Southern dusky salamander
Eurycea quadridigitata—Dwarf salamander
Plethodon glutinosus glutinosus—Slimy salamander
Pseudotriton montanus ssp.—Mud salamander
Pseudotriton ruber vioscai—Southern red salamander
Stereochilus marginatus—Many-lined salamander

Family Proteidae: Mud Puppies and Waterdogs

Necturus punctatus—Dwarf waterdog

Family Salamandridae: Newts

Notophthalmus viridescens—Newt

Family Sirenidae: Sirens

Pseudobranchus striatus striatus—Broad-striped dwarf siren
Siren intermedia intermedia—Eastern lesser siren
Siren lacertina—Greater siren

Order Anura: Frogs and Toads

Family Pelobatidae: Spadefoot Toads

Scaphiopus holbrooki—Eastern spadefoot toad

Family Ranidae: True Frogs

Rana areolata ssp.—Crawfish frog
Rana catesbeiana—Bullfrog
Rana clamitans clamitans—Bronze frog
Rana grylio—Pig frog
Rana heckscheri—River frog
Rana sphenocephala—Southern leopard frog
Rana virgatipes—Carpenter frog

Family Microhylidae: Narrowmouth Toads

Gastrophryne carolinensis—Eastern narrowmouth toad

Family Bufonidae: Toads

Bufo quercicus—Oak toad
Bufo terrestris—Southern toad

Family Hylidae: Tree, Cricket and Chorus Frogs

Acris gryllus gryllus—Southern cricket frog
Hyla cinerea—Green treefrog
Hyla crucifer—Spring peeper
Hyla femoralis—Pine woods treefrog
Hyla gratiosa—Barking treefrog

Hyla squirella—Squirrel treefrog
Hyla versicolor—Gray treefrog
Limnaoedus ocularis—Little grass frog
Pseudacris nigrita—Southern chorus frog
Pseudacris ornata—Ornate chorus frog

Order Testutinata: Turtles

Family Chelydridae: Snapping Turtles

Chelydra serpentina serpentina—Common snapping turtle

Family Kinosternidae: Mud Turtles

Kinosternon bauri palmarum—Striped mud turtle
Kinosternon subrubrum subrubrum—Eastern mud turtle
Sternotherus odoratus—Stinkpot

Family Emyidae: Box and Water Turtles

Chrysemys concinna concinna—Eastern river cooter
Chrysemys floridana floridana—Florida cooter
Chrysemys scripta scripta—Yellowbelly slider
Clemmys guttata—Spotted turtle
Deirochelys reticularia reticularia—Eastern chicken turtle
Malaclemys terrapin centrata—Carolina diamondback terrapin
Terrapene carolina carolina—Eastern box turtle

Family Trionychidae: Soft-shelled Turtles

Trionyx ferox—Florida softshell
Trionyx spiniferus asperus—Gulf Coast spiny softshell

Family Chelonidae: Sea Turtles

Caretta caretta caretta—Atlantic loggerhead

Order Crocodilia: Crocodilians

Family Alligatoridae: Alligators

Alligator mississippiensis—American alligator

Order Squamata

Suborder Lacertilia: Lizards

Family Iguanidae: Iguanid Lizards

Anolis carolinensis—Green anole
Sceloporus undulatus undulatus—Southern fence lizard

Family Scinidae: Skinks

Eumeces egregius similis—Northern mole skink
Eumeces fasciatus—Five-lined skink
Eumeces inexpectatus—Southeastern five-lined skink
Eumeces laticeps—Broad-headed skink
Scincella lateralis—Ground skink

Family Teidae: Whiptails

Cnemidophorus sexlineatus sexlineatus—Six-lined racerunner

Family Anguidae: Lateral-fold Lizards

Ophisaurus attenuatus longicaudus—Eastern slender glass lizard
Ophisaurus compressus—Island glass lizard
Ophisaurus ventralis—Eastern glass lizard

Suborder Serpentes: Snakes

Family Colubridae

Carphophis amoenus amoenus—Eastern worm snake

Cemophora coccinea copei—Northern scarlet snake
Diadophis punctatus punctatus—Southern ringneck snake
Drymarchon corais couperi—Eastern indigo snake
Elaphe guttatta guttata—Corn snake
Elaphe obsoleta quadrivittata—Greenish rat snake
Farancia abacura abacura—Eastern mud snake
Farancia erytrogramma ssp.—Rainbow snake
Heterodon platyrhinos—Eastern hognose snake
Heterodon simus—Southern hognose snake
Lampropeltis calligaster rhombomaculata—Mole kingsnake
Lampropeltis getulus getulus—Eastern kingsnake
Lampropeltis triangulum elapsoides—Scarlet kingsnake
Masticophis flagellum flagellum—Eastern coachwhip
Nerodia cyclopion floridana—Florida green water snake
Nerodia erythrogaster erythrogaster—Redbelly water snake
Nerodia fasciata fasciata—Banded water snake
Nerodia taxispilota—Brown water snake
Opheodrya aestivus—Rough green snake
Pituophis melanoleucus ssp.—Pine snake
Regina rigida rigida—Glossy crayfish snake
Rhadinaea flavilata—Pine woods snake
Seminatrix pygaea—Black swamp snake
Storeria dekayi—Brown snake
Storeria occipitomaculata—Redbelly snake
Thamnophis sirtalis sirtalis—Eastern garter snake
Thamnophis sauritus sauritus—Eastern ribbon snake
Virginia striatula—Rough earth snake
Virginia valeriae valeriae—Eastern earth snake
Coluber constrictor priapus—Southern black racer
Tantilla coronata—Southeastern crowned snake

Family Viperidae: Vipers

Agkistrodon contortrix contortrix—Southern copperhead
Agkistrodon piscivorus ssp.—Cottonmouth
Crotalus adamanteus—Eastern diamondback rattlesnake
Crotalus horridus atricaudatus—Canebrake rattlesnake
Sistrurus miliarius—Pygmy rattlesnake

Family Elapidae: Coral Snakes, Cobras

Micrurus fulvius fulvius—Eastern coral snake

[1] Johnson *et al.*, 1974; Sandifer *et al.*, 1980; Wiegert and Freeman, 1990.

Appendix 6. Birds of Sapelo Island [1]

Class Aves

Order Graviformes
  Family Gaviidae
    Gavia immer—Common loon
    Gavia stellata—Red-throated loon
Order Podicipediformes
  Family Podicipedidae
    Podiceps auritus—Horned grebe
    Podiceps nigricollis—Eared grebe
    Podilymbus podiceps—Pied-billed grebe
Order Procellariiformes
  Family Hydrobatidae
    Oceanites oceanicus—Wilson's storm petrel
    Puffinus gravis—Greater shearwater
    Puffinus griseus—Sooty shearwater
    Puffinus lherminieri—Audubon's shearwater
Order Pelecaniformes
  Family Sulidae
    Morus bassanus—Gannet
  Family Pelecanidae
    Pelecanus occidentalis—Brown pelican
  Family Phalacrocoracidae
    Phalacrocorax auritus—Double-crested cormorant
  Family Anhingidae
    Anhinga anhinga—Anhinga
Order Ciconiiformes
  Family Ardeidae
    Botaurus lentiginosus—American bittern
    Ixobrychus exilis—least bittern
    Ardea herodias--great blue heron, great white heron
    Casmerodius albus—great egret
    Egretta thula—snowy egret
    Egretta caerulea—little blue heron
    Egretta tricolor r)—Louisiana heron
    Bubulcus ibis—Cattle egret
    Butorides striatus—green-backed heron
    Nycticorax nycticorax--black-crowned night-heron
    N. violacea—yellow-crowned night-heron
  Family Threskiornithidae
    Eudocimus albus—white ibis
    Plegadis falcinellus—glossy Ibis
  Family Ciconiidae
    Mycteria americana--wood stork

Order Anseriformes
Family Anatidae
Aix sponsa—Wood duck
Anas acuta—Pintail
Anas americana—American wigeon/Baldpate
Anas clypeata—Shoveler/Northern shoveler
Anas crecca—green-winged teal
Anas discors—Blue-winged teal
Anas platyrhynchos—Mallard
Anas rubripes--American black duck
Anas strepera—Gadwall
Aythya affinis—Lesser scaup
Aythya americana—Redhead
Aythva collaris—Ring-necked duck
Aythya marila—Greater scaup
Aythya valisineria—Canvasback
Branta canadensis—Canada goose
Bucephala albeola—Bufflehead
Bucephala clangula—Common goldeneye
Lophodytes cucullatus—Hooded merganser
Melanitta fusca—White-winged scoter
Melanitta nigra—Black scoter
Melanitta perspicillata—Surf scoter
Mergus serrator—Red-breasted merganser
Oxyura iamaicensis—Ruddy duck
Order Falconiformes
Family Cathartidae
Coragyps atratus—black vulture
Cathartes aura--turkey vulture
Family Accipitridae
Accipiter cooperii—Cooper's hawk
Accipiter striatus—Sharp-shinned hawk
Buteo jamaicensis—Red-tailed hawk
Buteo lineatus—Red-shouldered hawk
Circus cyaneus—northern harrier
Pandion haliatus—Osprey
Haliaeetus leucocephalus--bald eagle
Family Falconidae
Falco sparverius—American kestrel
Falco columbarius—Merlin
Falco peregrinus--peregrine falcon
Order Galliformes
Family Cracidae
Ortalis vetula—Chachalaca
Family Meliagridae
Meliagris gallopavo—Wild Turkey

Order Gruiformes
    Family Rallidae
        Coturnicops noveboracensis—Yellow rail
        Fulica americana—American coot
        Gallinula chloropus—Common gallinule
        Laterallus jamaicensis—Black rail
        Porphyrula martinica—Purple gallinule
        Porzana carolina--sora
        Rallus elegans—King rail
        Rallus limicola—Virginia rail
        Rallus longirostis--clapper rail
Order Charadriiformes
    Family Charadriidae
        Charadrius alexandrinus—Snowy plover
        Charadrius melodus—Piping plover
        Charadrius semipalmatus—Semipalmated plover
        Charadrius vociferus--killdeer
        Charadrius wilsonia--Wilson's plover
    Family Haematopodidae
        Haematopus palliatus--American oystercatcher
    Family Recurvirostridae
        Himantopus mexicanus—black-necked stilt
        Recurvirostra americana--American avocet
    Family Scolopacidae
        Actitis macularia—spotted sandpiper
        Arenaria interpres—ruddy turnstone
        Calidris alba—Sanderling
        Calidris alpina—dunlin
        Calidris bairdii—Baird's sandpiper
        Calidris canutus—Red knot
        Calidris fusciollis—White-rumped sandpiper
        Calidris maritima—Purple sandpiper
        Calidris mauri—Western sandpiper
        Calidris melanotos—Pectoral sandpiper
        Calidris minutilla—least sandpiper
        Calidris pusilla—semipalmated sandpiper
        Capella gallinago—Common snipe
        Catoptrophorus semipalmatus—willet
        Limnodromus griseus—short-billed dowitcher
        Limnodromus scolopaceus—Long-billed dowitcher
        Limosa fedoa—Marbled godwit
        Numenius americanus—Long-billed curlew
        Numenius phaeopus—Whimbrel
        Philobela minor—American woodcock
        Pluvialis squatarola—Black-bellied plover
        Tringa melanoleuca—greater yellow legs
        Tringa flavipes—lesser yellowlegs
        Tringa solitaria—Solitary sandpiper
    Family Stericorariidae

Stercorarius parasiticus—Parasitic jaeger
Stercorarius pomarinus—Pomarine jaeger
Family Laridae
Chlidonias nigra)--black tern
Gelochelidon nilotica—gull-billed tern
Larus argentatus—Herring gull
Larus atricilla—Laughing gull
Larus delawarensis—Ring-billed gull
Larus marinus—Great black-backed gull
Larus philadelphia—Bonaparte's gull
Sterna antillarum—least tern
Sterna caspia Pallas--Caspian tern
Sterna forsteri—Forster's tern
Sterna hirundo—Common tern
Sterna maxima maxima Boddaert--royal tern
Sterna sandvicensis—Sandwich tern
Family Rhynchopidae
Rynchops niger--black skimmer
Order Columbiformes
Family Columbidae
Columba livia—Rock dove
Columbina passerina—Ground dove
Zenaida macroura—Mourning dove
Order Cuculiformes
Family Cuculidae
Coccyzus americanus—Yellow-billed cuckoo
Coccyzus erythropthalmus—Black-billed cuckoo
Order Strigiformes
Family Strigidae
Bubo virginianus—Great horned owl
Otus asio—Screech owl
Strix varia—Barred owl
Tyto alba—Barn owl
Order Caprimulgiformes
Family Caprimuligidae
Caprimulgus carolinensis—Chuck-will's-widow
Chordeiles minor minor—Nighthawk
Order Micropodiformes
Family Micropodidae
Chaetura pelagica—Chimney swift
Family Trochilidae
Archilochus colubris—Ruby-throated hummingbird
Order Coraciiformes
Family Alcedinidae
Megaceryle alcyon—belted kingfisher

Order Piciformes

Family Picidae

Centurus carolinus—Red-bellied woodpecker
Colaptes auratus—Common flicker
Dryocopus pileatus—Pileated woodpecker
Melanerpes erythrocephalus—Red-headed woodpecker
Picoides pubescens—Downy woodpecker
Picoides villosus—Hairy woodpecker
Sphyrapicus varius—Yellow-bellied sapsucker

Order Passeriformes

Family Tyrannidae

Contopus virens—Eastern wood pewee
Empidonax virescens—Acadian flycatcher
Myiarchus crinitus—Great crested flycatcher
Sayornis phoebe—Eastern phoebe
Tyrannus tyrannus—Eastern kingbird

Family Hirundindae

Hirundo rustica—Barn swallow
Iridoprocne bicolor—Tree swallow
Petrochelidon pyrrhonota—Cliff swallow
Progne subis —Purple martin
Stelgidopteryx ruficollis—Rough-winged swallow

Family Corvidae

Corvus ossifragus--fish crow
Corvus brachyrhynchos—Common crow
Cyanocitta cristata—Blue jay

Family Paridae

Parus bicolor—Tufted titmouse
Parus carolinensis—Carolina chickadee

Family Sittidae

Certhia familiaris—Brown creeper
Sitta canadensis—Red-breasted nuthatch
Sitta carolinensis—White-breasted nuthatch
Sitta pusilla—Brown-headed nuthatch

Family Troglodytidae

Cistothorus platensis—sedge wren
Cistothorus palustris--marsh wren
Thryothorus indovicianus—Carolina wren
Troglodytes aedon—House wren
Troglodytes troglodytes-Winter wren

Family Sylvidae

Polioptila caerulea—Blue-gray gnatcatcher
Regulus calendula—Ruby-crowned kinglet
Regulus satrapa—Golden-crowned kinglet

Family Turdidae

Catharus guttatus—Hermit thrush
Catharus ustulatus—Swainson's thrush
Dumetella carolinensis—Catbird
Hylocichla mustelina—Wood thrush

Mimus polyglottos—Mockingbird
Sialia sialis—Eastern bluebird
Toxostoma rufum—Brown thrasher
Turdus migratorius—Robin

Family Motacillidae
Anthus spinoletta—Water pipit

Family Bombycillidae
Bombycilla cedrorum—Cedar waxwing

Family Laniidae
Lanius ludovicianus—Loggerhead shrike

Family Sturnidae
Sturnus vulgaris—Starling

Family Vireonidae
Vireo flavifrons—Yellow-throated vireo
Vireo griseus—White-eyed vireo
Vireo olivaceus—Red-eyed vireo
Vireo solitarius—Solitary vireo

Family Parulidae
Dendroica caerulescens—Black-throated blue warbler
Dendroica coronata—Yellow-rumped warbler
Dendroica discolor—Prairie warbler
Dendroica dominica—Yellow-throated warbler
Dendroica magnolia—Magnolia warbler
Dendroica palmarum—Palm warbler
Dendroica petechia—Yellow warbler
Dendroica pinus—Pine warbler
Dendroica tigrina—Cape May warbler
Dendroica virens—Black-throated green warbler
Geothlypis trichas—Yellowthroat
Icteria virens—Yellow-breasted chat
Mniotilta varia—Black-and-white warbler
Parula americana—Northern parula
Protonotaria citrea—Prothonotary warbler
Seiurus aurocapillus—Ovenbird
Seiurus motacilla—Louisiana waterthrush
Seiurus noveboracensis—Northern waterthrush
Setophaga ruticilla—American redstart
Vermivora celata—Orange crowned warbler
Vermivora chresoptera—Golden-winged warbler
Vermivora pinus—Blue-winged warbler
Wilsonia citrina—Hooded warbler

Family Thraupidae
Piranga olivacea—Scarlet tanager
Piranga rubra—Summer tanager

Family Fringillidae
Cardinalis cardinalis—Cardinal
Guiraca caerulea—Blue grosbeak
Passerina ciris—Painted bunting
Passerina cyanea—Indigo bunting

Family Emberizidae

Ammospiza caudacuta—sharp-tailed sparrow
Ammospiza maritima—seaside sparrow
Aimophila aestivalis—Bachman's sparrow
Junco hyemalis—Dark-eyed junco
Melospiza georgiana—Swamp sparrow
Melospiza melodia atlantica—Song sparrow
Passerculus sandwichensis—Savannah sparrow
Passerella iliaca—Fox sparrow
Pipilo erythrophthalmus—Rufous-sided towhee
Pooecetes gramineus—Vesper sparrow
Spizella passerina—Chipping sparrow
Spizella pusilla—Field sparrow
Zonotrichia albicollis—White-throated sparrow

Family Icteridae

Agelaius phoeniceus—red-winged blackbird
Dolichonyx oryzivorus—Bobolink
Icterus galbula—Northern oriole
Icterus spurius—Orchard oriole
Molothrus ater—Brown-headed cowbird
Quiscalus major Vieillot--boat-tailed grackle
Quiscalus quiscula—Common grackle
Sturnella magna—Eastern meadowlark

[1] From "Birds of Sapelo Island," Georgia DNR.

Appendix 7. Mammals Known or Likely to Occur on Sapelo Island [1]

Class Mammalia

Order Marsupialia

Family Didelphiidae

Didelphis marsupialis—Opossum

Order Insectivora

Family Soricidae

Blarin brevicauda—Short-tailed shrew

Cryptotis parva parva (Say)—least shrew

Family Talpidae

Scalopus aquaticus howelli (Jackson)—eastern mole

Order Chiroptera

Family Vespertilionidae

Myotis austroriparius—Southeastern myotis

Myotis lucifugus lucifugus—Little brown myotis

Pipistrellus subflavus subflavus—Eastern pipistrelle

Eptesicus fuscus fuscus—Big brown bat

Lasiurus borealis borealis—Red bat

Lasiurus cinereus cinereus—Hoary bat

Lasiurus intermeditius floridanus—Northern yellow bat

Lasiurus seminolus—Seminole bat

Nycticeius humeralis humeralis—Evening bat

Plecotus rafinesquii macrotis—Rafinesque's big-eared bat

Family Molossidae

Tadarida brasiliensis cynocephala—Brazilian free-tailed bat

Order Primates

Family Hominidae

Homo saplens L.--human

Order Lagomorpha

Family Leporidae

Sylvilagus palustris palustris (Bachman)—marsh rabbit

Order Rodentia

Family Sciuridae

Sciurus carolinensis—Gray squirrel

Family Muridae

Microtus pennsylvanicus pennsylvanicus (Ord)—meadow vole

Mus musculus—House mouse

Oryzomys palustris palustris (Harlan)—marsh rice rat

Peromyscus gossypinus gossypinus (LeConte)—cotton mouse

Sigmodon hispidus hispidus Say and Ord--cotton rat

Rattus norvegicus norvegicus (Berkenhout)—Norway rat

Rattus rattus—Roof rat, Black rat

Order Carnivora

Family Procyonidae

Procyon lotor solutus Nelson and Goldman--raccoon

Lutra canadensis lataxina F. Cuvier--river otter

Mustela vison lutensis (Bangs)—mink

Order Artiodactyla
  Family Suidae
    Sus scrofa domesticus—Domestic hog
  Family Cervidae
    Odocoileus virginianus virginianus (Zimmerman)—white-tailed deer
  Family Bovidae
    Bostaurus—Cow
Order Xenarthra
  Family Dasypodidae
    Dasypus novemcinctus—Nine-banded armadillo
Order Sirenia
  Family Trichechidae
    Trichechus manatus latirostris—Florida manatee/West Indian manatee
Order Cetacea
  Family Delphinidae
    Tursiops truncatus (Montague)—bottle-nosed dolphin

[1] Johnson *et al.*, 1974; Sandifer *et al.*, 1980; Wiegert and Freeman, 1990.

Appendix 8. List of selected publications from the University of Georgia Marine Institute

(Collected reprint volume and contribution numbers in parentheses)

Alberts, J.J., Ertell, J.R., and Case, L. 1990. Characterization of organic matter in rivers of the southeastern United States. Verhandlungen Internationale Vereinigung Limnologie 24:260-262. (22-638)

Alberts, J.J. and Filip, Z. 1989. Sources and characteristics of fulvic and humic acids from a salt marsh estuary. Science of the Total Environment 81/82:353-361. (21-620)

Alberts, J.J. and Filip, Z. 1994. Effect of organic solvent pre-extraction of source substrates on elemental composition, Fourier Transform Infrared spectra and copper binding in estuarine humic and fulvic acids. In: N. Senesi and T.M. Miano, editors. *Humic Substances in the Global Environmental and Implications on Human Health.* Elsevier Science B.V., p. 781-790. (712)

Alberts, J.J. and Filip, Z. 1994. Humic substances in rivers and estuaries of Georgia, USA. Trends in Chemical Geology 1:143-162. (751)

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