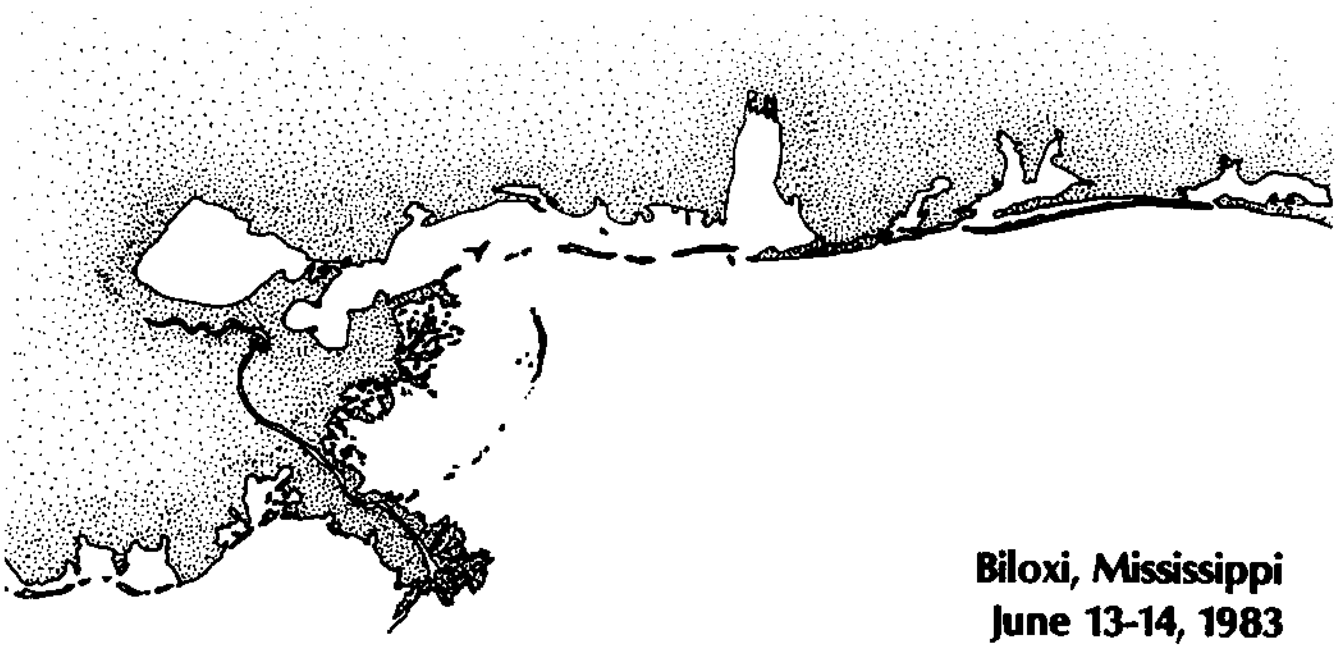
proceedings of the

Northern Gulf of Mexico Estuaries and Barrier Islands Research Conference



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Proceedings of the
NORTHERN GULF OF MEXICO ESTUARIES AND BARRIER ISLANDS RESEARCH CONFERENCE

Edited by
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PREFACE

On the 13th and 14th of June 1983 over one hundred and forty individuals participated in a research conference dealing with the barrier islands and estuaries of the northern Gulf of Mexico. This multi-disciplinary conference was initiated by the Coastal Field Research Laboratory, Gulf Islands National Seashore and by the Natural Science Division, National Park Service, Southeast Regional Office, and also sponsored by the Mississippi Bureau of Marine Resources, the Mississippi Sea Grant Advisory Service, Gulf Coast Research Laboratory, and the Mississippi-Alabama Sea Grant Consortium.

Directed towards professionals, planners, decision-makers, and citizens the conference focused on Northern Gulf of Mexico barrier island and estuarine resource, resource management, coastal zone management, and research issues. Papers were presented by 42 individuals on barrier island and estuarine resources, resources management, fish and shellfish resources, terrestrial resources, water resources, energy exploration and development, environmental asessment, and the future of science, research, and resources management as we approach the year 2000 from 1984. The authors were representative of academia, industry, and government.

The conference was held at the Gulf Coast Research Laboratory J.L. Scott Marine Education Center were the formal presentations took place. Posters were displayed at the William M. Colmer Visitor Center, Gulf Islands National Seashore on Monday evening of the Conference by David Brannon of NASA's Earth Resources Laboratory, Julia and Thomas Lytle of Gulf Coast Research Laboratory, the U.S. Fish and Wildlife Service, Barry A. Vittor and Associates, Inc., and the U.S. National Park Service.

Stephen V. Cofer-Shabica,
Nancy B. Cofer-Shabica, and
Edwin W. Cake, Jr., Editors
Miami, FL, and Ocean Springs, MS
December 1983

ACKNOWLEDGEMENTS

No conference is the product of one or two persons. If the endeavor is successful, it is generally due to those behind the scenes who contribute much but remain nameless. For this conference, which we believe to have been successful, we wish to thank the following for giving much: Millie Spencer, Judy Crawford, Chris Korsmo, and Christian Wright of Ocean Springs for the delicious baked "goodies" that we enjoyed on the first day of the Conference; Susie Saucier and LuJuana Henley of the Mississippi Sea Grant Advisory Service who labored long at the registration desk, helped with the pre-Conference correspondence, and typed the Proceeding's abstracts; Sue Skinner of Gulf Islands National Seashore who organized the morning coffee breaks and assisted at the registration desk; Gerald Corcoran and his staff of the Gulf Coast Research Laboratory J.L. Scott Marine Education Center for making sure that everything flowed smoothly; Jim Wood of the National Park Service, Southeast Regional Office, and Larry Austin and Hermin Hemmitt of Biscayne National Park for editorial and typing assistance.

We thank Rick Leard of the Mississippi Bureau of Marine Resources, Harold Howse of the Gulf Coast Research Laboratory, and David Veal of the Mississippi Sea Grant Advisory Service for their institutions' sponsorships.

Special thanks are due June Erickson of the Coastal Field Research Laboratory who was responsible for the Abstracts and Programming, and the organization and transcription of the Conference tapes; Molly Shabica and Rachel Shabica of Lincoln School, Rhode Island, for their assistance during the Conference discussions and at Registration; Jay Gogue of the Natural Science Division, Southeast Regional Office, National Park Service for providing the catalyst for making the Conference possible; and all of the speakers who took time from often hectic schedules to prepare their excellent contributions. To all, thank you.

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INTRODUCTION

This conference brings together much of the current knowledge of the barrier islands and estuaries of the Northern Gulf of Mexico. We had originally planned on simply publishing the Abstracts and Discussions of the Conference. However, we found that a substantial body of information was presented and thus encouraged individuals to submit formal papers. Forty-four presentations were made during the Conference. Of those, fifteen papers were prepared and are included, along with the Abstracts, in the Proceedings. The volume is divided into four sections: *ESTUARIES, OFFSHORE PETROLEUM EXPLORATION AND DEVELOPMENT, BARRIER ISLANDS, and RESOURCES MANAGEMENT*. Following each of the sections are the session Discussions. These were taped, transcribed, and proofed. Only those changes which improved clarity were permitted.

Beyond the spectrum of current knowledge, the Conference also made us aware of informational gaps in that knowledge. Information that resource managers need to make enlightened decisions about the future of this region and its resources. With our present and future studies we need to be able to better predict the future. We need to know and understand the trends that are leading us to future coastal issues. And then, finally, to go beyond our predictive ability to guide ourselves to where we should be and to how things should be in the twenty-first century.

ESTUARIES

Estuaries, including coastal bays, sounds, and lagoons, provide productive and stable habitats for the reproduction, growth, production, and ultimately the survival of commercially, recreationally, and biologically important animal and plant species. Mississippi Sound, identified as part of Gordon Gunter's "Fertile Fisheries Crescent" has one of the most diverse and productive of benthic faunas. We also find that the surf-zone ecosystem of the barrier islands is critical to certain fin fish. Within the estuary are the marshes, more productive than Iowa corn fields, that serve as feeding areas, migratory routes, and nursery grounds for vertebrates and invertebrates alike. We are aware of a consistent decline in the ground fish stocks of the Northern Gulf of Mexico. Is this a natural, cyclic phenomenon, or is something going wrong in the ecosystem? Pollution and human-related modifications of the estuary may and do endanger portions of the ecosystem. Heavy metal pollution of bay sediments and organisms reflect the industrialization and urbanization of our coasts. Early warning systems with indicator organisms that allow us to monitor the health of the estuary have been developed. Physical models of dredging activities and pollution distribution and transport help in land-use planning and decision making. We need to strengthen and comply with Federal and state resource protection statutes concerning coastal barriers, their adjacent estuaries, and the faunas and floras that depend thereon. Cake poignantly summerizes this intimate, natural resource relationship:

"NO COASTAL BARRIERS, NO WETLANDS, NO SEAFOOD."

COASTAL BARRIERS AND SHELLFISH: THE RELATIONSHIPS BETWEEN COASTAL BARRIERS OF THE GULF OF MEXICO AND THE CRUSTACEAN AND MOLLUSCAN SHELLFISH THAT INHABIT AND DEPEND ON THE ESTUARIES BOUNDED BY THOSE BARRIERS

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ABSTRACT Coastal barriers of the northern Gulf of Mexico are extremely important to the survival, growth, production, and reproduction of commercially and recreationally important species of crabs, shrimps, clams, mussels, oysters, scallops, and squid. The barriers along the Florida-to-Texas coast form the seaward boundary of bays, sounds, and lagoons that in turn provide productive and stable habitats for the blue crab *Callinectes sapidus* Rathbun, the stone crab *Menippe mercenaria* (Say), several species of penaeid shrimps, *Penaeus* spp., two species of hard-shell or quahog clams, *Mercenaria* spp., several species of edible mussels, *Geukensia demissa granosissima* (Sowerby) and *Modiolus modiolus squamosus* Beauperthuy, the American oyster *Crassostrea virginica* (Gmelin), the bay scallop *Argopecten irradians concentricus*, and the brief thumbstall squid *Lolliguncula brevis* (Blainville). Important estuarine systems that are protected (fronted) by coastal barriers include (from east to west): Charlotte Harbor–Pine Island Sound–San Carlos Bay, Tampa Bay complex, Apalachicola Bay complex, St. Andrew Bay–St. Joseph Bay complex, Choctawatchee Bay–Santa Rosa Sound–Escambia Bay complex, Mobile Bay–Bon Secour Bay complex, Mississippi Sound, Chandeleur Sound–Breton Sound complex, Barataria Bay, Timbalier Bay–Terrebonne Bay complex, Galveston Bay complex, Matagorda Bay–Espiritu Santo Bay–San Antonio Bay complex, Aransas Bay–Redfish Bay–Corpus Christi Bay complex, and the Laguna Madre–Baffin Bay complex.

Coastal barriers enclose and protect the nearshore and inshore estuaries upon which these shellfish species depend for all or part of their life cycles. The estuaries provide ideal habitats for extensive submerged and emergent grassbeds and marshes upon which crabs, shrimp, mussels, and scallops depend; they protect and promote the extensive oyster reefs and clam beds; and they serve as nursery grounds for numerous species of transient shellfish that inhabit the continental shelf as adults. The salinities of those estuarine waters provide the required environmental balance for rapid shellfish growth and in some cases the control of stenohaline predators and competitors of oysters and clams. The riverborne nutrients that are trapped by coastal barriers foster excellent shellfish growth and production. Coastal barriers prevent the destruction of shoreward shellfish beds by storm waves and currents and reduce the hazards of hydrocarbon pollution from offshore oil and gas activities and accidents. In the absence of those barriers, the production of crustacean and molluscan shellfish in the northern Gulf of Mexico would be insignificant.

Insular and peninsular lagoons and bayous on the mainland side of coastal barriers are often inhabited by transient or limited populations of crabs, oysters, quahog clams, and ribbed mussels. Those shellfish provide human visitors and terrestrial wildlife with food. Molluscan shell remains become important constituents of barrier sedimentary facies. In the absence of large sediment loads, relict shells and living oysters form extensive intertidal and supratidal barriers across the mouths of many rivers and bays in Florida, Louisiana, and Texas, including the 26-mile (42-km) long discontinuous barrier reef that separates the Atchafalaya and East Côte Blanche bays along the Louisiana coast from the open Gulf of Mexico.

This paper reviews the importance of coastal barrier islands and spits in the northern Gulf of Mexico to the crustacean and molluscan shellfish fisheries which dominate the commercial and sportfishing industries of that region. Without those barriers, most of those shellfisheries and the natural production upon which they depend would be nonexistent. It also reviews the federal statutes that protect the coastal zone, its barriers, and, therefore, its shellfish.

INTRODUCTION

Coastal barriers (islands, spits, headlands, peninsulas) are composed of sand and other loose sediments of terrigenous or marine origin that are transported, deposited, and reworked by waves, currents, storms, and winds (Leatherman 1979). In the Gulf of Mexico, barriers were created and evolved during the past 2,000 to 4,000 years from riverborne and nearshore marine sediments including the remains of marine and estuarine organisms. Coastal barriers usually separate a larger, deeper offshore body of water (in this case, the Gulf of Mexico) from a smaller, shallower shoreline water body (e.g., bays, lagoons, sounds) (Leatherman 1979). During this presentation I shall refer to those estuarine water bodies adjacent to, bounded by, and protected by coastal barrier islands and spits as barrier estuaries (e.g., bays, lagoons, sounds, etc.). The crustacean and molluscan shellfish species that inhabit and/or depend on those coastal barrier estuaries and the life history requirements that those barriers and estuaries provide are the subject of this review and discussion.

Leatherman (1979) presented an excellent synopsis of coastal barriers, the processes that form, modify, and destroy them, and their specific characteristics. Shepard and Wanless (1971) provided an excellent, detailed description and account of the Gulf of Mexico coast, its barriers, and indirectly, its coastal estuaries. Their account includes aerial photographs, nautical charts, and descriptions of the barrier-estuary ecosystems discussed in this presentation. Gunter (1967) reviewed the relationships between coastal estuaries and finfish and shellfish fisheries of the Gulf of Mexico. You are urged to consult those publications for additional information on the ecological, chemical, geological, and physical processes that control coastal barriers and their dependent, estuarine shellfish faunas.

Coastal geologists have vigorously debated the issues related to the origin(s) of Gulf coast barriers (see Fisher 1967, 1968; Hoyt 1967, 1968a, 1968b, 1970; Otvos 1970a, 1970b, Shepard 1960). I shall not reiterate those issues here, but simply list them for review purposes. According to those geologists, Gulf coast barriers probably formed 1) during or since the sea-level rise that followed the last glacial epoch, 2) as a result of coastal submergence of beach or dune ridges, or both, 3) as a result of the emergence of submarine shoals, 4) as complex spits on submerging shorelines in association with extensive river deltas, and/or 5) as a result of submergence of coastal headlands along drowned river valleys.

The purpose of this presentation is to review the relationships that exist between our coastal barrier islands and spits, the inshore estuaries that those barriers protect, and the crustacean and molluscan shellfish that reside therein and depend thereon. Throughout this conference we shall be discussing many concepts and problems that relate to coastal barrier and estuarine resources of the Gulf of Mexico. A synoptic review such as this is appropriate, therefore, for a common understanding of the barriers and estuaries and the processes and problems involved therewith. In my brief comments, I shall review our coastal barrier estuaries, the commercially and recreationally important and estuarine-dependent shellfish resources that inhabit or depend thereon, and the impact of human activities on those natural resources.

Coastal Barriers of the Gulf of Mexico

For the purpose of this presentation, coastal barriers of the Gulf of Mexico are separated into three categories on the basis of geomorphology: 1) barrier spits (peninsulas), 2) barrier islands, and 3) bay barriers. Barrier spits form in open water along the flanks of river deltas as a result of wave- and tide-induced littoral currents that transport sediments (usually sand) from the rivers to the spit-formation sites (Leatherman 1979). Saint Joseph Spit (including Cape San Blas) which forms the seaward boundary of St. Joseph Bay, Florida, and Fort Morgan Peninsula at the mouth of Mobile Bay, Alabama, are examples of the first category. Barrier islands are not connected to the mainland that they usually parallel; however, they depend on the same terrigenous deposits, meterological phenomena, and littoral currents as barrier spits for their existence. Florida's St. George Island and Mississippi's offshore barrier islands are examples of the second category. Bay and baymouth barriers connect or "bridge" headlands that protrude into the sea; they derive their sediments from eroded headlands and from the remains of marine and estuarine animals (e.g., oyster shells). Bay barriers are breched by temporary openings and inlets and they usually protect (front) lagoons and saltmarsh ecosystems (Leatherman 1979). The baymouth bars across Alligator Harbor, Florida, and Bay Joe Wise, Shell Island Bay (Lanaux Island), and Caminada Bay (Grand Isle), Louisiana, are examples of the third category.

Barrier islands can be further categorized on the basis of their origin as 1) unbuilt (emergent), longshore, submarine bars (de Beautmont—Johnson Theory: de Beaumont 1845, Johnson 1919); 2) spit growth and subsequent segmentation by inlets (Gilbert-Fisher Theory: Gilbert 1885, Fisher 1967); 3) mainland beach ridge submergence (Hoyt Theory: Hoyt 1967); and 4) delta island formation through deposition and reworking of major river deltas (Otvos 1970a, Leatherman 1979). Mississippi's barrier islands (Petit Bois, Horn, and East and West Ship islands) are perhaps examples of emergent, submarine bars; Gasparilla Island, Florida, is an example of a segmented barrier spit; St. Vincent Island, Florida, is an example of a submerged beach ridge; and the Chandeleur and Grand Terre islands of Louisiana are examples of reworked (Mississippi) river delta sediments. Cat Island, Mississippi, is perhaps an example of a composite barrier formed by a migrating emergent bar that has joined with a submerged mainland beach ridge.

Marine geologists recognize at least five important processes that affect and/or control coastal barriers: 1) the eustatic rise of sea level of approximately 1 foot (30 cm) per century at present, caused by melting of polar ice caps and glaciers; 2) winds, waves, and sea-level rise that cause island roll-over, landward migration, and shoreward displacement of sediments; 3) littoral sand transport by currents and waves that result in down-drift migration; 4) tropical storms and surges that result in the formation of inlets and overwash fans; and 5) winds, waves, currents, etc., that cause incidental or transient reshaping or shoreline modification and sediment reworking (Shepard and Wanless 1971, Leatherman 1979). These processes are continually at work as singular entities and as synergistic phenomena, but may not be apparent without prolonged geological and geographical studies. They are responsible, however, for present day coastal barriers, and indirectly, for many of the natural processes that take place in the estuaries protected by those coastal barriers.

Shepard (1960) examined the coastal barriers of the Gulf of Mexico and concluded the following: 1) They are composed of belts of sand between 20 and 60 feet (6.1 to 18.3 m) thick that are separated from the mainland by shallow bodies of water that are up to 15 miles (24 km) wide. 2) They are much longer than wide with lengths of up to 85 miles (137 km) and widths of up to 4.3 miles (7 km). 3) They have straight, seaward margins in contrast to lobate, crenulate, or cuspate lagoonal shorelines. 4) They have three major subdivisions: a) an outer beach with a broad berm, b) a belt of dunes (ridges), and c) an inner flat or salt marsh. 5) They often contain interior swales, swamps, marshes, ponds, and tidal lagoons between the dunes and ridges, as well as maritime pine and oak forests.

Shepard (1960) defined four types of coastal barriers with intermediate gradiations including 1) long, straight, or smoothly curving barriers such as the almost continuous islands along the Texas coast; 2) segmented chains of islands with intervening passes that are approximately as wide as the lengths of the islands that they separate such as Mississippi's offshore barrier islands; 3) cuspate islands or spits such as St. Joseph Spit (and Cape San Blas), Florida; and 4) lobate or crescenic islands and spits such as those small islands along the southwest coast of Florida.

According to Shepard (1960), Gulf coast barriers differ with respect to their separation from the mainland and include 1) those with intervening lagoons or sounds that have become largely filled with terrigenous sediments (e.g., Laguna Madre, Texas); 2) those joined to land at one or both ends and enclosing substantial water bodies (e.g., St. Joseph Spit, Florida), and 3) those true barrier islands with no mainland connection and which separate large coastal sounds from the open Gulf of Mexico (e.g., Mississippi's offshore barrier islands).

According to Tanner (1960), the Florida coastline (and therefore its barriers) are controlled by a large number of factors including, but not limited to, the following: 1) energy level (mean annual breaker height); 2) littoral drift rate; 3) equilibrium potential, 4) down-shore variability; 5) tectonic stability; 6) sea-level stability; 7) material (sediment) present; and 8) non-marine agencies (e.g., rivers). Tanner divided the Florida coastline into low (<10 cm), moderate (10 to 50 cm), and high (>50 cm) wave energy categories based on mean annual breaker heights. Florida's Gulf coast barriers occur primarily (80%) along the moderate wave-energy shoreline and secondarily (20%) along the low wave-energy shoreline. No barriers of consequence occur along the "zero energy" "oyster coast" between Tarpon Springs and the Ochlockonee River where salt marshes predominate over a drowned karst (limestone plateau) and where little or no sand is available for barrier development. Although barriers will form along shorelines with mean annual breaker heights of 6 to 100 cm, the presence or absence of a barrier is not necessarily an indication of energy level (except along a "zero energy" coast) (Tanner 1960).

In general, the entire Gulf of Mexico coastline is being drowned at a rate of approximately one foot (30 cm) per century due to eustatic sea-level rise, it is exposed to mean annual breaker (wave) heights of less than 10 cm per year; and its respective parts can be separated into a continuous barrier-coast (Texas), a discontinuous barrier and marsh coast (Florida, Alabama, and Mississippi), and a deltaic coast (Louisiana) along which marshes and marsh/mud islands predominate (Shepard and Wanless 1971).

Coastal barriers provide boundaries between the inshore estuaries and the open ocean environment with its higher wave energies and eroding currents, its higher salinity and numerous stenohaline predators (especially predators of sessile mollusks such as clams and oysters), and its reduced productivity potential. Through wind and water action they provide sediments, detritus, and dissolved nutrients to landward waters. Most barriers have tidal lagoons, fresh or brackish water ponds, and swales with wetland communities as well as other lowlands that trap, and eventually release precipitation to shallow aquifers and adjacent estuaries. These aquatic and wetland habitats provide nursery grounds, food and nutrient resources for all shellfish, and permanent habitats for oysters, mussels, and clams. With the exception of those barriers (or parts thereof) that contain high density, urban development (e.g., those along the lower west coast of Florida, Santa Rosa Island, Florida, Dauphin Island, Alabama, Grand Isle, Louisiana, and Galveston Island, Texas), the waters of barrier estuaries are of sufficient bacteriological and virological cleanliness to permit the direct harvest of molluscan shellfish (e.g., clams and oysters) for raw (half-shell) consumption.

Coastal Barrier Estuaries of the Gulf of Mexico

At least 18 major coastal barrier-estuarine complexes exist along the Gulf coast of the United States between Cape Sable, Florida, and the Rio Grande River (Table 1). Those 18 complexes are separated from the Gulf by approximately 1,036 linear miles (1,667 km) of barrier islands and spits that account for 56% of the approximate 1,840-linear mile (2,961-km) shoreline of the U.S. Gulf coast (NOAA National Ocean Survey Chart No. 411: Gulf of Mexico). Approximately 656 miles (1,055 km, 36%) of the remaining coastline is fronted by "zero" to low-wave energy wetlands (salt marshes and mangrove swamps) and include the Ten Thousand Island complex of Florida, the "big bend" area of the west Florida coastline (the "oyster coast") between Tarpon Springs and the Ochlockonee River, and the active and relict deltaic wetlands adjacent to the outlets of the Mississippi and Atchafalaya rivers in Louisiana. Gunter (1967) noted that 33 individual estuaries occurred along the Gulf coast and averaged 550 mi^2 (1,425 km^2) in area. The 18 estuaries considered in this presentation include all but a few of those and combine the remainder into bay complexes where they are functionally and geomorphologically connected (e.g., the Tampa Bay complex that includes Sarasota, Tampa, Old Tampa, Hillsborough, and Boca Ciega bays).

The bays, harbors, lagoons, and sounds that occur between coastal barriers and the mainland in the northern Gulf of Mexico are all estuaries (or parts thereof) according to Pritchard's (1967) definition: ***semi-enclosed coastal bodies of water which have free connections with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage.*** Pritchard (1967) separated estuaries into four categories based on geomorphology: 1) drowned river valleys; 2) fjord estuaries; 3) bar-built estuaries; and 4) estuaries produced by tectonic processes. All major river mouths qualify as drowned river valley estuaries (e.g., Pensacola Bay, Florida; Mobile Bay, Alabama; and Galveston and San Antonio bays, Texas). Because of its geomorphology, no fjord-type estuaries exist along the Gulf of Mexico coastline. The Apalachicola Bay complex (including St. George and St. Vincent sounds) and Mississippi Sound are notable examples of Pritchard's bar-built estuary category which is the most common type along the Gulf coastline. Although tectonic formations such as geosynclines are found along the Louisiana and Texas coasts, no true tectonic estuaries presently occur in the Gulf of Mexico. For the purpose of this review and discussion a composite category termed ***coastal barrier estuary*** includes all estuaries bounded by or separated from the Gulf of Mexico by barrier islands, spits, or both.

The largest estuarine system in the Gulf of Mexico is that dominated by the Mississippi and Mobile rivers and their tributaries. The coastal influence of those rivers extends from Mobile Bay to Atchafalaya Bay. Gunter (1963) described the coastal area from Mobile Bay, Alabama, to Port Arthur, Texas (420 linear miles, 777 km), as the "fertile fisheries crescent." Because of "zero" to low wave-energies and other subtle geomorphological processes (e.g., subsidence), only "crescent" bays and sounds immediately adjacent to the Mississippi River Delta (e.g., Chandeleur and Breton sounds and Barataria, Timbalier, and Terrebonne bays) that are fronted by coastal barriers are included in this discussion.

The entire coast of the State of Mississippi is fronted by one coastal barrier-estuary complex, the Mississippi Sound. That sound is separated from the Gulf of Mexico by six barrier islands (Dauphin Island, Alabama, and Petit Bois, Horn, East and West Ship, and Cat islands) with a linear beachfront of about 46 miles (74 km).

The Texas coast is fronted by 345 linear miles (555 km, 81% of the total coastline) of coastal barriers (and estuaries) including the longest continuous stretch of barrier islands in the world, the 273-mile (439-km) Matagorda–St. Joseph–Mustang–Padre islands complex. Padre and Mustang islands (which are joined except during storm tides and where artificial pass have been dredged) have a combined length of 132 miles (212 km), one of the longest barriers in the world. By comparison, the second longest, continuous stretch of coastal barriers is the North Carolina Outer Banks complex (221 miles, 356 km) that includes Bodie, Pea, Hatteras, Ocracoke, and Portsmouth islands, and Core, Shackleford, and Bogue banks (see Shepard and Wanless 1971).

Shellfish Fauna of Coastal Barrier Estuaries

Barrier estuaries provide the following life history requirements for their dependent shellfish inhabitants and transients: 1) They serve as nursery areas where abundant food supplies, microhabitats, and optimal physio-chemical conditions promote rapid growth and survival of larvae and juveniles, and maturation of adults. 2) They serve as traps (reservoirs) for waterborne nutrients, organic and inorganic chemicals, sediments, and detritus upon which shellfish and/or their food species depend. 3) They provide innumerable micro- and macrohabitats that serve as temporary and/or permanent locations for crustacean and molluscan shellfish, respectively. 4) They provide protection from extreme wave and current turbulence and resulting siltation (burial) associated with tropical storms and their surges. 5) They provide the geomorphic structure within which waters of favorable (reduced) salinities exist for proper shellfish osmoregulation and predator exclusion (especially for molluscan shellfish such as oysters).

The life cycle of the typical estuarine-dependent and vagile (motile) shellfish species reaches its ultimate development in coastal barrier estuaries. The general life history of species such as penaeid shrimps and the blue crab includes offshore spawning in high salinity, open Gulf waters (or in barrier inlets and passes), migration of larvae into the lower salinity estuaries, development and maturation of juvenile and adult stages within those estuaries, and ultimately, a seaward migration of juveniles and/or adults for mating and spawning (Gunter 1967). Sessile (nonmotile) species such as the American oyster and other bivalve mollusks spend their entire lives within a particular estuary. During planktonic development, however, the veliger larvae of bivalves may be transported via tidal currents into adjacent estuarine areas or into nearshore, open Gulf environments. Population distribution and productivity of nonmotile molluscan shellfish are controlled by the same estuarine features of food and nutrient availability, reduced predation from stenohaline predators, suitable substrates, reduced salinity, and "zero" or low wave and tidal energies as are the motile crustacean shellfish (Cake 1983).

The production of crustacean and molluscan shellfish in estuaries fronted and protected by coastal barriers is substantially greater than that in coastal areas that have no such barriers (with the possible exception of the "zero" wave energy environments along Louisiana's western (chenier) coast or Florida's drowned karst (or "oyster") coast. Geomorphic, hydrologic, and meterologic forces in those areas do not foster the growth and maintenance of nearshore coastal estuaries; however, their extensive salt-marsh ecosystems do promote excellent shrimp, crab, and bay scallop (Florida only) production.

Commercially and recreationally important shellfish species that reside in or depend on coastal barrier estuaries of the Gulf of Mexico for all or part of their life cycles include:

CRUSTACEANS

Callinectes sapidus Rathbun, the blue crab
Menippe mercenaria (Say), the stone crab
Penaeus aztecus Ives, the brown shrimp
Penaeus duorarum Burkenroad, the pink shrimp
Penaeus setiferus (Linnaeus), the white shrimp

MOLLUSKS:

Argopecten irradians concentricus (Say), the bay scallop
Crassostrea virginica (Gmelin), the American or eastern oyster
Geukensia demissa granosissima (Sowerby), the ribbed mussel
Macrocallista nimbosa (Lightfoot), the sunray venus clam
Mercenaria campechiensis (Gmelin), the southern quahog clam
Mercenaria mercenaria (Linné), the northern quahog clam
Mercenaria mercenaria texana (Dall), the Texas quahog clam
Modiolus modiolus squamosus Beauperthuy, the false tulip mussel
Rangia cuneata (Sowerby), the common rangia clam
Lolliguncula brevis (Blainville), the brief thumbstall squid

This list does not contain many of the shellfish species that have been eaten from time to time by epicurean shellfishermen or prehistoric, aboriginal Indians that once frequented the Gulf coast (Gibbons 1964, Gunter 1971, Percy 1973). (For additional information on the species listed above, please refer to Williams [1965], Andrews [1971], and Abbott [1974].)

Estuarine-dependent crustaceans are abundant throughout the northern Gulf of Mexico (Table 1; LaRoe 1980, Shrew et al. 1981, Beccasio et al. 1982). Blue crabs and penaeid shrimp utilize virtually every coastal estuary, but are concentrated in or immediately offshore of major barrier estuaries such as the Apalachicola Bay complex, the Mississippi Sound, the Mobile Bay–Bon Secour Bay complex, the entire coastline of Louisiana, and major Texas bays. Stone crabs are abundant along the lower Florida and Texas coasts, and either the same species or a very closely related (and presently undescribed) subspecies of *Menippe* is beginning to enter the crab fishery along the Alabama, Mississippi, and Louisiana coasts. In terms of monetary value, the penaeid shrimps are probably the most valuable shellfish species in the Gulf of Mexico.

Estuarine-dependent mollusks have discontinuous distribution and abundance patterns along the Gulf coast (Table 1). Major concentrations of the American oyster occur in the Apalachicola Bay complex, the Mississippi Sound, the Mobile Bay–Bon Secour Bay complex, the Barataria Bay complex, and the Galveston Bay complex. All Gulf coast barrier estuaries with appropriate (firm) substrates and suitable cultch materials (shells, reefs, rocks, etc.) will have viable oyster reefs, however, domestic wastes, diseases, high-salinity predators, water-flow modifications, and over-harvesting (or mismanagement ?) have reduced oyster abundance and/or usefulness to mankind or caused mass oyster mortalities, thereby reducing production in traditional oyster habitats (Cake 1983).

Southern quahog clams occur in moderate-to-high salinity waters of barrier estuaries along the Florida and Texas coasts. Northern quahog clams have been successfully introduced into the Tampa Bay complex, and Texas quahog clams are abundant along the flanks of the Mississippi River Delta (Chandeleur and Breton sounds, Barataria Bay). Sunray venus clams occur in the Tampa Bay complex, St. Joseph Sound, and St. Joseph Bay, Florida. Bay scallops are usually restricted to moderate-to-high salinity bays and sounds with low turbidity and large expanses of submerged seagrass beds, including St. Andrew and St. Joseph bays, the Tampa Bay complex, the Charlotte Harbor–Pine Island Sound complex, and elsewhere along the Florida coast where favorable conditions exist.

The ribbed and false tulip mussels are presently underutilized species. The ribbed mussel occurs in large concentrations throughout the northern Gulf of Mexico in *Spartina* salt marshes where it attaches via its byssus threads to the grass roots. The false tulip mussel, like the bay scallop, prefers nonturbid, moderate-to-high salinity bays and sounds such as St. Andrew and St. Joseph bays, where it occurs in large concentrations on submerged seagrass beds.

Several other underutilized mollusks warrant mention. The common rangia clam occurs in low-salinity areas of most estuaries of the north-central Gulf of Mexico. It is infrequently harvested for food or bait, but was formerly and extensively used by prehistoric aboriginal Indians (Percy 1973). The brief thumbstall squid is an excellent food and bait species that occurs in most barrier estuaries of the northern Gulf of Mexico (e.g., Mississippi Sound, Tampa Bay complex). Many other edible species of gastropods and bivalves occur in barrier estuaries of the Gulf but are presently underutilized including the whelks, *Busycon* spp., the Atlantic moon snail, *Polinices duplicatus* (Say), the southern oyster drill, *Thais haestoma* (Lamarck), and the pen shells, *Atrina* spp. (see Gunter 1971).

Current Status of Coastal Barrier Estuaries and Their Dependent Shellfish

Coastal barrier estuaries and their dependent shellfish faunas are adversely impacted by a number of human influences including agriculture, domestic, and industrial pollutants, and riverflow, wetland, and barrier modifications. Persistent, arthropod-specific pesticides from corpland runoff (e.g., DDT, Mirex®, etc.), toxic industrial chemicals (such as hydrocarbon residues and heavy metals that accumulate in estuarine sediments and food chains), and elevated levels of biochemical-oxygen-demanding wastes from various point and nonpoint sources kill large numbers of larval crustaceans, and to a lesser extent, larval mollusks. Numerous pollutants acting alone or synergistically reduce overall shellfish survival, growth, and production. Agriculture and domestic wastes (e.g., fertilizer runoff from croplands, sewage, etc.) may increase shellfish productivity if the receiving waters are not overloaded. Human pathogens from the domestic wastes will, however, contaminate filter-feeding (molluscan) shellfish thereby rendering them unfit for direct (raw) human consumption.

Riverine and estuarine modifications such as upstream dams and reservoirs, levees, dredged canals, filled wetlands, and artificial passes through barrier islands alter the natural current and tidal flow patterns and salinity regimes. The results of those modifications include the reduction of natural wetland and shellfish productivity, saltwater intrusion into normally intermediate salinity waters, and increased populations of high-salinity predators, competitors, and diseases (especially those that affect oysters). Adverse wetland modifications and concomitant productivity decreases and salinity alterations have reduced crab, shrimp, and oyster production in numerous Gulf of Mexico estuaries. Although of secondary importance, accidental and/or intentional vessel groundings, oil spills blow-outs, and other energy-related activities in coastal barrier estuaries may decrease shellfish production in the impacted areas. Other human activities including overharvesting and/or mismanagement of shellfish resources, especially when combined with the other negative impacts discussed earlier, have substantially reduced long-term shellfish production in some barrier estuaries.

Future Prospects for Coastal Barrier Shellfisheries

The overall outlook for coastal estuaries and their dependent shellfis faunas is not very optimistic at this time (1983). Human encroachmen coastal wetland and barrier modification and destruction, and eustati sea-level rise are slowly, but surely, decreasing the productivity and viabi ity of shellfisheries in our barrier estuaries. Federal and state resourc management officials are aware of the many problems that affect th dwindling shellfish resources, and slowly, but surely, progress is bein made to protect and perhaps restore them. Federal antipollution legisl tion including the Federal Water Pollution Control Act of 1972, the Clea Water Act of 1977, and amendments thereto may help to stem the risin "tide" of pollution in Gulf of Mexico estuaries. The National Coast Zone Management acts of 1972 and 1980 have provided the Gulf state with regulatory mechanisms to protect their coastal wetlands and resource The recent enactment of the Coastal Barrier Resources Act of 1982, how ever, may be the most important step that we as a nation have taken t protect the Gulf coast barriers and their adjacent estuaries. All or parts 30 Gulf coast barriers are now protected by federal or state statutes an regulations including the Coastal Barrier Resources Act (Table 1). At lea six barrier islands (or parts thereof) are designated as federal wilderne areas and protected by the U.S. Wilderness Act of 1964 including Florida Darling (Sanibel Island), Island Bay, Passage Key, and Cedar Keys Wilde ness areas, Mississippi's Petit Bois and Horn Island Wilderness, and Loui ana's Breton (and Chandeleur) Island Wilderness.

Beccasio et al. (1982) compiled a list of national and state wildli refuges, parks, and aquatic preserves along the Gulf coast of the Unit States. At least 40 of those facilities directly protect coastal barriers, th adjacent estuaries, or parts thereof. The State of Florida has an act marine and estuarine preservation system that now includes more th 15 aquatic preserves along its Gulf coast. Most notable among those a the Boca Ciega Bay—Pinellas County, Apalachicola Bay, St. Joseph Ba

TABLE 1.

Coastal barrier estuaries of the northern Gulf of Mexico. (East-to-west listing.)

Estuarine Complex	Coastal Barriers	Shellfish* Inhabitants
Marco Island	Cape Romano Isl.★	1, 2, 4, 7, 10, 11, 12
	Kice Isl.	
	Marco Isl.◆	
	Little Marco Isl.	
	Keewaydin Isl.★	
Estero Bay	Bonita Beach Isl.◆	1, 2, 4, 6, 7, 10, 11, 12
	Little Hickory Isl.◆	
	Long Isl.★	
	Black Isl.★	
	Estero Isl.◆	
Charlotte Harbor–Pine Island Sound–San Carlos Bay		1, 2, 4, 6, 7, 9, 10, 11, 12
San Carlos Bay	Sanibel Isl.●◆	
Pine Island Sound	Sanibel Isl.●◆	
	Captiva Isl.◆	
	N. Captiva Isl.★	
	Lacosta Isl. (Cayo Costa)★	
Charlotte Harbor	Lacosta Isl. (Cayo Costa)★	
	Gasparilla Isl.◆	
Gasparilla Sound	Gasparilla Isl.◆	
	Little Gasparilla Isl.●	
Lemon Bay	Don Pedro Isl.★	
	Bocilla Isl.★	
	Knight Isl.★	
	Peterson Isl.	
	Manasota Key★	
Tampa Bay		1, 2, 3, 4, 6, 7, 9, 10, 11, 12
Sarasota Bay	Casey Key★	
	Siesta (Sarasota) Key◆	
	Lido Key◆	
	Longboat Key◆	
	Anna Maria Key◆	
	Passage Key●	
Boca Ciega Bay–Tampa Bay	Egmont Key●	
	Mullet Key●	
	Cabbage & Shell Keys★	
	Long Key◆	
	Treasure Isl.◆	
	Sand Key◆	
St. Joseph Sound–Anclote Anchorage	Sand Key◆	
	Clearwater Beach Isl.◆	
	Caladesi Isl.●	
	Honeymoon Isl.●	
	Anclote Keys●	
Apalachicola Bay		1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12
Alligator Harbor	Alligator Harbor Spit◆	
St. George Sound	Dog Isl.★	
	St. George Isl.●◆	
Apalachicola Bay	St. George Isl.●◆	
	Little St. George Isl.●	
	St. Vincent Isl.●	
St. Vincent Sound	St. Vincent Isl.●	
Indian Lagoon	St. Vincent Isl.●	
	Indian Peninsula★	
St. Andrew Bay–St. Joseph Bay		1, 2, 3, 4, 6, 7, 8, 10, 11, 12
St. Joseph Bay	Cape San Blas★	
	St. Joseph Spit●◆	
St. Andrew Sound	Crooked Isl.●◆	
St. Andrew Bay	Shell Isl.●◆	
Choctawhatchee Bay–Santa Rosa Sound		1, 5, 6, 7, 10, 11
Choctawhatchee Bay	Moreno Point (Peninsula)★◆	
	Santa Rosa Isl.●◆	
Santa Rosa Sound (east)	Santa Rosa Isl.●◆	
Pensacola Bay–Santa Rosa Sound		1, 5, 6, 7, 10, 11
Santa Rosa Sound (west)	Santa Rosa Isl.●◆	
Pensacola Bay–Escambia Bay	Santa Rosa Isl.●◆	
Big Lagoon	Perdido Key●	
Perdido Bay	Perdido Key●	1, 6, 7, 10, 11
	Alabama Point	
Mobile Bay–Bon Secour Bay	Fort Morgan Peninsula★◆	1, 5, 7, 9, 10, 11
	Dauphin Isl.★◆	
Mississippi Sound	Dauphin Isl.★◆	1, 3, 5, 6, 7, 9, 10, 11, 12
	Petit Bois Isl.●	
	Horn Isl.●	
	E & W Ship Isl.●	
	Cat Isl.★	
Chandeleur Sound–Breton Sound	Chandeleur Isl.●	1, 2, 3, 5, 7, 9, 10, 11, 12
	Breton Isl.●	
Barataria Bay	Grand Terre Islands★	1, 3, 5, 7, 9, 10, 11, 12
	Grand Isle◆	
Timbalier Bay–Terrebonne Bay	East Timbalier Isl.	1, 5, 7, 9, 10, 11, 12
	Timbalier Isl.★	
	Isles Derniers★	
Galveston Bay	Bolivar Peninsula★◆	1, 2, 3, 5, 7, 9, 10, 11, 12
	Galveston Isl.◆	
	Follets Isl.★◆	
Matagorda Bay–Espiritu Santo Bay–San Antonio Bay		1, 2, 3, 5, 7, 9, 10, 11, 12
Matagorda Bay	Matagorda Peninsula★	
Espiritu Santo Bay	Matagorda Isl.	
San Antonio Bay	Matagorda Isl.	
Aransas Bay–Redfish Bay–Corpus Christi Bay		1, 2, 3, 5, 6, 7, 9, 10, 11, 12
Aransas Bay	St. Joseph (San Jose) Isl.★◆	
Redfish Bay	St. Joseph (San Jose) Isl.★◆	
	Mustang Isl.●◆	
Corpus Christi Bay	Mustang Isl.●◆	
Laguna Madre–Baffin Bay	Mustang Isl.●◆	1, 2, 3, 6, 7, 8, 9, 10, 11, 12
	N. Padre Isl.●◆	
	S. Padre Isl.★◆	
	Brazos Isl.★	

*Shellfish Species: 1 = American oysters; 2 = Southern quahogs; 3 = Northern/Texas quahogs; 4 = Sunray venus clams; 5 = Rangia clams; 6 = Bay scallops; 7 = Ribbed mussels; 8 = False tulip mussels; 9 = Brief squid; 10 = Penaeid shrimps; 11 = Blue crabs; 12 = Stone crabs

★Barriers (or parts) protected by the Coastal Barrier Resources Act.

●Barriers (or parts) protected by other federal/state statutes.

◆Barriers with extensive residential/urban development.

and St. Andrew Bay aquatic preserves. Federal protection of coastal barriers and estuaries is also extended under the National Seashore (NS) and National Wildlife Refuge (NWR) systems. Most notable of the coastal barriers protected by those systems are the St. Vincent (Island) NWR, Florida, the Gulf Island NS (Florida: Santa Rosa Island and Perdido Key; Mississippi: Petit Bois, Horn, and East and West Ship islands), Breton NWR (including the Chendeleur Islands), Louisiana, and Padre Island NS, Texas.

Mankind must reverse the trend of barrier estuary pollution and modification, as well as wetland destruction in general if the nation's estuarine-dependent shellfish resources are to flourish and continue to provide a renewable seafood heritage. The recent adage of "NO WETLANDS, NO SEAFOOD" should be expanded to imply "NO COASTAL BARRIERS, NO WETLANDS, NO SEAFOOD." Federal and state resource-protection statutes and management agencies must be strengthened and/or expanded with regard to coastal barriers, their adjacent estuaries, and the shellfish faunas that depend thereon. Attempts by various parties and agencies to weaken, delay, or negate barrier resource protection and water pollution control must be countered by continued vigilance, improved resource assessment and monitoring, and effective coastal zone management. As the protective statutes mentioned previously come up for congressional reauthorization, we must insist and ensure that those statutes are strengthened and expanded rather than weakened and reduced. The formal designation of the Louisiana Shoalwater Bay - Chandeleur Sound National Marine Sanctuary under the auspices of the U. S. Marine Protection, Research, and Sanctuaries Act of 1972 is a step in the right direction. (That designation has not been finalized at the time of this writing.)

Through his Horn Island logs, pen and ink sketches, and water color paintings, the noted Mississippi artist, Walter Inglis Anderson, constantly reminds us of our barrier island heritage and of our ultimate responsibility to discover the barriers' secrets and protect and enhance their natural resources including their dependent shellfish faunas (Anderson 1973). Anderson's appreciation and reverence for shellfish is evident in his unique blue crab illustrations and water colors. We should all spend long periods of time on coastal barriers like Walter Anderson did so as to appreciate their complexity and natural resources, instead of simply visiting them for brief periods during our hurried research.

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AN ANALYSIS OF MACROBENTHIC INVERTEBRATE ASSEMBLAGES IN RANGER LAGOON, HORN ISLAND, MISSISSIPPI

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ABSTRACT: A baseline survey of macrobenthic invertebrates of Ranger Lagoon, Horn Island, Mississippi, was conducted from February 1981 through January 1982. Geomorphological parameters were delineated through mapping and substrate analysis, while biological parameters were generated from monthly and quarterly sampling regimes. Hydrological parameters were determined monthly. Five macrohabitats were delineated from the total area of the lagoon: sand (70%), silt (24%), intertidal (5%), grassbeds (0.5%), and oyster reefs (0.5%). One hundred nine taxa from 10 phyla were collected and identified. Polychaetes and crustaceans dominated the fauna (34% each), followed by molluscs (19%), and miscellaneous species (13%). Ten numerically dominant species were determined from the data and those species were ubiquitous. Community structure analyses indicated that each macrohabitat was characterized by specific patterns of seasonal variations in density, diversity, richness, and equitability. The silt macrohabitat tended to exhibit low diversity while grassbeds showed high diversity. Numerical classifications of quarterly data produced 10 station/date groups and 9 species groups. These groups were categorized into 3 assemblages and 3 species-group types. Classification of assemblages and species-group types was based on geomorphology, hydrology, community structure, seasonality, and nodal analyses of the numerical classification.

Introduction

Horn Island is one of several barrier islands in the northern Gulf of Mexico designated as a wilderness area by the U.S. Congress (Public Law 95-625). Those areas are typically characterized by diverse floral and faunal components. Variations in life forms are enhanced by a vast system of insular waters. Approximately 63 ponds and lagoons are located on Horn Island; some are stable while others are ephemeral (Shabica and Watkins 1982).

This study emphasized the geomorphological and biological features of Ranger Lagoon, otherwise referred to as "Lagoon C" (Richmond 1962) and "Lagoon 28" (Shabica and Watkins 1982). Ranger Lagoon is a typical barrier island lagoon with a *Juncus-Spartina* shoreline and a diurnal tidal inlet connected to Mississippi Sound.

Several authors have conducted faunal studies on Horn Island (Moore 1961; Richmond 1962, 1968; McGraw 1980; Hase 1982), but no quantitative studies of insular benthos have been performed. In an effort to document the resources of insular waters, one of several recommendations proposed by the National Park Service was to investigate the invertebrate populations of the ponds and lagoons (Shabica and Watkins 1982).

Methods

Geomorphological features were determined prior to faunal sampling. A modification of the Plane Table method was utilized for mapping the shoreline of the lagoon and the macrohabitats within the lagoon ecosystem (Fig. 1). Sediment samples were taken from five macrohabitats and were analyzed using the procedures of Folk (1968) and Inman (1962). Hydrometer and dry-sieve procedures were performed in those analyses.

Two objectives were established for faunal sampling. First, a determination of community structure in each of five macrohabitats was made. That entailed the monthly collection of three samples from each macrohabitat (Fig. 1). Community structure of each macrohabitat was described by numerical dominance, faunal density, Shannon diversity, Margalef richness, and Pielou evenness (Odum 1971).

The second objective was to describe the spatial and seasonal distribution of benthos across the entire lagoon. Twen-

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ty quarterly samples were taken along seven transects extending from north to south shorelines and were appropriately spaced to ensure fair representation of each macrohabitat (Fig. 1). Cluster analyses were utilized to delineate faunal assemblages and provide evidence of assemblage seasonality. Transformed species counts (Log n+1) and normal standardizations were used in numerical classifications. Both normal and inverse analyses were made using the Bray-Curtis measure of dissimilarity and flexible sorting clustering strategy (Clifford and Stephenson 1975). Species with three occurrences or less were considered as rare species and were not included in cluster analyses. Analyses of constancy and fidelity were applied to interface the results of the two classifications (Boesch 1977). A modified box corer with a surface area of 225 cm^2 was used for all faunal sampling.

Hydrologic parameters were recorded at all monthly stations during each sampling period. Salinity (+0.5 ‰) was determined with an American Optical refractometer. Temperature (+0.6°C) and dissolved oxygen (±0.1 ppm) were recorded with a Yellow Springs Instrument Company Model 57 oxygen meter.

Results

Grain size analyses indicated that two major sediment types existed in Ranger Lagoon. First, a poorly-sorted, fine sand with a high percent of silt occurred in the silt and oyster macrohabitats. Second, a well-sorted sand with a high percent of medium-to-coarse sand grains occurred in the sand, intertidal, and grassbed macrohabitats. Based on that sediment characterization, the sand, intertidal, and grassbed macrohabitats are hereafter termed "consolidated macrohabitat" when certain analyses group those stations into one unit.

Hydrological parameters differed little between macrohabitats throughout the study period. Temperatures ranged from 13 to 31°C; salinities varied from 10 to 29‰; and, dissolved oxygen ranged from 3.2 to 10.4 ppm. Dissolved oxygen tended to be lowest in the silt macrohabitat and highest in the grassbeds. Temperatures were highest in summer and lowest in winter. Salinities increased gradually from a low in winter to a high in fall. Dissolved oxygen was lowest in summer and highest in winter.

One hundred nine taxa from 10 phyla were identified from the 25 stations sampled. Eighty taxa were identified to species. Polychaetes and crustaceans each comprised 34% of the species, followed by molluscs and miscellaneous species with 19%, and 13% of the sample population, respectively.

The abundance distributions of the 10 numerically dominant species illustrated tangible seasonal trends. Those trends were often similar between species. Ubiquitous species were very important in determining the overall community structure features in Ranger Lagoon.

The monthly community structure data illustrated distinct differences between silt, oyster, and consolidated macrohabitats. Silt macrohabitat densities and diversities were low and relatively stable year-round. Oyster macrohabitat densities and diversities were unstable; erratic fluctuations in those parameters coincided with population explosions of ***Corophium louisianum*** Shoemaker and ***Cymadusa compta*** Smith. On the other hand, the consolidated macrohabitat illustrated three seasons of faunal composition:

1. Moderate densities and very high diversity were present during late winter and spring;
2. Low densities and diversity were characteristic of summer; and,
3. Very high densities and moderate diversity were found in fall and early winter.

The normal classification of quarterly data produced 10 station/date groups. Those groups were categorized into three assemblages. The inverse classification of quarterly data produced nine species groups. Those groups were categorized into habitat-preferred species, seasonally restricted species, and ubiquitous species types. Cluster analyses also delineated another macrohabitat which was characterized by a sandy sediment and was restricted to an area adjoining the tidal inlet.

Analysis of constancy provided a better understanding of quarterly data. Assemblage 1 (all silt collections and summer

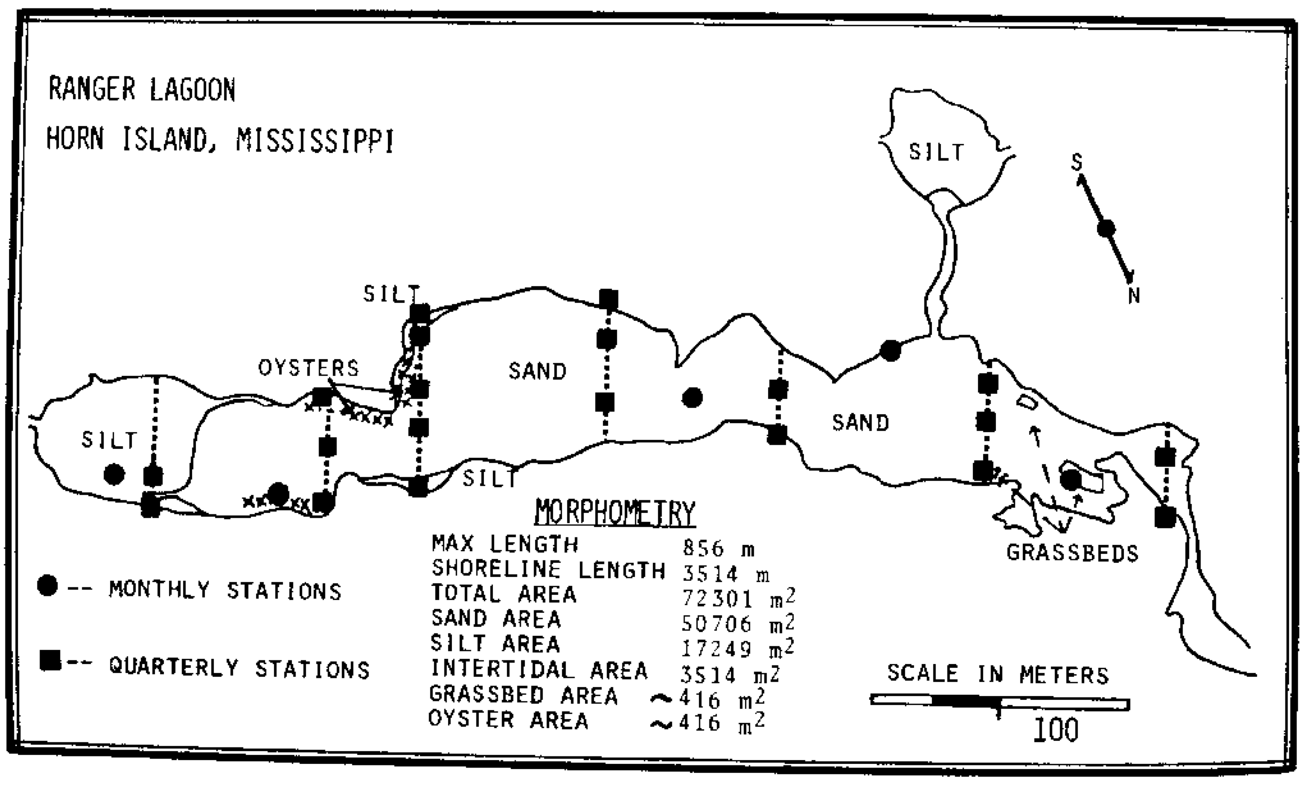

Fig. 1. Map of Ranger Lagoon, Horn Island, Mississippi, indicating morphometry and sample stations from February 1981 through January 1982.

collections from the consolidated macrohabitat) was characterized by the ubiquitous species and very low numbers of seasonally restricted species (Fig. 2). Assemblage 2 (consolidated macrohabitat from mid-winter through spring) was characterized by low to very high constancies of every species group with the exception of species group 5. Assemblage 3 (all oyster collections and fall collections for the consolidated macrohabitat) was best represented by habitat-preferred species and the ubiquitous group.

Fidelity analysis (Fig. 2) indicated very little species-group affinity for Assemblage 1, low to high affinities by all species groups for Assemblage 2, and strong affinities by the habitat-preferred and seasonally-restricted species for Assemblage 3.

Discussion

One of the most important observations from this study is that Ranger Lagoon is a faunistically heterogeneous system with species exhibiting particular preferences for certain macrohabitats (especially silt and oyster) and definite seasonality (consolidated macrohabitats). The relationships between species and sediment are well documented (Yonge 1956; Young and Rhoads 1971; Orth 1973; Harry 1976; Holland et al. 1977; Maurer et al. 1978; Woodin and Jackson 1979; Peterson 1979). Equally documented are the relationships between benthos and seasonality (Holland and Polgar 1976; Holland et al. 1977; Cammen 1979; Poore and Rainer 1979; Maurer et al. 1979). This study was not designed, however, to delineate the factors responsible for species distributions.

Several observations made during the course of this study may provide clues to the reasons why the benthos distributed themselves in the manner described herein. Based on hydraulics, the lagoon may be divided into two zones:

1. Low-energy, relatively stable bottom that is unaffected by tide; and,
2. High-energy, relatively unstable bottom that is affected by tide.

Manifestations of tidal flow and geomorphology of the lagoon may include:

1. A possible gradation of sand grain sizes with small particles in diverticula of the lagoon and large particles near the tidal inlet;
2. Possible large amounts of interstitial detritus in low-energy zones and small amounts in high-energy zones; and,

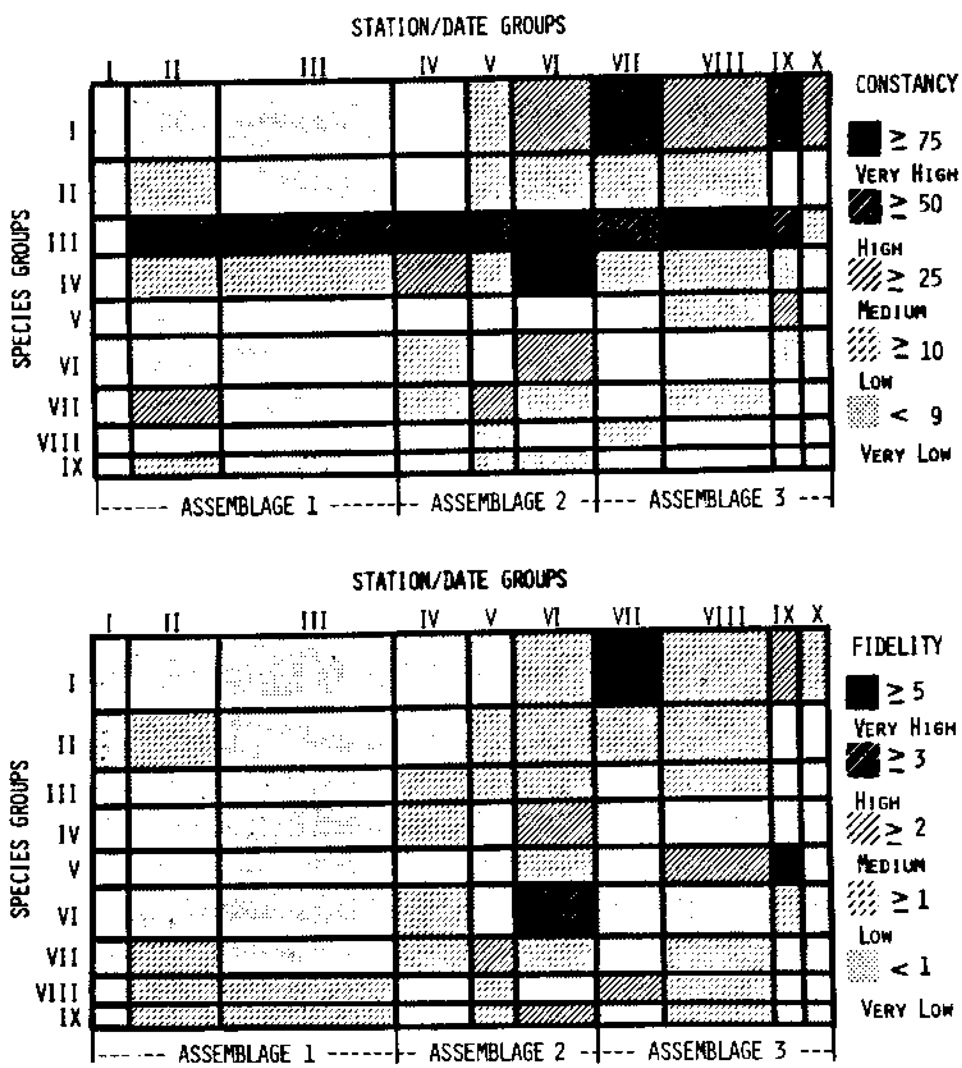

Fig. 2. Constancy and fidelity analyses of quarterly data.

3. Poorer water quality in diverticula of the lagoon than of water near the tidal inlet.

The cluster analyses grouped silt and oyster macrohabitats into specific groups. Both areas had poorly-sorted, fine sand rather than well-sorted sand. These two macrohabitats also clustered independently from one another. Silt areas were devoid of secondary firm substrata whereas oyster beds contained shells and shell hash. The separation of the sand macrohabitat into sand and near-inlet sand macrohabitats was probably influenced by hydraulics.

Future benthological studies involving Ranger Lagoon and other insular waters of barrier island zones should include procedures for determining the complex array of factors that make these ecosystems the dynamic and life-sustaining environments that they have proven to be.

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BIVALVES AS INDICATORS OF ENVIRONMENTAL POLLUTION: A PILOT STUDY OF OYSTERS (CRASSOSTREA VIRGINICA) IN MOBILE BAY

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ABSTRACT: The results of the first two years of a long-range study of oysters (*Crassostrea virginica*) in Mobile Bay as biological indicators of organic pollutant pressure on the estuary are presented. A new and sensitive methodology for tissue analysis for a wide variety of organic pollutants, involving separation from natural lipids by gel permeation chromatography followed by fused silica capillary GC/MS analysis, is reported. Using this procedure, a large number of organic contaminants have been identified in oysters from Mobile Bay. Inter-site, seasonal and annual variation in types and quantities of organic pollutants has been demonstrated. Such data will be available as an essential environmental baseline for the future evaluation and planning of industrial development in the Bay.

Introduction

In many portions of the industrialized world, estuarine ecosystems are facing increasing pressures from the activities and the by-products of large-scale technological operations. The impact of these processes on the marine estuarine environment can potentially jeopardize resources of great economic importance. Of the many possible damaging materials that often find their way into bays and estuaries, it is the organic pollutants of agricultural and industrial origin that are most often biologically detrimental. The impact of these type pollutants on marine and estuarine ecosystems is well documented for certain specific contaminants, such as crude oil, petroleum by-products, pesticides, chlorinated biphenyls (PCB's), etc. (NRC 1980). A large number of aquatic and marine-interfacing animals have been shown to bioaccumulate many of these type materials, and a wide variety of physiological and pathological effects have been documented (Anderson et al. 1974; Anderson 1977; Bayne et al. 1979; Heckman 1982). In addition, crude oil and its combustion products contain substantial amounts of polycyclic aromatic hydrocarbons, which are known to be carcinogenic (Gelboin and Ts'O 1978). On the other hand, the biological effects of other types of organic contaminants released into estuarine waters are unknown (NRC 1980).

It is clear, therefore, that significant organic discharges into fragile estuarine ecosystems will have serious repercussions in terms of both the economics of local seafood industries and the public health. A first and essential step in evaluating these potential problems is to assess the levels of organic pollutants that are assimilated into living organisms in bay ecosystems. Such baseline information is essential for current and future decision-making involving resources and industrial development.

Bivalves have been employed in several studies as biological indicators or monitors of estuarine pollution (NRC 1980). They possess several interesting characteristics which make them ideal bioindicators of pollution:

1. Since most bivalves are filter-feeders their tissues accumulate and concentrate a wide variety of environmental contaminants.
2. Because they concentrate pollutants at much greater levels than those found in the current water column, accurate analyses are therefore easier and reproducible.
3. Their sessile nature allows an evaluation of local pollution problems.
4. Bivalves roughly reflect the relative composition of contaminants in the ambient water, as relatively little metabolism of most compounds has been reported (Lee et al. 1972; NRC 1980).
5. There is a persistence of many pollutants in their tissues, even after long depuration periods (Neff 1976; Boehm and Quinn 1977).
6. They represent a time-integrated sample, rather than a measurement of a single point in time (e.g., a water sample). Hence, sampling of bivalve tissues eliminates the need for frequent water sampling.
7. Finally, the ease of collecting and high densities of some species in coastal waters make them a readily available monitor.

Though the interpretation of pollutant levels in bivalves must be with full cognizance of their limitation (as regards to seasonal reproductive and lipid cycles), the concept of using bivalves as bioindicator organisms of estuarine pollution is a direct and practical method for pollution analysis. Using this method, it is possible to show exactly which contaminant compounds are reaching and influencing biotic systems.

In 1981, we began a study of the extent of organic pollution in Mobile Bay, Alabama, by identifying and quantifying the major agricultural and industrial organic compounds found in the tissues of the American oyster (Crassostrea virginica). This species is distributed widely in the lower half of the Bay, and there are several large commercial reefs at the southwestern edge. Mobile Bay, however, faces a series of growing environmental pressures. Industrial and technological development is proceeding rapidly in the Bay area. The Tennessee-Tombigbee Waterway is nearing completion. Barge and tanker traffic will soon increase dramatically, as will the potential for chemical spills and accidents. Oil and natural gas exploration is underway in the Bay and immediately offshore. Since significant finds have been reported, the anticipated pipelines, storage facilities, refinery operations and associated petrochemical industries will all increase industrial pollution possibilities in the near future. Already during the past year, the illegal dumping of highly toxic drilling mud has occurred at a test oil rig just east of Dauphin Island. An increasing volume of hazardous chemical waste is also passing through the Bay. A vessel designed for open ocean incineration of hazardous wastes is stationed in Mobile, and applications for storage tanks to hold large quantities of these materials are currently being sought. Major industrial developments, particularly involving the chemical and petrochemical industries, have been built in the past few years on the edges of the Bay and more are in the planning stages. The state docks and navigation channels will soon be enlarged and deepened. The metropolitan area is also expanding in population. Since the waters flowing into Mobile Bay drain a watershed that includes sizeable portions of three states (the fourth largest discharge rate of all river sysyems in the United States; Loyacano and Busch 1979), these growing environmental problems, when coupled with agricultural and industrial pollutants already in the freshwaters from upstream, cause concern for the future ecological status of the Bay. With no previous comprehensive background information available on organic pollutants in Mobile Bay and no current on-going monitoring program, a baseline assessment of the chronic pollutant load on Mobile Bay was needed in order to acccurately evaluate the impact of current as well as future developments in Mobile Bay.

The purpose of this paper is 1) to report a new and sensitive procedure for separating, detecting and quantifying selected pollutants from tissues of bivalves, and 2) to report results to date of our study on oyster samples from Mobile Bay.

Collection of Samples

For the initial year of the study (1981), samples were collected from four commercially-important reefs or bed sites, all located at the southwestern edge of Mobile Bay (Fig. 1). These sites were Buoy Reef, Sand Reef, Cedar Point Reef, and Dauphin Island Bay. In addition, samples were also collected from two sites near Cedar Key, Florida, to serve as controls from a non-industrially-impacted area. This area is not affected by industrial effluents and has no major river discharges nearby. For the second year of the study, two additional sites were added in Mobile Bay. These were Whitehouse Reef and St. Andrews Bay (Fig. 1).

Collections were made in April and October in 1981, while in 1982 a summer

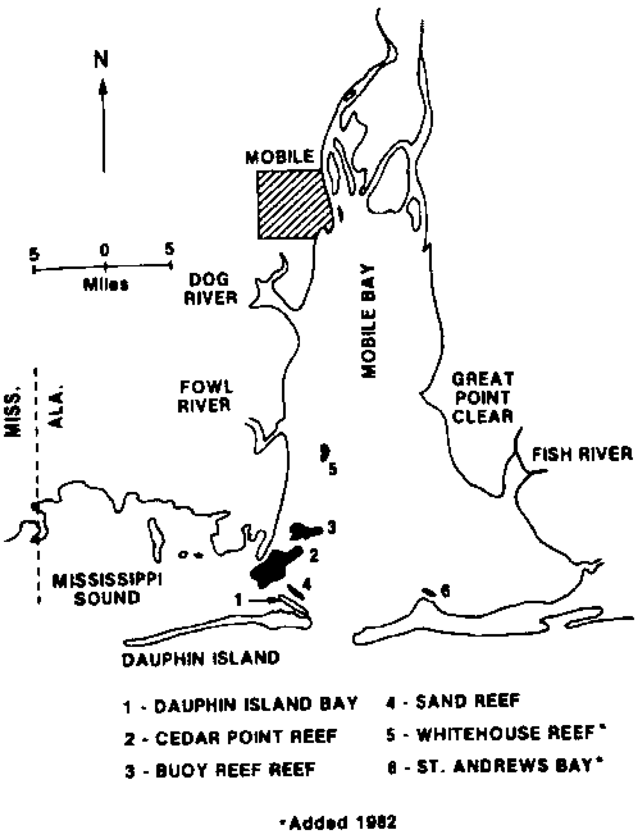


Fig. 1. Oyster collection sites in Mobile Bay, Alabama.

collection in July was added. Thirty to forty oysters were collected at each of the above mentioned sites. The oysters were shucked on site, combined, frozen immediately on dry ice and transported back to UAB for extraction and gas chromatography/mass spectrometry (GC/MS) analysis.

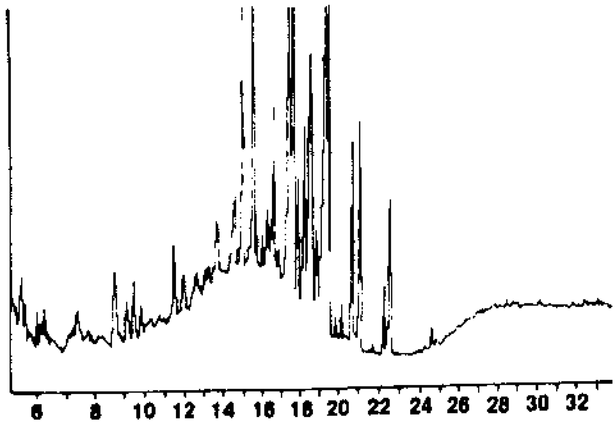
Extraction Procedures

In previous studies employing the use of bivalves for pollution analysis, a number of extraction and analysis procedures have been reported (Goldberg 1976). These methodologies fall principally into two basic techniques: 1) separation of the lipids from the oysters by saponification with strong alkalai, followed by extraction of contaminants with an appropriate solvent (Dunn 1976; Warner 1976), or 2) separation of the lipid fraction from pollutants in the oyster with the use of adsorption chromatography (Teal and Farrington 1977). Both of these techniques suffer from severe limitations. The alkalai procedure is satisfactory for polycyclic aromatic hydrocarbon analysis. However, any pollutants that contain labile halogen groups, such as the DDT group of compounds, would be hydrolized and subsequently lost by this procedure. Likewise, the adsorption chromatographic method suffers from incomplete separation of polar pollutants from the lipids in the oyster. In addition, reproducibility of the exact activity of these type columns is poor. In Fig. 2 the separation of lipids from the same oyster fraction by adsorption chromatography is compared with the new gel permeation chromatography (GPC) procedure herein described.

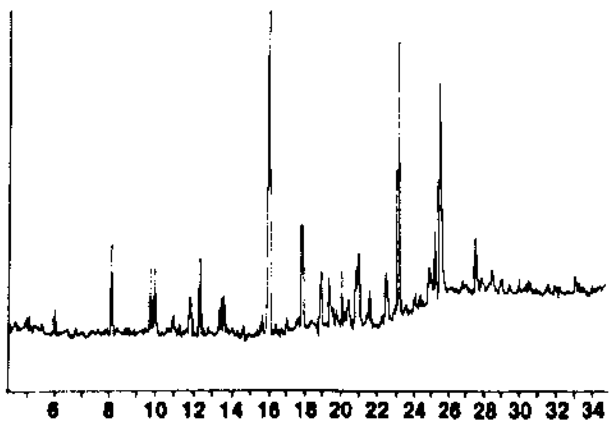
A 100 g sample from each bed site was homogenized to give a homogeneous pool of oyster tissue from each site. Oyster tissue (25 g) from the homogenate pool, previously stored at 0° C, was placed in a 250 ml Erlenmeyer flask and thoroughly disrupted by a Polytron homogenizer. Ethyl ether/hexane (25/75, 100ml) and Na_2SO_4 (100g) were added and this mixture homogenized for another five minutes. The solvent was decanted and the oyster/Na_2SO_4 residue was extracted with 2x100 ml of ethyl ether/hexane. The extracts were combined and dried by passing through a Na_2SO_4 column (1"x2" bed). The effluent was collected in a Kuderna-Danish flask fitted with a small magnetic stirring bar in the bottom of the reservoir. A Snyder column was placed on the top of the assembly and the volume reduced to 5.0 ml, using a boiling water bath with constant stirring. The Snyder column was rinsed with ether/hexane and replaced with a micro-Snyder column. The volume was again reduced to 5.0 ml and the sample stored at 0° C.

A gel permeation column was prepared by soaking Bio-Beads (100g SX2, 200-400 mesh, Pharmacia) in 5 volumes of cyclohexane overnight. The slurried packing was poured into a Pharmacia DR25 column (800mm x 25mm ID) fitted with two flow controllers. The column was packed and run by gravity flow, using cyclohexane as the solvent. The column effluent was led into a Perkin Elmer LC-75 variable wavelength UV detector set at 254 nm, which was used to moniter for UV-absorbing compounds eluting from the column. The concentrated oyster sample was thawed and 1.0 ml of the sample was injected onto the gel column via a three-way valve, using a teflon-lined syringe with Leur-Lock adapters. The sample was eluted from the column at a flow rate of 3.0 ml/min. Following the elution of the lipid peaks, the cyclohexane eluent was collected in a separate receiver for a period of time (previously determined during recovery curve data collection) that would allow all pollutants of interest to pass through (Fig. 2). This eluent was then concentrated to a volume of 0.5 ml and the sample utilized for GC/MS analysis.

Several oyster samples obtained from commercial sources were homogenized and prepared as described previously. Prior to the addition of solvent and Na_2SO_4, they were spiked with increasing amounts of standards (3.0 ml of the compounds listed in Table 1 in concentrations ranging from 0.02 ng/µl to 10 ng/µl). Prior to applying the oyster samples to the gel



Incomplete separation of peaks from Dauphin Island Bay oyster sample using florisil column chromatography.



Separation of peaks from spiked oyster, using gel permeation chromatography.

Fig. 2. Separation of pollutants from lipids in oyster tissue using different methodologies.

permeation column, a sample of the mixed standards was passed through the column, while monitering the effluent at 254 nm, to determine their elution times. Comparing the elution times of the standards with that of the lipid components of an oyster sample showed that near complete separation between the lipid fraction and the standard fraction was obtained. Fig. 2 demonstrates the difference in the efficiency of the separation of lipids and standards between adsorption column chromatography and this GPC method. Following the same procedure, the spiked oyster sample was then chromatographed, and the eluent collected and treated as described above for determination of percent recovery. Table 1 shows percent recovery of the standards used to spike the oyster tissue described above.

TABLE 1. Percent recovery of pollutants from spiked oyster tissue, using gel permeation chromatography.

POLLUTANT	% RECOVERY
D_{10}- anthracene	100
naphthalene	68
2-methylnaphthalene	70
1-methylnaphthalene	68
acenaphthalene	62
acenaphthene	75
fluorene	76
phenanthrene	75
anthracene	83
fluoranthene	75
pyrene	84
chrysene	84
benzo(a)anthracene	92
benzo(b)fluoranthene	99
benzo(k)fluoranthene	93
benzo(a)pyrene	91
heptachlor epoxide	67
endrin	97
4,4'-DDE	54
4,4'-DDD	83
4,4'-DDT	70

The recoveries for most of the compounds are good and are much improved over previously reported methods.

GC/MS Analysis

Analyses were conducted on a Hewlett Packard 5985A computerized gas chromatograph/mass spectrometer, using electron impact ionization (EI) and positive ion detection. Quantification was accomplished by comparison with standard curves on all pollutants, and identification was confirmed by single ion monitoring (SIM) using three specific ions at a specific retention time. D_{10}-anthracene was added to both standards and samples as an internal standard and quantification areas were normalized to the d_{10}- anthracene. The GC column conditions used were 50-300°C, increasing at a rate of 10 C/min after a 1 min hold at 50°C. Samples were analyzed on a 25-meter HP SE-54 fused silica capillary column interfaced directly into the mass spectrometer ion source. Data were collected at an electron multiplier voltage of 2200v, a mass peak threshold of 10 counts and two A/D conversions per data point. The a.m.u. scan range was 35-300 for the first 9 minutes retention time and 35-450 from 9 minutes till the end of each chromatographic run. Reconstructed selected ion chromatograms were used to locate and quantify the compounds identified.

Results and Discussion

In the course of the initial two years of study, a large number of organic contaminants have been identified and quantified in the oyster tissues. The results for 1981 and 1982 are reported in Tables 2 and 3, respectively. Many of the compounds identified appear on the Environmental Protection Agency's list of priority pollutants. Some are polycyclic aromatic hydrocarbons and are typical of industrial by-products of petroleum-based industries. Others are pesticides and herbicides associated with agriculture. Many of the compounds shown are known to be detrimental to human health when present in sufficient quantities (Waldbott 1973; Gelboin and Ts'O 1978; McKercher and Plapp 1980). However, it is to be noted that the concentrations of all of the individual components shown in Tables 2 and 3 are very low, only in the parts per billion range. During the past decade, concentrations in bivalve tissues of a number of these same contaminants were found at considerably higher levels at several locations along the North American coastline (Kidder 1977; NRC 1980). In addition, for the two years thus far examined, with the exception of Cedar Point Reef in spring 1981 and DDT and its derivatives (discussed later), the levels of pollutants found in oyster tissues in the non-industrially impacted sites at Cedar Key, Florida, are not greatly different from most sites in Mobile Bay. Hence, at this point in time, based on our initial findings, it would appear that the concentrations of individual pollutants shown are likely below the levels that would indicate a specific health hazard, considering normal consumption patterns. However, since unequivocal guidelines are not available for seafood contamination (except for certain pesticides; McKercher and Plapp 1980), even low concentrations of various organic pollutants must be viewed with some caution.

A number of additional compounds which were not initially screened for were added in fall 1982 because of new industrial activity in the Bay. For example, dibenzofuran and dibenzothiophene were searched for, as well as additional polynuclear aromatic compounds that might indicate crude oil contamination. However, no trace of these compounds was found. Also, because of the passage in the Bay of dioxins and PCB's in vessels equipped for open ocean incineration, these compounds were searched for, but none were evident in these samples.

Seasonal and inter-site variability in levels and types of organic pollutants are demonstrated in Tables 2 and 3. Comparing the results from the two years of sampling, annual differences can also be seen, at least in part reflecting differences between

TABLE 2. Quantification of compounds found in oysters in 1981. Concentrations in ppb

Compound examined		Buoy Reef Mobile Bay	Sand Reef Mobile Bay	Cedar Pt Mobile Bay	Whitehouse Reef Mobile Bay	D.I. Bay Mobile Bay	St.Andrews Mobile Bay	Cedar Key Florida Bay	Cedar Key Florida Bridge
Naphthalene	SP	NC	NC	2.8	NC	**	NC	17.5	17.9
	S								
	F	2.0	2.0	1.6	NC	2.0	NC	3.6	1.8
1-Methyl Naphthalene	SP	NC	NC	2.6	NC	**	NC	8.9	6.8
	S								
	F	**	**	**	NC	1.5	NC	2.2	1.4
2-Methyl Naphthalene	SP	NC	NC	4.2	NC	**	NC	14.2	16.0
	S								
	F	**	1.8	2.7	NC	5.5	NC	8.0	6.3
Acenaphthalene	SP	NC	NC	0.5	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
Acenaphthene	SP	NC	NC	1.7	NC	**	NC	4.8	3.0
	S								
	F	**	**	**	NC	**	NC	**	**
Fluorene	SP	NC	NC	2.8	NC	**	NC	**	1.8
	S								
	F	**	**	**	NC	1.4	NC	**	**
Phenanthrene	SP	NC	NC	6.0	NC	**	NC	**	**
	S								
	F	**	**	**	NC	3.6	NC	**	**
Anthracene	SP	NC	NC	3.8	NC	**	NC	**	2.8
	S								
	F	**	**	**	NC	1.3	NC	2.8	**

NC denotes not collected
** denotes conc. below limits of detection

(continued on next page)

TABLE 2. (continued) Quantification of compounds found in oysters in 1981. Concentrations in ppb

Compound examined		Buoy Reef Mobile Bay	Sand Reef Mobile Bay	Cedar Pt Mobile Bay	Whitehouse Reef Mobile Bay	D.I. Bay Mobile Bay	St.Andrews Mobile Bay	Cedar Key Florida Bay	Cedar Key Florida Bridge
Methyl Phenanthrene	SP	NC	NC	**	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
C-2 Phenanthrenes	SP	NC	NC	**	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
C-3 Naphthalenes	SP	NC	NC	**	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
Fluoranthene	SP	NC	NC	5.6	NC	**	NC	1.4	**
	S								
	F	**	**	**	NC	**	NC	**	**
Pyrene	SP	NC	NC	5.6	NC	5.6	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
2,4'-DDT	SP	NC	NC	9.7	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
4,4'-DDE	SP	NC	NC	14.4	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
4,4'-DDD	SP	NC	NC	26.5	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
4,4'-DDT	SP	NC	NC	18.7	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
1,2-Benzanthracene	SP	NC	NC	15.3	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
Chyrsene	SP	NC	NC	10.3	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
Benzo(b)fluoranthene	SP	NC	NC	52.9 #	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
Benzo(a)pyrene	SP	NC	NC	10.1	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**
Benzo(ghi)perylene	SP	NC	NC	84.8	NC	**	NC	**	**
	S								
	F	**	**	**	NC	**	NC	**	**

NC denotes not collected
** denotes conc. below limits of detection
# The value of 52.9 is the total for all the Benzofluoranthenes both (b)and (k)

years (during the same seasonal collecting time) in current flow and immediate or recent past pollutant distribution in the water column. A comparison of the spring and fall samples from each year (Tables 2 and 3) demonstrates the general trend of more pollutants occurring in oyster tissues during spring , with much less in the fall. This can likely be attributed to 1) the effects of a higher freshwater influx during the spring, with resulting increased runoff of agricultural chemicals and larger quantities of industrial compounds reaching the oyster beds, and 2) to the seasonal loss of lipids in oysters during the latter portion of the year that is associated with the reproductive cycle (Galtsoff 1964).

In both years, inter-site variability is evident. Some sites, for example Dauphin Island Bay in 1982 (Table 3), show total annual levels of all pollutants that are slightly higher than other sites. Contaminants indicative of gasoline or diesel fuel have been found at some sites.

TABLE 3. Quantification of compounds found in oysters in 1982. Concentrations in ppb.

Compound Examined		Buoy Reef Mobile Bay	Sand Reef Mobile Bay	Cedar Pt Mobile Bay	Whitehouse Reef Mobile Bay	D.I. Bay Mobile Bay	St.Andrews Mobile Bay	Cedar Key Florida Bay	Cedar Key Florida Bridge
Naphthalene	SP	45.0	42.2	47.1	49.5	58.6	NC	53.0	27.1
	S	28.9	118.7	51.5	14.7	45.6	40.3	68.5	42.1
	F	3.2	18.3	8.2	10.7	13.8	9.1	13.5	6.3
1-Methyl Naphthalene	SP	3.0	3.0	5.8	3.3	6.0	NC	2.8	**
	S	1.5	1.8	3.0	1.5	3.8	3.8	5.8	3.0
	F	1.2	3.8	1.7	2.6	2.4	2.8	2.9	1.7
2-Methyl Naphthalene	SP	10.0	9.8	40.2	11.7	43.6	NC	31.6	**
	S	8.4	9.9	14.7	5.1	9.9	12.1	44.1	13.5
	F	2.8	16.3	7.9	12.5	9.1	12.9	12.4	7.3
Acenaphthalene	SP	**	**	2.0	2.0	2.0	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	0.2	0.7	**	0.8	0.4	0.7	0.8	0.4
Acenaphthene	SP	2.0	2.0	4.1	4.8	5.0	NC	3.8	**
	S	**	**	2.0	**	4.8	5.0	15.3	**
	F	1.1	1.1	**	0.5	1.3	0.8	1.0	0.5
Fluorene	SP	2.0	15.0	17.4	13.5	27.2	NC	4.2	**
	S	**	1.9	2.0	**	**	**	28.1	**
	F	1.5	2.3	2.0	2.5	2.1	1.8	2.0	1.2
Phenanthrene	SP	83.5	84.0	130.1	49.0	227.0	NC	86.5	47.8
	S	**	47.0	101.0	**	89.1	80.1	91.1	81.1
	F	11.2	12.0	11.2	25.3	13.4	11.0	27.1	12.7
Anthracene	SP	1.8	**	**	**	**	NC	**	**
	S	**	1.6	**	**	4.1	**	17.4	**
	F	0.5	**	0.6	**	0.7	0.8	1.8	**
Heptachlor	SP	**	**	**	**	53.0	NC	**	**
	S	22.0	**	**	**	27.2	**	**	**
	F	**	**	**	**	**	**	**	**
Aldrin	SP	**	**	**	**	**	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	**	**	**	**	**	**	**	**
Heptachlor Epoxide	SP	**	**	**	**	**	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	**	**	**	**	**	**	**	**
Fluoranthene	SP	**	**	25.3	25.3	51.6	NC	**	**
	S	**	**	23.1	**	91.3	**	**	**
	F	5.3	4.9	2.3	3.8	9.8	5.4	22.4	5.8
Pyrene	SP	**	**	**	50.0	**	NC	25.9	**
	S	**	**	**	**	67.8	**	**	**
	F	4.6	3.5	1.7	3.6	7.3	2.9	6.2	5.3
Endrin	SP	**	**	**	**	**	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	**	**	**	**	**	**	**	**
4,4'-DDE	SP	62.0	**	**	22.1	50.1	NC	**	**
	S	62.0	36.1	58.4	**	**	**	**	**
	F	**	3.5	3.7	9.9	**	**	**	**
4,4'-DDD	SP	22.0	55.0	**	60.7	55.0	NC	**	**
	S	**	**	21.4	**	**	**	**	**
	F	**	**	1.1	4.0	**	**	**	**
4,4'-DDT	SP	**	**	**	23.1	**	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	**	**	2.0	**	**	**	**	**

NC denotes not collected
** denotes conc. below limits of detection

(continued on next page)

TABLE 3 (continued) Quantification of compounds found in oysters in 1982. Concentrations in ppb.

Compound examined		Buoy Reef Mobile Bay	Sand Reef Mobile Bay	Cedar Pt Mobile Bay	Whitehouse Reef Mobile Bay	D.I. Bay Mobile Bay	St.Andrews Mobile Bay	Cedar Key Florida Bay	Cedar Key Florida Bridge
1,2-Benzanthracene	SP	**	**	**	**	**	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	**	**	**	**	7.0	**	**	**
Chrysene	SP	**	**	**	**	**	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	3.2	**	**	**	8.3	**	10.9	4.9
Benzofluoranthenes	SP	**	**	**	**	**	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	**	**	24.2 #	**	**	**	**	**
Benzo(a)pyrene	SP	**	**	**	**	**	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	**	**	**	**	**	**	**	**
Benzo(ghi)perylene	SP	**	**	**	**	**	NC	**	**
	S	**	**	**	**	**	**	**	**
	F	**	15.2	**	9.9	**	**	**	8.8

NC denotes not collected

** denotes conc. below lits of detection

the value of 24.2 is the total for all the Benzofluoranthenes both (b) and (k)

The increased levels of naphthalene and phenanthrene in 1982 (Table 3) at sites such as Cedar Point and Dauphin Island Bay are likely indicative of high boating activity in these areas. It is also interesting to note that, when compared to other sites in spring 1981, oysters at Cedar Point Reef contained a greater diversity and quantity of organic pollutants. This was possibly the result of intense boating and localized construction activity during this time, associated with the building of the new Dauphin Island bridge, originally destroyed in 1979 by Hurricane Frederic. Other than reflecting such local changes in environmental conditions, the remainder of the inter-site variability seen in Tables 2 and 3 can be accounted for by differences in current patterns or regional pollutant inputs upstream.

DDT and its metabolites (DDD and DDE) were detected at several sites in 1982 (Table 3) and at Cedar Point Reef in 1981. These levels can be attributed to agricultural runoff during high freshwater influx in spring and early summer, and most likely are the results of the past use of DDT, as we noted comparable levels of its degradation products DDD and DDE. The control sites at Cedar Key, Florida, showed little or no pesticide residues. This can be attributed to the lack of a large freshwater effluent draining agricultural areas near Cedar Key. The presence of these type compounds in Mobile Bay indicates the potential vulnerability of estuaries draining large agricultural areas.

Summary

Overall, it appears that organic pollutants in Mobile Bay oysters, based on the sites examined, are not present in high concentrations at this time. A potential human health threat or severe organic contamination of living organisms near the major oyster-producing regions of Mobile Bay is not presently indicated. However, to this point, we thus far have only a preliminary baseline picture of the present situation and have only screened for selected non-acidic pollutants. We are currently investigating methodology for separating, identifying and quantifying acidic compounds using GPC. The next step in our study is to expand the data base to include other sites closer to pollutant sources in the upper Bay, using other bivalve species (primarily *Rangia cuneata*) that are more tolerant to freshwater. In addition, we plan to transplant bivalves to suspected "hotspots" within the Bay to evaluate local conditions. These techniques will allow us to better ascertain the overall environmental quality of Mobile Bay. Such information on the current state of the Bay will serve as an essential environmental baseline to monitor potential changes that may well occur in an area that is rapidly undergoing technological and industrial development.

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A REVIEW OF SURF ZONE ICHTHYOFAUNAS IN THE GULF OF MEXICO

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ABSTRACT: High energy surf zone habitats bordering the Gulf of Mexico provide an important resource, from both a recreational and biological perspective. Because of the overriding effect of high wind-driven wave energy, such areas show well defined physical characteristics and form a broad filtration system, removing detrital and planktonic components from the water column and concentrating nutrients along the swash zone. Organisms capable of utilizing these regions often show high degrees of morphological, physiological or behavioral specialization and form a very characteristic assemblage. Biological knowledge of surf zone ichthyofaunas in the Gulf of Mexico is still limited, with Horn Island in the northern Gulf and Mustang Island in the western Gulf being the most studied. Surf zone fish faunas are dominated numerically by relatively few species, although over 76 species, most of them rare, have been recorded from the south shore of Horn Island. The faunas are temporally dynamic on both a seasonal and daily basis. Since the surf zone area is utilized by a species often only during part of its life cycle, a strong seasonal periodicity occurs. In general, young fishes occur off high energy beaches in the spring and summer, remaining into early fall. By October and November, in the Northern Gulf, few fishes remain in the habitat, but by early spring numbers begin increasing again. The importance of the region to larger fishes is less well known, in part because of sampling problems. Daily variation also occurs, with the greatest biomass generally before dawn. Numerically dominant species from Gulf of Mexico surf zones include anchovies *(Anchoa lyolepis* and *A. hepsetus)*, scaled sardine *(Harengula jaguana)*, menhaden *(Brevoortia patronus)*, kingfishes *(Menticirrhus americanus, M. littoralis, M. saxatilis)*, mullets *(Mugil curema, M. cephalus)*, croaker *(Micropogonias undulatus)* and pompano *(Trachinotus carolinus)*. This region is thus used by a number of commercially important fishes. Various species including Florida pompano, gulf kingfish and scaled sardine are strongly dependent on surf zone areas as a nursery. Striped anchovy, white and striped mullets, gulf menhaden and spot also may be dependent (in terms of juvenile survival) on these high energy systems. Much additional information, especially on horizontal numerical density gradients of organisms seaward from the swash zone, and energy transfer in the surf ecosystem, is needed. It is important to emphasize, however, that the value of a habitat to a species should not be judged solely by the duration that an organism occupies it, but by how critical a role the habitat plays in the life cycle of the species. Temporally dynamic surf zones utilized by various fishes and invertebrates, especially during portions of their early life history, may have a much greater role in the life cycles of the coastal organisms than previously realized.

INTRODUCTION

High energy beaches form an extensive but discontinuous border around the Gulf of Mexico, occurring along mainland coasts as well as on barrier islands. Barrier island beaches are significant, comprising 26% of the linear coastal beach system in Alabama and 39% in Mississippi (Taylor et al. 1973). The coastline of the western Gulf of Mexico is bordered by extensive barrier islands also (Hill and Hunter 1976).

The purpose of this paper is to review studies of fish assemblages occurring off high energy beaches in the Gulf of Mexico, with emphasis on the northern Gulf, and to relate this information to our understanding of the coastal ecosystems in general. In any review such as this, geographic level differences affect one's ability to make generalizations. However, since high energy beach systems are united by well defined physical characteristics caused primarily by wave action, it may be less difficult to make generalizations for these habitats compared to other marine or estuarine areas. The scope of the habitat sampled in the various studies, while variable, has usually included the surf (strictly defined), the transition, and swash zones (Fig. 1). For the purpose of this paper I will use the term surf zone in the broad sense (cf. McLachlan et al. 1981a) covering the habitat from the breaker zone to the water's edge at the swash zone. The terminology for beaches follows

McLachlan (1980b) where exposed beaches are those experiencing moderate to heavy wave action, having the reduced layers deep, and generally lacking macrofaunal burrows.

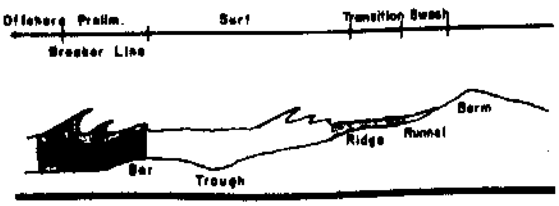

Fig. 1. A diagrammatic representation of the near-shore, open beach habitat. Hatched areas indicate regions of higher wave energy. Modified from Ingle (1966 and Schiffman 1965).

High energy beach systems, characterized by pounding surf and a shifting sand substrate, offer a particularly harsh environment to living organisms. Hedgpeth (1957) considered such areas to be less favorable for life than other shore habitats, except gravel or cobble beaches. Because of the harshness, high energy beach systems support a specifically adapted invertebrate (e.g. Dahl 1952; Riedl and McMahan 1974; Diaz 1980; Dye et al. 1981) and vertebrate (e.g. Gunter 1958; McFarland 1963b; Anderson et al. 1977; Modde and Ross 1981) fauna. However, to species adapted to this environment, the wave energy may provide a considerable advantage. For instance, species of the mole crab (*Emerita*) depend on water currents generated by receding waves for nutrition. Mole crabs feed on plankton and detritus by filtering the backwash from waves with their plumose antennae (Dahl 1952; Efford 1966; Ansell et al. 1972; Leber 1982). The often abundant haustoriid amphipods may have similar ecological roles (Dahl 1952; Dexter 1969). Wave energy supplies plankton and detritus to the filter feeding bivalve *Donax*, as well as facilitating horizontal movement by physical displacement (Wade 1967). Wave energy is also likely exploited by fishes in exposing prey and in concentrating plankton along the swash zone.

Beaches operate as large filtration systems along the swash zone and thus carry out an invaluable role as biological purification systems for coastal water. Riedl (1971) estimated that an average beach would filter approximately 10 m^3 m^{-1} beach per day, and McLachlan (1979) determined filtration rates of 3.8 to 15.2 m^3 m^{-1} per day. Filtration is positively related to beach slope, tidal range, substrate particle size and exposure, and inversely related to wave frequency (McLachlan 1979; 1982).

Pearse, Humm and Wharton (1942) provided one of the first studies on high energy beach ecosystems. One of their conclusions identified the importance of sand beaches as great digestive and incubating systems in which bacteria break down organic remains providing a supply of inorganic nutrients to the surrounding water. Bacterial concentrations in high energy beaches can be substantial. For example, Meyer-Reil et al. (1978) determined an average total bacterial biomass of 5.0 g dry weight per m^2 of beach (taken to a depth of 10 cm) for surf zones of the Baltic Sea.

Recent studies of McLachlan (1980a) and McLachlan et al. (1981a) indicate that surf zones, from the intertidal and subtidal areas to the perimeter of the surf cells, form a functional ecosystem. The argument for this is that the amount of inorganic nutrient material liberated in the surf zone through the mineralizing activity of the interstitial microfauna and macrofauna is sufficient to support local plankton blooms. Because surf zone areas often have a cellular circulation sufficient to retain nutrients long enough for plankton blooms to occur, the beach system may be only slightly subsidized with the bulk of the energy turnover occurring within the system. The degree of subsidy likely varies between different beaches and seasons, in part through the differential importation of particulate organic material, carrion (McLachlan et al. 1981a) and fish feces. Whether surf zones of the Gulf of Mexico constitute semi-enclosed ecosystems is not known; however, the conclusion gains support by work of McFarland (1963a) who suggested that net primary production in the surf zone of Mustang Island may be able to maintain the entire heterotrophic component of the zone during the summer. Gunter (1979) also reported localized plankton blooms off Texas beaches, again suggesting the localized release and retention of nutrients in the surf zone.

Primary production in surf zones is accomplished essentially by phytoplankton. For instance, Ansell et al. (1972) found that Indian beaches had essentially no primary production by interstitial or attached micro-organisms. Instead, surf zone organisms were dependent on the water overlying the sand for food requirements, through primary production, detrital input or carrion. Phytoplankton production varies seasonally. McFarland (1963a) found that plankton metabolism paralleled fish abundance, being higher in summer and lower in the winter for the surf zone of Mustang Island, Texas. Carrion importation, while non-predictable, may at times provide substantial energy subsidies as well (Brown 1964; Gunter 1979). Lenanton et al. (1982) have recently shown that detached plants washed into surf zones may harbor an invertebrate fauna, especially amphipods, which constitute an important element in the diet of some Australian surf zone fishes. The dominant macrofaunal invertebrates in surf zone areas are detrital feeders (primarily deposit feeders) (Hill and Hunter 1976) or planktivores (McLachlan et al. 1981b; Shelton and Robertson 1981).

Gunter (1958) commented that "Vertebrate life of the beach environment is little known." Today, such a statement largely remains true for most surf zone systems in North America, including the Gulf of Mexico. For instance, Bagur (1978), in an annotated bibliography of United States barrier islands, listed only two studies dealing with fishes from surf zone areas of

Gulf of Mexico barrier islands, yet the outer beaches of barrier islands form an extensive border around the Gulf. More recently, Modde (1980), Modde and Ross (1981), McMichael (1981), Modde and Ross (1983), Ruple (1983), McMichael and Ross (in prep.) and Ross et al. (in prep.) have examined various aspects of the ichthyofauna associated with the Horn Island, Mississippi surf zone. In addition, Shelton and Robertson (1981) studied macroinvertebrate assemblages along two high energy beach systems in the northern Gulf of Mexico off of Texas, and Naughton and Saloman (1978), and Saloman and Naughton (1978; 1979) studied fishes and invertebrates from the swash zone of Panama City Beach, and fishes from Pinellas County beaches in Florida. The only other high energy beach system well studied in regard to fishes in the entire Gulf of Mexico is Mustang Island, Texas (Gunter 1945; 1958; McFarland 1963b).

While many high energy beaches in the Gulf of Mexico remain to be studied, I believe it timely and important to review what is known about surf zone ichthyofaunas. The outer beaches are the first line of defense against coastal storms (Nummedal 1982), but they are also the coastal environment first in line of impact from offshore pollution. Surf zone areas may be one of the most sensitive regions of the coastal environment, but their dynamic nature makes detection of man-made perturbation difficult (Dye 1981; McLachlan et al. 1981b). Because general knowledge of the northern Gulf of Mexico is limited, this review should help provide coastal planners and fisheries managers with the necessary information to make educated decisions concerning management of high energy beach systems, and species utilizing them.

FISHES

Species Composition

Surf zone fish faunas are characterized by relatively few species making up the majority of individuals. In the Gulf of Mexico between 4-10 species comprised 90% of the individuals collected (Table 1). The same pattern is true for the Atlantic coast of the United States as Anderson et al. (1977) found that five fish species comprised over 90% of the specimens collected from Folley Beach, North Carolina and Schaefer (1967) reported that less than ten species comprised 90% of the catch from a Long Island beach over a three year period. The data for biomass are much more limited, but suggest for both Mustang and Horn island surf zones a somewhat more even distribution between species, with 13 and 16 species, respectively, making up 90% of the biomass. Anderson et al. (1977) found that five species of fishes only made up 69% of the biomass of the Folley Beach surf zone, again indicating a greater evenness.

The total number of fish species reported from Gulf of Mexico surf zones ranges between 44-76, with a strong mode in the 40's (Table 1). The higher species number reported by Modde and Ross (1981) is likely due to more months being sampled as well as the small mesh size used. In fact, there is a significant relationship between the number of species collected and the number of months sampled ($r_s = .86$, $P < .01$) for the available studies (Table 1). The Spearman rank correlation statistic (r_s) was calculated following Siegel (1956) after correcting for ties. The greatest decline in species versus sampling effort occurs in studies of less than eleven months. In addition to sampling effort, comparison of species numbers between studies is complicated by differences in technique, sampling efficiency of gear (including mesh size and net dimensions), and timing, both seasonal and diel, of the sampling.

Various authors, including Gunter (1958), McFarland (1963b), and Modde and Ross (1981) have commented on the apparent high faunal similarity of surf zone ichthyofaunas from different areas. This is of course especially true for comparisons within a single geographic region. A listing of the eight most abundant species reported from the Gulf of Mexico surf zones certainly supports the statement of high faunal similarity (Fig. 2). Fishes broadly characteristic (based on number) of high energy beach areas include scaled sardines *(Harengula jaguana)*, gulf menhaden *(Brevoortia patronus)*, bay anchovies *(Anchoa mitchilli)*, dusky anchovies *(A. lyolepis)*, striped anchovies *(A. hepsetus)*, sea catfish *(Arius felis)*, Atlantic threadfin *(Polydactylus octonemus)*, silversides *(Menidia peninsulae* and *M. beryllina)*, white mullet *(Mugil curema)*, Florida pompano *(Trachinotus carolinus)*, Atlantic bumper *(Chloroscombrus chrysurus)*, Atlantic croaker *(Micropogonias undulatus)*, gulf kingfish *(Menticirrhus littoralis)*, and pinfish *(Lagodon rhomboides)*. The studies used in Fig. 2 did not address larval fishes and are also likely biased in varying degrees against larger fishes that may escape from small seines. Two studies cited in Table 1, McFarland (1963b) and Ross et al. (in prep.) partially controlled for escapement of larger fishes by using longer seines (cf. Table 1). Only Ruple (1983) (not listed in Table 1), has studied larval fishes.

The 69 species of larval fishes recorded by Ruple (1983) from the Horn Island surf zone is very similar to the number of species represented by juvenile and adult individuals for Horn Island (cf. Table 1). However, species composition of larvae differed from juvenile and adult fishes. Five taxa, *Bairdiella chrysoura, Trinectes maculatus, Dormitator maculatus, Gobionellus* spp. and *Myrophis punctatus* were common as larvae but were rarely collected as juveniles or adults. Conversely, *H. jaguana, T. carolinus* and *M. littoralis*, common as juveniles or adults, were rarely collected as larvae. Species numerically dominant as juveniles and adults, which were also listed by Ruple (1983) as being dominant as larvae, include engraulids, spot, gulf menhaden and pinfish. Thus, for some fish species the surf zone environment is used only by larval stages with the juvenile nursery ground located elsewhere, primarily in lower salinity environments. For the second group, spawning occurs further offshore (Ruple 1983) so that the surf zone is not encountered until the larval stage is near completion. The surf zone functions as a nursery for the juvenile stage of these species. The third group apparently spawns in both nearshore as well as more offshore waters (Ruple 1983), but reaches the barrier island surf zone as larvae and remains in the area as juveniles or even adults.

Only several Gulf of Mexico studies have evaluated the biomass of fishes in surf zone habitats. McFarland (1963b) reported a very similar ranking of species importance for both number and biomass, with the five numerically dominant species included within the top eight in importance based on biomass. Ross et al. (in prep.) in contrast, found more of a difference as only four of the top five species based on number were included in the upper 10 based on biomass. The primary reason for this is the use of a much smaller mesh size in the latter study resulting in the retention of numerous early juvenile stages of many species. The eight most important species from Horn Island, based on biomass, were striped mullet, sheepshead, sea catfish, spadefish, gulf kingfish, scaled sardine, bluntnose stingray and pinfish.

The zonation of fishes in surf zone environments is also likely important, both in abundance and species composition. Ruple (1983) for instance, found differences in both number and kind of larval fishes in the inner and outer areas of the Horn Island surf zone with more larvae being collected in the outer surf areas. Juvenile kingfish seem most abundant within the swash zone (pers.obs.). However, there is little additional information on species zonation, in part due to the

Table 1. Species numbers and abundance of numerically and gravimetrically dominant fish species reported from surf zone environments in the Gulf of Mexico. (S = stretched mesh; B = bar mesh)

Total Species	Species Comprising 90% Number	Species Comprising 90% Weight	Location	Number of Sample Months	Gear Size Length	Gear Size Mesh	Source
-	6	-	Mustang Island, Texas	16	15.2m	8.4mm-S	Gunter 1945
44	8	-	Mustang Island, Texas	11	15.2m	6.4-8.4 mm-S	Gunter 1958
47	10	13	Mustang Island, Texas	11	193m	19mm-S	McFarland 1963b
25	5	-	Gilchrist, Texas	2	30.5m	19mm-S	Reid 1955a;b
38	8*	-	Gilchrist, Texas	1	30.5m	19mm-S	Reid 1956
76	5	-	Horn Island, Mississippi	21	9.1m	3.2mm-B	Modde & Ross 1981
57	6	16	Horn Island, Mississippi	12	50m	3.2mm-B	Ross et al. in prep.
44	6	-	Panama City, Florida	12	30.5m	6.4mm-B	Naughton & Saloman 1978
48	-	-	Passe-a-Grille & Bella Vista Beaches, Pinellas Co., Florida	14	15.2m	9.5mm-S	Springer & Woodburn 1960
62	5	-	Barrier Island Beaches, Pinellas Co., Florida	12	30.5m	6.4mm-B	Saloman & Naughton 1979
22	7	-	Sanibel Island, Florida	10	30.5m	6.3mm	Gunter & Hall 1965

* comprised 97% of catch

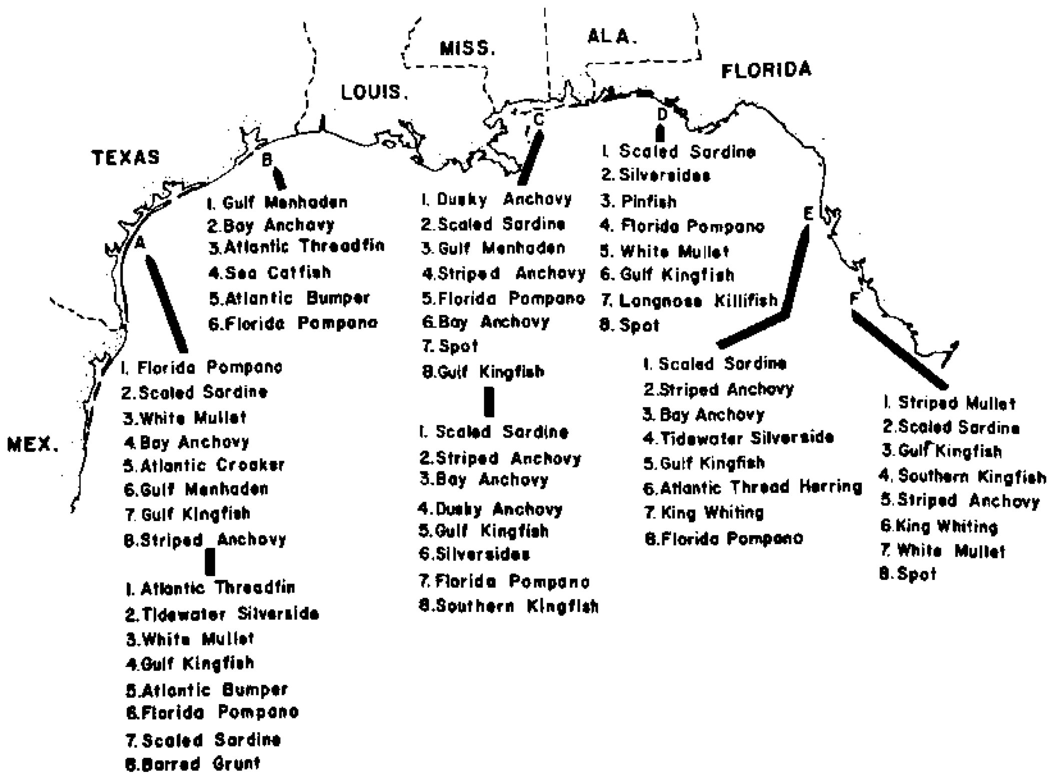

Fig. 2. A listing of the 6-8 most abundant fishes from surf zone environments in the Gulf of Mexico. A = Mustang Island, B = Gilchrist, Texas, C = Horn Island, D = Panama City, E = Pinellas Co., F = Sanibel Island. Sources for each area are given in Table 1 except that data from Gunter 1945 and Reid 1956 are not shown. Earlier studies are listed above later studies from the same area.

difficulty of sampling the various regions of the surf zone.

Temporal Dynamics

Fish assemblages utilizing surf zone habitats show strong temporal structuring on a seasonal and diel basis and also from the timing in the life history of a species when the habitat is occupied. Such dynamism makes it difficult to compare studies due to possible seasonal or diel differences in collecting effort, or gear susceptibility of different life history stages.

Seasonal changes in surf zone ichthyofaunas have been documented for all areas listed in Fig. 2. The seasonal pattern demonstrates both qualitative and quantitative effects. The general pattern is for fish abundance to be lowest off Gulf beaches in the winter, rising to peak abundances in the summer or fall. McFarland (1963b), Modde and Ross (1981), Naughton and Saloman (1978) and Saloman and Naughton (1979) all found the greatest concentration of fishes during late summer to fall. During 1978-79 density of fishes was highest during the summer (June - August) on Horn Island ($x= 2.8$ m^{-2}) and this value significantly exceeded spring and fall levels (Kruskall-Wallis Test, $P < .05$) of .8 and .5 m^{-2}, respectively (Ross et al. in prep.). The density of fishes reported by McFarland (1963b) from Mustang Island was approximately an order of magnitude lower, being .3 m^{-2} in the spring-summer and .02 m^{-2} in the winter. Much of the difference may be due to the larger mesh size used by McFarland which would have allowed the numerous smaller fishes to escape.

The standing crop for Horn Island was also significantly greater in the summer with an average of 5.2 g m^{-2} (Ross et al. in prep.). In comparison, Naughton and Saloman (1978) recorded an annual standing crop of .75 g m^{-2} for Panama City Beach with a June - August average of 2 g m^{-2}. The spring-summer standing crop reported by McFarland (1963b) for Mustang Island was 11.7 g m^{-2}, exceeding the Horn Island value. The ranges, however, overlap.

In contrast to the seasonal pattern of the Gulf of Mexico studies, Anderson et al. (1977) reported that the greatest number and weight of fishes was taken from a North Carolina surf zone in the winter, although more species were collected during the summer. In part, they attributed the winter rise in catch to decreased net avoidance of larger fishes caused by lower water temperatures.

Surf zone habitats may be briefly encountered by fishes moving along the coasts through passes into more protected waters, or by species that remain in the outer beach system for longer periods of time. Greeley (1939) considered that fishes using a Long Island, New York, beach during the summer were divisible into permanent residents, immature summer residents and migrants. McFarland (1963b) further subdivided use categories into: 1) year-round residents, 2) spring-summer residents, 3) summer residents, 4) winter-spring residents and 5) transients. Residency has been used in the spirit expressed by Modde (1980) as, "...species which indicated adolescent utilization of the surf zone by a relatively uniform increase in length throughout a given season, and [which] usually exhibited a high frequency of occurrence." Resident species may not necessarily rank highly by number or biomass. Few species occur year-round in surf zone environments. McFarland (1963b) listed only three of 47 species for Mustang Island in this category, these being striped mullet, sea catfish and pinfish. Modde (1980) considered only one species, the southern stargazer *(Astroscopus y-graecum)*, to be a permanent resident of the Horn Island surf zone.

Seasonal groups of fishes utilizing high energy beaches in the Gulf of Mexico have been described by Gunter (1945; 1958), McFarland (1963b), Saloman and Naughton (1979), and Modde and Ross (1981). These groups are summarized in Table 2, but due to differences in the studies, the groups may be based solely on species contributing most to percent number, or to a consideration of residency groups where frequency of occurrence in individual collections is balanced against numerical abundance. Florida pompano typically occur off beaches from spring through summer and into fall, as do scaled sardines. On Horn Island, Modde (1980) showed that *H. jaguana* generally remained in the surf zone further into fall than *T. carolinus*, and this also appears to be true for the Florida beach studied by Saloman and Naughton (1979). Gulf kingfish also occupy surf zones from spring through fall. This species first occurs in the spring in the northern and western Gulf (Table 2; Modde 1980; McMichael 1981), with the greatest abundance from June to October. In Florida, Saloman and Naughton (1979) reported an abundance of gulf kingfish into the winter. Other fishes frequently categorized as spring-summer residents include white mullet, Atlantic threadfin (off Texas beaches), and bay anchovy. Fishes reported as common fall residents are bay and striped anchovies. Winter residents include bay anchovy and tidewater silverside.

Diel changes in number and kind of fishes in surf zones are apparently substantial, but less studied. In the Gulf of Mexico day-night ichthyofaunal changes have been systematically

Table 2. Seasonal components of surf zone fish faunas in the Gulf of Mexico. Rankings are based on numerical abundance unless indicated.

LOCATION	SPRING	SUMMER	FALL	WINTER	SOURCE
Mustang Is.	bay anchovy white mullet Atlantic threadfin	Atlantic threadfin scaled sardine Florida pompano	bay anchovy scaled sardine Florida pompano	white mullet bay anchovy	Gunter 1945
Mustang Is.	Florida pompano white mullet Atlantic croaker	Florida pompano scaled sardine menhaden	scaled sardine Florida pompano bay anchovy	tidewater silverside longnose killifish	Gunter 1958
Mustang Is.[1]	Atlantic threadfin tidewater silverside gulf kingfish Florida pompano scaled sardine	crevalle jack Atlantic bumper Atlantic croaker Spanish mackerel harvest fish		silver perch	McFarland 1963b
Horn Island[2]	dusky anchovy scaled sardine mojarras *(Eucinostomus* sp.) Florida pompano	flat anchovy Spanish sardine white mullet striped mullet gulf kingfish	striped anchovy gulf kingfish	gulf menhaden pinfish spot striped mullet	Modde and Ross 1981
Pinellas Co.	striped anchovy bay anchovy tidewater silverside scaled sardine king whiting	scaled sardine gulf kingfish king whiting Florida pompano tidewater silverside	scaled sardine Atlantic thread-herring tidewater silverside striped anchovy gulf kingfish	bay anchovy gulf kingfish scaled sardine tidewater silverside striped anchovy	Saloman and Naughton 19[illegible]

[1] Seasonal categories are: spring-summer, summer, winter-spring; inclusion is based on residency.
[2] Inclusion is based on frequency of occurrence.

studied only for Horn Island (Modde and Ross) 1981; Modde and Ross 1983; Ruple 1983; McMichael and Ross in prep.; and Ross et al. in prep.). Studies of diel changes of fishes from U. S. Atlantic surf zones are also few (e.g. Merriman 1947; Daly 1970), even though such data are recognized as being important (Anderson et al. 1977).

Modde and Ross (1981) found that the greatest number of fishes were present in the Horn Island surf zone between 0300 and 0900 h CST. This pattern occurred over the entire period, March to September, in which 24 h seining was done. A later study on Horn Island using a 50 m block net enclosing 300 m^2 (Ross et al. in prep.) showed less defined patterns. Biomass and standing crop did not differ significantly over a 24 h period, although variation was greatest around dawn and dusk. Larval fishes also exhibit diel changes. Ruple (1983) found that larval density in both the inner and outer surf zone region was significantly greater at night.

Species composition changes over a 24 h period in the surf zone environment. For instance, in June, July and October, 1979, McMichael and Ross (in prep.) found the greatest abundance of gulf kingfish in the morning, generally around sunrise. Abundance of dusky anchovy and scaled sardine was greatest early in the morning, followed by a mid-morning peak of striped anchovy (Modde and Ross 1981). Pompano were generally more abundant later in the day, but did not show well developed diel abundance patterns.

Time of day is undoubtedly not the only factor important in influencing diel changes in number and standing crop of fishes in surf zones. Tide level is also of likely importance as Modde and Ross (1981) found that tide was the most important environmental factor influencing clupeoid abundance on a seasonal basis. However, the analysis did not include time as a variable and was limited to fishes collected during the day. The available information suggests that clupeoid fishes may be more variable on a 24 h basis than percoids such as gulf kingfish or pompano.

Uses of the Surf Zone Habitat by Fishes

The surf zone region may be used by various life history stages of fishes as a shelter from predation by larger fishes, or as a feeding, or spawning area. Use as a nursery area (a shelter and feeding site for young fishes) is included in these categories. As a group, fishes in the various resident categories likely use surf areas for most or all of these functions, although few studies have addressed this problem.

The summer resident fishes of the Horn Island surf zone are divisible into two groups: 1) those using the surf zone as a feeding area and perhaps also as a shelter area; and 2) those using the area primarily as a shelter area (Modde and Ross 1983). The logic in assigning fishes to these two groups was the relationship between daily time of greatest feeding activity in the surf zone and time of greatest abundance. The approach assumes that feeding periodicity of fishes captured nearshore reflects their activity further offshore. Scaled sardines, Florida pompano, gulf kingfish and striped anchovy all use the area as a feeding site, while dusky anchovy feed very little during their period of greatest surf zone abundance. Fishes, such as dusky anchovy, which feed offshore and then move into surf zones may serve as importers of organic material which may be directly utilized by particulate feeders such as *Emerita* or trapped by the filtering action of the swash zone for later consumption by other macro- or meiofaunal elements. An analogous role has recently been shown by Meyer et al. (1983) for coral reef fishes that feed away from the reef site at night and import nutrients to the reef proper when schools of resting fishes form over the reef during the day.

Trophic studies of surf zone fishes in the Gulf of Mexico include the work of Modde and Ross (1983) for *T. carolinus*, *M. littoralis*, *H. jaguana*, *A. lyolepis* and *A. hepsetus*; McMichael (1981) and McMichael and Ross (in prep.) for *M. littoralis*, *M. americanus* and *M. saxatilis* and Finucane (1969) for *T. carolinus* and *T. falcatus*. Clearly, there is a great need for additional inquiry into trophic relationships of surf zone fishes.

Trophic input to surf zones, as discussed earlier, is primarily in the form of particulate organic material and phytoplankton. McFarland (1963b) pointed out that planktivorous fishes dominated the surf zone of Mustang Island, and on Horn Island the numerically dominant fishes are again primarily planktivores. Only gulf kingfish and larger Florida pompano (of the five species studied by Modde and Ross 1983) utilized benthic prey. The importance of plankton to the surf zone ecosystem is illustrated by the partial food web for the summer, subtidal beach area of Horn Island (Fig. 3). Since studies of invertebrate zonation and feeding relationships are not available for this area, data are used from other regions. More detailed food webs for other surf zone areas are given in Hedgpeth (1957) and McLachlan et al. (1981a). Various species of *Donax* (Dahl 1952; Brown 1964 and Leber 1982) and *Emerita* (Dahl 1952; Leber 1982) are known to be particulate feeders utilizing organic deposits and phytoplankton. Macroinvertebrates other than *Donax* and *Emerita* are listed together in Fig. 3. Data on food habits of various macrofaunal invertebrates from surf zones, including polychaetes, cumaceans, amphipods (especially Haustoriidae) and isopods, are given in Brown (1964), Dahl (1952), and Dexter (1969). These organisms include direct and indirect deposit feeders and phytoplanktivores.

Assigning fishes to trophic groups is difficult since there are often ontogenetic trophic progressions (e.g. Ross 1978; Livingston 1982). While such progressions occur for Horn Island fishes, the broad trophic categories result in minimal distortion. Size groups which show changes are listed separately. In particular, larger bay anchovies consume fishes as well as zooplankton; larger scaled sardines become more herbivorous; and larger pompano and gulf kingfish prey increasingly on fishes. Feeding data on

A. mitchilli are from Darnell (1958) and Carr and Adams (1973), and data for *Menidia beryllina* are also from Carr and Adams. Food habits of *M. cephalus* are described by Darnell (1958), Odum (1970) and DeSilva and Wijeyaratne (1977). Less information is available for *M. curema*, although it is also considered to consume benthic microplant material and macroplant detritus (Odum 1970).

While the majority of trophic units utilize water column prey, the abundant benthic macroinvertebrates, *Donax* and *Emerita*, are also important food items to certain fishes, especially gulf kingfish and Florida pompano. It is particularly intriguing to note the consumption of *Donax* siphon tips, primarily by small kingfish and pompano. Browsing (sensu Choat 1982) of infaunal invertebrates has recently been examined by Woodin (1982) and Peterson and Quammen (1982). The latter authors found that siphon nipping substantially reduced growth rates of the bivalve *Protothaca staminae* in sandy habitats, but had little effect on clam mortality. Browsing by surf zone fishes on *Donax* siphon tips may represent an important energy pathway from particulate organic matter and primary production into higher consumer levels. Larger kingfish and pompano abandon browsing and consume entire *Donax*.

Surf zones are important nursery areas for certain fish species. Post-larval and juvenile fishes comprise the most numerous element of the surf zone ichthyofauna (Modde 1980; Modde and Ross 1981), and late larval and juvenile stages of some species may remain in the surf zone for a considerable period of time (cf. Table 2). Species which appear to be highly dependent on surf zones as nursery areas are: Florida pompano (Modde 1980; Finucane 1969), gulf kingfish (Modde 1980; McMichael and Ross in prep.), scaled sardines (Modde 1980) and striped anchovy (Ruple 1983). While dusky anchovy are often abundant in surf zones, Modde (1980) found that there was no increase in size structure over time, indicating a continual influx and departure of juvenile fish. Both white and striped mullet also appear to use surf zone regions as nursery areas (Anderson et al. 1977), as do gulf menhaden and spot (Ruple 1983) and the two additional species of *Menticirrhus*, *M. saxatilis* and *M. americanus* (Greeley 1939; Irwin 1970; McMichael and Ross in prep.). In addition, species of generally lower abundance such as *Astroscopus y-graecum* are closely associated with surf zone areas. Recently, Lenanton (1982) pointed out the importance of alternative, non-estuarine, nursery areas for Australian coastal fishes. He found that a number of species considered to be estuarine dependent were not exclusively so. The important point is that, while estuaries are extremely important nursery areas, many other coastal habitats are used as well. The importance of the surf zone habitat to species using it for a short time is difficult to discern. If many species move along the outer, exposed beaches feeding on abundant zooplankton before entering estuaries, then the quality of the surf zone habitat may have a much further reaching effect on population success of commerical, sport and non-game fishes than we can understand by looking at lists of species which remain in the area and are highly abundant.

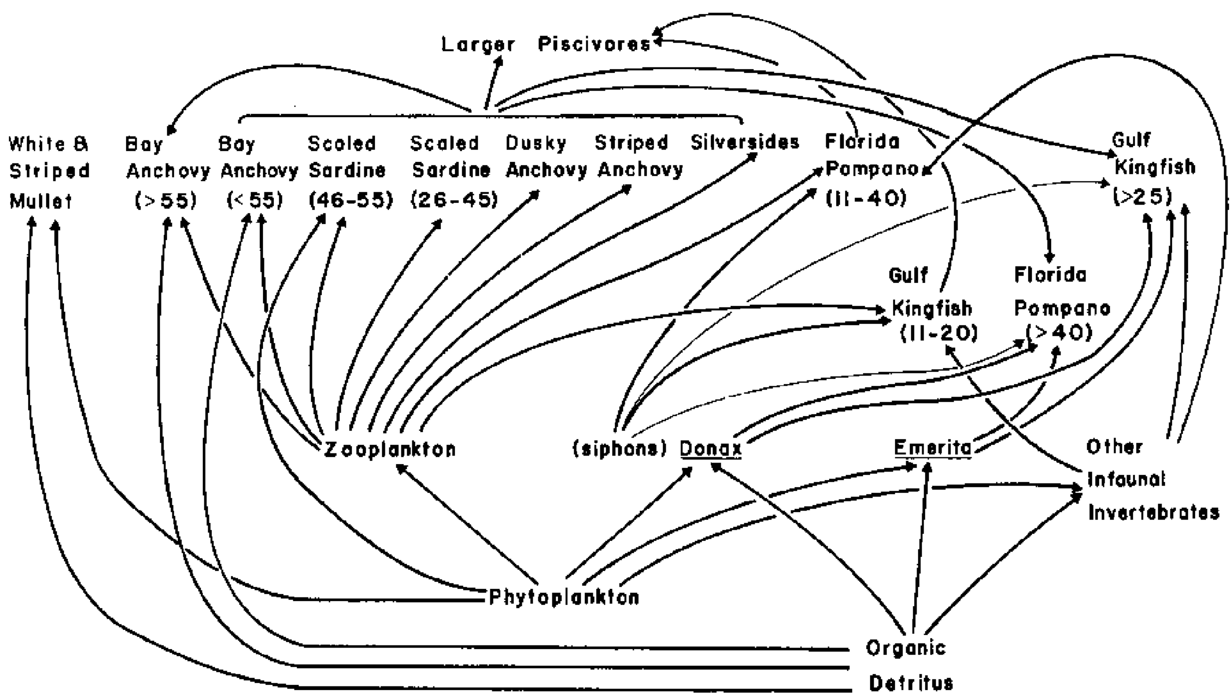

Fig. 3. A partial summer food web for the sub-tidal exposed beach of Horn Island, Mississippi. Numbers refer to sizes in mm standard length.

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THE FOOD OF RED DRUM (*SCIAENOPS OCELLATUS*) LARVAE AND EARLY JUVENILES TAKEN FROM MISSISSIPPI SOUND AND THE NORTHERN GULF OF MEXICO

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ABSTRACT: Gut contents from 222 specimens of 1.8 to 12.6mm SL *Sciaenops ocellatus*, collected during September and October 1980 from surface and near bottom waters of Mississippi Sound and the northern Gulf of Mexico were examined to determine the type and size of food organisms present. Food organisms were identified to lowest possible taxon and life stage, and least dimension measurements were made on each individual. Diets among different size groups of larvae, and site of capture were compared. Copepods and crustacean nauplii dominated the diets of most fish. *Oithona* sp., *Euterpina acutifrons, Acartia tonsa* and *Paracalanus* sp. were the copepods most often eaten by larval red drum. Nauplii of crustaceans and barnacles, along with crustacean eggs and decapod postlarvae were other important food items. A more comprehensive study of the trophic dynamics and growth of planktonic red drum is planned.

INTRODUCTION

Virtially nothing is known of the diet and trophic relations of young, planktonic red drum, *Sciaenops ocellatus*. The only previous analysis was based on juveniles captured in seine hauls behind a barrier island near Caminada Pass, Louisiana (Bass and Avault 1975). Knowledge of early trophic dynamics is essential to our understanding of survival during vulnerable early life stages of fishes when for many species mortality determines year class abundance (Gulland 1965; May 1974). This study was undertaken to examine the food habits of red drum larvae and early juveniles in view of the direct relation that feeding (along with temperature) has on growth which is probably the ultimate determinant of survival. Our results represent only the initial phase of a more comprehensive investigation into the relations between red drum larvae and their planktonic prey, and the consequences to larval growth and condition.

MATERIALS AND METHODS

Larvae were collected during September and October 1980 in stepped oblique tows using a one meter diameter, 335 micron mesh conical plankton net. Collections were made within Mississippi Sound and at three locations outside the barrier islands during a year-long (1979–80) ichthyoplankton survey of those waters (Figure 1). Early juveniles were collected in a hand-pulled beam plankton net, mesh size 1 mm, along the north shore of the west end of Horn Island in October 1975.

Larvae were preserved in 10% formalin in the field and were later transferred to 5% formalin for long-term storage. Standard length (SL) of each fish was measured to the nearest 0.01 mm before removal and dissection of the entire gastrointestinal tract. Food items were identified to the lowest taxon possible, counted and their life stage noted. Maximum body width or diameter of most food items was measured. All measurements were made with an ocular micrometer in a stereomicroscope.

Larvae were grouped into 18, 0.5 mm size intervals for interspecific diet comparisons. Percent frequency of occurrence (%FO) and percent of total number (%N) of prey ingested by larvae per size class were calculated for each food item. An estimate of relative importance of each food item was obtained by multiplying %FO by %N.

Patterns in larval red drum diet were determined using the techniques of numerical classification. Entities (fish size classes and/or collection sites) and attributes (types and sizes of prey items) were clustered using the Canberra metric coefficient of dissimilarity as the distance measure (Clifford and Stephenson 1975):

$$D_{12} = {}^{1}/n \sum_{1}^{n} \frac{/ X_{1j} - X_{2j} /}{(X_{1j} - X_{2j})}$$

where D is a measure of dissimilarity between fish size classes (or collection sites) 1 and 2; X_{1j} and X_{2j} are values for the jth prey item in larvae of each size class (or at each site) and n is the number of prey items found in larvae of the two size classes. The results of the Canberra metric comparisons were sorted using a flexible sorting strategy (Lance and Williams 1966; 1967) with the cluster intensity coeffieicnt, β, set at the conventional value of −0.25. Fish size and prey groupings along with collection site and prey groupings were based on dendrograms and two-way coincidence tables containing untransformed data. For the inverse analysis on which the constancy table was based each prey taxon was standardized by dividing the number of prey in a single fish by the total number of individuals in that taxon from all fish. Constancy or the percent occurrence of a food item in a particular fish size class was calculated for each major prey type.

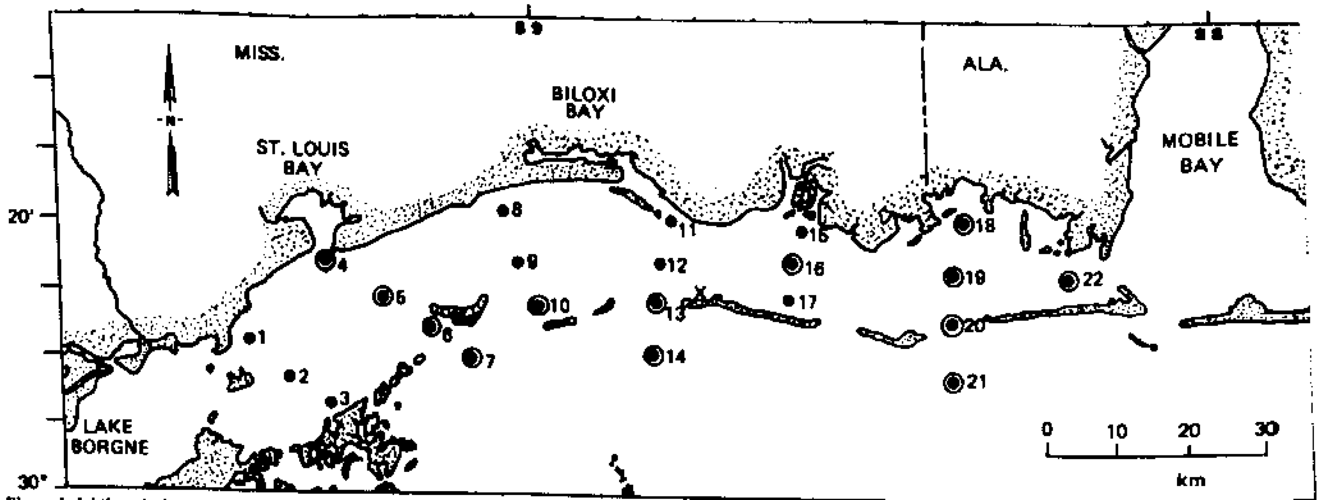

Figure 1. Ichthyoplankton sampling stations in Mississippi Sound and vicinity occupied during the 1979–80 year-long survey (dots). Circled dots indicate stations where red drum larvae were captured (Laroche and Richardson, unpubl. data). The X marks the location of beam plankton net collections.

RESULTS

Gut contents of 222 red drum ranging in size from 1.78 to 12.63 mm SL were examined. Based on similarity in gut contents the young red drum clustered into four size classes: class I, 1.50 to 2.99 mm; class II, 3.00 to 5.49 mm, class III, 5.50 to 8.49 mm; and class IV, 8.50 to 12.99 mm (Figure 2). Forty-eight different food items were found among the gut contents of these fish. Inverse cluster analysis resulted in five food groups based on occurrence in similar sized fish (Table 1).

TABLE 1.

Composition and size range of food groups based on gut contents of red drum larvae and early juveniles and determined by inverse clustering using the Canberra metric coefficient with flexible sorting.

Group I Size Range 0.02 to 0.13 mm
- Centric Diatoms
- Dinoflagellates
- Pelecypoda veligers
- Tintinnids

Group II Size Range 0.04 to 0.19 mm
- *Acartia tonsa* copepodites
- Barnacle nauplii
- Copepod nauplii
- Crustacea nauplii
- *Euterpina acutifrons* copepodites
- *Oithona* sp. copepodites
- Ostracoda
- *Paracalanus* sp. males

Group III Size Range 0.06 to 0.46 mm
- *Acartia tonsa* females
- Cladocera
- *Corycaeus* sp. females
- Copepod eggs
- *Euterpina acutifrons* females
- *E. acutifrons* copepodites
- *Farranula rostrata* copepodites
- *Oithona* sp. females
- *Oithona* sp. copepodites
- *Oncaea* sp. females
- *Oncaea* sp. copepodites
- *Paracalanus* sp. females
- *Paracalanus* sp. copepodites

Group IV Size Range 0.15 to 0.43 mm
- *Acartia tonsa* females
- *Centropages* sp. copepodites
- *Corycaeus* sp. copepodites
- Copepod metasomes or urosomes
- *Eucalanus* sp. copepodites
- *Farranula rostrata* females
- *Macrostella gracilis* females
- *Oithona* sp. females
- *Oncaea* sp. copepodites

Group V Size Range 0.20 to 0.66 mm
- *Acartia tonsa* males
- *A. tonsa* copepodites
- Amphipoda
- Decapoda postlarvae
- Decapoda metanauplii
- *Paracalanus* sp. females
- Polychaeta
- *Sagitta* sp.

The smallest red drum larvae, 1.78 to 2.99 mm SL (size class I), fed primarily on copepod nauplii and eggs, 36.7 and 35.3% of total food items (%N) (Table 2). Barnacle nauplii and tintinnids were next in dietary importance and although they each made up only ∿6.5% of all food items, they were eaten by 20 and 35% of the larvae in the size class (%FO). Copepod eggs were also numerically important in 3.00 to 5.49 mm SL larvae (size class II). *Oithona* copepodites, however, were the prey most consistently ingested by these larvae (Table 3). Size class III larvae (5.50 to 8.49 mm SL) also fed on copepod eggs, 46.3%N and 46.2%FO, however *Oithona* and *Paracalanus* copepodites were ingested by more of these size larvae (Table 4). The numerically dominant prey of the largest larvae, 8.50 to 12.99 mm SL (size class IV) were decapod postlarvae, *Acartia tonsa* copepodites, and polychaetes; accounting for 28.6, 23.8, and 19.0%, respectively (Table 5).

TABLE 2.

Food items making up more than 1% of the total number of items (N = 556) found in the guts of 40 red drum larvae of size class I (1.50 to 2.99 mm SL). %FO = %frequency of occurrence of those items and FxN is the product of %FO and %N. Ten food items were not shown and made up less than 1% of the total. F=females, M=males, C=copepodites.

Food Items	Size Range	%N	%FO	FxN
Copepod nauplii	0.04–0.12 mm	36.7	95.0	34[illegible]
Copepod eggs	0.06 mm	35.3	27.5	97[illegible]
Barnacle nauplii	0.10–0.19 mm	6.5	20.0	13[illegible]
Tintinnids	0.02–0.08 mm	6.6	35.0	23[illegible]
Oithona sp. F	0.17–0.12 mm	2.5	15.0	[illegible]
Oithona sp. C	0.15–0.19 mm	2.3	22.5	[illegible]
Oithona sp. C	0.10–0.14 mm	2.2	17.5	[illegible]
Unidentified Calanoids	0.06–0.23 mm	1.9	5.0	[illegible]
Copepod Heads		1.9	5.0	[illegible]
	Total	95.9		

TABLE 3.

Food items making up more than 1% of the total number of items (N = 1664) found in the guts of 137 red drum larvae of size class II (3.00 to 5.49 mm SL). %FO = %frequency of occurrence of those items and FxN is the product of %F and %N. Twenty-two food items were not shown and made up less than 1% of the total. F=females, M=males, C=copepodites.

Food Items	Size Range	%N	%FO	FxN
Copepod eggs	0.06 mm	40.4	43.8	1770
Oithona sp. C	0.15–0.19 mm	14.4	74.5	1073
Copepod nauplii	0.04–0.12 mm	11.5	51.8	596
Oithona sp. F	0.17–0.23 mm	8.6	49.6	427
Oithona sp. C	0.10–0.14 mm	8.4	58.4	491
Paracalanus spp. C	0.18–0.25 mm	3.0	25.5	77
Copepod Heads		2.2	19.7	43
Paracalanus spp. C	0.10–0.17 mm	1.7	16.1	27
Barnacle nauplii	0.10–0.19 mm	1.7	7.3	12
Unidentified Calanoids	0.06–0.23 mm	1.6	16.8	27
Copepod nauplii	0.13–0.29 mm	1.5	51.8	78
	Total	95.0		

As red drum larvae grew they fed on increasingly larger prey (Table 6). Larvae in size class I fed primarily on food groups I and II. Size class II larvae fed on prey from all five food groups but relied mostly on food groups II and III, while size class III larvae ingested prey primarily from groups III and IV. Size class IV larvae, the largest and most advanced fish in this study fed almost exclusively on food group V. In most specimens examined the most consistently eaten food groups (highest constancy value) also accounted for the food group eaten in the greatest quantity, i.e., with the highest value for mean number of food items per larva. Prey in food group I were never ingested by the two largest size classes of fish, and prey from food group V were never ingested by the smallest larvae.

Only red drum within the size range 1.78 to 4.98 mm SL (N=168) were taken at all collection locations within Mississippi Sound and adjacent

TABLE 4.

Food items making up more than 1% of the total number of items (N = 790) found in the guts of 37 red drum larvae of size class III (5.50 to 8.49 mm SL). %F = %frequency of occurrence of those items and FxN is the product of %F and %N. Twenty-five food items were not shown and made up less than 1% of the total. F=females, M=males, C=copepodites.

Food Items	Size Range	%N	%FO	FxN
Copepod eggs	0.06 mm	46.3	46.2	2139
Oithona sp. C	0.15–0.19 mm	15.8	89.7	1417
Paracalanus spp. C	0.18–0.25 mm	7.3	74.4	543
Paracalanus spp. C	0.10–0.17 mm	4.1	48.7	200
Oithona sp. F	0.17–0.23 mm	2.9	35.9	104
Copepod heads		2.9	41.0	119
Acartia tonsa F	0.33–0.46 mm	2.8	35.9	101
Euterpina acutifrons F	0.21–0.28 mm	2.0	25.6	51
Oithona sp. C	0.10–0.14 mm	2.0	28.2	56
Paracalanus spp. F	0.29–0.39 mm	1.6	38.5	62
Euterpina acutifrons F	0.16–0.20 mm	1.5	28.2	42
Corycaeus sp. F	0.21–0.34 mm	1.1	15.4	17
	Total	90.3		

TABLE 5.

Food items making up more than 1% of the total number of items (N = 21) found in the guts of six red drum larvae of size class IV (8.50 to 12.99 mm SL). %FO = %frequency of occurrence of those items and FxN is the product of %F and %N. F=females, M=males, C=copepodites.

Food Items	Size Range	%N	%FO	FxN
Decapod postlarvae	0.43–0.66 mm	28.6	50.0	1430
Acartia tonsa C	0.20–0.29 mm	23.8	33.0	785
Polychaeta	0.29 mm	19.0	16.7	317
Oithona sp. F	0.17–0.23 mm	9.5	33.3	316
Acartia tonsa M	0.23–0.34 mm	4.8	16.7	80
Oithona sp. C	0.10–0.14 mm	4.8	16.7	80
Unidentified calanoids	0.24–0.43 mm	4.8	16.7	80
Gammarid amphipods	0.23–0.26 mm	4.8	16.7	80
	Total	100.0		

TABLE 6.

Constancy (C), the percent occurrence of a food group within a fish size class, and the mean number of food items per fish ($\bar{X}$) within a size class. Four fish size classes and five prey groups were determined from cluster analyses using the Canberra metric coefficient with flexible sorting.

Food Groups and Size Ranges (mm)	Larval Fish Size Classes and Size Ranges (mm) I (1.50–2.99)	II (3.00–5.49)	III (5.50–8.49)	IV (8.50–12.99)
I (.02–.13)	C = 0.58 $\bar{X}$ = 0.283	C = 0.05 $\bar{X}$ = 0.001	C = -- $\bar{X}$ = --	C = -- $\bar{X}$ = --
II (.04–.19)	C = 0.46 $\bar{X}$ = 0.622	C = 0.65 $\bar{X}$ = 0.198	C = 0.08 $\bar{X}$ = 0.014	C = -- $\bar{X}$ = --
III (.06–.48)	C = 0.29 $\bar{X}$ = 0.288	C = 0.59 $\bar{X}$ = 0.548	C = 0.79 $\bar{X}$ = 1.518	C = 0.02 $\bar{X}$ = 0.007
IV (.13–.43)	C = 0.07 $\bar{X}$ = 0.004	C = 0.30 $\bar{X}$ = 0.033	C = 0.37 $\bar{X}$ = 0.056	C = -- $\bar{X}$ = --
V (.20–.66)	C = -- $\bar{X}$ = --	C = 0.07 $\bar{X}$ = 0.006	C = 0.13 $\bar{X}$ = 0.028	C = 0.30 $\bar{X}$ = 0.407

coastal waters. Comparisons of diet at site of capture, therefore, were limited only to those larvae which belonged to size classes I and II (in part). Based on the composition of larval gut contents, three groups of stations resulted from cluster analysis (Figure 3). The levels of dissimilarity at which stations joined one another were not as high as for larval size classes (Figure 2). Except for the middle group, stations 21, 20, 14, and 13, station groups included sites in both western and eastern regions of the Sound, i.e., typically regions with different hydrographic regimes (Eleuterius 1976).

DISCUSSION

Patterns in trophic ontogeny of red drum were similar to those observed in numerous other fishes (Arthur 1976; Hunter 1980; 1981). As they grew, red drum larvae began ingesting a greater variety of larger prey, yet small prey, e.g., copepod eggs and nauplii, were still important in the diets of all but the largest larvae, >8.5 mm SL. In general, the diet of red drum larvae was similar to the diet of another sciaenid, the Atlantic croaker, despite specific differences in time and locations of capture in the northern Gulf (Govoni et al. 1983). Life stages of calanoid copepods and invertebrate eggs (mostly copepod eggs) had the highest relative importance values among food items ingested by ≤10 mm SL Atlantic croaker larvae, as in red drum larvae.

Copepod eggs were the dominant food item of 3 of the 4 size classes of red drum examined. The highest relative importance value of this food item, however, occurred among 5.50 to 8.49 mm (size class III) larvae. In most fish of this size class the guts containing adult female copepods of the genera *Oithona*, *Euterpina*, and *Corycaeus* also contained eggs. Frequently eggs still within the undigested egg sac were found alongside the copepod urosome. The occurrence of large numbers of eggs in the guts of these larvae could have resulted from active feeding on egg-carrying copepod females, rather than on the eggs themselves. There is some evidence that the larvae of at least one group of fishes, the cottids, preferentially ingest egg brooding copepods (Laroche 1982).

The diet of the largest size class of red drum, 8.50 to 12.99 mm SL, indicated that these fish were changing from a planktonic to demersal existence. Although planktonic prey were still ingested, e.g., *Acartia tonsa* was second in relative importance, benthic amphipods and polychaetes

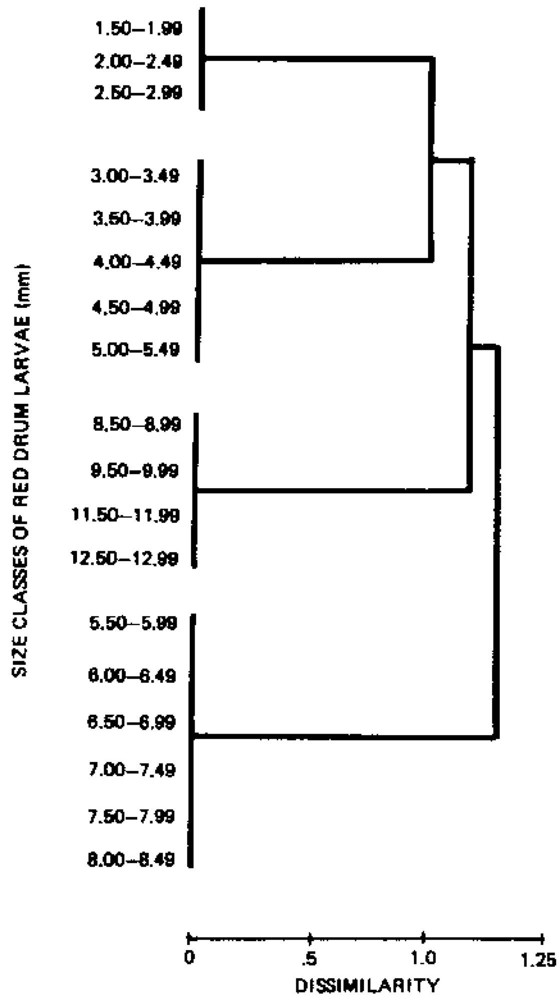

Figure 2. Size groups of red drum larvae and early juveniles based on gut contents as determined by cluster analysis using the Canberra metric coefficient with flexible sorting.

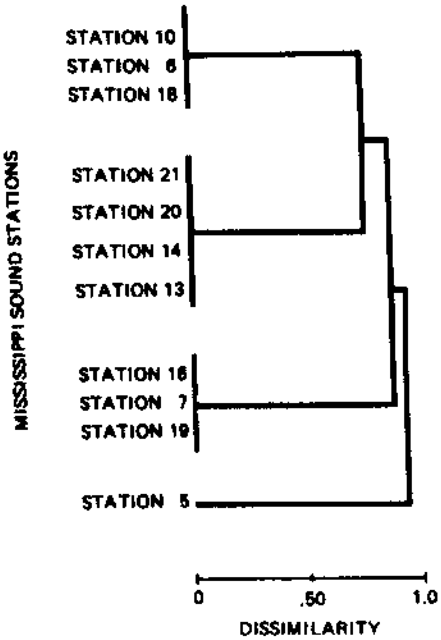

Figure 3. Station groups within Mississippi Sound and adjacent coastal waters based on diets of red drum larvae (1.5 to 4.99 mm SL) collected at those sites as determined by cluster analysis using the Canberra metric coefficient with flexible sorting.

along with postlarvae of shrimp-like decapods were consistently eaten. Other field studies have shown that within the 15 to 50 mm size range there is a shift in diet of red drum juveniles from copepod life stages to mysid shrimp, grass shrimp, young blue crabs, amphipods, polychaetes, and fish (Odum 1971; Bass and Avault 1975). This distinct change in prey types to larger more benthic forms may explain the decrease in mean number of prey per fish from 20.3 in size class III to 3.5 in size class IV. Fewer large prey than small ones would have to be ingested to satisfy metabolic energy demands.

As red drum larvae are transported shoreward from spawning grounds they are exposed to prey populations that vary according to the prevailing estuarine conditions. In Mississippi waters red drum spawning occurs during late summer and early fall (Red Drum Fishery Profile, 2nd Draft, 1982; Laroche and Richardson, unpubl. data). At this time water temperatures and salinities are more homogeneous throughout the Sound than at any other time of the year (Christmas and Eleuterius 1973). In late fall population levels of calanoid copepods; e.g., *Acartia tonsa*, *Paracalanus parvus*, *Centropages furcatus*, *Eucalanus pileatus*, and *Temora turbinata*, inside Mississippi Sound were several orders of magnitude greater than populations of cyclopoids; e.g., *Oithona colcarva*, *Corycaeus* sp., and *Oncaea venusta*, or harpacticoids; e.g., *Euterpina acutifrons* (McIlwain 1968; Perry and Christmas 1973). Zooplankters of the size range found in the guts of red drum larvae would not have been effectively sampled by the 360 micron mesh nets used by these workers. However, with calanoid copepod densities at the levels that have been reported, densities of calanoid copepodites within the Sound should have been sufficient enough to appear in the diet of larval red drum. Two possible explanations exist for their absence: 1) densities of calanoid copepodites were not high enough in September and October 1980 for successful larval feeding, 2) larvae were actively selecting the copepodites and adults of *Oithona*. This cyclopoid copepod was disproportionately more abundant in larval red drum guts than has been historically reported from the plankton in these waters.

Station clusters based on gut contents within Mississippi Sound were difficult to interpret especially since concomitant microzooplankton samples were not available for comparison with larval gut contents. Two station groups which included sites from both eastern and western regions of the Sound suggested that red drum larvae ingested similar prey throughout the Sound. Four offshore and island pass stations; 20, 21, 13, and 14, made up a third group where there was a preponderance of small larvae which had ingested prey associated primarily with a Gulf of Mexico neritic zooplankton community, e.g., *Oithona*, *Euterpina*, and *Oncaea*.

In the fall of 1983 we initiated a more intensive study which will address more specific questions about interactions between red drum larvae and their planktonic prey. Unlike most previous studies of larval fish feeding, this one will be more integrative in approach. Potential planktonic prey will be as intensively sampled as the larvae and their abundance and distribution will be compared with larval feeding and growth.

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BENTHIC MACROINFAUNAL COMMUNITY CHARACTERIZATION IN MISSISSIPPI SOUND AND ADJACENT WATERS

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ABSTRACT: A spatially intensive two season benthic sampling program in Mississippi Sound, lower Mobile Bay, and adjacent offshore waters was conducted for the U.S. Army Corps of Engineers, Mobile District, as part of their Dredged Material Disposal Study Program. Through the use of multivariate statistics, five inshore and three offshore habitats and macroinfaunal assemblages are delineated according to gradients of sediment texture, salinity, depth, and associated fauna. the inshore habitats include: (1) a shallow, coastal margin mud habitat along the west, northwest, and eastern Mississippi Sound; (2) a lower Mobile Bay mud habitat; (3) a deep, muddy sand habitat in the open Sound; (4) a deep, sand habitat at tidal passes; and (5) a shallow sand habitat in the Sound. The offshore habitats are defined according to their sediment composition as: (1) mud-sandy mud, (2) muddy sand, and (3) sand habitats. Density, frequency of occurrence, biomass, feeding type, and environmental parameters showing high correlation are compared and discussed for dominant and characteristic taxa at each habitat type.

Comparisons with similar benthic investigations along the Gulf coast show that the study area supports one of the most diverse (828 taxa) and productive (832-35,537 individuals/m2) benthic faunas for the region.

Benthic macroinfaunal assemblages described for the various habitats are comprised of ubiquitous and/or restrictive faunal components. The ubiquitous component consists of taxa either opportunistic (generalists) in their ability to exist within a habitat or variety of habitats, or characteristic specialists found within a particular habitat type. The restrictive faunal components are comprised primarily of taxa characteristic of specific habitats (e.g., shallow, coastal margin mud), as determined by correlations with environmental parameters.

Life history and feeding strategies of fauna within each assemblage are discussed in relation to natural variability within the study area and their presumed responses to "cause and effect" of activities. Application of results from the benthic characterization study to management practices of dredged material disposal, energy resource exploration, and fisheries activities are discussed.

A STUDY OF THE SEASONAL PRESENCE, RELATIVE ABUNDANCE, MOVEMENTS AND USE OF HABITAT TYPES BY ESTUARINE-DEPENDENT FISHES AND ECONOMICALLY IMPORTANT DECAPOD CRUSTACEANS ON THE SABINE NATIONAL WILDLIFE REFUGE

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ABSTRACT: Economically important estuarine-dependent species generally spawn offshore, migrate into the estuarine zone to grow, and eventually return to the Gulf to complete the cycle. Salt intrusion resulting in marsh deterioration is currently a large problem in Louisiana's estuarine zone. Upon completion of the Calcasieu Ship Channel in 1941, salinity began to rise on Sabine National Wildlife Refuge. This resulted in vegetative changes that eventually resulted in extensive marsh loss in an area labeled Unit 1. To moderate salt intrusion the U.S. Fish and Wildlife Service installed two low-level weirs with gates, and an earthen plug, on the west side of Lake Calcasieu. This study is designed to provide biological and physical information to allow proper management of these weirs such that organisms may pass. Passive traps were designed and placed in strategic canals to determine migratory routes and seasonal presence.

Hog Island Gully and West Cove Canal were determined to be the main routes of migration. Bay anchovy (*Anchoa mitchilli*), Gulf menhaden (*Brevoortia patronus*), and grass shrimp (*Palaemonetes* sp.) were the most abundant organisms taken in the traps. Atlantic croaker (*Micropogonias undulatus*), blue crab (*Callinectes sapidus*), white shrimp (*Penaeus setiferus*) and brown shrimp (*Penaeus aztecus*) were the most abundant economically important species taken along the Gulf menhaden.

Bay anchovies were present year round but had peak abundance in October through April. Young-of-the-year menhaden began recruitment into the marsh in November and December. Peak catches occurred in March and April and most had emigrated by July. Blue crabs were present year round with no particular peaks in abundance. Atlantic croakers began immigration in mid-October that continued until early May. Peak catches occurred in December through February. Juvenile white shrimp began recruitment in mid-July and peak abundance at the trap sites occurred from October through December. This peak was caused by the mass emigration coinciding with cold fronts, presumably due to rapid temperature drops. Brown shrimp began a recruitment in late March and peak abundance at the trap sites occurred from May through July.

Shallow marsh trawling revealed a different community structure than the trap sites. Gulf menhaden was the most abundant organism, followed by the endemic marsh species such as sheepshead minnow (Cyprinodon variegatus), rainwater killifish (Lucania parva), tidewater silversides (Menidia beryllina), and sailfin molly (Poecilia latipinna). Economically important species such as the croaker, penaeid shrimps and blue crab were plentiful, but the year-round residence nature of the shallow marsh community allowed them to be more abundant.

Canal trawling revealed this habitat was dominated by the economically important species: menhaden, penaeid shrimps, croaker, blue crab, and sand seatrout (Cynoscion arenarius). This was probably due to the transient nature of the organisms in the canals.

Monthly, 24-hour plankton samples are being taken to determine if organisms, particularly penaeid shrimps, enter the marsh in the postlarval stage. Fluorescent pigment marking of fish (approx. 500,000) revealed fishes do not necessarily move in and out of the marsh through the same routes. Few shrimp tagged in the marsh were recaptured there, although many of them were taken in Lake Calcasieu. An experimental long-haul seine was tested for gear selectivity against a 6' and 16' otter trawl. Small plexiglass traps used in the shallow marsh were unsuccessful, but a square throw trap was used with limited results. Single and double push trawls were tested for gear selectivity. Diel trap studies were conducted to determine daily movement from March to August. Data analysis is presently beginning for these subprojects.

POTENTIAL EFFECTS OF WATER CONTROL STRUCTURES ON FISHERIES PRODUCTION IN A SOUTHWEST LOUISIANA COASTAL MARSH

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ABSTRACT: A two-phase fisheries study is underway in the marsh east of Lake Calasieu, Louisiana. The first phase involves analysis of weekly, 24-hour samples from six fish traps at the mouth of Grand Bayou. The traps have been in operation since October 1981. The data will be used to (1) determine relative species abundance and seasonal presence of juvenile organisms migrating through Grand Bayou, (2) correlate migrations with changes in selected environmental parameters, and (3) compare results obtained in this phase and a similar study on the west side of Lake Calcasieu.

The second phase, which began in February 1983, is the comparison of fisheries production from two 86-acre, shallow marsh lakes. The two study lakes are similar in all observable respects except for the presence of a low-level, fixed crest water control structure on one. All organisms emigrating from the two lakes are captured in fish traps and the catches analyzed daily. Hourly readings are continually recorded for salinity, temperature, dissolved oxygen, pH, water depth, and flow velocity and direction. Sampling will continue through March 1984. Then the control structure will be switched to the other lake. Sampling will again proceed for 13 months to test for unrecognized inherent differences between the two lakes.

Data from the second phase will eventually be used to (1) determine whether semi-impoundment of a marsh nursery by a low-level, fixed crest water control structure alters the number, biomass, size, or timing of organisms migrating toward the Gulf, and (2) correlate Gulfward movement of organisms environmentally.

The final objective of both study phases is to recommend modifications, if necessary, in the design and/or operation of water control structures proposed for bayous draining the 113,000-acre marsh watershed east of Lake Calcasieu.

SUMMARY OF GROUNDFISH SURVEYS IN THE NORTH CENTRAL GULF OF MEXICO, 1972-1981

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ABSTRACT: Groundfish surveys in the north central Gulf of Mexico have been conducted continuously since September 1972, with at least one survey per year. Stock biomass reportedly was low at the inception of the surveys. Immediately after inception of the surveys the stocks reached their highest levels and have declined ever since. Species composition within the stock consists of approximately 175 species of finfish and 50 crustaceans. Major components (by weight) of the groundfish consist of 8 to 10 species of finfish dominated by sciaenids in general and croaker specifically. Average weight of individual croaker has decreased concurrently with decreased biomass.

The primary user of groundfish in the northern Gulf of Mexico is the shrimp fleet. Because of the presumed impact on stock size, a discard study was initiated to determine the magnitude of the catch taken and discarded by the shrimp fleet. Shrimp/finfish ratios were determined from commercial fishing operations as well as from NMFS research efforts. Within four geographical areas (Texas, Louisiana, Mississippi, Alabama, and Florida), the ratios were separated according to depth and season and then used to estimate total discards. Species composition and relative abundance also was determined for each geographical area, season, and depth zone.

PRELIMINARY RESULTS OF THE MISSISSIPPI SOUND AND ADJACENT AREAS STUDY

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ABSTRACT: In 1977, Congress authorized the Corps of Engineers to conduct a study to determine whether present and proposed dredging activities in coastal Mississippi and Alabama could be modified to increase economic efficiency and promote environmental quality. The study area encompasses portions of Alabama and Mississippi from Lake Borgne on the west to the eastern shore of Mobile Bay, extending south to the 120-foot depth contour in the Gulf of Mexico and north to Interstate Highway 10.

The three-phase study program was developed to: (1) provide an overview of the resources and economy of the area, (2) investigate existing dredging and dredged material disposal practices, (3) analyze the effect of these practices on the resources and economy, and (4) determine if these practices should be modified.

As part of the first phase of the study effort, completed in 1979, a number of data gaps were identified for further study. These data gaps related to water circulation, sediment transport, properties of dredged material, location of critical environmental areas, and values of submerged bottoms.

The second phase of the study effort, scheduled for completion in May 1983, was aimed at filling these data gaps and developing and adapting numerical models to aid in understanding the ecosystem and predicting future conditions. Extensive data collection efforts were undertaken in 1980-81 to develop baseline data for macroinfauna, sediment distribution, and hydrodynamic conditions in Mississippi Sound and the inshore Gulf of Mexico.

A two-dimensional depth integrated numerical model was developed for Mississippi Sound which is to be utilized to simulate changes in circulation patterns resulting from various dredged material disposal options within the sound. Conditions were simulated in the model using average tidal height, high or low levels of freshwater discharge and various wind directions and speeds. General circulation patterns were determined for each of these conditions. Once this was completed, several disposal options for the Pascagoula Harbor, Mississippi area were simulated in the model.

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One of the options evaluated involved the disposal of sandy material as a subtidal fan near the east end of Horn Island. As designed in the model, the fan appeared as an extension of Horn Island, with the same width of the island extending approximately 2 1/2 miles on an east-west axis. Evaluation of results from the model indicate that currents would be developed over this fan with sufficient velocity to cause the transport of material in an east-northeast direction. This movement of material into the sound could possibly result in damage to the grassbeds known to exist on the sound side of Horn Island. Redesign of this option would need to be investigated to determine a more suitable location for disposal.

Other disposal options have been investigated and the impacts of these options on the resources of the area will be discussed in the presentation.

MODELING HYDRODYNAMICS AND SEDIMENT TRANSPORT IN MISSISSIPPI SOUND AND ADJACENT AREAS

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ABSTRACT: The Mississippi Sound and adjacent areas are a region receiving greater attention due to increasing utilization of its resources, including the dredging of shipping channels and the disposal of dredged materials. A study of the area was initiated by the U.S. Army Engineer District, Mobile (SAM) in 1977, to determine whether the present and proposed dredged material disposal methods for maintenance and construction should be modified in any way at this time in the interest of economic efficiency and environmental quality. To address varied planning objectives, the Waterways Experiment Station (WES) in conjunction with SAM developed a systematic approach to measure, analyze, and model the hydrodynamic and transport processes that take place in the subject area. The approach taken involved the collection of synoptic field data (tidal elevations, current speed and direction, temperature and salinity, meteorological and wave data, and water column and sediment samples), data analyses (including harmonic analysis of tide and current data), development of a Gulf of Mexico tide model (for providing open-sea boundary conditions to a local model), and the development of a two-dimensional hydrodynamics and salinity transport model of the region. After the investigation began a parallel research effort was undertaken (by ARAP under contract to WES) to develop a generalized package to model the three-dimensional character of coastal currents and sediment transport with initial application to Mississippi Sound.

This presentation highlights all phases of the work scope but places emphasis on results from the 3-D model simulations. Compatibility with the 2-D model (WIFM) is maintained by use of the same algebraically-stretched grid in the horizontal directions. Special model computational features include a time-splitting or mode separation technique, implicit finite difference algorithms, a vertically-stretched coordinate, quadratic stress laws, and turbulence parameterization.

Results obtained during a five-day simulation period in September 1980 typify the various computations performed and the good agreement with measured data obtained. Large spatial and temporal variation of bottom shear stresses were found to exist within the area. Rate of resuspension of local sediments (primarily Smectite) has been determined experimentally and was found to increase with increasing shear stress, decreasing salinity, and shorter time-history of the bottom sediment structure.

TIME SERIES OF WAVE HEIGHTS DURING COLD FRONTS, OFFSHORE LOUISIANA

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ABSTRACT: Wave attack is one of several factors responsible for coastal erosion in Louisiana. Present knowledge of wave conditions is limited to hindcast studies using wind statistics, scant visual observations in the surf zone, and largely unprocessed wave spectral data collected by the Ocean Data Gathering Program from 1968 to 1971. Highest waves are generated by winds of tropical cyclones and cold fronts; however, during rough weather, wave measurements are even more limited. Recently, instruments were installed at several offshore platforms in the Gulf of Mexico to collect hourly wave and meteorological data, such as significant wave height, maximum wave height, wave period, water level, wind speed and direction, pressure, and temperature. Time series graphs of wave heights have been correlated with meteorological phenomena of several cold fronts during 1981 and 1982. Differing intensity and duration of meteorological conditions cause extreme variation in wave height time series. Meteorological factors affecting waves during cold fronts are assessed as to their relative importance. In addition, wave height time series of cold fronts are compared with those of hurricanes. An understanding of wave phenomena during cold fronts has many applications, including prediction of sand transport, critical erosion areas, and offshore wave conditions.

ESTIMATES OF MATERIAL LOADINGS TO MISSISSIPPI SOUND AND MOBILE BAY

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ABSTRACT: Estimated annual loadings of several constituents (total solids, total phosphorus, total nitrogen and total organic carbon) to various subareas of Mississippi Sound and Mobile Bay showed differences throughout the region which were related to hydrologic inflows and adjacent coastal developments. Loadings were highest around areas with substantial urban and industrial developments (Mobile Bay and Pascagoula) and lowest in those areas with relatively sparse development (St. Louis Bay). A statistically significant relationship was found between individual loadings and the overall water quality in the adjacent areas (p 0.05). Although the relationship was based on a small population of samples, it indicated areas of degreaded water quality. A simple loading model constructed on the relationship may be useful in future environmental management applications.

STRATEGY OF POLLUTANT ASSESSMENT IN COASTAL WATERS

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ABSTRACT: Mississippi Sound is a narrow body of water extending along the Mississippi coast from Lake Borgne to Mobile Bay. Though historically a valuable fishery nursery area, the Sound has also become the site of industrial complexes that now dominate the economy of South Mississippi. Because the impact of industrial and municipal pollutants on our coastal estuaries was virtually unknown, a 4-year Sea Grant study was begun in 1979 to describe pollutant distribution, investigate pollutant transport processes and develop land use guidelines.

Sampling and analysis efforts were devoted to sediments collected throughout the Sound. Sediments from 37 surface samples and 45 coring sites were collected in 1979-1981. More concentrated sampling occurred in the Pascagoula River and Biloxi Bay where residential and commercial development is the most intense. The predominace of organic wastes in industrial effluents emptying into Sound water necessitated an analysis program that stressed organic pollutants. Ten-foot sediment cores were sectioned and all core segments and surface grabs were analyzed for hydrocarbons, total organic carbon, total Kjeldahl nitrogen, phenols and grain size. Total organic carbon values documented high pollution levels in the eastern Sound particularly in the Escatawpa River where organic carbon is 20-40 times background values and are as high as 25% of sediment weight. Total Kjeldahl N values showed maxima of only a few ppt at areas in the Sound near fish processing plants and other contributors of nitrogenous wastes. Phenols occurred at highest levels in the eastern Sound near industrial sources, but values at most sites fell below the 1 ppm level. Hydrocarbons showed the most profound pollutant concentrations in the Sound. Values in Bayou Casotte and other eastern Sound regions were as high as 13,000 ug/g and were 100-1000 times background values. Gas chromatograms revealed basically three sources of pollutant hydrocarbons in these sediments: petroleum associated with an oil refinery, fuel oil and sewage. Of particular concern is the presence of significant levels of polynuclear aromatic hydrocarbons in many of the sites with hydrocarbon pollution. Tracer studies using lignin compounds in paper mill wastes in the Pascagoula and Escatawpa Rivers suggest that organic pollutants from the paper mill and other sources are transported only short distances and accumulate in sediments very near the pollutant source in the rivers and bays. Geographic distributions of pollutants based on surface sample analysis has been complemented with depth profiles for all core samples to summarize the most important geological and chemical features of the sedimentary column.

Because dredging and other waterway engineering projects affect varying strata in the sediment column, these depth profiles give sediment data in a format that engineering groups can use to determine the potential hazards of sediment disturbances.

Toxicological examination of sheepshead minnows, mysid shrimp and amphipods reveals significant mortalities from bioassay exposures to surficial sediments from some regions of the Sound particularly the eastern Sound. These toxicities, settling rate determinations, leachability, community structure vulnerability and sediment disturbance probability are factors that have been numerically rated and combined to form an "environmental stress index" for all regions of the Sound. These indices summarize all pertinent environmental conditions and can help designate "danger spots" where especial care must be exercised in future developments.

DISCUSSION

SCHULTZ: I have a question for Rick Sherrard concerning sampling procedure in the lagoon. What measures did you take in sampling that same spot on the second run?

SHERRARD: Each monthly sample was taken in the same general area. We made provisions for oyster sampling at exactly the same spot. In other words, I tried to locate around the center of each sample site during each sampling period.

SHABICA: Were the stations marked within the lagoon?

SHERRARD: Yes, they were. I placed 1.27 cm diameter tubing at each station, and after each sampling, I tried to make a notation of where exactly the sample was taken... in reference to the tubing, and so therefore I tried to get away from sampling the exact spot that I had sampled the previous month.

CAKE: A question for Paul Johnson: When will the data be released from your study of Mississippi Sound and in what format?

JOHNSON: The report is out and is undergoing review in the Mobile District Corps of Engineers. I have a copy here that people can preview this evening if they are interested, and at that time I'll take names of people interested in copies of the report.

HERKE: I'd like to ask Dr. Settine a question. It's pretty hard to summarize all you were saying in 12 minutes, although I got the general impression that Mobile Bay was still in pretty good condition. Was that correct?

SETTINE: I would say that the levels of pollutants we've seen so far give us a baseline of upper Mobile Bay and that appears in pretty good condition. We are going to extend our study into mussels or other bivalves that will withstand freshwater since we really need to get further up into the bay, closer to the pollutant discharge source.

SCHULTZ: I've got another question concerning the lipid content of the oysters studied. You said it changed with season? I was wondering if you did any follow-up water and sediment analysis, to see if perhaps the rates of absoption were also different.

SETTINE: The answer to that question is no, we haven't, and the reason for that is the initial study that was put in. We were going to do one water column and a site. But because of funding considerations, that was one of the things that got left out. GC/MS analysis is reasonably expensive. We're talking about $100 an hour for GC/MS spec. time. Naturally, we had to cut some things and that's one of the things that got cut out.

SHABICA: I have a question for Steve Ross. This afternoon we'll get into oil and gas exploration. Maybe this is premature, but I was wondering if you'd care to speculate a little bit about the effects of hydrocarbons on your surf zone ichthyofauna, if you've been looking at it at all.

ROSS: Yes, I'll speculate. I haven't done any direct work with that, but the dominant zooplankter in the surf zone system, *Acartia tonsa*, is highly susceptible to low level oil pollution. During spring through fall, the prevailing winds are southerly, such that any offshore accident involving oil or any other material would bring that material into the coastal beaches at a time when there is the greatest density of larval and juvenile fishes in that system. Such an event would have, I think, a reasonably good chance of causing some significant negative effects there.

CAKE: During your analysis of oyster tissues, did you identify any constituents that were classified overall as pollutants, that would be deleterious to the oysters first, and to human consumers second?

SETTINE: Most of the materials that we have been picking up have been polycyclic aromatic compounds. I don't know the effect on oysters, I'd have to ask Ken that question but I do know they're not very good for humans. They're definitely the types of things that are carcinogenic.

CAKE: Where were those oysters from?

SETTINE: From Mobile Bay sites they were at very low levels, parts per billion.

CAKE: That means we'd have to be eating thousands of them for lunch today to be affected?

SETTINE: Probably more than that, I would say. I haven't stopped eating ousters yet. Notice I said yet. But the kinds of concentration we're talking about in parts per billion, are not the kinds of things at the moment we need to worry about in terms of human consumption. What we're really trying to do is set up a baseline to see if these types of compounds go up, because they are good indicators of severe pollution from oil exploration and from just general traffic and industrial development, and if they go up and they start getting into parts per million range, then I think we need to be more concerned.

CAKE: Do you consider your findings a baseline? Did you start your study prior to the drilling activities in lower Mobile Bay, or did you go on line with your study after they began drilling?

SETTINE: I think we started prior to it. The first collection was in the spring of '81 and I think was just prior to the time they started putting the well in.

CAKE: So, you do have what you would consider baseline data? How about the effects of any drill mud release? Could you pick that up or was that effect noticed?

SETTINE: I don't think we picked it up in the oyster itself. I did some of the analysis work on some of the sediment around the drill mud where it was dumped, and you can definately pick it up, but we didn't really see any increase in the oysters. There are not enough oyster beds near where they dumped it.

CAKE: I assume that all of those activities were directly or indirectly related to boat traffic and other chemical sources and none to the wastes of refineries or anything like that. Correct?

SETTINE: Not that we can tell at the moment. Again, this is only the second year of study. I think that definitely this next year when we move further up in the bay, closer to the pollution sources, with other bi-valve systems, we'll be able to point our fingers. Right now we can't really say.

JOHNSON: I was going to ask if they planned to move further up the bay so the sources of pollutants they're looking for may be more easily found within the vicinity of petrochemical industries or paper mills.

SETTINE: Right. Now I've already started working on the mussels. We collected some mussels, Rangia cuniata. I don't know if you call them mussels or clams, but anyway, they're little bi-valve creatures. We started collecting them this year and we've already worked on the technology for doing the gel permeation and being able to trace pollutants in these. The reason for it, of course, is that this year, in the later collection, we're moving further on up into the bay closer to pollutant sources. We might even go right on up into the Theodore Ship Channel itself. In order to do that, we've got to have something else besides oysters, and so that's on tap. We're also going to transplant some oysters to some "hot spots." We're taking oysters from areas that we've analyzed. We know basically what the baseline is, and we're going to move these in and place them closer to some of the industrial activity.

VITTOR: Bob, you might make some comments abou the timing of the sampling in regards to the oi drilling in the bay as far as the timing of the start of your study. For example, the first drilling began in summer, 1979 and the subseque drilling which I think you were referring to ha some impact. What is going on right now?

SETTINE: Right, but in either case I don't really see any major impact because of the dril ing as of yet in the oyster beds we've looked at.

ROHR: The question I have, since I did a thesi on age and growth of red drum in Mississippi an Chandeleur Sounds, is what part of the water column were these young red drum coming from offshore into the Sound, John? I just thought this may be of interest since we have great debate on how the ground fish species are comin in and out, and this might throw some light on the question.

STEEN: This was an interesting point, Bennie. As I mentioned, the samples were taken from the upper and lower half of the water column. We looked at the way all fish were feeding by cluster analysis. We then divided the fish into size groups and determined whether they were caught in the upper or lower half of the water column and clustered this data. We found no differences in the gut contents of fish that were feeding at the top and at the bottom within a size group, but there were differences among the size groups. However, our raw numbers suggested that a considerable number of fish were caught at the surface, many more than were caught in the bottom waters. But, the actual numbers of food organisms per fish in the gut were considerably higher from the fish in the bottom half of the water column. These samples, I've been told, were collected primarily during daylight hours. I'm not exactly sure what this means without having taken the actual zooplankton samples from these areas at the same time.

OFFSHORE PETROLEUM EXPLORATION AND DEVELOPMENT

Offshore oil and gas exploration and development activities are the subjects of an often controversial nature. Industry, environmental groups, and the public are often at odds on how best to accomplish the energy "requirements" of the United States. We note that the offshore oil and gas industry in the northern Gulf of Mexico has an excellent environmental record. There are reasons for this. Through careful environmental and construction planning, the industry has demonstrated that the ecological perturbations associated with oil and gas exploration and development can be minimized, even in critical animal habitats. We believe it is of great interest that of the total oil introduced annually into the world's oceans, 9.8% is from natural seepage, and 1.3% is from offshore production activities. To assist in offshore oil and gas exploration planning, detailed maps are made of the seafloor geology, and sensitive physical, cultural, and biological features and resources. These environmental baselines provide gauges for measuring the health of the environment and for predicting future environmental perturbations. In looking towards the people that are most affected, the sociological and economic effects of offshore oil and gas exploration and development on coastal communities is detailed. Although the record is excellent, we should not be lulled into a sense of complacency. As the Santa Barbara and IXTOC I oil spills demonstrated, accidents do occur and they can cause long term biological, ecological, and ultimately human perturbations.

STUDIES ON THE ENVIRONMENTAL EFFECTS OF OFFSHORE PETROLEUM EXPLORATION AND PRODUCTION OPERATIONS IN THE GULF OF MEXICO

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ABSTRACT: Within the last ten years, three major studies have been conducted to assess the environmental effects of offshore Gulf of Mexico petroleum platforms and the materials discharged from them during exploration and production operations. Offshore petroleum platforms serve as "artificial reefs" and support a rich and diverse biological community. Motile invertebrates and fish are attracted to these structures for the food and shelter they provide. The major discharges during petroleum exploration and production activities include drilling fluids (drilling muds), drill cuttings and produced water. There is a reduction in the numbers and biomass of the fouling and benthic organisms in the immediate vicinity of the discharges. However, it appears that the impacts on the marine ecosystem are minor.

INTRODUCTION

The first offshore well was drilled in the Gulf of Mexico more than 40 years ago. However, substantial offshore development did not begin until 1953, when ownership and jurisdiction over the resources of the Outer Continental Shelf were defined legally by the Submerged Lands Act and the Outer Continental Shelf Lands Act (Bedinger et al. 1981). By 1983, more than 27,000 wells had been drilled, and approximately 3,800 structures associated with offshore petroleum production had been located in the Gulf of Mexico. A typical offshore production area may contain production platforms, quarters platforms, satellite jackets (single well platforms), flarestacks and pipelines. The majority of these structures are off Louisiana (Gallaway 1982).

Several materials are discharged from these offshore platforms during oil and gas operations. The major discharges include drilling fluids (drilling muds), drill cuttings and produced water, which release hydrocarbons, trace metals and other substances into the marine environment.

Within the last ten years, three major studies have been conducted to assess the impacts of these offshore oil and gas operations on the Gulf of Mexico ecosystem. The first of these projects, "The Offshore Ecology Investigation," was performed in 1973-1974 in Timbalier Bay, Louisiana and the adjacent offshore area (Ward et al. 1979). Between 1975 and 1980, the environmental impacts of Buccaneer Gas and Oil Field, 50 km southeast of Galveston, Texas, were studied (Jackson and Wilkens 1980). In 1978-1979, ecological investigations of petroleum platforms in the central Gulf of Mexico off Louisiana were conducted (Bedinger 1981a).

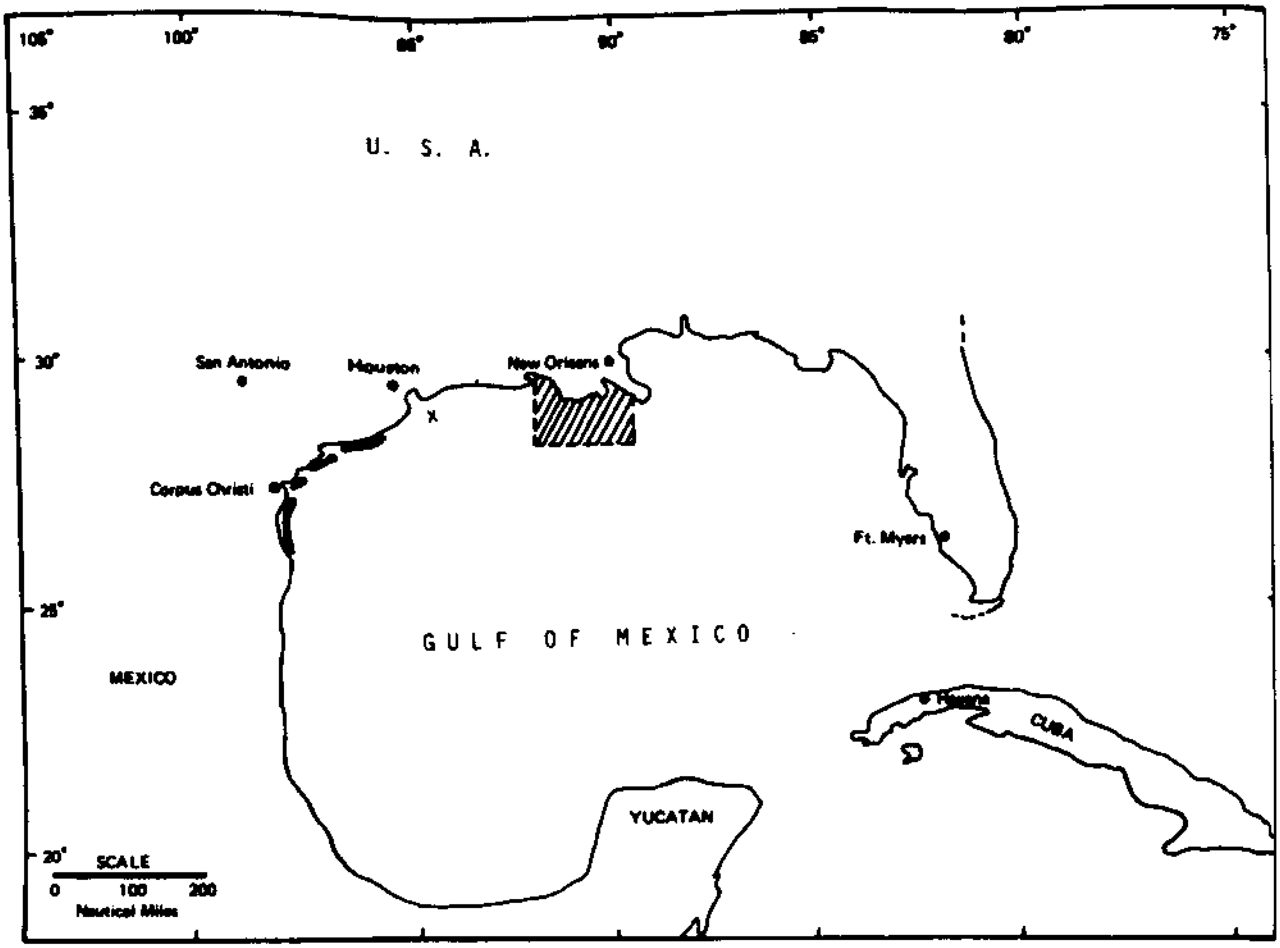

Figure 1. Location of study sites for the ecological investigations of offshore petroleum exploration and production operations in the Gulf of Mexico. The shaded area indicates the location of the offshore Louisiana studies. The (X) marks the location of Buccaneer Gas and Oil Field. (Map modified from Bedinger 1981b).

The location of the study areas is shown in Figure 1.

This paper describes the results of research on the effects of offshore petroleum platforms and the materials discharged during the exploration and production operations on the Gulf of Mexico ecosystem.

PETROLEUM PLATFORMS AS ARTIFICIAL REEFS

Petroleum platforms serve as artificial reefs for a rich and diverse community of fouling organisms that attach themselves to the platform legs. Motile invertebrates and fish are attracted to these platforms for the food and shelter they provide. It was estimated that 3,500 petroleum structures in the Gulf of Mexico provided approximately 1,600 ha (4000 acres) of artificial reef habitat (Gallaway 1982).

Many of the organisms that utilize the offshore petroleum platforms in the Gulf of Mexico have been identified. Fotheringham (1977) listed more than 100 species of invertebrates and 16 species of algae at Buccaneer Gas and Oil Field. Gallaway and Martin (1980) collected 72 species of fish and 31 species of macrocrustaceans in the trawling program at the same study site. At the central Gulf of Mexico platforms, more than 150 species of invertebrates were reported by Gallaway et al. (1981a), and a total of 120 species of algae were identified from offshore Louisiana petroleum platforms by Bert and Humm (1979).

Although many of the species observed inhabit both coastal and offshore platforms, there are differences in the dominant fouling organisms with distance from shore (Table 1). At a nearshore platform, 4.8 km from the Louisiana coast, barnacles (*Balanus amphritrite niveus*) are dominant in biomass; while at the offshore Louisiana platforms, most of the biomass is contributed by bivalves, such as the tree oyster *Isognomon bicolor*. Macroalgae are rare at the shallow coastal platforms where the water is turbid, whereas they are abundant at the offshore platforms (Gallaway et al. 1981a). Other common representatives of the fouling community on the Gulf of Mexico petroleum platforms include amphipods, anemones, bryo-

TABLE 1. Dominant fouling fauna, in biomass, on petroleum platforms in the central Gulf of Mexico (modified from Gallaway et al. 1981a).

DEPTH (m)	COASTAL (4.8 km)*	OFFSHORE (42 km)*	OFFSHORE (53 km)*
1	Barnacles (92%) Anemones (4%) Bivalves (3%) Other (1%)	Bivalves (65%) Barnacles (27%) Brittle Stars (8%)	Bivalves (92%) Barnacles (6%) Other (2%)
10	Barnacles (88%) Bivalves (10%) Other (2%) (12 m)†	Bivalves (93%) Barnacles (5%) Other (2%)	Bivalves (97%) Barnacles (2%) Other (1%)
20	---	Bivalves (99%) Other (1%)	Bivalves (99%) Other (1%)
30	---	Amphipods (97%) Brittle Stars (3%) (35 m)†	Bivalves (89%) Amphipods (6%) Anemones (4%) Other (1%) (46 m)†

†water depth of platform
*distance from shore

zoans, crabs, flatworms, hydroids, nematodes, nemerteans, polychaetes and sponges (Gallaway et al. 1979; Gallaway et al. 1981a).

The dominant fish at the nearshore petroleum platforms in the northwestern and central Gulf of Mexico are blennies, ranging from 8-16 fish/m^2; sheepshead; Atlantic spadefish; gray triggerfish; and schools of moonfish, lookdown, bluefish and blue runner. At the Louisiana offshore platforms the most abundant fishes are spadefish. Lookdowns, moonfish, blue runner, sheepshead, gray triggerfish, gray snapper, red snapper and several species of jack fish (amber jack, almaco jack, bar jack) also are common. In addition, many species of tropical fish (coral reef fauna) occur at the offshore platforms (Gallaway et al. 1981a).

There has been considerable debate as to whether petroleum platforms increase the abundance of fish or simply dislocate and/or concentrate them. The number of individuals of some species, such as barracuda, blennies, triggerfish, damselfish and angelfish, appears to be increased as a result of the structures. These species are dependent upon the reef habitat during some portion of their life cycle. Species whose populations may be concentrated but not increased, are bluefish, red snapper, jacks and groupers (Gallaway et al. 1981a).

MAJOR DISCHARGES FROM OFFSHORE EXPLORATION, DEVELOPMENT AND PRODUCTION ACTIVITIES

Drilling Fluids and Drill Cuttings

Drilling fluids (drilling muds) are one of the major materials released into the marine environment during drilling operations. They function to: 1) ensure controlled and efficient drilling by maintenance of well pressure and well properties of the borehole, 2) remove drill cuttings from the hole, 3) cool and lubricate the drill bit and drill pipe (string), 4) permit logging and geological evaluations, and 5) minimize corrosion.

Drilling fluids are generally water-based colloidal suspensions containing barite (barium sulfate), bentonite, ferrochrome lignosulfonate and other components to control their density, viscosity, pH, etc. Water-based drilling fluids are discharged intermittently during the drilling operation, with discharge volumes ranging from 16-160 m^3/discharge. A total of 900-5,000 m^3 of drilling fluids may be discharged during exploration of a single well 3,000 m deep. An additional 11,000-33,000 m^3 of drilling fluids per platform (assuming 10-30 wells/platform) may be released during development (Menzie 1982).

Drill cuttings, another major discharge during exploration and development operations, consist of formation solids carried from the drilling hole to the surface by the drilling fluids. This solid material is discharged continuously during drilling at a rate of 11-112 tons/day. A total of 800-1,300 tons of drill cuttings may be released during the drilling of exploratory wells, ranging from 1,700-5,000 m in depth. An additional 9,000-27,000 tons of cuttings may be discharged from a platform (assuming 10-30 wells/platform) during development (Menzie 1982).

TABLE 2. Ranges of LC50 values in parts per million (ppm) and their relative toxicity.*

< 1 ppm = Very Toxic
1 - 100 ppm = Toxic
100 - 1,000 ppm = Moderately Toxic
1,000 - 10,000 ppm = Slightly Toxic
> 10,000 ppm = Practically Nontoxic

*IMCO/FAO, UNESCO, WMO. 1969.

Impacts on Marine Organisms

The environmental effects of drilling fluids and cuttings have been studied by several investigators. Gettleson (1980) observed a statistically significant reduction in benthic meiofauna during drilling operations. The decrease in number of individuals was greatest within 100 m from the platform, but reduced populations extended to 1,000 m. However, within three months after drilling was completed, partial recovery of the benthic organisms had occurred.

The toxicity of drilling fluids to marine organisms also has been studied. More than 400 acute toxicity tests have been conducted on drilling fluids, using at least 72 water-based drilling fluids and 62 species of marine organisms, including phytoplankton, copepods, isopods, amphipods, mysids, decapods, gastropods, bivalves, echinoderms, polychaetes, and fish (National Academy of Sciences 1983). The acute toxicity of a substance is given in LC50 values. The LC50 value is the calculated concentration of a test material at which 50 percent of the organisms die during the period of exposure (generally 96 hours); the lower the LC50 value, the greater is the toxicity of the substance (Table 2). For most of the drilling fluids tested, the 96-hour LC50 values ranged from 10,000->100,000 ppm, indicating a low acute toxicity to the species analyzed (Table 3). Only about seven percent of the species tested showed a LC50 less than 1,000 ppm. In general, the drilling fluids showed greater toxicity to larval and early life stages than adults (National Academy of Sciences 1983).

Produced Water

The major material discharged into the Gulf of Mexico during petroleum production operations is a brine solution called produced water, formation water or brine effluent. This water is present in oil and gas reservoirs in varying amounts ranging from about 1-99 percent of the total fluid produced.

Produced water contains dissolved inorganic salts (cations, such as sodium, magnesium, calcium; and anions, such as chloride, sulfate, carbonate, bicarbonate), hydrocarbons, trace metals and other organic and inorganic components. At the Buccaneer Gas and Oil Field, the volume of produced water ranged from 14-23 m^3/day, with a mean of approximately 120 m^3/day (Gallaway et al. 1980). The average daily produced water discharge (120 m^3/day) contained 3.4 ppm alkanes, 6.1 ppm benzene, 5.5 ppm toluene, 1.2 ppm ethylbenzene and 460 ppm sulfur (Middleditch 1981). The trace metals in the produced water included barium (1.4 ppm), strontium (70.7 ppm), copper, iron and manganese (Tillery 1980a).

A recent inventory of various sources of petroleum in the marine environment estimates that produced water and spills associated with offshore production operations only accounted for about 1.3 percent of the 6.1 million metric tons of hydrocarbons discharged annually into the ocean (Table 4).

Impacts on Marine Organisms

The effects of produced water discharges on the fouling community, fish, benthos, and bacteria at Buccaneer Gas and Oil Field were studied by several investigators (see Jackson and Wilkens 1980).

Fouling Community. Examination of the fouling organisms on the platform leg directly beneath the produced water discharge indicated a statistically significant reduction in biomass and recolonization rates. However, the effects were restricted to a vertical distance of approximately 1 m and a horizontal distance of about 10 m. At depths greater than 1 m, recolonization rates were equal to or greater than the rates at the control sites (satellite jackets) (Gallaway et al. 1981b). Respirometry experiments conducted on the surface fouling community exposed to produced water showed low rates of primary production and increased oxygen consumption, indicating stress (Gallaway et al. 1981b).

Fish. The fish studied included those species that were directly dependent on fouling organisms for food and cover (e.g., blennies, sheepshead, triggerfish), and those attracted to the structures for cover alone (e.g., spadefish, red snapper, groupers). The crested blenny, the most abundant platform-associated fish, did not appear to be affected by produced water. In fact, there were more blennies directly beneath the produced water outfall than at the control station, probably because of greater habitat availability (Gallaway et al. 1981b). Blennies live in the empty barnacle shells that remain after the barnacle dies. Spadefish, which feed on plankton in the water column, showed evidence of disease (lesions and fin rot) in the winter at both the production platform and control site. These epidemics may have been the result of stress from change in habitat (spadefish move from the upper part of the water column

TABLE 3. Summary of results of acute toxicity tests with drilling fluids and marine/estuarine organisms. *†

Organism	Number of Species Tested	Number of Fluids Tested	Number of Bioassays	Number of LC50 Values (ppm)					
				Not Determin-able	<100	100-999	1,000-9,999	10,000-99,999	>100,000
Phytoplankton	1	9	12	5	0	0	7	0	0
Invertebrates									
Crustaceans									
Copepods	2	17	39	4	2	11	15	7	0
Isopods	2	4	6	0	0	0	0	1	5
Amphipods	4	8	19	0	0	0	0	5	14
Mysids[a]	5	18	41	1	0	1	0	21	18
Shrimp[a]	10	40	76	0	0	12	15	31	18
Crabs[a]	6	18	35	1	0	0	5	16	13
Lobsters[a]	1	2	7	0	0	0	1	3	3
Molluscs									
Gastropods	5	5	10	0	0	0	0	2	8
Bivalves[a]	7	14	33	0	0	0	1	15	17
Echinoderms									
Sea Urchins[a]	1	2	4	0	0	0	0	1	3
Polychaetes	6	14	28	0	0	0	0	9	19
Finfish[a]	12	32	90	0	0	0	3	52	35
TOTALS	62	72[b]	400	11	2	24	47	163	153
Percent, as a fraction of the total number of drilling fluid bioassays				2.8	0.5	6.0	11.3	40.8	38.3

[a]Includes results for embryonic, larval and early life stages.

[b]In many cases, the same drilling fluid was used for bioassays with several species. In a few cases, more than one investigator evaluated the toxicity of a single drilling fluid.

*Most LC50 values are based on 96-hour bioassays.

†From National Academy of Sciences 1983.

to the bottom), increased fish density, change in food from plankton to suspended particulates, and apparent reduction in feeding efficiency in the winter. However, diseased spadefish were rare at the sunken liberty ship V. A. Fogg, which lies about 27 km south of Buccaneer Gas and Oil Field. Thus, it is possible that the winter disease epidemics in spadefish may be related to low-level discharge of contaminants at Buccaneer Gas and Oil Field (Gallaway et al. 1981b). However, other fish studied, including sheepshead, triggerfish and red snapper, showed no increase in disease (Gallaway et al. 1981b).

Benthos. The benthic community was dominated by polychaetes and amphipods. The numbers of these benthic organisms were reduced beneath the Buccaneer Gas and Oil Field production platforms, but the decrease was restricted to an area within 100 m of the platforms. It was not clear whether the effect was due to periodic contact with toxic substances in the produced water, substrate disturbance from currents eddying around the platform leg, or some other cause (Harper et al. 1981).

Bacteria. Bacterial numbers and biomass were slightly higher in the sediment and water column at the control sites than at the production platform at Buccaneer Gas and Oil Field. However, the numbers of oil- and sulfur-degrading bacteria were greater at the production platforms. Other studies conducted in the Gulf of Mexico indicated that enzymatic reactions such as cellulolysis, proteolysis, and sulfur oxidation did not appear to be affected by chronic low levels of oil contamination (Brown et al. 1981).

Toxicity Studies. The acute toxicity of produced water from Buccaneer Gas and Oil Field was tested on brown and white shrimp, barnacles and the crested blenny. The 96-hr LC50 values ranged from 8,000-408,000 ppm (Table 5). The most sensitive organisms were larval brown shrimp, and the least sensitive were the adult blennies (Rose and Ward 1981). Acute toxicity tests on juvenile white shrimp conducted by an

TABLE 4. Estimate of petroleum hydrocarbons introduced annually into the oceans from all sources.*

	Best Estimate (million metric tons/yr)	Percent
Natural seeps	0.6	9.8
Offshore production	0.08	1.3
Transportation		
LOT tankers	0.31	5.1
Non-LOT tankers	0.77	12.6
Dry docking	0.25	4.1
Terminal operations	0.003	0.05
Bilge bunkering	0.5	8.2
Tanker accidents	0.2	3.3
Nontanker accidents	0.1	1.6
Coastal refineries	0.2	3.3
Atmosphere	0.6	9.8
Coastal municipal wastes	0.3	4.9
Coastal industrial wastes	0.3	4.9
Urban runoff	0.3	4.9
River runoff	1.6	26.2
TOTAL	6.113	100

*From National Academy of Sciences 1975.

earlier investigator resulted in 96-hr LC50 values that exceeded 100,000 ppm (Zein-Eldin and Keney 1979). When biocides were added to reduce the bacteria in the production facilities, the produced water was considerably more toxic to the shrimp, and the 96-hr LC50 values ranged from 1,850-6,500 ppm (Zein-Eldin and Keney 1979).

HYDROCARBON AND TRACE METAL ANALYSES

Seawater, sediment and tissues of a variety of species associated with petroleum platforms in the Gulf of Mexico have been analyzed for petroleum hydrocarbons and trace metals.

Hydrocarbons

The hydrocarbons in the produced water at Buccaneer Gas and Oil Field were apparently rapidly diluted upon mixing with the seawater, since no concentration gradients were noted by Middleditch (1981). Although the hydrocarbon concentrations in the sediment beneath the structures showed considerable variation with season, they were consistently higher at the production platform than at the satellite jacket 300 m to the northeast (Middleditch and West 1980).

Barnacles, the fouling mat (including algae, sponges, hydroids and bryozoans), fish, shrimp and other benthic organisms, and plankton were analyzed for petroleum hydrocarbons. Barnacles and the fouling mat collected at 3 m from the surface showed the highest concentrations of petroleum hydrocarbons. The barnacles contained up to 4 ppm of petroleum alkanes (Middleditch 1981). The mean concentration of hydrocarbons in the fouling mat was 122 ppm (Middleditch and West 1980). The crested blenny and sheepshead, which feed on the fouling community, contained a mean petroleum hydrocarbon concentration in the muscle tissue of 6.8 ppm and 4.6 ppm, respectively. The red snapper and spadefish, which do not utilize the fouling community as a food source, showed lower levels of petroleum contamination in the muscle tissue, 1.3 ppm and 0.6 ppm, respectively (Middleditch 1981). Most shrimp contained no petroleum hydrocarbons, and other benthic organisms did not yield consistent results (Middleditch 1981).

Trace Metals

The trace metals analyzed included barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, strontium, vanadium and zinc. The sources of these metals are drilling fluids; produced water; petroleum seepage and spills; supply, service and pleasure boats; sacrificial anodes and anticorrosion materials (Tillery et al. 1981).

Sediment within 100 m of the production platform at Buccaneer Gas and Oil field contained higher concentrations of barium, cadmium, chromium, cobalt, lead, strontium and zinc than sediment in the control area (Anderson et al. 1981). Elevated barium concentrations in the sediment also were recorded as far as 1,000 m from six drill sites in the Gulf of Mexico (Gettleson and Laird 1980).

The organisms analyzed for trace metals in the Buccaneer Gas and Oil Field study included barnacles, sheepshead, spadefish, red snapper, triggerfish, shrimp and crabs. Barnacles contained higher concentrations of barium, cadmium, cobalt, copper, iron, lead, manganese, nickel, strontium and zinc at the production platforms (Anderson and Schwarzer 1979). The fouling mat also showed higher concentrations of most of these metals at the production platform than at the control site (Tillery 1980a). However, the differences were not statistically significant (Anderson and Schwarzer 1979; Tillery 1980a). Gray triggerfish and sheepshead, which graze on the fouling community, showed higher concentrations of zinc and iron than the other fish analyzed. Trace metal concentrations varied widely among benthic organisms (Anderson and Schwarzer 1979). In general, there was no evidence of significant trace metal contamination of the marine organisms associated with the production platforms at Buccaneer Gas and Oil Field (Tillery 1980b).

OTHER FACTORS TO CONSIDER

The studies on the offshore Gulf of Mexico petroleum platforms have attempted to attribute observed biological differences to oil and gas

TABLE 5. Summary of acute toxicity data for produced water.*

TEST ORGANISM	LC50† (ppm)
Brown Shrimp	
Larva	8,000 - 12,000
Subadult	60,000 - 183,000
Adult	78,000 - 178,000
White Shrimp	
Subadult	56,000 - 133,000
Adult	37,000 - 92,000
Barnacle	33,000 - 154,000
Crested Blenny	158,000 - 408,000

†Range of mean LC50s from tests conducted under varying conditions (e.g. season, temperature, produced water).

*Test series no.1, modified from Rose and Ward 1981.

operations. However, many other factors may account for the biological differences reported. Most marine species exhibit extensive seasonal and annual variability in abundance, as well as patchiness in distribution. Natural catastrophes, such as tropical storm "Debra" and massive flooding of the Mississippi River, such as that which occurred during the central Gulf of Mexico study, may have masked most of the platform-related effects (Bedinger 1981b). The massive discharges of hydrocarbons and metals from inland urban and industrial wastes, transported by the Mississippi River, probably exert a far greater effect on the central Gulf of Mexico ecosystem than petroleum exploration and production operations in the area (see Table 4). The difficulty of establishing adequate controls also may have affected the results of some of the studies. The above factors need to be considered in assessing the impacts of offshore oil and gas activities in the Gulf of Mexico. However, even when biological differences have been shown to be related to discharges from petroleum operations, the significance of the findings has been difficult to evaluate at the population or ecosystem level, because very little is known about the biological and physical processes which regulate the marine ecosystem (Gallaway 1981). On the basis of the research conducted within the last ten years on the Gulf of Mexico ecosystem, it appears that the environmental effects of offshore exploration and production operations are minor.

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ENVIRONMENT AND CONSTRUCTION TECHNIQUES INVOLVED WITH THE INSTALLATION OF THREE LARGE DIAMETER NATURAL GAS PIPELINES IN SENSITIVE COASTAL AREAS

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ABSTRACT: This presentation outlines and discusses the activities surrounding installation of three large diameter natural gas pipelines traversing sensitive coastal habitats. Discussion is presented on the project environmental and construction planning, pipeline routing, facility siting, wildlife timing considerations, and special mitigative construction techniques designed to minimize environmental impacts. The three projects presented are:

1. Cognac Project - Discussion is presented on the planning and installation of the 40-mile, 18-inch diameter Cognac natural gas pipeline originating at Shell Oil's Cognac platform offshore Louisiana in 1,000 feet of water and proceeding northward to a landfall at the mouth of the Mississippi River, then traversing two wildlife refuge systems to a receiving station tie-in.

2. Matagorda Project - Discussion is presented on the planning and installation of the 40-mile, 24-inch diameter Matagorda natural gas pipeline originating offshore Texas and proceeding northward and crossing Matagorda Island, a natural barrier island, then proceeding across San Antonio Bay and through the critical habitat of the Whooping Crane adjacent to Aransas National Wildlife Refuge to a tie-in point just north of the refuge.

3. Savannah Project - Discussion is presented on the construction of an LNG facility and subsequent installation of two, 30-inch diameter natural gas pipelines traversing the Savannah National Wildlife Refuge, a high energy tidal area.

SOCIOECONOMIC ASPECTS OF PETROLEUM PRODUCTION IN THE GULF OF MEXICO

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ABSTRACT: The Minerals Management Service, which is responsible for leasing offshore acreage for oil and gas development and monitoring industry operations, must evaluate potential environmental and socioeconomic impacts of lease offerings and of the resulting exploration and development of oil and gas resources. In this study, the specific interest was to expand the existing capabilities for assessing socioeconomic impacts of the federal oil and gas recovery program offshore. The object was, through the use of indicators, to develop data that will contribute to the quantitative understanding of factors that affect the economies of coastal areas in the Gulf of Mexico.

Previous indicators used to measure socioeconomic factors failed to differentiate impacts of oil and gas development onshore, in state waters, in the federal OCS, and in foreign countries. The use of mobile drilling rigs was proposed as an indicator of geographic location of current drilling operations, shore bases, types of wells, types of rigs, and, indirectly, of employment. Comparisons between operations in state offshore waters and in federal waters were used to differentiate impacts of the federal program. For three months (July-September 1982), the location of mobile drilling rigs was plotted on mylar overlays with a federal lease map as the base. Rig locations and descriptive data (shore bases, rig type, well type) were examined with commercially available software on a microcomputer. Supporting information was obtained from industry and government sources.

The following conclusions were reached: (1) In the Gulf of Mexico approximately 90% of the drilling operations on mobile rigs are located in the federal Outer Continental Shelf. Only 10% are in State waters. (2) Drilling operations in state waters declined more rapidly than in federal waters. (3) Twice as much drilling from mobile rigs occurs offshore from Louisiana as from Texas. Drilling operations are minimal elsewhere in the Gulf. (4) In the Gulf of Mexico approximately two-thirds of the shore bases (marine service industries) are located in Louisiana. The remainder are in Texas. (5) The type of mobile drilling rig used most frequently in the Gulf of Mexico is the Jackup rig. (6) Employment on mobile rigs in the Gulf of Mexico approximates 10,000 workers. Employment in offshore oil and gas operations (including platforms, boats, and service companies) approximates 40,000 workers. Employment in the oil and gas industry in the coastal area and offshore combined approximates 125,000 workers directly employed in oil and gas extraction and 100,000 employed in refining, processing, transportation, and manufacturing. (7) The payroll generated by oil and gas production offshore in the Gulf of Mexico approximates $4.7 billion annually. (8) Development drilling and wildcat drilling decreased slightly offshore, while exploration drilling increased.

Besides the IXTOC oil spill, the major sources of tar balls beached along the Gulf, as perceived by the public, are natural seepage and oil industry activities which include tankering and offshore oil and gas exploration and production. Maritime transportation accidents and operational discharges contribute 88% of the oil entering the Gulf from the two offshore oil industry activities. Often implicated as the source of tar balls, crude oil spilled from oil exploration and production off the coast of Louisiana does not form tar residues during weathering. The results of analysis of the oil impacting the islands and beaches along the Mississippi and Alabama coasts showed that the oil was not very weathered and was from at least two and probably three unknown sources of oil. Beached tar samples off the coast of Texas were linked to tanker bilge washings. It is unknown why these incidents occurred over a 4-month period during the summer months of 1982.

GULF OF MEXICO OCS GEOLOGIC MAPPING

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ABSTRACT: Regional geologic mapping in the Gulf of Mexico has mainly involved the USGS Office of Marine Geology in Corpus Christi, Texas, and the Minerals Management Service's Gulf of Mexico OCS Region office in New Orleans, Louisiana. The major areas of concentration for these studies in the Gulf are at the Shelf-Slope Interface. Primarily, three areas have had detailed surveys and mapping completed. These areas are South Texas, the Outer Shelf and Upper Slope of Southwest Louisiana, and the area around the Mississippi River Delta. Utilizing the studies of these three areas, and other data gathered by USGS, by industry, and from a scattering of other studies, a regional physiography and a series of seafloor geohazard maps can be constructed for the Gulf of Mexico.

This discussion will basically focus on the seafloor morphology and shallow geology of the continental Shelf-Slope Interface. The major points to be addressed are: (1) where the coverage has been, (2) what products are or will be available, and (3) how the information is used in our office.

The mapping completed by the Minerals Management Service has provided an understanding of the tectonics, the shallow geology, the seafloor morphology, and the processes involved in sedimentation and mass movement of the Gulf of Mexico. Emphasis of mapping has been on the continental shelf-continental slope interface where the major shelf building processes are at work, and where the focus of oil and gas exploration and production is moving in the future.

ENVIRONMENTAL MONITORING OF AN EXPLORATORY PETROLEUM DRILLING OPERATION IN A NORTH CENTRAL GULF OF MEXICO ESTUARY

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ABSTRACT: A twenty month monitoring program was conducted from July 1978 to February 1980 to assess the impact of drilling a zero-discharge test well on the environmental quality of the lower Mobile Bay estuary. Collections for hydrographic, chemical, sedimentologic, and biological parameters were made at fourteen fixed stations arranged around two concentric rings with radii of 500 and 1500 meters from the test well. Sampling was performed prior to, quarterly during, and shortly after drilling operations. In addition, five biomonitoring stations distributed throughout the lower bay system were sampled weekly for hydrography, and bi-weekly for _in situ_ monitoring of hydrocarbons and trace metal levels in caged blue crabs (_Callinectes sapidus_) and oysters (_Crassostrea virginica_).

Results to be presented indicate a clear demonstration of the clean operation of the test well over the duration of the monitoring program and provide an excellent baseline of important environmental parameters of the Mobile Bay estuary. Natural environmental variability induced by seasonal changes and periodic climatological extremes will be discussed. Finally, parameters will be evaluated as to their ability to provide meaningful information during monitoring of future development of oil resources in Mobile Bay and similar Gulf estuaries.

MEASURING SENSITIVE GULF OF MEXICO RESOURCES FOR REGIONAL ENVIRONMENTAL ASSESSMENT

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ABSTRACT: Recent streamlining of the Department of Interior's offshore oil and gas leasing program has led to basic changes in the scope of Environmental Impact Statements (EIS) on lease offerings. In the past, lease offerings involved individual blocks nominated by industry, but now, in order to expedite oil and gas development, entire planning areas in the Federal OCS Regions are available. The Gulf of Mexico Region is divided into the Eastern Planning Area (EPA), Central Planning Area (CPA), and Western Planning Area (WPA).

Prior to these changes, impact statements were site specific with a focus mainly on areas likely to be impacted from individual blocks. This concept was altered for the Regional EIS for the lease offerings in 1983 which include all 3 planning areas. The Department's new policy created the need to broaden the scope of environmental analysis. Data had to be reformatted to facilitate regional description of resources, comparative analyses, and sensitivity indexing of coastal land segments.

The first step in this process was to divide the planning areas into geographic units. The EPA was broken down into 5 subareas, the CPA into 4 subareas, and the WPA into 3 subareas. State waters and adjacent shorelines were divided by county boundaries into segments within the larger subareas. The most sensitive physical, cultural, and biological features and resources in the Gulf were then defined and the areal and linear data were mapped on separate overlays on 1:250,000 scale base maps from the NOS/USGS topographic/bathymetric map series. Codes were assigned to each polygon or land segment relative to the resource and its location. Each overlay was digitized, and measurements in areas and statute miles were calculated on an automated geographic information system operated by the National Coastal Ecosystems Team of the U.S. Fish and Wildlife Service.

The measurements of the selected resources are shown in tabular form on Visual No. 14 in the visuals set published with the Gulf of Mexico Regional EIS. Visual No. 10 in the same set is a map of the Gulf at a scale of 1:1.2 million that provides a general view of the location and extent of these resources.

UNUSUAL STRANDINGS OF TAR ON NORTHERN GULF OF MEXICO BEACHES DURING THE SUMMER OF 1982

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ABSTRACT: On June 3, 1979, a Petroleos Mexicanos (PEMEX) exploratory well, IXTOC I, blew out in the Bay of Campeche, Mexico, spilling over 3 million barrels of oil into southern Gulf waters over a 10-month period. Only 2% of the IXTOC spilled oil initially impacted the Texas beaches, yet 20% of the oil from the blowout was observed passing through the Texas OCS region. Much of the spilled oil from IXTOC still remains unaccounted for.

Since the 1979 blowout, tar material washing ashore along the Gulf coast is often attributed to the IXTOC spill by observers. According to Captain Hinson, Commanding Officer of the U.S. Coast Guard in Corpus Christi, Texas, oil from the IXTOC blowout was still beaching in 1982 along the Texas coastline in a very early stage of weathering. During the spring and summer of 1982, BLM personnel involved with the IXTOC damage assessment study received quite a number of inquiries concerning some unusual strandings of tar material.

A heavy oiling of Padre and Mustang Islands in Texas occurred March 23 and again on April 1 and 2. Tar material up to 8 feet in diameter washed ashore onto Padre Island National Seashore. On June 17, a business owner in Grand Isle, Louisiana called the Coast Guard complaining of large oil patches along the beach. During a field trip of the New Orleans Geological Society on June 5 and 6, a heavy tarring of a beach near Ocean Springs, Mississippi was seen. National Park Service rangers stationed on the Gulf Islands National Seashore stated that they have never seen such a large influx of tar material on Ship and Horn Islands. A team of BLM EAD personnel travelled to Mississippi and Alabama to observe and collect beached oil residues for identification purposes. On June 22, 17 pelicans and heavy globules of oil washed ashore on St. Vincent Island in Apalachicola Bay, Florida. Finally around July 4, a bad storm washed large amounts of tar balls onto the beach in Sarasota, Florida. Tar samples were collected and analyzed at every location except Apalachicola, Florida. Analyses showed that these were isolated incidents and that the oil was not from the IXTOC blowout, except possibly the Sarasota beaching.

LAGNIAPPE FROM THE OCS EIS PROCESS---

A RECREATIONAL PERSPECTIVE

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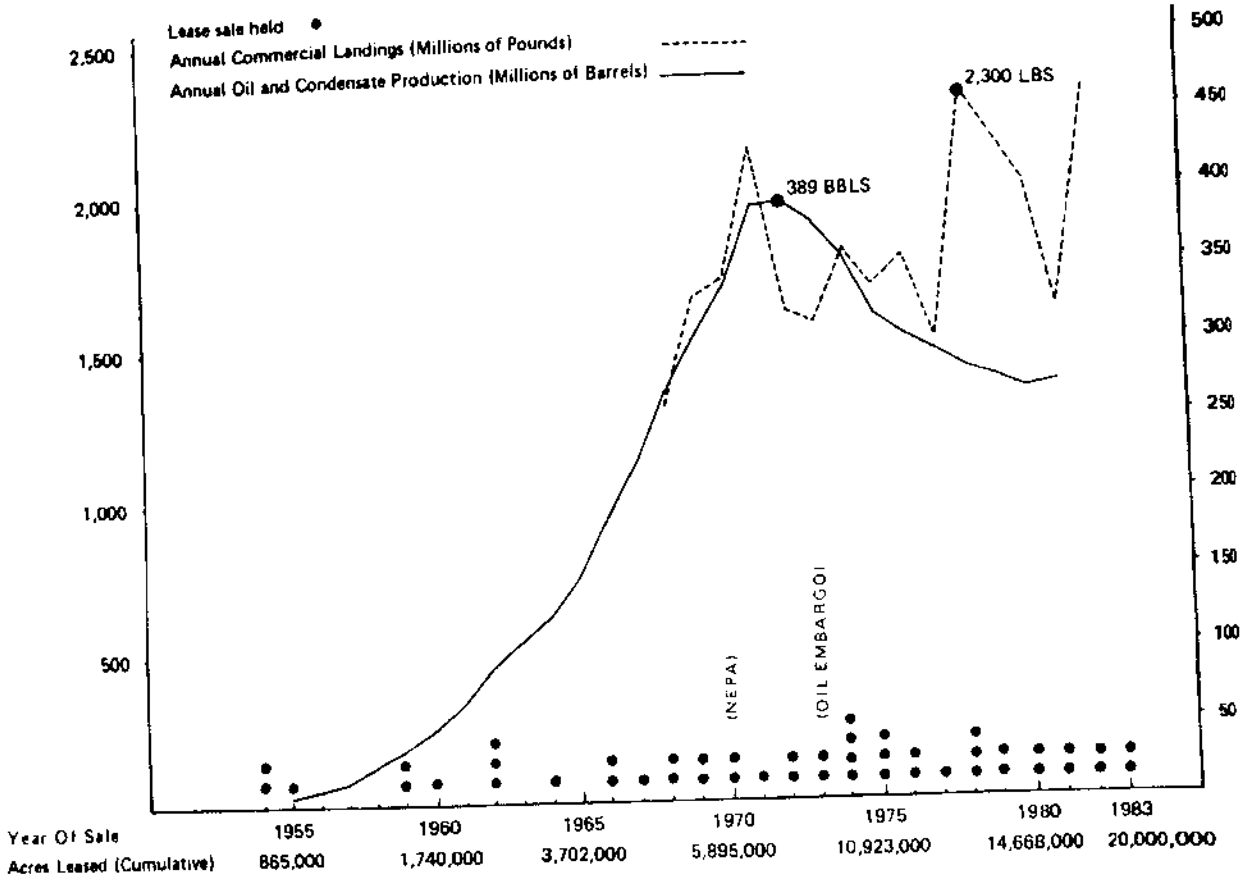
ABSTRACT: Although we began an outer continental shelf (OCS) oil and gas leasing program in the early 1950's, it was not until the early 1970's that we instituted a national environmental consciousness (National Environmental Policy Act, 1970) and it was not until 1973 that we were made abruptly and painfully aware of our dependence on a reliable supply of oil and gas (1973 oil embargo). Subsequently our nation adopted several energy strategies, all of which included acceleration of OCS exploration and development for oil and gas. In spite of these paradoxical national environmental and energy production goals adopted 10 years ago, the Northern Gulf of Mexico has remained our most prolific offshore source of our national oil and gas supplies accounting for 24% of our natural gas and 9% of crude oil production in 1981 and our most productive offshore fisheries zone accounting for 36% of the nation's commercial seafood poundage in 1982.

For the first 19 years of the program (1954-1973) we leased an average of from 300,000 to 400,000 acres a year in the Gulf of Mexico. In the 10 years following the 1973 oil embargo, we have increased our leasing by 2 to 3 times for an annual average of one million acres. Although this leasing activity has stimulated increased exploration, oil production from the Northern Gulf of Mexico (OCS) has declined from its peak of 389 million barrels (bbls) in 1972 to 270 million bbls in 1981. Production of natural gas, a more environmentally acceptable source fuel, has consistently increased from expanded and accelerated leasing over the last 30 years throughout the Gulf reaching a production level of 4,837 billion cubic feel (BCF) in 1981. Historically, the Central Gulf offshore area has been responsible for 95% of our oil and 85% of our total gas production and the Western Gulf contributes the remainder. The Eastern Gulf offshore area remains a nonproducing exploration zone.

Cumulatively, we have leased almost 17 million acres gulfwide from 46 sales through 1982. We began preparing environmental impact statements (EIS's) in 1970 and have since published a continuous series of 20 somewhat repetitive documents representing 26 separate Gulf of Mexico lease offerings covering all planning regions. Additionally, we have invested over $45 million in Gulf of Mexico environmental studies over the last 10 years. Environmental issues have changed little since environmental concerns have been officially incorporated into the Gulf of Mexico leasing process in 1970. Adding environmental concerns has had little impact on where we have leased in the central and western zones of the northern Gulf of Mexico but has led to changes in how we lease and has led to a broader view and understanding of the regional ramifications of offshore energy development.

GULF OF MEXICO OCS
Acres Leased - Oil Produced - Fish Harvested
1955 - 1983



Louisiana: 90% OCS Structures — 95% Oil Production
68% Commercial Fish Landings — 85% Gas Production

Often the knowledge gained through the environmental studies and analysis process is best applied to decisions removed from the lease - no lease decision process. A case in point is the recreational implications of the OCS leasing and development program. Although there is evidence of debris from oil and gas operations occurring on the OCS along some Gulf of Mexico shorefronts, the most dramatic and sustained impact on recreational activity has been the development of a unique recreational fishery of growing proportions. We are only now beginning to understand the scope and magnitude of the rig fishing phenomena (commercial as well as recreational), however, the potential exists to perpetuate and expand these incidental public benefits regardless of the future discovery of commercial oil and gas fields in the Gulf of Mexico. Most all users of the OCS stand to gain from a planned approach toward making maximum use of the 4000 oil and gas structures now in the Gulf of Mexico. The environmental studies and EIS analytical process has provided the impetus which has encouraged a realization of this potential.

Hopefully, as we approach our third millennium determined to broaden our horizons through establishment and management of Fishery Conservation Zones (FCZ's) and Exclusive Economic Zones (EEZ's) we will use the credible information and experience gained in the OCS of the Northern Gulf of Mexico to lend perspective between risk and reality which can lead to a continued growth of the compatible multiple uses of our ocean resources.

DISCUSSION

CAKE: This question is directed to Barry. Your group conducted the preliminary study of the Mobil Oil rig site in lower Mobile Bay. You, I take it, were not involved with the recent investigation of the oil drilling mud spills?

VITTOR: No, we were not involved. In fact, our program ended in February of 1980. We completed our report in June of 1980. There was a hiatus in the drilling operation during that period. I think there was a period of about a year between when we finished our monitoring operation and when they began drilling the four new appraisal wells, but we were not involved at that point.

CAKE: From your initial gut reaction, however, has there been some effect on the area that you looked at, and is someone else now looking at that problem?

VITTOR: We have received an extensive report, data compilation, of the studies that were done to document the impacts of an acknowledged dump of material in Mobile Bay. I think it was 4,000 cubic yards including a lot of drilling mud fluid and so forth. We haven't been involved at all in examining the impact of that. However, we do understand there has been a substantial impact based on accumulations of oil and grease in bottom areas that appear to be, and I say appear to be because we haven't seen any hard conclusions made by anybody at this point, devastating to the benthos in that area. One of the points that has been made during several of the studies, in addition to the importance of spatial and temporal variability, and long rangeness of monitoring studies or baseline studies, was that standardization of the measurement techniques is also extremely important. This is something that we certainly would stress for any monitoring program subsequent, for example, to the one we conducted through 1980. Unfortunately, we do not see this. So I don't think anybody will ever compare the more recent results with ours. The data were not collected or treated the same way.

RAINEY: Barry, I was going to ask you some questions too. You mentioned that although you were not involved, that there was some impact that occurred a year later. Is this what you're talking about? The drilling muds and cuttings? Where were they coming from?

VITTOR: Well, I'm getting into quicksand, now, but as I've tried to point out at the end of my presentation, we always hope that the safeguards that are initiated and agreed to by all parties are implemented in fact, and unfortunately this wasn't the case. There was an acknowledged deliberate disposal in the bay of waste material from the site. As I say, it was about 4,000 cubic yards of material.

RAINEY: An Accident?

VITTOR: No, this was deliberate.

RAINEY: One other guestion: you showed two slides looking at the lighter hydrocarbons, particularly methane, and you had an unusual peak. The second slide you showed after that looked at the ratio of C_1 to C_2 and C_3 which is used to identify biogenic versus petrogenic, and you also had an unusual peak. Was the peak due to petrogenic or biogenic factors?

VITTOR: The peak appeared to be biogenic. Again though, we honestly couldn't discriminate so far as causes are concerned. We just didn't have adequate sample control.

SHERRARD: This question is for Marion Fischel. The State of Mississippi right now is mostly concerned with onshore oil activity, as you know, and two of the major problems that I've noticed with exploration and production of these facilities are the discharges of drilling fluids and produced water, respectively, that contain sufficient amounts of hydrocarbons to produce oil sheens in the area that they are discharged. Can you comment on the possibility that these effects might also be exemplified in the marine systems?

FISCHEL: There is a lot of information in your question and I'm not sure I remember it all, but from what I mentioned in my talk, produced water does have an effect on the organisms, but the effect is very localized. Produced water contains hydorcarbons, trace metals, and other components such as sulfur. Sulfur was a very large component at the Buccaneer Gas and Oil Field. However, analysis of the water in the vicinity of the produced water discharge showed no concentration gradient at Buccaneer Gas and Oil Field, so it was very rapidly dispersed. But each platform is different. Buccaneer Gas and Oil Field is in a very dynamic hydrographic area. You have strong currents. The situation in the offshore marine environment is going to be different from a quiescent bay such as the area you were talking about. I didn't get all the rest of your question. My point is that you're going to have an effect, but the effect is localized. The drilling muds do have an effect in terms of smothering. They also have a slight toxicity. Anywhere you have a petroleum platform, you do have a reduction in the fauna. The point I was trying to make is that the effect is minor. One other thing you might want to consider is that the amount of hydrocarbons and metals that are released from petroleum activities offshore are minor compared to releases from tankers, as was shown in a slide in a later talk. So that's another factor to consider.

SHERRARD: I would like to pursue one other point. I assume that most of the offshore facilities utilize the same equipment for separating the oil or the gas condensate from the water content. All of these facilities do not work all of the time, as we well know, and you have a large build-up of either crude oil or gas condensate within the treaters, and it's the discharge from these treaters that I'm mostly concerned with. I don't see any problem with putting produced water with the high chlorides content into a brackish system, as opposed to a freshwater system. Of course, we can't allow that to happen. But I'm particularly concerned with the hydrocarbon content within the produced water and that material that just can't possibly be knocked out with the conventional heater-treaters.

FISCHEL: Well another thing you might want to consider is that hydrocarbons, in comparison to other chemicals, have a rather low toxicity; and it's true that the produced water does release hydrocarbons but compared to the dioxins, the kepones, and other such materials, the toxicity is low, and the same is true for the drilling muds. The figures I gave of the toxicity (the LC50s) indicate that oil is certainly not as toxic a material as some other chemicals. In terms of economics, the oil companies don't want to release hydrocarbons in the produced water, because every time they release hydorcarbons, they are losing money. So they're doing, I think, the best job possible to extract all the oil from the produced water and release as little as possible, but there is always some oil that gets out.

CAKE: I enjoyed that talk on tar balls. I just wanted to question you a little bit about tar balls that are presently on the beach at Santa Rosa Island, Florida. From listening intently to you, we are at this point, unable to determine their exact origin. Is that the bottom line?

RAINEY: Well, every time I go down to Santa Rosa, I collect some tar material and bring it back. I've never had any of it analyzed. I don't know anyone who has analyzed it. Again, most of the work on beached tar has been in the Florida area by the NOAA Laboratory in Miami, as I showed. There is a Dr. Amos with the University of Texas who is looking at the tar material on the Texas coast and that's primarily identified as coming from tankers and some natural seeps. From what I've read, most people associate it with tankers. In fact, the samples that I collected, the researchers said was probably from tankers. Now I have a little problem with "probably tankers." What you need to positively identify oil, is to also have the source and to analyze that at the same time, in order make a positive identification. I think that we need some more studies looking at central Gulf of Mexico tar materials.

CAKE: Have the rangers on Horn, Petit Bois, and Ship Islands noticed any tar balls in the recent past?

HOLLOMON: It's really moderate compared to what it was in the past. Pat Toops said 1980 was a year of high tar influx. By personal observation 1981-82 was quite thick in comparison to 1983. This year the beaches are almost tar free.

CAKE: But they are there during this particular time of the year. So it's a pretty widespread thing, Gail, and I just wondered if we can pinpoint its source? Did any of it come from the IXTOC blowout? Are the tar balls too unweathered to be from that source?

RAINEY: Well, it does seem to be a seasonal phenomena, and maybe we could talk about this later because if you're seeing some more tar material coming ashore, I don't know to what extent and we need to talk about this, because according to the Park Service personnel that I've talked with, they didn't really see much tar material on the barrier islands. Last summer was very unusual. When we got out there, I was even surprised at the extent. It's heavy right now. So again, it's something that's a seasonal phenomena and I think we ought to start talking about it and start looking into it and then keeping track of it so we can account for it. I'm interested in it, also. As far as identifying it as IXTOC, none of the other oil checked out as IXTOC so I doubt it.

CAKE: You mentioned the Sarasota balls. Did they come from IXTOC?

RAINEY: The Sarasota, no. They were unable to say that the Sarasota wasn't IXTOC, which is a little bit different.

CAKE: Process of elimination.

RAINEY: In the process of elimination, they couldn't do it. With some of the other ones, they positively could. Now they did find (Ed Overton with Lassiter's laboratory in New Orleans) a tar sample in Gulf Shores which he said was positively IXTOC, and that was last summer also. That was the only case that I heard of any oil outside of the Texas coastline being attributed to IXTOC. The Van Fleet study that was conducted offshore Florida as part of the IXTOC damage assessment study, indicated that they could account for all of the oil except for around 14 percent. This 14 percent could possibly have been IXTOC, which is fairly low when you consider the amount of oil that entered the area at that time.

SHABICA: This comment is directed to Gail and Marion about OCS oil spill problems. I get the overall impression that the extent of oil problems from outer continental shelf oil and gas exploration and development is fairly minimal. The major problem seems to be oil tankers pumping their bilges and things like that. I was just wondering if you would like to comment on that, and then perhaps comment on -- Gene also might want to comment -- the probabilities of having a major oil spill based on industry's experience, especially in Louisiana and Texas.

GONSOULIN: As long as Jon (Frank) doesn't write all this down and publish it tomorrow in the newspaper, I'll comment. I think the question is a valid one. Regarding the probability of major oil spills along the Gulf Coast, there certainly is a probability whenever you deal in this kind of business that these things could occur. But I think that if you look at the long range, long term record of the oil and gas industry, you have to come away with the idea and the knowledge that these spills are a rare occurrence over time. The effects that they seem to have upon environmental systems appear to be far less substantial than they were once thought to be. Now that may sound like rhetoric, because there is a lot that is still to be learned about the effect of hydrocarbons on these systems. But as I mentioned before in the talk that I gave you, we have certainly found that the estuarine, barrier island and marsh systems seem to be far more resilient than perhaps they were once thought to be. Their recovery from various impacts is a lot faster. I might also add that what I didn't mention at the end of the talk is that we have instituted a fairly large research program through funding with the Gas Research Institute, to measure pipeline impacts and recovery and determine the best reclamation-type practices to be associated with pipeline installations in coastal systems and other areas across the country. We are also concerned with areas in the xeric communities such as deserts, construction in mountainous terrain where erosion is severe, and so forth. So there is an industrywide effort, and has been for a number of years, to isolate and identify the causes that may be associated with environmental degradation and energy development. I might also extend one final thing to everybody that is here. As you go back to your respective jobs, if we at SONAT, and particularly my group, can be of any help to any of you in sharing some of the development knowledge that we have been fortunate enough to accumulate over the last few years on coastal systems, siting installations, pipeline installations, etc., we'll be glad to do that. We've been actively working with the State of Florida to do this kind of thing and we'll be happy to share information with you.

RAINEY: In the Regional EIS, I do an analysis of the rates of oil spillage, looking at historic oil spillage. For spills over 1,000 barrels, I believe it's one spill for every billion barrels produced from platforms. For pipelines, it's 2.03 spills for every billion barrels produced. For spills less than 1,000 barrels, I don't have the statistics on the top of my head, but I have calculated them up to from zero to one barrel based on the historic oil spill information that we have. One thing you have to keep in mind is that a lot of the spills that occur offshore do not go to the shore. A very small percentage of them head toward the shore, and I think most people have a picture of them being spilled and immediately heading toward shore and hitting the beach. A majority of them are taken offshore by the currents and dispersed. South Louisiana crude is very light crude and it disperses very rapidly. As far as looking at minimal effects, I guess I wanted to say that I consider myself an environmentalist. I've been with MMS for three years and have been researching oil spill impacts. What I said today about tar balls, I truly believe that as far as the offshore oil industry is concerned, you're not going to be able to identify an impact. I think that we still need to keep monitoring the activities as there could be some long term effects that we haven't caught onto, but we have to look pretty deep to find any serious detrimental effects going on. I think that speaks for itself.

FISCHEL: I just wanted to give a few figures on oil introduced into the oceans. This is from National Academy of Sciences. There was a slide I was going to use but because of the lack of time I didn't. In 1975, the National Academy of Sciences estimated that of more than 6 million metric tons of hydrocarbons introduced into the ocean, the majority came from tankers, which contributed more than 2 million tons, and river runoff such as the Mississippi River which also contributed almost 2 million tons. Offshore production contributed less than 2 percent of the total amount, and by offshore production I mean the hydrocarbons from produced water, the hydrocarbons from the accidental spills that occur occasionally, and also the the drilling muds. So in reality, offshore petroleum production contributes a very small amount of these hydrocarbons to the ocean.

GONSOULIN: I just wanted to say that I've enjoyed all the talks today, and I think all the speakers deserve another round of applause.

BARRIER ISLANDS

Barrier islands are the most obvious and dynamic landform in the nearshore coastal zone. Hurricanes are probably the greatest agents of change, although human activities both commercial and recreational can have sgnificant effects on the geology and ecology of the islands. During the last 100 years Louisiana barrier islands have experienced a 41% land-loss. Programs are in progress to inventory and predict future coastal shoreline conditions to enable more refined management and development of the area. A knowledge of the physical processes and natural forces responsible for the evolution and modification of islands should provide coastal developers with a "go/no-go" gauge for seaside development. Unaltered barrier islands provide endangered and threatened species with an undisturbed habitat. Water circulation in the estuaries is highly influenced not only by the wind, tides, and mixing of salt and freshwater, but also by the barrier islands, oyster reefs, and channels. Dredging activities can upset these patterns. Inlets are extremely dynamic features of barrier islands especially along the rapidly transgressive shorelines of abandoned Mississippi River deltas. Inlets provide the communication link between the open ocean and the estuaries. Sediment supply and dispersal are important not only to barrier island formation and evolution, but also to the very existence of an island. The evolution of Isles Dernieres, Louisiana, and the factors responsible for their morphology demonstrate how dynamic and ever-changing barrier islands are. Sand dunes are effective sand traps and storage areas for barrier islands. Their presence, either naturally or through construction, can postpone the eventual loss of transgressive barrier islands. It should not be forgotten that barrier islands, like estuaries, are ephemeral entities and that in time will either erode or fill. In the natural course of events, this may take hundreds of years. Influenced by man, however, this could occur within a human lifetime.

STUDIES OF THE BIOLOGY OF ENDANGERED AND THREATENED SPECIES OF GULF ISLANDS NATIONAL SEASHORE, MISSISSIPPI

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ABSTRACT: Endangered and threatened species of the Mississippi unit of Gulf Islands National Seashore were studied between 1978 and 1982. Four reptile and seventeen bird species were identified whose populations are considered in trouble. Five of these species (American alligator, Osprey, Snowy Plover, Gull-billed Tern, Least Tern) nest on the islands. The Southern Bald Eagle nests on the adjacent mainland and has nested on East Ship Island. Reddish Egrets were found throughout the year and may nest on East Ship Island and/or Horn Island. The Burrowing Owl, Merlin, and Peregrine Falcon were rare winter residents. Several listed species are transient on the islands. One of these, the Brown Pelican, has been appearing with increasing frequency and throughout the year; it may soon attempt breeding in the area. No evidence for Red-cockaded Woodpeckers could be found, though there is a single report of this species from Horn Island. Wilson's Plover, though not on official lists, nests in low numbers on the islands and may be in more trouble than some officially listed species.

INTRODUCTION

Gulf Islands National Seashore in Mississippi includes four barrier islands, a small spoil island, and a mainland park at Davis Bayou in Ocean Springs. The islands from east to west are: Petit Bois, the spoil island, Horn, East Ship, and West Ship. They range from 10 to nearly 20 km from the mainland and form the southern boundary of the Mississippi Sound (Figure 1). Meadows (1975) briefly described the history of the islands and their physical and biotic features. Petit Bois, Horn, and East Ship islands include forested areas. All except the spoil island include marsh and brackish water lagoons. Petit Bois and Horn islands were designated as wilderness areas under authority of the Wilderness act of 1964 and the National Parks and Recreation Act of 1978 (Public Law 88-577, 99th Congress, 1964; and Public Law 95-625, 92 Stat. 3489, 95th Congress, 1978). While each of the islands has been subjected to varying ownership and use, the sometimes harsh environment of the Gulf of Mexico maintains them in a relatively undisturbed state.

Table 1. Categorization and status of vertebrates known from Gulf Islands National Seashore, Mississippi, whose populations are considered endangered, threatened, or otherwise in trouble.

		Listed Status[2]			
		Fed.[3]	Miss.[4]	Ala.[5]	Blue List[6]
Reptilia					
American alligator (*Alligator mississippiensis*)	Res[1]	E	E	T	NA
Loggerhead Turtle (*Caretta c. caretta*)	Tr	E	E	E	NA
Green sea turtle (*Chelonia mydas*)	Tr	E	E	E	NA
Leatherback sea turtle (*Dermochelys coriacea*)	Tr	E		T	NA
Aves					
Brown Pelican (*Pelecanus occidentalis*)	Tr	E	E	E	NA
White Pelican (*Pelecanus erythrorhynchus*)	Tr		U		S
Double-crested Cormorant (*Phalacrocorax auritus*)	Tr		U		S
Reddish Egret (*Dichromanassa rufescens*)	Res?		R	T	S
Black-crowned Night Heron (*Nycticorax nycticorax*)	Tr		U	S	S
Mottled Duck (*Anas fulvigula*)	Res		R	T	
Southern Bald Eagle (*Halieetus l. leucocephalus*)	Tr	E	E	E	NA
Northern Harrier (*Circus cyaneus*)	W		U		S
Osprey (*Pandion haliaetus*)	Res		U	E	S
American Kestrel (*Falco sparverius*)	W		U		S
Merlin (*Falco columbarius*)	W		U	S	S
Peregrine Falcon (*Falco peregrinus*)	W	E	E	E	NA
Snowy Plover (*Charadrius alexandrinus*)	Res		R	E	S
Gull-billed Tern (*Gelochelidon nilotica*)	Su		R		S
Least Tern (*Sterna antillarum*)	Su		R		S
Burrowing Owl (*Speotyto cunicularia*)	W		U		S
Red-cockaded Woodpecker (*Picoides borealis*)	?	E	E	E	NA

[1]Res = resident; Tr = transient; W = winter resident; Su = summer resident.

[2]E = endangered; T = threatened; R = rare; S = special concern; U = status undetermined; NA = not applicable.

[3]Listed in Federal Register, 17 January 1979, 44(12):3636-3654.

[4]Reptiles listed in Cliburn and Jackson (1975); birds listed in Jackson (1975).

[5]Reptiles listed in Mount (1976); birds listed in Keeler (1976).

[6]Birds listed in Arbib (1978).

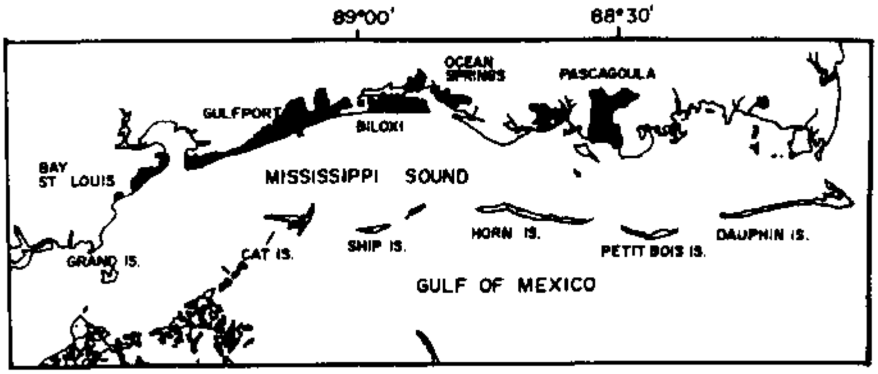

Figure 1. Coastal Mississippi showing the relative locations of islands mentioned in this report. Petit Bois, Horn, and East and West Ship Islands are part of Gulf Islands National Seashore. A small spoil island referred to in the text is located just west of the west tip of Petit Bois Island.

In part because of geography and their undisturbed state and in part because other such environments have been destroyed by man, the Mississippi barrier islands provide refuge for a number of endangered and threatened species (Table 1). Federally listed endangered species known from the islands include: (1) American alligator, (2) loggerhead sea turtle, (3) green sea turtle, (4) leatherback sea turtle (5) Brown Pelican, (6) Southern Bald Eagle, (7) Peregrine Falcon, and (8) Red-cockaded Woodpecker. In addition to these, several other bird species known from the islands have been singled out for special concern by the state of Mississippi (Jackson 1975), the National Audubon Society (Arbib 1978), and the state of Alabama (Keeler 1976). In this report I will document the status, seasonality of occurrence, relative abundance, and habitats used by those species known from the islands and which are included on the Federal list or at least two of the latter three lists (Table 1).

METHODS

Between October 1978 and December 1982, I visited the islands on 106 dates to collect distributional and ecological data on the species listed in Table 1. Specific efforts made on each trip depended on which island or islands were visited, which parts of the larger islands were visited, and the time of year. Trips were also organized around specific objectives. For example, intensive searches were made for Snowy Plover and Wilson's Plover nests in March and July in order to define the limits of the breeding season for these species. Similarly, special efforts were made in late June and early July to locate nesting sea turtles, since this is the time period during which nesting activity has been previously reported. Horn Island, in keeping with its larger size and greater diversity, was visited most frequently.

Bette J. Schardien and C. Dwight Cooley assisted with most field work. Wayne C. Weber, Opal Dakin, Ren Lohoefener, and several other students provided occasional assistance. Park Rangers on Horn and West Ship Islands occasionally collected data for us. Until August 1979, we were dependent on Park Service transportation to, from, and among the islands. After August 1979 a boat was made available to us by Eco-Inventory Studies, Inc. Use of the boat enabled us to visit more of the islands on each trip as well as to quickly move from site to site.

Observations of the various species were made with the aid of binoculars or a 20X spotting scope. Photographic records of each species were made whenever possible. Aerial surveys (using a Cessna 172) facilitated location of nesting seabirds, Osprey nests, and alligators. Specific attempts were made to locate alligator and sea turtle nest sites from the air, but none were found. Most field work was done during the day, though we did attempt to census alligators at night by using spotlights. These attempts were largely ineffective because of the difficulty of moving around the islands at night without motorized transportation. Banding of the various sea bird species allowed some study of movements relative to nesting and wintering areas and will facilitate more detailed studies of species population dynamics in the future.

SPECIES ACCOUNTS

AMERICAN ALLIGATOR

Cook (1942:2) noted that the American alligator occurred in "lakes and shoals" on Horn and Cat Islands. In 1923 a large number of alligators was killed on Horn Island for a New Orleans leather company (Richmond 1962). We encountered alligators on Petit Bois, Horn, and East and West Ship islands.

Most alligator sightings on Petit Bois Island were in the extensive cattail marshes on the eastern half of the island, but two sightings were made of ca 1 m alligators in small ponds near the west end of the island. The largest number of alligators seen on one date on the island was 8 observed during an aerial survey on 14 April 1979. During aerial surveys trails made by alligators through marsh vegetation could always be seen. Although no alligator nests were found, individuals observed ranged in size from less than 1 m to more than 3 m long. There were no beach ponds on the south side of Petit Bois Island during this study and we found no evidence of alligators on Petit Bois outside of marsh areas.

Alligators were seen on nearly every trip to Horn Island and on every aerial survey over Horn Island. Maximum numbers seen in a single day included six, each about 1.3 m long and each in a separate small pond on the south beach on 20 March 1982. During aerial surveys a maximum of five were seen on 14 April and 25 May 1979 and 21 April 1980. Distances and inaccessibility of many ponds on Horn Island seriously limited our ability to census alligators. However, based on our numerous observations at widely scattered points and on the size range of individuals observed (ca. 0.3-4 m long), I feel that minimally 40-50 alligators are present on Horn Island. The population could easily be double that figure. More effort and more efficient means of censusing this species are needed to allow statistically derived estimates of alligator numbers on Horn as well as on the other Mississippi islands. The presence of very small individuals is indicative of some breeding success. While we located no alligator nests during our study, a nesting population must certainly be located in the marsh areas between Big Lagoon and the Ranger Station, a second population is located in the extensive cattail marshes between the Ranger Station and the west edge of Arcturus Flats, and a third breeding population likely exists in the cattail marshes extending from the east edge of Arcturus Flats to near Dead Pond. Considerable movement likely occurs between the two western populations, as evidenced by frequent alligator tracks crossing the road leading to the Ranger Station. The third population may be quite isolated by Arcturus Flats. Assumption of breeding in all three areas is based on the extent of habitat available and on the observation of very small individuals in each area. Young alligators tend to stay in the vicinity of their nest site (Chabreck 1966).

Larger alligators on Horn Island seem to move considerable distances over short periods of time and are not limited to the marsh areas of the island. On almost every visit we were able to find alligator tracks extending from beach ponds to marsh areas. Just southeast of Big Lagoon is a cattail pond that is away from the south beach and near the tree line. This pond seemed to always have alligators - at times as many as four individuals could be seen at once, including one at least 3 m long and another less than 1 m long. These alligators frequently moved from the cattail pond and over the top of 6 m high dunes and into low slash pine forest bordering the marsh associated with Big Lagoon. Tracks from the same cattail pond also often led to beach ponds to the south. On 20 May 1979, alligator tracks suggested to Ranger Jerry Case that when there were many large dead red drum (Sciaenops ocellata) on the beach, the alligators would scavenge on them. On many occasions we observed alligator tracks leading into the Gulf or Mississippi Sound, though there were usually also tracks leading back up the beach from the water. Alligators were occasionally seen sunning on the beach between ponds and the Gulf.

The larger alligators often showed no fear of man, allowing us to approach to within 5-6 m before diving underwater. On several occasions alligators approached us to within 5-6 m apparently out of curiosity. This apparent lack of fear of man coupled with the movements across open beaches may occasionally lead to human-alligator interactions—as evidenced by a bludgeoned and decapitated ca. 1 m alligator found on 22 December 1979 northwest of the Ranger Station.

The largest number of alligators we saw on East Ship Island was two. These were seen during the aerial survey on 14 April 1979 near cattails in the western most pond within the wooded area. Both were between 2 and 3 m long. When we visited this pond on 9-10 July 1979, it was all but dry, though in subsequent years alligators were again seen there. The marsh habitat of East Ship Island looks good for alligators and I suspect that there could be as many as 15-20 individuals. Lack of beach ponds and dense thickets surrounding most marsh areas likely keep this population more isolated from human visitors than is the case on Horn Island.

Three large alligators (ca. 2, 3, and 4 m) were seen on West Ship Island at three scattered ponds during the aerial survey on 14 April 1979. A single 3 m alligator was seen about 500 m east of the Ranger Station on West Ship Island on 25 February 1979. The lack of trees on West Ship Island facilitated aerial surveys and I believe the alligator population on this island is quite small - perhaps no more than 10-15 individuals - likely the smallest population on National Seashore islands. Prior to hurricane Camille in 1969, this population would have been connected to that on East Ship Island. Now that it is isolated, it may not be able to sustain itself. Lack of beach ponds on West Ship may be quite fortuitous, because of the excessive human visitation to the island and the greater probability of human-alligator encounters away from marsh areas.

SEA TURTLES

Sea turtles apparently regularly use the waters near the Mississippi Gulf islands during summer months, but there is little evidence of any nesting activity from the area. Walter Anderson (Sugg 1973:76, 159) reported finding unsuccessful sea turtle "crawls" on the Gulf beaches on Horn Island in 1959 and 1965. The first of these records was on 4 June 1959:

> "...and on the way back a turtle's nest. The day before on a walk to the east there were seven places where turtles had simply crawled up, turned around, and gone back into the water. I think it may possibly have been the same turtle, suffering birth pangs and each time climbing up, 'finding it was a mistake,' then trying again - finally getting rid of them.
>
> I had three of them for supper."

The second Anderson record occurred on about 18 June 1965:

> "I found where a turtle had crawled up on the beach four times without laying, apparently unable to find the right place - the beach would look high from the water but sloped on the inside."

The only other nesting record I have information about was reported to me by Dr. A. V. Hays, a Gulfport physician. On a 4th of July outing in either 1964 or 1965, he and his family found about 50 eggs in a nest on the Gulf side of Ship Island near the trees [now East Ship Island]. Turtle tracks in the sand had betrayed the nest. They collected three of the eggs and took them to Gulfport where they buried them in their back yard - they did not hatch.

While no species identification was made for any of these records, the loggerhead is the species most likely to be found nesting in the northern Gulf of Mexico (Rebel 1974).

Although there are few nesting records, loggerhead, green, and leatherback sea turtles are regularly seen in waters around the islands or found dead on island beaches. I suspect that most fatalities are drownings due to turtles being caught in shrimpers' nets. The magnitude of such mortality could be quite high and certainly deserves investigation. Richardson and Hillestad (1978) have reported high mortality of sea turtles due to drowning in shrimp nets off the Georgia coast.

Another likely cause of sea turtle mortality in Mississippi waters is ingestion of plastic bags. The favored food of sea turtles is jellyfish and the turtles apparently cannot distinguish these man-made "jellyfish" from real ones. Certainly there is an abundance of plastic bags in the Sound and Gulf during shrimping season and in summer when weekend visitors to the islands are in the greatest numbers. Walter Anderson (Sugg 1973:80) noted three dead sea turtles on the south beach of Horn Island in a six-month period and commented: "Since those are the only sea turtles I have seen in that period, it may mean something."

Aside from the above, my records for individual species include the following:

Loggerhead - Anderson (Sugg 1973:28) described what was probably a loggerhead (a magnificent big purple brown and yellow turtle") he saw in the Ship Island channel on 10 August 1948. Loggerheads were reported nesting on nearby Errol and Chandeleur Islands, Louisiana, in the early 1960's (U.S.D.I. 1979:II-40). On 12 October 1980 I found a rotting loggerhead on the Sound beach of West Ship Island.

Green - Richmond (1962) recorded a green sea turtle from Horn Island. I have found no other records of this species from the vicinity.

Leatherback - On 6 July 1979 we found and photographed a large dead leatherback in the surf near the south beach of Horn Island and the wreck of the Arcturus. The leatherback had been dead for some time and was attracting numerous sharks. On 20 July 1979 Park Rangers Spirtes and Jones from the Ranger Station on West Ship Island spotted and photographed another recently dead leatherback floating about 0.8 km east of West Ship Island. A loop of rope was found tied around the turtle's right front flipper. On 26 June 1981, campers on Petit Bois Island described a large sea turtle with "three ridges on its back" that they had found dead on the north shore of Petit Bois. Unfortunately we were involved in a boat accident enroute to investigate the sighting and were not able to confirm it.

WHITE PELICAN

Burleigh (1944:344) reported the White Pelican to be "extremely scarce in the Mississippi Sound" and gave no specific records of it from the area of Gulf Islands National Seashore. In recent years, however, the species has been reported from the islands on several occasions (Table 2) spanning the dates 9 October through 22 April. Most records have been in spring, and most have been of large flocks. The species has been reported from all of the large islands, often seen in flight or at rest on sand bars or the ends of the islands. White Pelicans have occasionally been seen feeding in larger ponds and lagoons on the islands.

BROWN PELICAN

While Brown Pelicans nest in the Chandeleur Islands in nearby Louisiana, there are no records of them nesting in Mississippi. Burleigh (1944: 344-345) noted that the species could be found in Mississippi Sound throughout the year: in limited numbers during the spring months, but in flocks of a hundred or more individuals at other times of the year. As the Brown Pelican disappeared as a breeding bird in Louisiana in the 1950's (Williams and Martin 1969), its numbers in Mississippi also declined (Turcotte 1965). Brown Pelicans appeared in Mississippi in increasing numbers following the reintroduction of the species to traditional nesting areas in Louisiana beginning in 1968 (Nesbitt and Williams 1978). They have not yet returned in such numbers as Burleigh recorded, but in recent years the frequency of sightings, numbers of individuals sighted, and proportion of adults to immatures have increased steadily (Table 2). Groups of young pelicans attending spring development of nesting seabird colonies on the spoil island between Horn and Petit Bois islands offer some hope that the species might soon establish a breeding population in the state.

DOUBLE-CRESTED CORMORANT

Cormorants are a common sight on pilings along the Mississippi coast except during the summer. Surprisingly there are few records from the area of Gulf Islands National Seashore. At least during 1959 though they were apparently numerous on Horn Island - and in trouble. Walter Anderson noted (Sugg 1973:52): "I am in a flux of cormorants; they lie dead on both beaches..." Perhaps they were suffering the same fate as the Louisiana pelicans. Williams and Clawson noted 12 cormorants near Horn Island on 12 February 1961 (Gandy and Turcotte 1970:5). We saw as many as 5 from the south beach of Horn Island each day from 13 to 15 October and single birds on 3, 4, and 5 December 1978 at Petit Bois Island. In 1979 we saw up to 4 cormorants each

Table 2. Records of White and Brown pelicans from the Mississippi islands of Gulf Islands National Seashore.

No.	Date	Location	Observers[1]	Reference
White Pelican				
?	14 Apr 62	Horn I.	MOS	Gandy and Turcotte, 1970
40	13 Mar 70	Horn I.	DB	pers. comm.
25	8 Mar 77	E. Ship I.	WW	Weber and Jackson, 1977
65	10 Mar 78	E. Ship I.	WW	Jackson and Cooley, 1978
2	1 Dec 78	Petit Bois I.	JJ	pers. observ.
17	25 Feb 79	W. Ship I.	JJ,DC	Jackson and Schardien, 1979
10	22 Apr 79	Horn I.	JJ,DC	Jackson and Schardien, 1979
21	9 Oct 80	W. Ship I.	JW	pers. comm.
1	12 Oct 80	W. Ship I.	JJ	pers. observ.
1	13 Oct 80	W. Ship I.	JJ	pers. observ.
1	18 Mar 82	Horn I.	SS	pers. comm.
6	23 Dec 82	Horn I.	JJ	pers. observ.
Brown Pelican				
2	12 Feb 61	Horn I.	LW,SC	Gandy and Turcotte, 1970
60	Jul 65	Horn I.	WA	Sugg 1973:169
4	11 May 68	Horn I.	MOS	Anon. 1968
1	4 May 75	Petit Bois I.	DB	pers. comm.
3	13 Sep 75	Petit Bois I.	DB	pers. comm.
1	11 Apr 76	Horn I.	DB	pers. comm.
3	early June	Horn I.	RM	Jackson, 1976
12	early May 77	Spoil I.[2]	ML	Weber and Jackson, 1977
6	14 May 77	Spoil I.	MH	Weber and Jackson, 1977
5a[3]	28 Jun 77	Spoil I.	WW,JT,RR	Weber and Jackson, 1977
3a	17 Jun 77	W. Ship I.	EA	Jackson and Cooley, 1978
1i[3]	28-29 Jul 78	W. Ship I.	EA,LC	Jackson and Cooley, 1978
24i	12 Mar 79	Horn I.	JT,GG	Jackson and Schardien, 1979
1	6 May 79	Horn I.	JC	Jackson and Schardien, 1979
2i	24 May 80	Horn I.	JC	pers. comm.
3i	9 May 81	Spoil I.	JJ	pers. observ.
3i	9 May 81	Petit Bois I.	JJ	pers. observ.
1i	9 May 81	Horn I.	JJ	pers. observ.
14i, 3a	26 Jun 81	Spoil I.	JJ	pers. observ.
9i, 7a	26 Jun 81	Petit Bois I.	JJ	pers. observ.
30	11 Jul 82	E. Ship I.	BF	pers. comm.
3i	22 Dec 82	Horn I.	JJ	pers. observ.
1i, 1a	23 Dec 82	Horn I.	JJ	pers. observ.

[1] Key to observers' initials: CT=Connie Toops, DB=Donald Bradburn, DC=Dwight Cooley, DS=Dave Spirtes, EA=Eve Angeloff, GG=Gordon Gunter, JC=Jerry Case, JJ=Jerome Jackson, JT=Judy Toups, JW=J. Webster, LC=Leslie Cupp, LW=Lovett Williams, MH=Martha Hays, ML=Mark Lewis, MOS=Mississippi Ornithological Society, RM=Robert McDonald, RR=Robert Russel, SC=S.G. Clawson, SS=Stephen Shabica, WA=Walter Anderson, WW=Wayne Weber, BF=Brian Fitzgerald.

[2] All references to Spoil Island here refer to the spoil island just west of Petit Bois Island in the Horn Island Pass.

[3] a = adults, i = immature

day between 23 and 25 February on West Ship Island, one to 5 birds on 14, 20, 21, and 22 April on Horn Island, 5 birds on buoys near Petit Bois Island on 28 December, and single birds on Horn Island on 25, 29, and 30 December. In 1980 we found single cormorants on 11 October at East Ship Island and on 14 October on West Ship Island. I believe that this species is a regular visitor in low numbers on the barrier islands. Its conspicuousness is certainly enhanced by its preference for perching on pilings – most records from the islands were of such birds.

MERLIN

Burleigh (1944:361-362) felt that the Merlin was largely a transient on the Mississippi coast during spring and fall and rarely to be observed during winter months. He did, however, have two December records, including a record of a single bird seen on Petit Bois Island on 21 December 1937. Weber (Weber and Jackson 1977) noted a Merlin on East Ship Island on 10 May 1977, two during January and February 1978 on Horn Island, and one from 11 to 17 February 1978 on East Ship Island. We found two on Horn Island on 14 October 1978 and one on Petit Bois Island on 3 December 1978. On 22 December we watched a female Merlin hunting from a dead tree overlooking tidal flats at the mouth of Big Lagoon on Horn Island. From these records it seems clear that a few individuals winter on the Gulf islands. Habitats preferred always included a tall perch site, such as a dead tree, and open grassland or tidal flat.

PEREGRINE FALCON

Peregrine Falcons regularly migrate along the Mississippi coast and few winter on Mississippi Gulf islands. Most Mississippi records are from the islands. Burleigh (1944:361) reported the species from Cat, Deer, and Horn Islands, and noted that Laughing and Ring-billed gulls and the larger shorebirds were its major prey. Late spring dates from the National Seashore include one seen on 11 May 1975 by Donald Bradburn (pers. comm.) near the eastern end of the woods on Horn Island, and one seen by Wayne Weber (Weber and Jackson 1977) on 11 May 1979 on East Ship Island. The earliest fall date for the seashore (and for coastal Mississippi) is for a Peregrine seen on 11 September 1959 on Horn Island by Walter Anderson (Sugg 1973:98). Burleigh (1944:361) had an early fall date of 13 September 1940 for a Peregrine on Cat Island and Park Ranger Dave Spirtes reported one seen in mid-September 1978 on West Ship Island. Our records for the Seashore include a female that I photographed just southeast of Big Lagoon on Horn Island on 23 and 26 December 1978. In 1979 we found a Peregrine on West Ship Island on 25 February and another, a male, at the east tip of Horn Island on 30 December. On 11 October 1980 I observed a male near the east edge of trees on East Ship Island, and on 9 March 1981 I found a male perched on a 5 m post about 1 km east of the Ranger Station on West Ship Island. The Peregrine Falcon seems to be a regular but rare winter resident on the islands.

SNOWY PLOVER

The Snowy Plover was recorded as a breeding bird on Ship Island by Burleigh (1944:369) who also cited a manuscript by Arthur H. Howell to the effect that the species nests sparingly on Horn and Petit Bois islands. Gandy and Turcotte (1970:46) mention a specimen (Ab2881) in the Mississippi Museum of Natural Science that was collected on Ship Island on 21 June 1939 by L.W. Rowen. Richmond did not include the species in his list of birds from Horn Island until 1968 (Richmond 1968). Numerous records published in the "Birds Around the State" section of the Mississippi Kite document the occurrence of Snowy Plovers on each of the islands of Gulf Islands National Seashore. Our studies indicate that the species can be found on the islands at all months of the year and that it probably nests sparingly on all of the islands. During winter months we found the birds in small groups on broad beach areas at the ends of the islands and along the Gulf beach of Horn Island at Arcturus Flats and Big Lagoon. The largest groups we observed included eight Snowy Plovers near the wreck of the Arcturus on Horn Island on 15 October 1978 and seven at the east end of Petit Bois Island on 3 December 1978.

We found Snowy Plover nesting activity in three areas on Horn Island: between dunes on the Gulf side of the island between the Ranger Station and Big Lagoon, and in a broad flat midway between Gulf and Sound beaches within 200 m of the west tip. On West Ship Island nesting was found only near the west tip. Each of 22 nests found had a clutch of 3 eggs. Egg dates ranged from early April to mid-July, though courtship behavior and nest scrapes were found on Horn Island as early as mid-March. The latest downy young found were banded in a broad sand-shell flat of dredge material near the Sound and about 300 m east of the west tip of West Ship Island on 18 July 1982. This and a single nest found near the west tip of Horn Island were the only evidence of Snowy Plover nesting near the Sound side of the islands. At least at Arcturus Flats and on the broad flats between the Ranger Station and Big Lagoon, Snowy Plovers seemed almost colonial. The closest active nests found were ca 50 m apart, but within favorable habitat as many as 4 nests were found within a radius of about 300 m.

All nests were in broad open sand/sand-shell flats and most were behind large dunes. Early in the season nests tended to be on open high areas within a depression behind a dune. As the season progressed and temperatures increased, most nests were shaded by vegetation during the afternoon and many were on the north slope of a dune rather than in the middle of a depression behind a dune. All nests were shallow scrapes in the sand that were lined with 3-5 mm bits of white or colored shell.

Fifteen Snowy Plovers were captured and color-banded on Horn Island and two were captured and color-banded on West Ship Island. From these marked birds we learned: (1) that pairs share incubation duties nearly equally, (2) that mates at least sometimes stay together from one year to the next, (3) that birds will return to the same nesting areas each year, (4) that some individuals will remain in the nestin area through the winter, and (5) that some indi viduals will leave a nesting area near the center of Horn Island to winter near the east tip of Horn or even near the west tip of Petit Bois Based on the proportion of marked and unmarked birds observed, I estimate that the breeding population of Snowy Plovers on the National Sea shore is between 30 and 40 birds. This specie narrow habitat preferences seem to keep it apa from the congeneric Wilson's Plover which we found nesting only on the Sound side of the islands and always near beach ponds or lagoons

REDDISH EGRET

The Reddish Egret is a species that has been reported with increasing frequency in recent years. Burleigh (1944:347-348) recorded the first observations of the species from Mississippi and considered it a scarce but regular summer visitor. While Richmond (1962) did not record the Reddish Egret from Horn Island, Anderson (Sugg 1973:174) reported the species from near Big Lagoon on 3 September 1965. We found Reddish Egrets on the islands in all months except November, January, and March and from all except the spoil island.

The few birds seen on West Ship Island (1 on 24 February and 13 April and 2 on 24 April 1979) were all red phase. On Horn Island the species was most commonly seen near beach ponds south of the Ranger Station and near Big Lagoon. I saw one white phase egret south of Big Lagoon on 21 and 22 April 1979. The largest number of Reddish Egrets seen on Horn Island during our study was three seen on 22 April 1979. On East Ship Island we saw up to eight Reddish Egrets on 10 July 1979. The only two records from Petit Bois are of a white phase bird near the east tip of the island on 9 May 1981 and of a red phase bird in the same shallow pond on 26 June 1981. Great Blue Herons (Ardea herodias) have nested each year in slash pines just east of Big Lagoon on Horn Island and in slash pines in the marshy interior of East Ship Island. It is possible that Reddish Egrets have nested in either or both locations, though none was seen during aerial surveys. Reddish Egrets are not yet known to nest in Mississippi, though they have nested on North Island, Louisiana, near the Louisiana-Mississippi border. All National Seashore records have been of birds in very shallow tidal pools; none has been seen near cattail marshes or interior ponds.

BLACK-CROWNED NIGHT HERON

The Black-crowned Night Heron was not known by Burleigh (1944) to occur on the Mississippi coast, but Richmond (1962) listed its occurrence as a summer resident on Horn Island. Imhof (1976: 80 - 81) considered the species a locally common permanent resident in Alabama. It formerly nested on Dauphin Island, Alabama, and Imhof suggests that it probably still breeds near Mississippi Sound. Lowery (1960:140) considered the species a permanent resident throughout Louisiana, "quite common in summer but scarcer in winter."

On 23 November 1976, Wayne Weber observed an adult Black-crowned Night Heron on East Ship Island (Jackson and Weber 1976) and during June and July 1977, he saw a subadult on East Ship Island (Weber and Jackson 1977). We found no Black-crowned Night Herons during our visits to the Mississippi islands, though Dwight Cooley found an adult on Dauphin Island, Alabama, on 31 March 1979. It seems from this scattering of records that the species must at least now be considered a rare and irregular visitor to the islands.

MOTTLED DUCK

The Mottled Duck is not so abundant in Mississippi as it is in Louisiana (Bellrose 1976) - certainly because of the lesser availability of coastal marsh environments in Mississippi. Neither Burleigh (1944) nor Richmond (1962) recorded the species, but small numbers are now known to occur and likely nest on Horn, East Ship, and West Ship islands. While we have no records for Petit Bois Island, I feel certain that the species also occurs in the extensive marshes of that island. There are nesting records from adjacent mainland marshes (Gandy and Turcotte 1970). Weber (Jackson 1976) reported a pair on Horn Island on 23 May 1976, and I found a pair at a pond on the Sound side of Horn Island north of the wreck of the Arcturus on 20 April 1979. On 9 October 1980, I found two Mottled Ducks on a large marsh pond near the center of East Ship Island, and on 13 October 1980 there was a single bird in a marsh pond just southeast of the Ranger Station on West Ship Island.

BALD EAGLE

During the course of our studies we saw no Bald Eagles on or near the Seashore islands. However, an adult Bald Eagle was seen at Horn Island on 30 October 1977 by Judy Toups, Larry Gates, John Isral, and others (Weber and Jackson 1978). Burleigh (1944:360) stated that Bald Eagles were once known to nest each year on Cat and Ship islands. On 10 April 1940 he observed a pair at a nest 50 feet up in a tall pine on Ship [East Ship] Island. In recent years a pair of eagles has nested along the Big Biloxi River in Harrison County. This nest was blown down by hurricane Frederic, but by November 1979, they were attempting to rebuild it. That attempt was abandoned, but a new active nest was found shortly thereafter a few kilometers away. It is quite possible that this species could again nest on the Gulf Islands. Indeed, with increasing human development on the mainland, the islands may be crucial to their survival in the region.

NORTHERN HARRIER

The Northern Harrier (formerly Marsh Hawk) seems to be a regular winter resident of the open grassy areas of the large islands. I have 22 records of the species spanning the dates 10 October through 14 April. Our highest count for one day was of four harriers seen on Horn Island on 15 October 1978. All birds for which sex was noted (19 of 22 observations) were females. Burleigh (1944:360) described the species as a common winter resident on both the mainland and barrier islands; he also commented on the preponderance of females in the wintering population. Walter Anderson (Sugg 1973:136) flushed a Northern Harrier from a rabbit it was eating on Horn Island, 28 March 1965. In recent years Northern Harriers have been noted on the Mississippi mainland during all months of the year (see "Birds Around the State" section of recent issues of the Mississippi Kite).

OSPREY

Richmond (1962:96) considered the Osprey to be only a summer resident of Horn Island, but Burleigh (1944:360-361) more correctly defined the species as a breeding bird that winters in the area in low numbers. We have

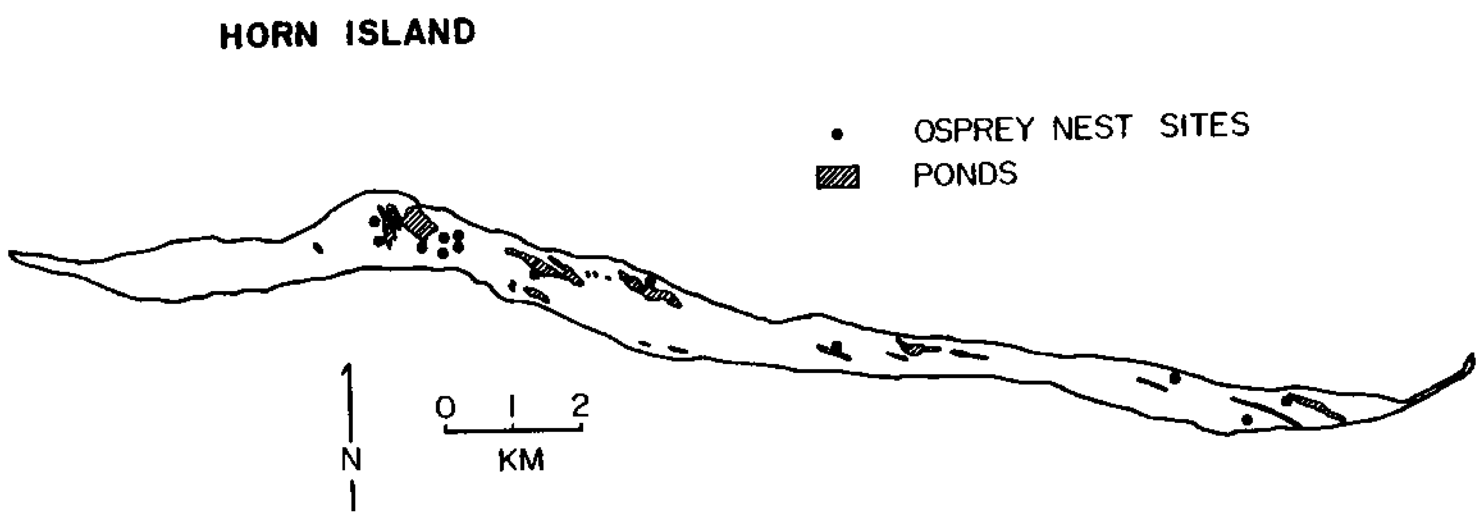

Figure 2. Distribution of active Osprey nests on Horn Island in 1980. Between 1978 and 1982 most of these sites have been active each year. Two additional sites just east of the Ranger Station and near the north beach were active in 1981 only. In December 1982 an additional nest was found just south of Alligator pond about 2 km east of the Ranger Station and ca 300 m north of the Gulf beach.

Osprey records from Horn and East Ship islands - where the species nests - from every month of the year.

In 1977, Robert P. Russell estimated that there were at least 13 active Osprey nests on Horn Island, though one was destroyed by a fire (Weber and Jackson 1977). The same year Weber reported at least four active Osprey nests on East Ship Island (Weber and Jackson 1977). During 1978-1979, we discovered and tagged 23 Osprey nest trees on Horn Island and 12 nest trees on East Ship Island. Of these, ten nest sites were active on Horn Island and six were active on East Ship Island during the 1979 breeding season (Figures 2 and 3). All successful nests on Horn Island in 1979 were located between the Ranger Station and Big Lagoon. All of the nests were in slash pines; six of the active nests were clustered around Big Lagoon. Unfortunately every Osprey nest on the islands was destroyed by hurricane Frederic in September 1979. The 3-5 Ospreys that spent the 1979-1980 winter on Horn and East Ship Islands began almost immediately to reconstruct nests in the same or adjacent trees. Most of the breeding population had returned by mid-February, 1980, and nests were rebuilt at every site that had been active in 1978. Between 1978 and 1982 the nesting population has remained stable with 9-11 nests each year on Horn Island and 6-11 active nests each year on East Ship Island. Nesting activity was underway by mid-February and by the third week in June most nests contained well-developed young. On 24 June 1980 during an aerial survey at Big Lagoon, I was able to spot several nests with downy-partially feathered young and one nest with two young perched on an adjacent branch. On Horn Island, Osprey nests east of the Ranger Station seemed to almost always fail , though determination of failure was evidenced only from the lack of nestlings or attentive adults seen during aerial surveys.

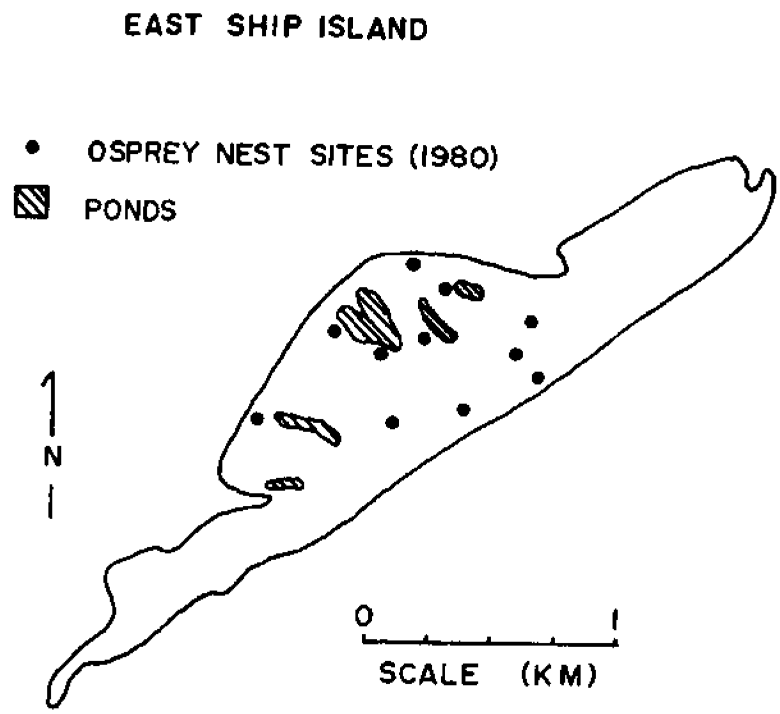

Figure 3. Locations of active Osprey nests on East Ship Island in 1980. Most of these nest sites have been active throughout the period 1978-1982.

While no Ospreys have nested on Petit Bois or West Ship islands, we have observed birds on each. Single birds were seen on Petit Bois on 14 April 1979, and on West Ship on 25 February 1979, 3 January 1980, and 9 March 1981. The latter bird headed west from the island, toward neighboring Cat Island, where we have annually observed 1-3 active nests. Other Osprey populations of the magnitude of those found on Horn and East Ship islands are on Round Island and along the Escatawpa River in Jackson County.

AMERICAN KESTREL

The American Kestrel is a common wintering bird in coastal Mississippi, but quite uncommon during the breeding season. We observed kestrels on Petit Bois, Horn, East Ship and West Ship islands on an almost daily basis on each trip between October and March. Cooley observed a kestrel on Horn Island on 5 July 1979, suggesting that the species could nest on the island. The largest number of individuals recorded on a single day was 8 on both 14 and 15 October 1978, near the south beach of Horn Island. These were seen in a grassy area of less than 200 m width and over a linear distance of less than 4 km of beach. Both sexes have been seen, but no attempt was made to document the sex ratio of wintering birds.

GULL-BILLED TERN

This is a species of limited occurrence in Mississippi, but one which has a long documented history in the state. Ernest G. Holt and Arthur H. Howell both recorded Gull-billed Terns as nesting on Petit Bois Island in 1913 (Burleigh 1944:382). Burleigh (1944 op. cit.) also commented on the lack of records for this species from the mainland. Three specimens in the Mississippi Museum of Natural Science were collected on Horn Island on 6 and 25 June 1941 (Gandy and Turcotte 1970). Richmond (1962) did not include the species as occurring on Horn Island. In 1976 Gull-billed Terns were noted on Horn Island and thought to be nesting on the Spoil Island in Horn Island Pass (Jackson 1976, Jackson and Weber 1976). Robert P. Russell observed three to four pairs of Gull-billed Terns courting on Horn Island between 17 and 19 May 1977 (Weber and Jackson 1977). Wayne Weber, Judy Toups, and Robert Russell reported six birds probably nesting again on the spoil island in Horn Island Pass on 28 June 1977 (Weber and Jackson 1977). We found two pairs of Gull-billed Terns nesting in the mixed congregation of sea birds on the spoil island in 1979. At least one downy chick was present on 6 July. In 1980 we found 8 nests in three groups (3, 3, and 2 nests) on the spoil island on 26 May. Two had single eggs, three had 2 eggs, and three had 3 eggs.

Extreme dates for the Gull-billed Tern on the Mississippi Islands appear to be an early date of 20 April for three birds we saw near the Arcturus in 1979, and a late date of 3 September noted for Horn Island by Walter Anderson in 1965 (Sugg 1973:173). Occasional individuals can probably be seen along the Mississippi coast during every month of the year, but the species is decidedly more uncommon during the winter months (see "Birds Around the State" sections of recent issues of the Mississippi Kite).

LEAST TERN

The Least Tern is the smallest and most abundant tern, generally arriving in coastal Mississippi by early April and leaving by mid-September (Jackson 1973, 1976a, Burleigh 1944:383). Burleigh (op. cit.) reported that it nested in small colonies on all of the Mississippi Islands and at one time along the beach at Gulfport. Two Horn Island specimens (Ab199 and Ab4652) were collected on 12 May 1937 and 25 June 1941, respectively, and deposited in the Mississippi Museum of Natural Science by Winston Nolan (Gandy and Turcotte 1970:62). In recent years a few pairs of Least Terns have been reported nesting on Petit Bois Island (Weber and Jackson 1977) and Horn Island (Sugg 1973:76; Jackson, pers. obs.); only on the mainland have there been large nesting colonies (Toups 1976, Jackson 1976a). In 1979, however, we observed nesting activities of approximately 1500 pairs of Least Terns on the spoil island in Horn Island Pass. We found no sign of Least Terns nesting on Petit Bois or West Ship islands in 1979, but did observe courtship of a few pairs near the Ranger Station on Horn island and near the west tip of East Ship Island. One tern was observed making a nest scrape on East Ship Island on 9 July, but no further evidence of nesting on Horn or East Ship was noted in 1979.

In 1980, only four Least Terns were seen at the spoil island on 26 May and no Least Terns were present on 25 June. Two nesting congregations were found on Petit Bois Island on 26 May: about 50 terns and nine nests with eggs were on dredge spoil near the north shore, about 500 m east of the west tip; and about 75 terns with a few nest scrapes were about 300 m west of the east tip. Also in 1980, several pairs had nest scrapes on the highest areas of the "East Horn Island" - the low eastern tip of Horn that had been separated from the main island by hurricane Frederic. None of those nests were successful. On West Ship Island a few pairs of Least Terns nested on a broad spoil flat about 100 m east of Fort Massachusetts. Three clutches of eggs and ten chicks - all singles and none older than about 10 days were found on 4 July.

On 9 May 1981 there were 15-20 Least Tern scrapes on the spoil island and no evidence of the species on Petit Bois. A few Least Terns were reported near the Ranger Station on Horn and near the Fort on West Ship, but no nesting was documented.

We did not visit the spoil island in 1982, but Judy Toups reported finding no nesting activity there. Our 18 July trip to East and West Ship islands also revealed no nesting activity, but was late in the nesting season.

It seems likely that the combined effects of weather, human disturbance, and predators (raccoons and hogs on Horn Island and raccoons on Petit Bois, East Ship and West Ship islands) will minimize nesting by this species on those islands and will certainly minimize nesting success. So long as the spoil island remains predator free, there is potential for nesting there, but the lack of nesting by Least Terns since 1979 may suggest otherwise. Without detailed study, we can only speculate that weather, competition from other nesting species, or some other factor such as lowered food resources has caused the dramatic population change that has occurred.

BURROWING OWL

The Burrowing Owl was a species unknown to the Gulf Islands National Seashore before 1978. On 15 October 1978, we discovered and photographed a Burrowing Owl at the west edge of Arcturus Flats on Horn Island. The bird flew from grassy dune to grassy dune and remained in the general area for most of the morning before we moved to another part of the island. On 23 February 1979 we discovered a second Burrowing Owl, this one roosting within Fort Massachusetts on West Ship Island. This owl was observed again on 24 and 25 February within the Fort. When flushed, the owl flew to the east side of the Fort and entered a concrete "pipe" that was mostly buried at a slight angle from horizontal. On 2 January 1980 we again found a Burrowing Owl within Fort Massachussets. The pipe used as refuge by the owl in 1979 was filled with sand and this bird remained within the dark recesses of the Fort. No Burrowing Owl was found at the Fort in 1981 or 1982. Burleigh (1944:389) cited records of Burrowing Owls from Cat and Deer islands and commented on the lack of records later than the middle of January. His earliest record was of a bird on Deer Island on 26 October 1940.

RED-COCKADED WOODPECKER

In 1968 the annual narrative report of Horn Island National Wildlife Refuge (U.S.D.I. 1968) reported a sighting of a single Red-cockaded Woodpecker on Horn Island. This endangered species is endemic to the mature pine forests of the southeastern United States (Jackson 1971, Hooper et al. 1980). Characteristically it nests in pines that average seventy-five years or older and lives in social groups called clans. While Red-cockaded Woodpeckers are known to excavate cavities in slash pines, such occurrences are rare and largely confined to south Florida (Patterson and Robertson 1981, pers. observ.). The fact that only slash pines occur on the barrier islands and that most of the forest areas are relatively young, suggest that the bird seen was most likely a vagrant. During 1978 and 1979 we searched pine stands on Petit Bois, Horn, and East Ship islands for evidence (see Jackson 1977) of past or present use of the trees by Red-cockaded Woodpeckers. We found no such evidence.

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ENVIRONMENTAL IMPLICATIONS OF METAL CONTAMINATION LEVELS IN CRASSOSTREA VIRGINICA FROM MOBILE BAY, ALABAMA AND ST. LOUIS BAY, MISSISSIPPI

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ABSTRACT: Trace amounts of a variety of metals in marine waters are generally looked upon as essential for the normal development of most fauna and flora. Elevated levels, however, can be toxic and may result in reduced reproductive productivity and a lessened ability to withstand environmental stress. Many fauna, in addition, lie on the food chain ending with man and thereby can serve as intermediate "metal concentrating agents". The common oyster Crassostrea virginica is a case in point because of its widespread commercial utilization as a food species and because it is also one of the most successful metal scavenging marine organisms. As such, analyses of this species can serve as a useful barometer of the general concentration of specific metals that are present in the host waters and the substrate. Samples of C. virginica from Mobile Bay, Alabama, for example, were found to contain high levels of a number of heavy metals. Cobalt, copper, iron, nickel, vanadium and zinc were 10 to 100 times more abundant than amounts found in identical species in St. Louis Bay, Mississippi. These tissue levels were found to directly reflect the abundance of each metal, not only in the bottom sediments of each of the two bays, but also in the hydrosol (colloidal matter less than 0.2 microns in size). Further, the availability of each metal was concluded to be a direct function of the manner by which the metals were partitioned in the bottom sediments and hydrosol. With the exception of nickel, all other metals in samples from Mobile Bay were found to be present in forms that would permit 50 percent, or more, to be released back into the water column or to be removed by filter-feeding organisms during normal biological activity (Sponsored by Mississippi-Alabama SEA GRANT Consortium).

INTRODUCTION

Metal resources, for years, have been used as an indicator of the wealth of a nation and have played a significant role in the technological development of man. Unfortunately, however, they have also been implicated as an etiological hazard. Knowledge of this fact is, by no means, new and can be traced to ancient scholars who lived more than one thousand years ago. Hippocrates (370 B.C.), Pliny (A.D. 23-79), and Dioscorides (A.D. 100) noted the toxicity of

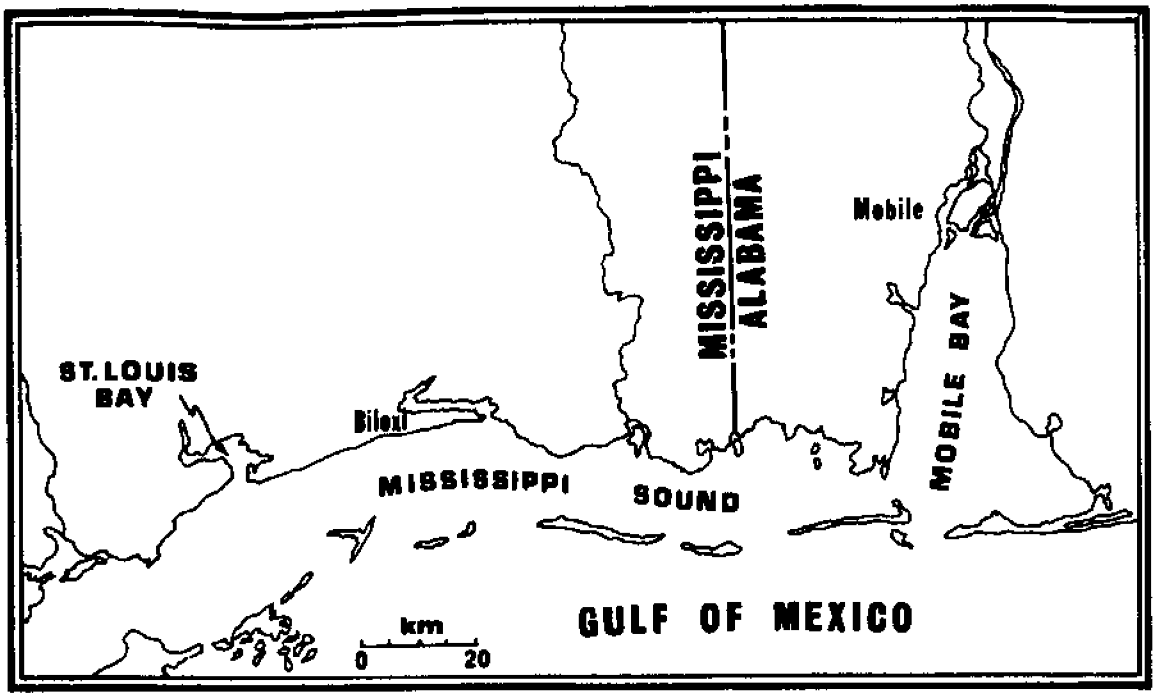

Figure 1.-- Location map showing Mobile Bay, Alabama and St. Louis Bay, Mississippi

effects of dredging and, more recently, Isphording and Elliot (1979) and Malatino (1980) established the levels of major and minor metals throughout the bay. Brannon et al, (1977), Gambrell, et al, (1980) and Isphording (1984) all provided information on metal distribution within the bay and, more importantly, on the manner by which individual metals were partitioned in the bottom sediments. Specifically, each metal was broken down into percentages held in the form of: (1) dissolved phases in interstitial water, (2) exchangeable ions, (3) organic and metallically-chelated compounds, (4) ions associated with disseminated manganese and iron oxide compounds (the "reducible" phase), and (5) structurally-coordinated ions (those held largely in the octahedral and tetrahedral sites in the component silicate minerals). The importance of partitioning each metal into these forms arises from the fact that, depending upon the manner by which a metal is held, it may or may not be in a form that allows its subsequent release back into the water column or allows the metal to be "stripped" from suspended sediment and fine particulate matter by marine organisms. Though the quantity of a metal found in the water column and in sediments does not necessarily bear a direct relationship with levels functionally available for biotic adsorption, the percentages found partitioned in the easily removable exchangeable, reducible and organic forms in sediments are more directly correlative. Further, studies have also shown that the relative toxicity of a metal in the water column can be traced not only to its ion activity but also to its form and speciation (see Windom and Smith, 1972). This investigation was therefore carried out to determine the levels of several heavy metal species present in the water column, bottom sediments and fine particle colloidal phase in both St. Louis Bay, Mississippi and Mobile Bay, Alabama and to compare these levels with amounts similarly present in the indigeneous oyster, Crassostrea virginica.

Faunal Contamination

Oysters are known to accumulate many heavy metals and are therefore considered as good indicators of metal pollution in the environment (Zaroogian, 1980; Ayling, 1974; Greig and Wenzloff, 1978; Siewicki, et al, 1983). A further advantage in using Crassostrea virginica as a pollution barometer arises from the fact that numerous stuies have also documented the toxicity levels of a number of different metals for this species and have established the mechanism of metal uptake and tissue accumulation (see Zamuda and Sunda, 1982; Zaroogian, et al, 1979; Cunningham and Tripp, 1973, etc.). Basically, however, oysters and other filter feeders obtain trace metals by ingesting sea water and suspended organic and fine particulate matter, retaining the trace elements and nutrients necessary for survival, and then excreting the residue. As with higher trophic forms, certain metals are essential for normal growth and development, but elevated levels can be toxic or result in altered productivity and a decreased capacity to withstand environmental stress (Zamuda and Sunda, 1982). Actual uptake of individual metal ions occurs, in part, by binding of the metal to ligand sites at cell surfaces, followed by subsequent passage into the tissues where the metal becomes fixed to metal-binding proteins (see Roesijadi, 1982). Once acquired in this form, later elimination of the metal is, at best, a slow process. Moody (1981) described the removal of oysters from Mobile Bay which had natural high levels of the metal lead; Aristotle (A.D. 300) described the properties of cadmium compounds and commented upon their health hazard; Ramazzini described mercury poisoning that he traced to mercurial unctions being used by surgeons in the early 1700's and chronic selenosis (selenium poisoning) was identified in Columbia, South America as early as 1560 and in Mexico some 200 years later. More recent investigations have caused a number of metals to become suspect in cardiovascular disease (vanadium, barium, copper, lithium, strontium), cancer (arsenic, beryllium, cadmium, lead and nickel), and artherosclerotic heart disease (vanadium). Discussions of each of the preceding can be found in Schroeder, 1960; Voors, 1971; Berg and Burbank, 1972 and Andelman, 1975. Other metals have been more directly identified as etiological factors in clinical disease. High levels of mercury in fish contaminated by industrial discharge were directly linked to mercury poisoning and related teratogenic effects in individuals living in the vicinity of Minimata Bay, Japan and, similarly, cadmium in drinking waters contaminated by mine wastes was traced as the causitive factor in Itai Itai Byo disease, also in Japan (see Kurland, et al, 1960).

Hence, even though a number of metals can be shown to be essential for life because of their function in metabolic and other biological processes (either as co-factors, such as calcium and magnesium or as critical constituents, in the case of iron and zinc), essentially all metals can be shown to produce harmful effects on the body when certain threshold levels are reached. Accumulation of such levels can be brought about by the consumption of forms lower in the food chain that have lived in an environment that was contaminated and which resulted in their own accumulation of a metal or metals. Such conditions are especially prevalent wherever large quantities of effluent are being discharged into restricted basins or estuaries. Mobile Bay is one such estuary and, because it has long been the site of extensive municipal and industrial discharge (and is also the site of a major commercial fishing industry), it was chosen as the site for the investigation described on the following pages. St. Louis Bay, Mississippi was selected as a "control" estuary because, while by no means pristine, it has not been as heavily impacted by such discharge and more closely reflects a "healthy" bay.

MOBILE BAY DESCRIPTION

Mobile Bay is the largest non-compound estuary in the northern Gulf of Mexico and serves as the primary depositional basin for rivers draining an area of 110,000 km^2 (see Figure 1). The watershed area contributing to Mobile Bay ranks sixth in the United States, in terms of area but if discharge alone is considered, the average rate of some 1,759 $m^3\ sec^{-1}$ is exceeded only by that of the Mississippi, Columbia and Yukon rivers.

Outflow of water from the bay is severely restricted and takes place through two relatively narrow passes. One, emptying into Mississippi Sound, carries off approximately 15% of the total discharge whereas that between Dauphin Island and the Fort Morgan Peninsula carries off the remaining 85%. The narrow openings available for discharged, combined with the shallow nature of the bay (3.3 m, average), extensive spoil banks associated with the ship channel and restricted circulation patterns, impede the natural "flushing" action that would normally take place with the result that the bay is characterized by different conditions of salinity, Eh, dissolved oxygen, etc. west of the ship channel than are found east of the channel (see Austin, 1954; Loesch, 1960; McPhearson, 1970). Further, the sediments that are deposited in the bay (some 4.3 million metric tons annually) are rich in organic matter, low in dissolved oxygen and are ideal sites for the accumulation of heavy metals. Exaccerbating the problem even more is the fact that the sediments are dominated by fine silt and clay-size particles which, because of their large surface area, enhance the liklihood of metal adsorption. The mineralogy of the bay sediments is an additional complicating factor becasue of the high percentage of smectite clays that comprise the bottom muds. These clays are characterized by high cation exchange capacities (200-500 meq per liter) and also have the ability of adsorbing significant amounts of organic contaminants. These factors, combined with the observation that some 162 million gallons of municipal and industrial wastes are discharged into the bay each day (Loyacano and Busch, 1979), assures this estuary of remaining in a state of constantly stressed water quality. The bay's sediments have, therefore, for years acted as "sumps" for large quantities of heavy metal and organic pollutants and amounts of some of these have now reached levels that are cause for concern. Though present State and Federal regulations now control the amount of various contaminants that can be discharged into rivers emptying into the bay, essentially unrestricted discharge occurred until as recently as 20 years ago. One company, for example, was recorded as releasing an average of 3,234 pounds of zinc per day into the Tombigbee River. Quantities on some days reached as high as 9,350 pounds. The imposition of stricter controls has now reduced zinc levels from this company to less than 100 pounds per day but, obviously, large amounts had already become incorporated into the bay sediments prior to such regulation. It is these previously accumulated metals (and those still being discharged at "authorized" levels) that are now finding their way into the bay's marine life. The quantities now being absorbed by the fauna are important, and of concern, in view of the fact that the fishery resources in the bay have an annual commercial value of over one million dollars and the fact that tens of thousands of people annually consume fish, crabs and oysters harvested from Mobile Bay.

Previous Work

A number of prior studies have been directed toward establishing the levels of various metals in both Mobile Bay waters and sediments. Windom (1973) carried out an extensive study on the water and sediment and assessed changes in concentrations of metals that were related to maintenance dredging of the ship channel. May (1973), similarly, examined the environmental levels of zinc in tissue of over 2,000 ppm. Depuration of the metal amounted to only 25 percent when the oysters were placed in tanks for a period of 6 months. Similarly, Greig and Wenzlof (1978) reported that relayed oysters showed no significant elimination of cadmium after 40 weeks in a low cadmium environment. Zaroogian (1980) noted in a recent study that (p.276) "...a highly significant linear relationship existed between cadmium concentration in the total soft parts and cadmium concentration in sea water....it thus appears that Crassostrea virginica does not regulate cadmium in its tissues." The consequences of this observation are that oysters apparently have the ability of concentrating some metals to quantities in excess of those normally found in the form of low molecular weight metalloenzymes (metallothioneins). As such, a "spillover" of metals into the high molecular weight fraction may occur and these may succeed in reaching sites of toxic action (i.e., enzymes and genetic material. The true toxicological status of a metal can therefore be assessed by determining the amount held in the form of metal-binding proteins versus that bound on soluble, high molecular weight proteins (see Brown and Parsons, 1978). Though some have argued that "spillover" does not take place in natural waters (Bascom, 1983), these conclusions were reached by evaluating species obtained from open marine environments. It is therefore likely that fauna contained in restricted estuaries receiving high levels of metal contaminants can behave in a manner similar to "dosed" laboratory specimens and can suffer the effects of "spillover". It thus seems likely that estuaries having high pollution levels should be viewed with concern from the standpoint of not only the health of the contained fauna but also because of the etiological effects that may result from the consumption of such fauna by others higher up in the trophic pyramid.

ANALYTICAL RESULTS

A comparison of the average heavy metal content of oyster tissue from specimens of Crassostrea virginica from St. Louis Bay, Mississippi and Mobile Bay, Alabama is presented in Table 1.

Mean values for Mobile Bay samples are seen to be anomalously higher than those from St. Louis Bay and range up to two orders of magnitude greater. This same feature can also be seen in Table 2 which compares zinc values from Mobile Bay oysters with those described from elsewhere in the Atlantic and Gulf Coasts.

To examine possible causes of such high values in Mobile Bay fauna, analyses were carried out to determine the amounts of various metals occurring in the bay's water, bottom sediment and hydrosol (the colloidal particulate material less than 0.2 microns in size that occurs just above the sediment-water interface. Similar data are also presented for St. Louis Bay for comparison. Table 3 strongly suggests that there is little liklihood that metals present either as free ions or complex ions in the water column are a significant cause of the high levels found in Mobile Bay oysters. This, because each of the bays was found to contain essentially the same quantity of each metal examined in the water column. When amounts in sediments were compared, however, significantly higher levels of all metals were found in Mobile Bay. This would at least make these suspect as a possible cause of the high levels found in the oysters. Transferance of metals from bottom sediments to oysters could take place by re-suspension of sediment particles into the water column by events disrupting the bottom (e.g., storms or dredging operations). Once re-suspended, the sediment could then become partially ingested by bottom fauna during the feeding cycle. Though most inorganic particles are filtered and rejected by oysters, a sizeable proportion of the metals held in sediments are in forms that permit them to be "stripped" by biological reactions taking place at cell surfaces. This is especially true for metals held as organic molecules or chelated forms adsorbed on clay mineral surfaces. Table 4 presents partitioned metal analyses from Mobile Bay bottom sediments and it can be seen that a large percentage of several of the metals do occur in this form (copper, zinc, barium and manganese). Similarly, elevated amounts are also seen to be held in the form of "reducible" ions

	Bay St. Louis* (ppm)	Mobile Bay (ppm)
Cobalt	< 0.04	11.0
Chromium	<0.1	<0.1
Copper	32.0	106.0
Iron	57.0	694.0
Nickel	<0.2	18.0
Titanium	< 2.0	<1.0
Vanadium	< 2.0	63.0
Zinc	821.0	1,887.0

Table 1.-- Average heavy metal levels in speciment of Crassostrea virginica. *Data from Lytle and Lytle (1982).

LOCATION	PPM
Mobile Bay, Alabama	1,887
San Antonio Bay, Texas	322
Flower Garden, Texas	268
Graveline Bayou, Mississippi	618
St. Louis Bay, Mississippi	821
U. S. Southeast Coast	654
Texas Gulf Coast	103
U. S. Gulf Coast	1,533

Table 2.-- Zinc levels (in ppm) in Crassostrea virginica for locations in Southeastern United States and the Gulf Coast (after Lytle, 1978).

	WATER		SEDIMENT		HYDROSOL	
	St. Louis Bay (ppb)*	Mobile Bay (ppb)	St. Louis Bay (ppm)*	Mobile Bay (ppm)	St. Louis Bay (ppm)	Mobile Bay (ppm)
Cobalt	<20	12	8	29	1	5
Chromium	<100	1	10	63	12	76
Copper	<10	3.5	10	32	15	56
Iron	54	32	21,000	35,648	17,112	31,767
Nickel	< 30	< 10	8	57	7	70
Titanium	<300	<200	278	4,944	166	1,755
Vanadium	<200	<200	6.4	163	9	93
Zinc	78	35	73	360	58	267

Table 3.-- Average heavy metal levels in water, sediment and hydrosol for St. Louis Bay, Mississippi and Mobile Bay, Alabama. *Data from Lytle (1978).

	PERCENT TOTAL METAL CONTENT			
	Pore Water & Exchangeable Ions	Reducible Phase	Organically Bound	Structural Ions
Copper	0.5	4.1	48.5	46.9
Zinc	0.9	15.1	49.8	34.2
Iron	1.5	73.8	16.1	8.6
Chromium	0.2	51.2	3.5	45.1
Nickel	0.4	30.3	2.6	66.7
Barium	2.1	53.9	30.9	13.1
Manganese	9.9	29.0	43.4	17.1

Table 4.-- Partitioned analyses for heavy metals from Mobile Bay bottom sediments.

(i.e., those associated with disseminated iron and manganese oxide/hydroxide compounds) and these might also be available for transfer to fauna under certain circumstances. The stability of compounds in which the metals are held as a reducible phase is known to be Eh dependent. Hence, any activity that acts to modify redox conditions might also create a situation whereby metals held in reducible forms could be stripped from the compounds and adsorbed by filter-feeding organisms. The relatively large size of most of the particles that occur in the bottom sediments and re-suspended load, however, casts some doubt on the overall importance of this fraction in supplying the great bulk of the heavy metals found in the bay oysters. Nutrients (and contaminants) extracted by oysters are thought to be derived only from sub-micron sized particulate material hence it is likely that only the finest clay particles would be involved in such transfer. The most probable source for such contamination, thus, would involve adsorption of metal ions from suspended small sediment particles and organic material just above the sediment-water interface. This phase, which is largely in a colloidal state, consists of material that is generally less than 0.2 microns in size and is characterized by rapid sorption, ion exchange and dispersion reactions (see Cross, 1979). As such, the "hydrosol" provides an ideal source for such contaminants and reference to Table 3 shows that the metal levels in this phase were comparable to those in the sediments, themselves. Because it consists of particles that are of a size and form that would permit metals to be extracted by normal metabolic and biological processes, it is therefore believed that differences in amounts found in this phase can be used to explain the levels of metals present in tissues of oysters from Mobile Bay and St. Louis Bay. Further, Shaw (1980) reported metal values in the blue crab *Callinectes sapidus* in Mobile Bay of the same order of magnitude as those found in oyster tissue. Because the crab is similar to oysters in its biologic uptake mechanism and affinity for specific metals, it is likely that this species also owes its high metal levels to ions extracted from the hydrosol phase of Mobile Bay waters.

SUMMARY

Data presented in this investigation support the conclusion that oysters can be used as a sensitive barometer of heavy metal contamination in marine and estuarine environments. Analysis of water column, bottom sediment and hydrosol geochemistry indicates that the accumulation of metals by oysters and other filter-feeding organisms is probably related to reactions occurring between tissue and the fine particulate fraction (organic and inorganic) present in the hydrosol. Free or complexed ions present in the water column are not thought to provide a significant source of metals to the fauna. Similarly, the bottom sediments, themselves, are of less importance except when extremely fine particles become re-suspended near the sediment-water interface. When this occurs, those metals held in exchangeable, reducible or as organic complexes adsorbed on clay mineral micelles can be extracted by filter-feeding organisms. The true pollutant hazard of a bay or estuary can, therefore, be most accurately evaluated by analysis of the fine particulate matter that occurs in the colloidal phase just above the sediment-water interface. It is this phase that most heavily impacts a water body's bottom feeding organisms.

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POPULATION CHARACTERISTICS OF THE SEA NETTLE CHRYSAORA QUINQUECIRRHA (DESOR, 1848) IN MISSISSIPPI SOUND WITH AN EXAMINATION OF BRACHYURAN ASSOCIATIONS

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ABSTRACT: Population characteristics and symbiotic associations of the sea nettle medusa, *Chrysaora quinquecirrha* DeSor, were investigated in Mississippi Sound, from 2 June to 18 August 1981. This jellyfish is considered a pest to swimmers and fishermen because of its great abundance, painful nematocysts, and summer occurrence. Medusae were taken at all sampling sites with peak abundance occurring in July, inshore, and in July and August, offshore. Mean bell diameters for males and females were not significantly different (73.7 and 74.8 mm respectively). Sex ratio was 1:1. Gonads were sufficiently developed to make a sex determination on medusae with a mean bell diameter of about 55 mm. As the study progressed, the medusae exhibited a significant size reduction, probably because of overpopulation and stress. Sixty-four medusae were dip-netted and examined for symbiotic associations. The majority (73%) had some form of brachyuran symbiont. Symbionts included *Libinia dubia, Callinectes sapidus, C. similis, Portunus gibbesii,* and *Pinnixa* sp. Field and laboratory observations showed that larval forms of *Libinia* are initially phoretic. In the post-larval stage, the crab becomes a commensal of the sea nettle. As the crab matures, the relationship changes from commensalism, to facultative parasitism, to predation. The other relationships are principally phoretic. The symbionts showed no preference as to the size and sex of the host medusa.

Introduction

The sea nettle jellyfish, ***Chrysaora* (= *Dactylometra*) *quinquecirrha*** (DeSor) (Cnidaria: Scyphozoa: Semaeostomeae), exhibits a typical scyphozoan life cycle in which there are medusoid and polypoid stages; the medusoid stage is dominant and conspicuous and the polypoid stage is a small larval form (Barnes 1974).

Sea nettles spend the summer and early fall in the medusoid stage and the winter and spring in the polypoid stage (Littleford 1939). Medusae of ***Chrysaora*** inhabit shallow coastal waters from New England to the tropics, where their large size, painful nematocysts, and summer occurrences make them a swimmer's nightmare. Schultz and Cargo (1971) found that when sea nettles are abundant, swimming declines in Chesapeake Bay, Virginia, with considerable economic loss to beach operators. They state that no other animal in Chesapeake Bay is so detrimental to recreational activities. This may also be true for Mississippi Sound. The sea nettle is probably the most abundant scyphomedusa in the Sound during the summer months. Medusae have been collected from May through November (Burke 1975). Their abundance when recreational activities are at their peak is a nuisance to swimmers and fishermen alike.

Various workers have examined the biological and ecological aspects of *C. **quinquecirrha*** in Chesapeake Bay (Littleford 1939; Cargo and Schultz 1966, 1967; and Cones and Haven 1969). No studies have been conducted in Mississippi Sound other than those of Phillips et al. (1969) on the trophic significance of jellyfish and Burke (1975) on the biology and distribution of macrocoelenterates in Mississippi Sound. Furthermore, L. P. Schultz of the Chesapeake Bay Biological Laboratory (in Phillips et al. 1969) stated that sea nettles in Mississippi waters differ in size, pigmentation, numbers of lappets and tentacles, stage of sexual maturation, and general ecology from those in Chesapeake Bay.

Marine crustaceans have been found living symbiotically with many members of other vertebrate and invertebrate phyla. Some of the more curious symbiotic associations are among certain representatives of the section Brachyura (true crabs) and medusae of the class Scyphozoa. On the east coast of the United States, juvenile spider crabs, ***Libinia dubia*** Milne-Edwards, have been found in association with the cabbage-head medusa, ***Stomolophus meleagris*** Agassiz (Corrington 1927; Gutsell 1928), and the moon jellyfish, ***Aurelia aurita*** (Linnaeus) (Jachowski 1963). In a study of Monterey Bay, California, Weymouth (1910) found megalops and postlarvae of ***Cancer gracilis*** Dana associated with schyphozoan medusae.

Symbiosis between *C. quinquecirrha* and certain brachyurans has been observed in Mississippi Sound. Phillips et al. (1969) noted juveniles of ***Libinia dubia*** and mature blue crabs, ***Callinectes sapidus*** Rathbun, associated with the sea nettle.

Presently the population of *C. quinquecirrha* in Mississippi Sound is poorly understood. There have been only four studies involving the sea nettle, two of which were published (Phillips et al. 1969; Burke 1975), and neither of those dealt exclusively with ***Chrysaora***. Studies of biotic interactions are not only useful in understanding symbiosis, but can be valuable as models for the elucidation of basic biological problems (Cheng 1967). Because of this lack of information about such an important pest, this study of the medusae of *C. quinquecirrha* was initiated. The objectives of this study were to determine the distribution and relative abundance; measure size and growth rate; determine sex ratio; determine the number and kind of brachyurans, as well as other forms of crustaceans, associated with the medusae; and investigate the mode and reason for contact between these heterospecific organisms.

Methods

Medusae were collected from three stations in Mississippi Sound (Fig. 1). The sampling sites for Station 1 were inshore and adjacent to Deer Island, sites for Station 2 were offshore on the Sound side of Ship and Horn Islands, and sites for Station 3 were on the Gulf side of Cat, Ship, and Horn Islands.

Collections were made weekly, June through August 1981, by shrimp otter trawls. Sex was determined by gonad analyses, and size was measured as bell diameter width. Medusae examined for symbionts were collected by dip-net during the trawls.

Results and Discussion

Tables 1 and 2 summarize the size data collected on the medusae of ***Chrysaora***. An analysis of variance (ANOVA) of bell diameters indicated no significant difference ($p < 0.05$) between male and female bell diameter means ($F = 0.123$, $df = 1{,}2015$). The medusae had a sex ratio of 1:1. Significant differences were noted between male and female mean bell diameters at Stations 1, 2, and 3 and between means in June, July, and August ($p < 0.05$).

Medusae were taken throughout the study except for the first two weeks (weeks 1 and 2 of June) at Station 1. Peak abundance at Station 1 was in July; at Stations 2 and 3 it was July and August. Peak abundance in July and August supports Burke (1975). After the third week of August, collecting was suspended until the last week of September; collections during that time at Stations 1, 2, and 3 contained only one female medusae (110 mm, 25°C, 27 ppt) at Station 1. The greatest numbers of medusae were collected at Stations 2 and 3 (offshore). The absence of large numbers of medusae at Station 1 (inshore) during the July-August peak supports Burke's (1975) suggestion that the Gulf of Mexico race of ***Chrysaora*** is probably neritic in origin. Why the inshore mean bell diameter is significantly smaller than the other two means is an enigma (Table 2, $F = 20.06$, $df = 2{,}2015$). Some limited reproduction inshore could account for the smaller mean bell diameter.

As the study progressed, there was a significant decrease in the mean bell diameter of the male and female medusae

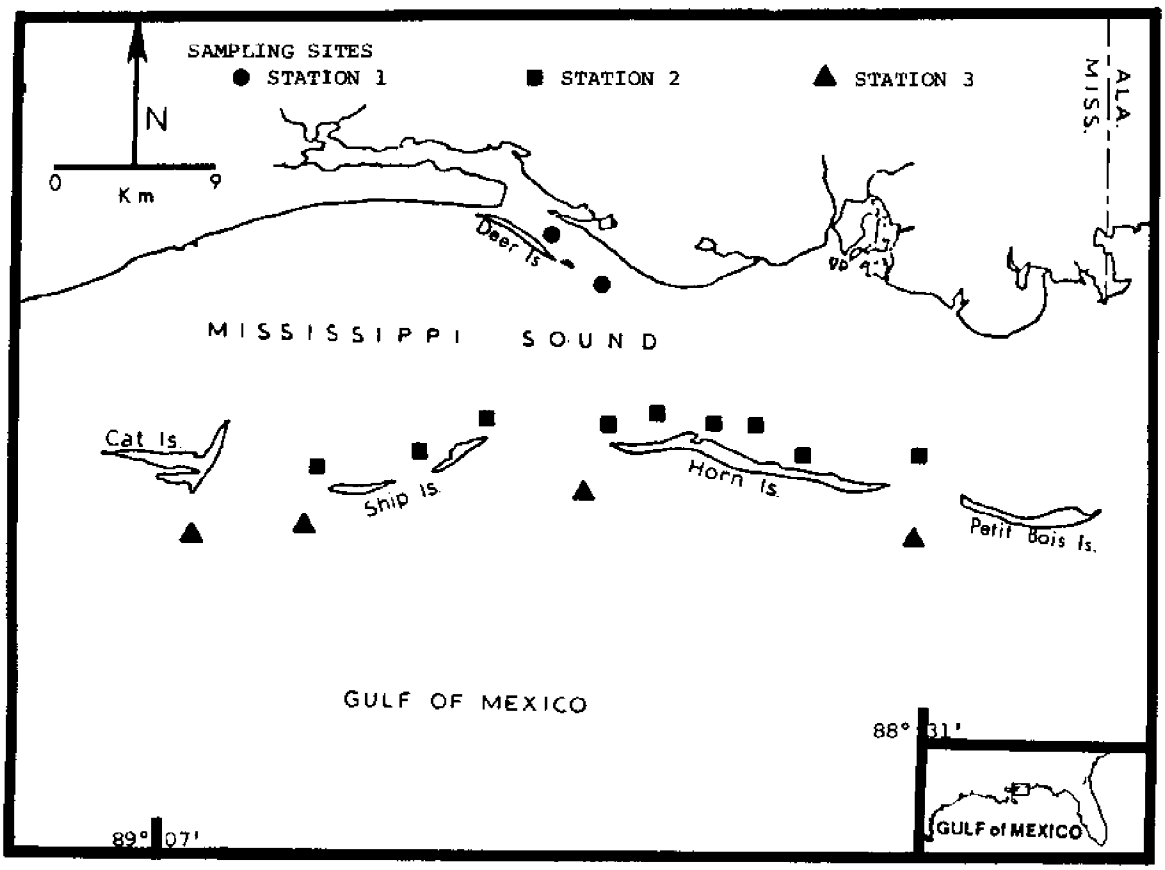

Fig. 1. Location of medusa sampling sites in Mississippi Sound, 2 June - 26 September 1981.

(Table 2, F = 127.52, df = 2,2015). During the months of July and August there was an increase in the relative abundance of *C. quinquecirrha* in Mississippi Sound. Assuming that this indicates an expanding population, the increased number of young could account for the smaller medusa size. Schultz and Cargo (1971) also observed a size reduction in Chesapeake Bay and suggested that the size reduction may possibly result from a reduced food supply through overpopulation. Another possibility for this size reduction is that the medusae may be stressed. During the study, temperatures were rising. Median upper lethal temperatures for the medusae in Chesapeake Bay are between 33.5 and 34.5°C and thermal discharges which raise water temperature above 30°C are probably stressful to the medusae of *C. quinquecirrha* (Gatz et al. 1973). Beginning with the first week of July, temperatures at all stations were 30°C or above. Another suggestion by Schultz and Cargo (1971) concerning the reduction in mean bell diameters is that the medusae may become sexually mature at smaller sizes later in the summer. Those medusae whose gonads were not sufficiently developed to make a sex determination averaged about 55 mm throughout the study (Table 1). If the hypothesis of Schultz and Cargo is correct and assuming the undetermined medusae are sexually immature, there should be a trend towards reduction in the mean bell size of the undetermined medusae (Table 2). No such trend occurred in the present study.

Of the 64 medusae of *Chrysaora* collected by dip-nets, 47 (73%) had some form of brachyuran association. The spider crab, *L. dubia*, with a frequency of 37.5%, was the most common symbiont of *C. quinquecirrha* in Mississippi Sound. Corrington (1927) hypothesized that for this association to occur, either the medusa must descend to the bottom where the benthic crab dwells or one of the larval stages must come in contact with the free-swimming medusa. Gutsell (1928) believed the spider crab entered the bell cavity of the medusa while in the megalops larval stage. Jachowski (1963) thought the association relied upon the contact of the jellyfish with the bottom. Observations by Phillips et al. (1969) indicated that the spider crab attached when the negatively phototaxic medusa was on or near the bottom and reported a 100% incidence of *Libinia* symbionts on sea nettles taken in bottom trawls. Aquarium observations of live medusae and spider crabs supported the hypothesis of Jachowski (1963) and Phillips et al. (1969).

Megalopae of *L. dubia* were found associated with 3.12% of the medusae collected. Larval forms of both heterospecific organisms are planktonic, thus enhancing contact potential. Sandifer and Engel (1971) found that two zoeal stages and one megalop stage of *L. dubia* were completed in less than nine days under culture conditions at 25.5°C-28.5°C and 22 ppt salinity. This short developmental period, coupled with the fact that a *L. dubia* megalop and a first crab stage were collected from the same medusa, suggest that *L. dubia* becomes associated with the medusa, not only in post-larvae, but in its larval form as well, possibly as early as the zoeal stage. This short larval development period could explain why the frequency of larval occurrence is low when compared to the frequency of juvenile *L. dubia*.

Megalopae of *C. sapidus* had the second highest frequency of occurrence (34.3%) and were the most abundant. Again, contact potential was enhanced because both the medusa and the megalop are planktonic. Like *Libinia*, newly hatched blue crabs pass through two free-swimming larval forms, the zoeae and megalopa. However, in this case the length of the larval development is much longer. Blue crabs have 7 zoeal stages over a period of 31-49 days and a subsequent megalopa stage of 6-20 days (Costlow and Bookhout 1959). The much longer larval development of *C. sapidus*, one of the most abundant crabs in the Sound, could explain why the blue crab megalops had a much higher frequency of occurrence and were found in greater numbers than the megalops of *L. dubia*. No post-larvae of *C. sapidus* were collected in association with *Chrysaora* medusae although such an association was observed in the past (Phillips et al. 1969).

Juveniles of *Portunus gibbesii* Stimpson had the third highest frequency of occurrence (6.25%). This is the first record of that symbiotic association. *P. gibbesii* is a good swimmer and occurs in the higher salinity passes and inlets

MEDUSAE CATEGORY		STATION	MEAN BELL DIAMETER AND RANGE (mm)
Males	(N = 67)	1	69.0 (40.0 - 125.0)
	(N = 382)	2	75.5 (38.0 - 185.0)
	(N = 544)	3	73.1 (45.0 - 125.0)
Total Males	(N = 993)		73.7 (40.0 - 185.0)
Females	(N = 68)	1	65.2 (44.0 - 110.0)
	(N = 375)	2	76.3 (40.0 - 160.0)
	(N = 579)	3	75.0 (40.0 - 180.0)
Total Females	(N = 1022)		74.8 (40.0 - 180.0)
Undetermined	(N = 125)	1	50.4 (20.0 - 60.0)
	(N = 130)	2	56.5 (31.0 - 80.0)
	(N = 251)	3	56.4 (20.0 - 88.0)
Total Undetermined	(N = 506)		54.9 (20.0 - 88.0)
Total	(N = 2521)		70.4 (20.0 - 185.0)

Table 1. Mean bell diameter and range of medusae of *Chrysaora quinquecirrha* collected from Mississippi Sound at Stations 1, 2, and 3.

MEDUSAE CATEGORY		MONTH	MEAN BELL DIAMETER AND RANGE (mm)
Males	(N = 87)	June	91.2 (38.0 - 185.0)
	(N = 335)	July	73.3 (40.0 - 105.0)
	(N = 571)	August	71.4 (40.0 - 125.0)
	(N = 993)		
Females	(N = 87)	June	89.1 (40.0 - 180.0)
	(N = 322)	July	76.2 (40.0 - 155.0)
	(N = 613)	August	72.1 (40.0 - 115.0)
	(N = 1022)		
Undertermined	(N = 93)	June	54.4 (20.0 - 80.0)
	(N = 168)	July	54.9 (20.0 - 80.0)
	(N = 245)	August	55.1 (25.0 - 88.0)
	(N = 506)		

Table 2. Mean bell diameter and range of medusae of ***Chrysaora quinquecirrha*** collected from Mississippi Sound in June, July, and August 1981.

of Mississippi Sound. The most probable method of association is for the crab to swim to the medusa and cling to the exumbrella. No larval forms were collected but the attachment of larvae of ***P. gibbesii*** cannot be discounted.

Of the medusae examined, 6.25% contained zoeae of ***Pinnixa*** sp., a small benthic crab occurring throughout the Sound. I was unable to determine whether the planktonic zoeae were associated with the ***Chrysaora*** or being fed on by the medusae since they were not observed while alive. If indeed the zoeae were associated with the medusae, this is also the first record of such an occurrence. It is interesting that most of the members of this family (Pinnotheridae) are parasites or commensals.

Heretofore I have discussed the method of contact between the symbionts and the medusae. I shall now consider the probable reasons for this contact. Cheng (1971) indicated that the most important aspect of symbiosis is the nature of the relationship. The purpose for such a relationship can involve shelter, support, transportation, food, or any combination of these.

One purpose of the spider crab-medusa relationship appears to be the procurement of food and shelter by the crab. Although dip-netting can disturb the original association, a number of spider crabs in the first crab stage and larger were observed clinging to the frilly folds of the manubrium. This is an optimal location for food procurement because of the manubrium's close proximity to the medusa's stomach. The four ciliated oral arms function like a conveyor, transporting food through the manubrium and into the stomach.

Oaks and Haven (1971) found ***L. dubia*** to be a predator of the polyps and medusae of ***C. quinquecirrha*** in Chesapeake Bay, Virginia. Juveniles as well as adults of ***L. dubia*** are known to feed on scyphozoan mucous and tissue in Mississippi Sound (Phillips et al. 1969; Branch 1974). Laboratory observations showed the amount of damage inflicted on a medusa was determined by the size and number of ***Libinia*** associated with it. While a one-to-one association was most common (Corrington 1927; Gutsell 1928), a specimen of ***Chrysaora*** was collected with 14 spider crabs, 1 specimen carried 7 individuals, and 3 specimens contained 2 ***Libinia*** each.

Megalopae of ***C. sapidus*** and a medusa were also observed in the aquarium. The megalops swam freely about the aquarium, returning only occasionally to the medusa. The ease with which the megalopae abandoned the medusa is probably one reason why this phenomenon is rarely observed. This association appears to provide advantages other than food. The megalopae were not observed feeding on the medusa in the aquarium, although they may feed on smaller plankton stunned by the nematocysts. One advantage seems to be that the medusae provide shelter and substrate for ecdysis, not only for larval forms, but for the other brachyuran symbionts as well. Exuviae (molts) from juveniles of ***P. gibbesii*** and ***Callinectes similis*** were found attached to several medusae. The frequency of brachyuran molting on ***Chrysaora*** is probably much higher than this study indicates because the fragile exuviae can be easily lost. The exuviae that were recovered were large enough to be tightly wedged inside the subumbrella.

Another advantage may be transportation. Eggs of ***Callinectes sapidus*** are hatched in high salinity water with successive molts transforming the zoeae to megalopae. During successive molts the larval forms move shoreward (up-estuary) towards lower salinity waters. Burke (1975) suggested the Gulf of Mexico race of ***Chrysaora*** is neritic in origin. During summer and early fall months, the medusae may also move into the Sound. Although some protection may be offered to the larval and post-larval forms by the medusae, their attraction of predatory fish makes it unlikely that this is the sole reason for the association. Phillips et al. (1969) reported that juveniles of the Atlantic bumper, ***Chloroscombrus chrysurus*** (Linnaeus), and the harvestfish, ***Peprilus alepidotus*** (Linnaeus), were commonly found in association with sea nettles. Also at Station 2, a softshelled specimen of ***Portunus gibbesii***, with the recently shed carapace lying next to it, was observed and recovered from the center cavity of the ctenophore ***Beroe ovata*** Chamisso and Eysenhardt. ***B. ovata*** does not possess nematocysts and could offer little in the way of advantages other than support or substrate.

A t-test was used to determine if the symbionts showed a preference for the size or sex of the host medusa. The mean size of the medusae were 96.6 $\pm$ 27.5 mm for those with symbionts and 87.59 $\pm$ 26.3 mm (S.D.) for those without symbionts. No significant difference exists between these means ($t = -1.196$, $df = 29$). For the medusae having symbionts the mean size of the male and female were 105.6 $\pm$ 26.0 mm and 101.6 $\pm$ 23.5 mm (S.D.) respectively. Again, no significant difference exists between these means ($t = 0.472$, $df = 36$).

To further describe the symbiosis between the sea nettles and the brachyurans, more specific terms are available. Specifically, the terms phoresis, commensalism, parasitism, and even predation are used to describe heterospecific associations. According to Cheng (1967) the relationships characterized by these terms can and do overlap.

The spider crab and the medusa fit into this category of overlapping relationships. Initially the larval association is phoretic with the medusa providing support, shelter, and transportation. In the post-larval stage, as ecological requirements change, the crab becomes a commensal of the sea nettle. As a commensal, the crab feeds on substances captured (or ingested by) the host medusa. As the crab matures, the relationship changes from commensalism to facultative ectoparasitism, and as the relationship reaches its conclusion, to predation. It is objectively impossible to discern where one type relationship ends and another begins and categorizing them by one term or another is arbitrary. The other relationships appear to be principally phoretic, possibly with some opportunistic commensalism. The spider crab-sea nettle symbiosis seems to follow another sea nettle symbiosis rather closely. In the harvestfish-sea nettle symbiosis, the association is initially commensal, becomes ectoparasitic as the fish feeds upon the host, and finally as its ecological requirements change, the fish becomes nonsymbiotic but continues to feed through autumn as a predator of *Chrysaora* (Mansueti 1963).

Conclusions

Chrysaora quinquecirrha (DeSor) was the most abundant medusa in Mississippi Sound during the study and were taken at all sampling sites. Medusae were more abundant offshore (Stations 2 and 3). The peak abundance of *Chrysaora* occurred in July inshore, and in July and August offshore.

No significant size difference existed between the means of the male and female bell diameters. Mean bell diameters for males and for females were 74.3 and 74.8 mm respectively. Gonads were sufficiently developed to make a sex determination on medusae with a mean bell diameter of about 55 mm. The medusae had a sex ratio of 1:1. As the study progressed there was a significant decrease in the mean bell diameter of male and female medusae. The occurrence of smaller medusae later in the summer was probably because of overpopulation and stress.

This study supported both hypotheses on the method of *L. dubia* attachment. The spider crab becomes associated with the medusa in its larval form, possibly as early as the zoeae, and in its juvenile form when the negatively phototaxic medusa is on or near the bottom.

In its larval form, the spider crab-medusa relationship is phoretic. In the post-larval stage, the crab becomes a commensal of the sea nettle. As the crab matures, the relationship changes from commensalism, to facultative ectoparasitism, and as the relationship reaches its conclusion, to predation. With the exception of *L. dubia*, the relationship between the brachyurans and *Chrysaora* is phoretic, possibly with some opportunistic commensalism. The benefits gained by the brachyurans were support or substrate for ecdysis, transportation, protection and to a lesser extent food. The symbionts showed no preference as to the size and sex of the host medusa. No other crustacean taxa were found to be associated with medusae of *Chrysaora*.

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GULF COAST RESEARCH LABORATORY: AN OVERVIEW

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ABSTRACT: The Gulf Coast Research Laboratory is Mississippi's institution of higher learning for research, education and service in the marine sciences. Since its establishment, the Gulf Coast Research Laboratory has developed an academic program that provides regular course work primarily during the summer, but occasionally night courses are offered during the academic year. The Graduate Research Program provides facilities, training and supervision to resident graduate students working on master's or doctor's degrees in various fields of marine science.

The 13 science sections have developed a year-round, full-time, applied and basic research program. Disciplines range from botany to systematic zoology, from chemistry to physiology and from geology to physical oceanography. While each section carries on research projects independent of the others, whenever possible the sections collaborate and employ the team approach to the investigation of problems.

During its brief existence, the Gulf Coast Research Laboratory has made substantial progress toward its goal to provide a well-balanced program of research, teaching and service in the marine sciences.

The Gulf Coast Research Laboratory is Mississippi's institution of higher learning for research, education and service in the marine sciences. It was created in 1947 under the auspices of the Mississippi Academy of Sciences. In 1950, it was chartered by the Mississippi State Legislature and placed under the Board of Trustees of State Institutions of Higher Learning, which governs all state-supported universities in this state.

The major functions of the Gulf Coast Research Laboratory include, but are not limited to, the following: Full time marine research; professional marine science education; public education on marine environment; assistance and advisory services to the Mississippi fisheries and seafood industries; professional and technical support to the Mississippi Bureau of Marine Resources in the management of marine fisheries; and professional advisory service and assistance on coastal problems to city and county governmental entities.

The Laboratory's main campus is located in Ocean Springs, and is situated on forty-five acres on the shores of the Mississippi Sound, a richly productive estuarine area that serves as a nursery ground for many commercial seafood species. The facilities on this campus are housed in twelve major structures, eight of which are of modern design, built of brick, glass and masonry, and most are air-conditioned. These structures include the Oceanography Building, A.E. Hopkins Teaching Laboratory, Anadromous Building, Research Facility Building, the Richard Caylor Building, Wm. M. Shoemaker Toxicology Building, dormitory, cafeteria, two research barracks, maintenance shop and storage facilities. An additional sixteen acres constitutes the Biloxi campus at Point Cadet. The Biloxi campus is the site of the new J.L. Scott Marine Education Center for public and professional education, as well as for research, in the marine sciences.

The Laboratory is affiliated with twelve Mississippi universities and colleges and forty-four out-of-state institutions for the purpose of providing academic training in the marine sciences to the students in these institutions. Formal lectures and regular courses are offered primarily in the summer, but occasionally night courses are offered for in-service science teachers during the academic year. The summer teaching faculty includes visiting professors from Vanderbilt University, Southeast Missouri State University, and the University of Kentucky, in addition to Laboratory faculty.

The Graduate Research Program provides facilities, training and supervision to resident graduate students working on master's or doctor's degrees in various fields of marine science. Graduate students typically finish their basic course requirements at their home university prior to commencing their residency at the Laboratory.

In conjunction with the academic program, Laboratory facilities are available from September through May for use by colleges and universities for scientific field trips. Field trip groups visit the barrier islands as well as collect specimens from the Mississippi coastal waters.

A special feature of the academic program is the J.L. Scott Marine Education Center. Although the facility is designed primarily for research and education for the professional student, a portion of it is open to the public. This includes the aquariums, demonstration laboratories, exhibits, and moving pictures dealing with various marine subjects. The objective is to educate the general public concerning the natural resources of Mississippi and the Gulf of Mexico - how they can be utilized but simultaneously protected and conserved.

The Gunter Library is probably the most complete one for the marine sciences on the northern Gulf coast. It contains over 24,015 reprints and over 10,000 books. More than 871 journals and periodicals are received regularly.

The Ichthyology Research Museum, part of the Systematic Zoology Section, now has about 20,410 catalogued lots of fishes representing about 190,000 specimens. The specimens comprise 251 families and 2,700 species. The fishes are primarily from the Gulf of Mexico, Central, and South America with special holdings from the Indo-Pacific. The Museum contains the largest collection of pipefishes in the world. The Museum was designated as one of five major regional Ichthyological collections in the final report of the American Society of Ichthyologists and Herpetologists Advisory Committee on collections.

The Laboratory operates a small fleet of vessels. The new 97-foot R/V TOMMY MUNRO is equipped for offshore oceanographic research and the 45-foot HERMES is a trawl boat used primarily for student field trips and collections closer to shore. Several small power craft are used by various projects.

The Gulf Coast Research Laboratory faculty carries on year-round, full-time, applied and basic research in various fields. The science sections and their research activities are as follows:

Analytical Chemistry Section: Conducts studies of heavy metals in surface sediments, pollutant tracers in rivers, lipid composition of marsh plants and marine sediments; investigates pollution records in sedimentary strata, phenol distribution as a function of industrial effluents, relation of hydrographic and geologic features of the Mississippi Sound to organic composition of sediments; evaluates seafood waste as fertilizer; studies impact of description of sediment associated nutrients to marine biota; studies nutrient budgets in rivers and bays of the Mississippi coast; and documents geochemical composition of all sediments in Mississippi Sound.

Botany Section: Research effort concentrates on the plant life of the coastal zone of Mississippi, especially the estuarine and marine ecosystems; studies systematics, morphology, physiology and plant ecology of plants of tidal marshes, seagrasses, marine algae and fungi; studies development and practical application of plant propagating and rehabilitation techniques to restore damaged salt marshes and seagrass meadows; and conducts vegetational studies including mapping, and frequent coast-wide field surveys of tideland and seagrass beds.

Ecology Section: Conducts research on the rate of phytosynthesis by phytoplankton in relation to the concentration of chlorophyll and other plant pigments, the composition of the phytoplankton community and light intensity; studies composition and distribution of zooplankton with emphasis on distribution of chaetognaths and on zooplankton as food for larval fish; and examines benthic community structure with emphasis on the identification of species group associations by cluster analysis.

Environmental Chemistry Section: Conducts studies of degradation rates of crude oil in marsh plants in accelerating degradation; organic geochemical studies of hydrocarbons and fatty acids in ancient plants and the fate of organic matter in marine sediments; maps the distribution of various organic contaminants in Mississippi Sound; examines abnormal pigments in marine crustaceans; development of fluorescence techniques for qualitative examination of polynuclear aromatics in sediments and high resolution glass capillary gas chromatographic procedures for organic pollutants; and studies development of an "index" system to rate the potential threat of polluted sediments to the biota of Mississippi Sound.

Fisheries Management Section: Studies the population dynamics of major oyster reefs in the waters of Mississippi Sound, with emphasis on the level of harvestable and sub-harvestable stocks; general ecology, oyster diseases and predators; and oyster reef rehabilitation resource and management.

Fisheries Research and Development Section: Deals mainly with the monitoring of commercially important finfish and shellfish from the northern Gulf region; data are used for management activities and providing stock assessement information to various fisheries; invertebrate research interests include crustacean systematics, brachyuran larval development and the use of closed recirculating sea water systems to molt and shed blue crabs; ichthyoplankton research group studies larval fish taxonomy, population dynamics and ecology - northern Gulf of Mexico sciaenids are the focus of ongoing studies of larval distribution, growth and trophic dynamics; and carries on work to restore striped bass in the coastal areas of Mississippi.

Geology Section: Conducts interdisciplinary studies of bottom-subbottom sediment of Mississippi coastal water bodies; field surveys of beach accretion-erosion cycles; detailed investigations of the Pleistocene-Holocene geological history of coastal plain, inshore and nearshore Gulf area, ranging from the southeast Louisiana terrace belt and Mississipp delta margins to the Florida panhandle Apalachicola coast; and studies lagoon, sound barrier island formation and evolution trends.

Microbiology Section: Studies pollution of the estuarine environment; bacterial pathogens of both fish and humans; and taxonomy and distribution of selected bacterial species in estuaries.

Microscopy Section: Conducts research on histological and ultrastructural aspects of organs, tissues and cells of marine and freshwater organisms; effects of carcinogens and other environmental toxicants; organization, development and effects of intracellular pathogens including protozoa and bacteria; and assists other Laboratory personnel in studies utilizing light microscopy, transmission electron microscopy and scanning electron microscopy.

Oyster Biology Section: Studies all aspects of biology, ecology, mariculture, and symbiology of the American oyster and other estuarine dependent molluscs of the northeastern Gulf of Mexico; assessment of marine and estuarine invertebrates of barrier islands including oysters; hatchery culture (of seed) depuration, relaying, and leasing studies on oysters; habitat suitability index modeling of Gulf coast oyster stocks; parasites of edible marine and estuarine molluscs of eastern Gulf of Mexico; mariculture and overwintering studies of warm water species in solar-heated raceways and greenhouses; and experiments with systems for maintaining and shedding (softshell blue crabs.

Parasitology Section: Studies various aspects of parasites and diseases of marine and estuarine animals, such as taxonomy, morphology, life histories, ecology, pathology, public health, and control methods; pathological changes caused by carcinogens and other toxicants; monitors and assesses stocks and biology of local adult commercial finfishes; rears fishes and invertebrates for toxicological and parasitological studies; and investigates free-living invertebrates with an emphasis on crustaceans.

Physical Oceanography Section: Conducts research on estuary hydrodynamics and physiochemical processes and characterization of estuaries, air-sea interaction, hydraulic processes in marshes, and dynamics of estuarine fronts; continental shelf circulation and cross-shelf exchange processes; and numerical hydrodynamic modeling and application of remote sensing technology.

Physiology Section: Studies salinity and temperature relationships of the commercial shrimp Penaeid aztecus Ives from the Gulf of Mexico with emphasis on ionic and osmotic regulation and metabolic and behavioral responses; aquaculture nutrition and feed development; culturing of algae Thalassiosira fluviatilis and Rhizosolenia alata, oceanic copepods Eucalanus sp. and the tropical Caribbean fishes, Rivulus mumaratus; toxicology studies with the chemical effluents from the Ocean Thermal Energy Conversion plants using marine animals like mullet (Mugil cephalus), Sargassum shrimp (Latreutes fucorum), filefish (Monocanthus hispidus) and copepods Eucalanus elongatus and E. pileatus; also studies the effects of unionized ammonia on the survival, behavior and molting process of blue crabs (Callinectes sapidus).

Systematic Zoology: Research on taxonomy, systematics and distribution of subtropical and tropical marine and estuarine fishes.

Toxicology Group: Studies the fate and disposition of xenobiotics in natural environments - includes assessment of degradation rate kinetics, effect on degradation rate of environmental parameters (salinity, biomass, TOC, temperature, pH, etc.) and geographic site, and comparison of laboratory systems (shake flask, microcosm) to field evaluations in predicting environmental fate of various chemicals; assesses toxicity as related to degradation of parent compound using indigenous fish and crustaceans; effect of pollutants on developing communities - temporal comparison of community development as affected by a variety of pollutant chemicals: species numbers and diversity are evaluated in a continuous-flow laboratory system utilizing natural seawater; use of small fish in carcinogenicity testing - evaluation of several fresh and saltwater fish species as indicators of carcinogenicity of halomethanes and other drinking water biorefactories; also evaluates actions and synergistic effects within the halomethane groups and between halomethanes and other materials, as well as factors which stress the test animals and mode of entry of test chemicals.

The faculty and scientific staff are provided professional services through the several support sections - Computer Center; Word Processing; Scientific Illustration; Water Analysis Laboratory; Finance Office; and Maintenance. The institution is served by the Public Information Office through the monthly publication of the newsletter Marine Briefs, the production of weekly 5-minute radio programs, continuous interactions with the news media; and copy editing manuscripts, typing printing masters, proofing them and coordinating the annual publication of Gulf Research Reports.

Since its establishment, the Gulf Coast Research Laboratory has made sustained and substantial progress, most of it since the mid-1960's toward its goal to provide a well-balanced program of research, teaching and service in the marine sciences.

THE PLANT COMMUNITIES OF PERDIDO KEY

GULF ISLANDS NATIONAL SEASHORE

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ABSTRACT: Following Hurricane Frederic in September 1979, a study of the series of plant communities, from pioneer beach to sand pine woods, was initiated. Three types of quantitative samples were made along four cross island transects which represented the eleven kilometers of the barrier island under the protection and management of NPS. This report will emphasize transect TW1, which was least disturbed by Frederic, and TP3 which was most disturbed. Vegetation zones on TW1 are: Pioneer beach, Ceratiola stabilized dunes, Pinus clausa woods, and Juncus marsh. On relatively undistrubed beach Uniola paniculata reaches coverage values above 20% in October, and Schizachyrium maritimum and eight other species each contribute 2% or less. Ceratiola ericoides covers 20% or more of stabilized dunes, with Uniola and Schizachyrium contributing more than 5% each. Pinus clausa, Quercus geminata, and Quercus virginiana are most conspicuous in sand pine woods, and Juncus marsh may have ten or more additional species depending on proximity to woods.

Transect TP3 sampled hurricane overwashed beach in which vegetation was essentially eliminated; immature and disturbed dunes, and soundside beach. Our emphasis was on the recovery of pioneer vegetation on overwashed beach, and implications that this data would have for the control of beach access, especially by ORV's. Beach vegetation recovery was led by Uniola growing from surviving rhizome fragments. Uniola coverage reached 5% by October 1980, 7% by 1981, and 8% by 1982. A broad pioneer dune developed in the overwash area sampled, but much of the overwashed beach along the island face retained the overwash profile following winter storms of 1980-81, and 1981-82.

Seedlings first contributed to revegetation of pioneer beach in spring and summer of 1981, and to a very small extent, during 1982. In 1981 seedlings were established as close as 11 meters from mean high tide, and a few specially protected seedlings became perennating plants by summer 1982. A controlled access route was opened to ORV's in late summer, 1981 and most seedlings were quickly eliminated. ORV permitting at this time prohibited further study of seedling survival.

Management considerations are required which provide for undisturbed research on pioneer beach, of sufficient duration, to determine the natural forward line of vegetation on Perdido Key. Such freedom from disturbance, if only for a study area, will allow predictions of the forward zones of each of the plant communities which reestablish between major storms on the barrier island.

STRATIGRAPHY, MORPHOLOGY AND STORM RESPONSE OF BARRIER ISLANDS ALONG THE NORTHERN COAST OF THE GULF OF MEXICO

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ABSTRACT: Barrier islands defend low-lying coastal lands against storms, they enclose and protect the rich natural resources of estuaries and marshes, and they have scenic qualities unparalleled elsewhere in the coastal zone. Because of their diversity barrier islands are often subject to conflicting land-use pressures. The resolution of such conflicts must be based on full understanding of the dynamic nature of the islands. This paper attempts to provide such understanding by reviewing the state-of-knowledge regarding the physical processes which have led to the development of our present barriers, and the natural forces of sediment dispersal which continue to modify them. Although barrier islands are of bewildering complexity at first glance, it is the thesis of this paper that their stratigraphy and morphology are controlled by relatively few factors. The Holocene sea level history and the longshore location of sediment sources and sinks appear to be the most important factors along the northern shores of the Gulf of Mexico. Storm effects are directly related to the stratigraphic development of the islands.

Sea level controls the location of the shoreline on the continental margin. Furthermore, the rate with which sea level has been changing relative to the local sedimentation (or erosion) rate determines the stratigraphy of the coastal deposits as well as the topographic profile of the barrier island surface.

Eustatic (global) sea level has risen about 100 m since the late Wisconsin glacial low stand (Dillon and Oldale, 1978). During its most rapid phase, global sea level rose about 1 cm/yr. Since about 4000 years b.p. there has been only slight net rise and se generally refer to this period as the holocene "still stand." Recent evidence, however, suggests that sea level has been oscillating with an amplitude of a couple of meters about a more or less stable mean during the last millenia (Colquhoun et al., 1981). The oldest barrier beach ridges along the stable sections of the Gulf Coast (S. Texas) date back to about 4000 years b.p. suggesting that a reduction in the long-term rate of sea level rise was responsible for incipient shoreline progradation. The Louisiana barriers which are located on a subsiding coastal plain, and therefore subject to a continued local sea level rise up to the present, are all younger.

The distinction between transgressive and regressive stratigraphic sequences is fundamental to the understanding of the evolution of a barrier island shoreline. A transgressive sequence is one where the shoreline has moved in such a way that sediments deposited in seaward environments stratigraphically end up on top of sediments in more landward environments. A regressive sequence has the reverse stacking. In response to rising sea level, shorelines may transgress or regress depending on sediment supply. Studies of the Holocene stratigraphy of Texas/Louisiana barriers have demonstrated that sandy sediments generally are being derived from delta front sands, or other "headlands," leaving such areas with a negative sediment budget and transgressive stratigraphy. The sediments are being delivered to the inter-deltaic embayments, yielding a positive sediment budget and regressive stratigraphy in those coastal sections (Nummedal, 1982; Morton and McGowen, 1980).

Barrier morphologies associated with these two types of stratigraphic sequences are very different. Morton and Nummedal (1982) documented that transgressive barrier shorelines are invariably highly erosive, consisting of a thin beach overlying back-barrier organic-rich muds. Old marsh commonly outcrops on the beach face. This type of barrier is commonly referred to as low-profile. Examples of such low-profile barriers include South Padre Island and the beach off Freeport, Texas, and the Fourchon beach in Louisiana.

Regressive barriers, on the contrary, are generally wide with multiple well-developed beach and dune ridges. Such barriers are referred to as high-profile. Examples along the northwest Gulf Coast include North Padre, Mustang and San Jose Islands, and the downdrift (east) end of Grand Isle, Louisiana.

The landfalls of Hurricane Frederic on Dauphin Island, Alabama, on September 12th, 1979, and Hurricane Allen on South Padre Island, August 10th, 1980, have provided abundant data for an assessment of storm impact on Gulf Coast barrier islands. Dauphin Island, which consists of a high-profile Pleistocene eastern core and a low-profile western Holocene spit, responded to the hurricane by being completely overwashed on its low profile segment. The wave destruction was worst immediately west of the Pleistocene core, probably because of refraction around the ebb-tidal delta at the entrance to Mobile Bay. The Pleistocene core suffered but minor damage (Nummedal et al., 1980). Allen's effects on Padre Island, Texas were similar: complete overwash and large-scale destruction on the low-profile southern part of the island, compared to dune scarping and temporary beach retreat on the high-profile northern part of the same island. High-profile barriers prevent washovers. Consequently, a larger percentage of storm-eroded sand remains on the shoreface during storms, from where it renourishes the beaches during the post-storm accretionary phase. Long-term beach retreat is therefore much slower than on low-profile barriers.

Conclusions: (1) The oldest Holocene barriers along the northern Gulf Coast are only about 4000 years old. This suggests that they became stabilized at a time when the consistent post-glacial sea level rise essentially came to an end. Many Mississippi delta barriers are much younger. (2) Gulf Coast barriers vary in topographic relief (profile) according to their stratigraphic evolution: regressive barriers are high-profile, transgressive ones are low-profile. (3) When subject to hurricane impacts the low-profile island segments respond by large-scale washover, property destruction, and net landward island migration. The high-profile islands, in contrast, respond with some dune scarping and temporary beach retreat.

Unfortunately, most recreational sea-side development has occurred on low-profile islands.

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MORPHOLOGY, SEDIMENTARY STRUCTURES AND SEDIMENT DISPERSAL PATTERNS WITHIN A TRANSVERSE BAR FIELD, HORN ISLAND, MISSISSIPPI

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ABSTRACT: This study was undertaken to characterize the morphology, sedimentary structures and sediment dispersal patterns within a transverse bar field on the sound side of Horn Island, Mississippi.

Seasonal beach and bathymetric mapping demonstrate westward migration of the bars during the winter storm season. The orientation of the bars remained transverse to the shoreline at all times and the form asymmetric with the steep flank facing northwest. No physical or biological sedimentary structures were found within underwater box cores taken along the shoreface. This homogeneity is attributed to extensive bioturbation and the clean, well-sorted nature of the sand.

A sediment dispersal model was inferred from data collected during fluorescent sand tracer experiments. When wave approach is from the northern directions, a current circulation pattern is set up whereby a steady state condition exists. Sediment eroded along the gentle flank of the bar may be: (1) transported offshore, (2) deposited in the bar embayment areas or (3) transported and deposited over the neighboring bar crest via rip currents. In this way, sediment is redistributed and bar morphology is maintained. Strong frontal passages causing easterly wave approach generate westward flowing currents that may be responsible for the westward migration and the asymmetric nature of the bars.

INTRODUCTION

Sediment transport patterns and resulting nearshore topography are governed by nearshore processes. The rate of transport depends on the size and quantity of the sediment present and the amount of energy brought into the system. Bar morphology and shoreface profiles respond to changes in energy input. Periods of high wave energy result in flat dissipative nearshore profiles, whereas, low wave energy builds steeper reflective nearshore profiles (Short, 1978; Wright et al, 1978, 1982). Moderate wave energy will result in varying nearshore morphologies exhibiting both dissipative and reflective elements.

A study was conducted along the low energy sound side of Horn Island, Mississippi with the objectives of (1) describing the transverse bars and documenting their seasonal changes, (2) describing the sedimentary structures found within a low energy, open water back barrier shoreface, and (3) defining the sediment transport patterns within the bar field. Beach and bathymetric profiles were surveyed seasonally to determine morphologic variations occurring within

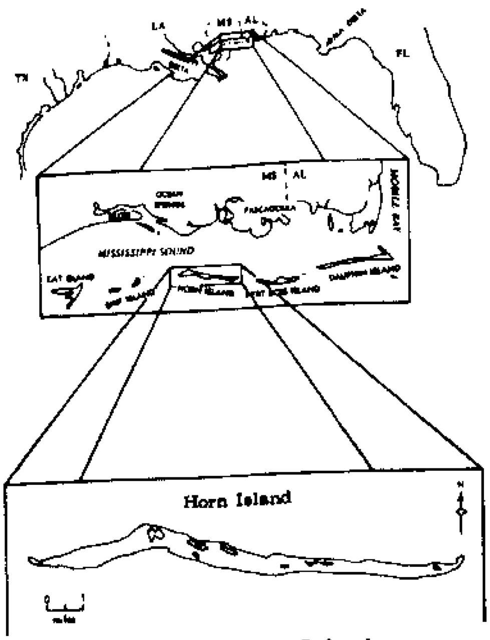

Fig. 1. Location map of Horn Island, Mississippi.

the bar field. Underwater box cores were obtained to document the physical and biological sedimentary structures found in a low energy, open water back barrier environment. Fluorescent tracer sands were used to delineate the sediment dispersal patterns occurring within this transverse bar field.

STUDY AREA

Horn Island, Mississippi is an east-west trending barrier island located in the northern Gulf of Mexico (Fig. 1). It is approximately 23 km. long and varies in width from 0.4 to 1.0 km. Sandy beaches characterize the back barrier sound environment. A shallow platform of varying width characterizes the back barrier shoreface of Horn Island (Fig. 2). Along this platform are irregularly shaped broad shoal areas, some extending more than one kilometer into the sound. Between these shoal areas the platform is more regular and narrow (250 meters). Sand bars are present along the length of the shoreface. A well defined transverse bar field characterizes approximately six kilometers of the WNW-ESE trending shoreline along the middle of the island. The study area, located within this transverse bar field, extends from the National Park Service pier to the Oyster Pond Inlet. The bars are oriented in a northeast-southwesterly direction. The alongshore spacing between the bars is approximately 125 meters with each bar being around 150 meters long.

PREVIOUS WORK

The relationships between bars and the sediment transport patterns within a nearshore zone have received considerable attention for the past few decades. Several authors have attempted to

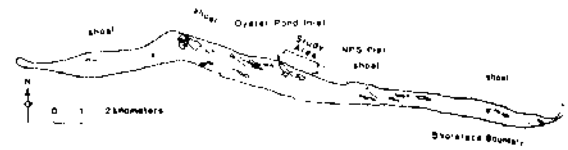

Fig. 2. Location of study area and shoreface boundary. Dashed line indicates break-in-slope between shoreface sands and sound muds.

explain the occurrence and morphologic response of nearshore bars to varying wave climates (King and Williams, 1949; Evans, 1939; Bruun, 1954; Sonu and Van Beek, 1971; Sonu and Russell, 1966; Short, 1975, 1978; Greenwood and Davidson-Arnott, 1979; Greenwood and Hale, 1981; Goldsmith et al., 1982; Wright et al., 1982; Sonnenfeld, 1983).

The early studies (King and Williams, 1949; Evans, 1939) focused on the description of nearshore bars and the effects that different variables (i.e. wave height, slope, etc.) have on the temporal and spatial characteristics of the bars. Other studies pertaining to bar dynamics have focused on theoretical modeling and/or laboratory experimentation (Bowen and Inman, 1971; Barcilon and Lau, 1973; Guza and Inman, 1975). Recent studies have addressed the cyclic nature of beach and bar transitions observed within the nearshore zone. Emphasis has been on documenting the sequential morphologic changes observed within the nearshore bar field in response to changes in wave conditions. The most detailed of these studies was conducted along the southeastern coast of Australia (Short, 1978; Wright et al., 1978, 1982). Short (1978) and Wright et al., (1978, 1982) proposed a model based on time series data of wave and beach conditions that describes the sequential changes observed in beach and bar morphologies from totally dissipative to totally reflective surfzone conditions. Each beach stage is a result of a fairly narrow range of incident wave conditions. The range of beach stages observed along a given shoreline is controlled by the range of wave conditions occurring in the area. Transition from one beach stage to another depends on the amount and duration of wave energy input to the system as well as the antecedent beach topography. Steadily increasing wave energy results in continuous beach changes ending with the fully eroded dissipative extreme. Decreasing wave energy input causes shoreward bar migration and eventually the fully accreted reflective beach stage. This relationship between wave height and beach stage allows construction of a beach stage curve for a given beach site and relates information about the morphodynamic character of the beach over time. This information may then be used to compare and contrast both temporally and spatially with other sandy beaches worldwide.

Transverse type bars occur as an intermediate bar stage in the aforementioned model. Other types of transverse bars have been observed on St. James Island, Florida (Niedorada and Tanner, 1970), Northern Ireland (Carter, 1978), the Danish North Sea Coast (Bruun, 1954), Silver Lake, Michigan (Evans, 1939), and Brazil (Tanner 1967). Although there is general agreement that transverse bars form in areas of relatively low wave energy and tidal range, where sediment supply is abundant and where shoreface gradients are low, there is still a certain amount of controversy regarding the formation and maintenance of these bars. Based on field measurements and laboratory experiments Niedoroda and Tanner (1970) and Niedoroda (1972) attribute the existence of transverse bars to their ability to refract incoming wave trains thereby focusing wave energy along the bar crests. This, in turn, generates current circulation patterns capable of maintaining the bar morphology. Barcilon and Lau (1973) state that the prevailing wave regime may help maintain the transverse bars but it is not the primary mechanism responsible for the formation of these bars. They suggest that sustained longshore tidal currents are responsible for the formation of transverse bars. Based on theoretical models and laboratory experiments, Bowen and Inman (1969, 1971) found that edge waves interacting with incoming waves produce currents capable of forming "rhythmic" nearshore sedimentary features.

Many techniques have been used to describe sediment movement in nearshore bar fields; however, only two studies have utilized fluorescent tracer sands. Greenwood and Hale (unpublished) described tracer dispersion along a crescentic bar system. The crescentic bars are situated in 3 to 5 meters of water along the open coast of Kouchibouguac Bay where they are affected by swell generated in the Gulf of St. Lawrence. Sonnenfeld (1983) conducted tracer studies along an inner bar system within a groin field on Lake Erie, Pennsylvania.

This is the first fluorescent tracer investigation of the sediment transport patterns within a transverse bar field along a protected microtidal back barrier environment.

METHODS

Beach and bathymetric profiles were surveyed in November prior to the onset of northerly winds and again in March before summer brings southerly winds and, therefore, negligible wave energy in the sound. Beach profiles were measured with a transit and stadia rod, bathymetric profiles were recorded on a strip chart fathometer. Transect lines ran perpendicular to the shoreline. The beach and bathymetric profiles had sufficient overlap to produce continuous profiles extending from the berm to just past the break-in-slope of the shoreface sands.

Twenty-one underwater box cores (27 x 22 x 15 cm) were taken to describe the sedimentary structures present within the shoreface. Cores were taken in mid-September to infer structures common to the low wave conditions characteristic of the summer months and a second set of cores were taken in March to document structures common to the higher wave conditions characteristic of the winter months. Cores were taken at each morphologic change found along a transect perpendicular to the shoreline. Cores were also obtained where changes in surface bedforms were observed.

Fluorescent tracer sands were used to monitor sediment movement within the transverse bar field. A spatial integration sampling method (McArthur, 1980; Komar, 1969; Sonnenfeld, 1983), where tracer concentrations are monitored over the sampling grid at a point in time, was used in this study. A radial sampling pattern was used to monitor the movement of the sands. Samples were obtained at 3, 6, 10, 20 and 35 meters from the injection point along radii spaced 30° apart. Injection points were chosen both on the bar crest midway along the axis of the bar and within the trough area between two bars.

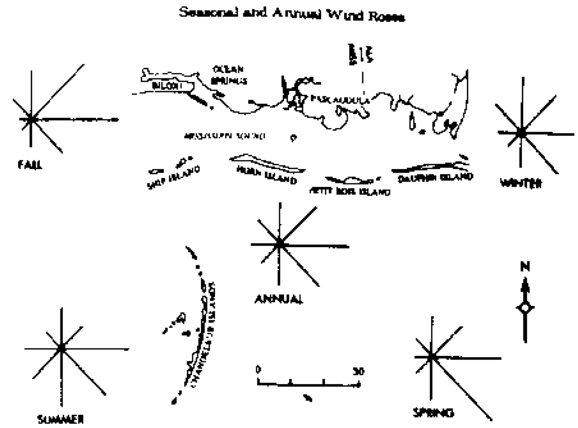

Fig. 3. Annual and seasonal wind roses for the Mississippi Sound.

WAVE CLIMATE

The study area is protected from storm-generated swell originating in the Gulf of Mexico. The local wind-generated waves resulting from the passage of frontal systems dominate the wave climate in the Mississippi Sound. Because the sound beaches are affected solely by waves generated locally in the sound, the fall and winter weather patterns (Fig. 3) exert a dominan influence.

Wave hindcast statisitcs from 20 years of data (Jensen, 1983) for a station close to the study area, show the average significant wave height to be .31 meters from the northwest, .12 meters from the north, .19 meters from the northeast and .39 meters from the east. Fetch is greatest from the east in the study area. Waves one meter high are not uncommon when strong easterly winds persist. As energy is proportional to wave height, the statistics clearly show that wave energy input to the stud area is low.

RESULTS

Profile Surveys

Visual observations, aerial reconnaissanc and beach and bathymetric mapping all verify that transverse bars are the only bar type present along the six kilometers of shoreface

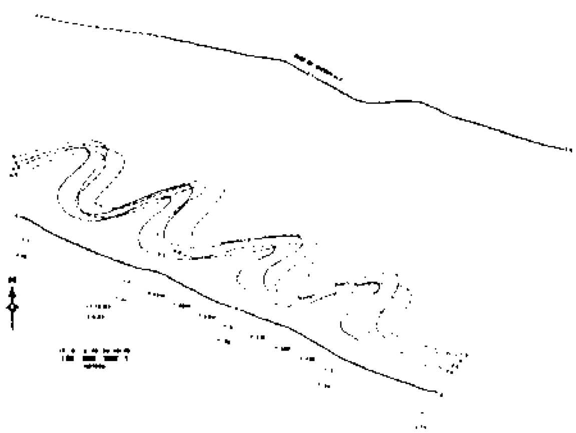

Fig. 4. Difference between the 0.8 and 1.0 meter contour line from the November to March surveys.

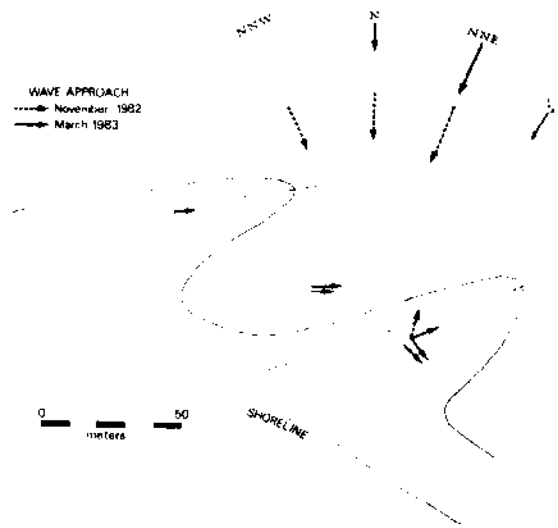

Fig 5. Directions of observed sediment transport along the bar and within the embayment area. Also, wave approach directions during the tracer experiments. The length of each wave approach arrow is proportional to its frequency of occurrence.

in which the study area is located. Contour maps constructed from the November 1982 and March 1983 profile surveys showed no change in the regularity of spacing between the bars or in the bar morphologies. Also evident from these maps is the asymmetric nature of the bars. The steep side of the bars face northwest, the gentle sides southeast. When these two maps are superimposed upon each other, they document a clear migration over the winter season. The difference in the position of the 0.8 meter and 1.0 meter contour line from the November survey to the March survey is plotted in figure 4. The bar axes moved an average distance of 11 meters towards the west during this time interval.

Sedimentary Structures

No physical or biological sedimentary structures could be identified through visual observation of the cores or by relief peels or radiographs. The sands within the cores were homogeneous. Plant material, shell fragments and scattered spots of organic matter were abundant throughout all the cores except those taken on the bar crest and close to the swash zone. These cores were also homogeneous but lacked the plant and shell material.

Tracer Dispersion

Figure 5 is a summary of the observed directions of sediment movement within the transverse bar field based on the dispersal patterns from the fluorescent sand tracer studies. The initiation of sediment movement and subsequent transport is a function of the amount and duration of wave energy input to the system. The amount of energy input to the study area is limited by the physical dimensions of the Mississippi Sound. Wave heights, periods and incidence angles acting on the bar field varied considerably throughout each tracer experiment. During this time, wave conditions changed from calm to a maximum wave height of .35 meters. At low tide, wave heights of .10 meters were observed to break along the bar axis. Wave approach varied from north-northwest to north-northeast during the November tracer experiments and from the north to northeast during the March tracer experiments. Wave approach from the east (greatest fetch) did not occur during the experiments. In response to these wave conditions sediment transport on the transverse bar is parallel to the bar axis moving towards the sound along the bar crest and also perpendicular to the axis down the gentle flank of the bar. Some transport is also observed obliquely down the steep side of the bar. Sediment movement within the embayment area is eastward, moving parallel to the shore within the broad areas, and turning towards the sound along the steep side of the neighboring bar.

DISCUSSION

Shoreface Sedimentary Structures

The total absence of physical or biological sedimentary structures was surprising as the sediment surface is characterized by well-defined bedforms. The homogeneity of these sediments is attributed to the biogenic activities of nearshore organisms and to the clean well-sorted nature of the shoreface sands. The copious amphipod and worm populations found in each box core are the probable cause for this homogeneity. Although the quantity of shell material and organisms was less within the bar crest cores and the cores taken close to shore, they were, nevertheless, present in these relatively higher wave energy environments. The conspicuous lack of evidence of trace fossils is also due in part to the fact that the organisms may ingest bacteria instead of filtering clay material.

In this case, feces remains and burrow liners would be difficult to observe.

Evidence for the rapid decay of surface bedforms from biogenic reworking was observed during diving operations only days after the passage of a storm. The ripples were rounded, tracks and burrow mounds from worms, shrimp and crabs disrupted and/or destroyed the sinuosity and form of the ripple marks. Periods of high wave energy are relatively short compared to times of low wave conditions when the abundant organisms may rework the sediments.

Sediment Dispersal Patterns

A generalized sediment dispersal pattern of the transverse bar field was constructed from information provided by the fluorescent tracer sand experiments (Fig. 6). Wave induced currents moving down the gentle sides of the bars into the embayment areas turn offshore as "rip currents" along the steep sides of the neighboring bars. When the rip currents are weak, offshore transport of sediment is negligible. Deposition of sediment may then occur within the bar embayment. When the rip currents are stronger they may "spill" over the neighboring bar crest depositing sediment and combining with the superimposed wave-induced currents moving down the gentle sides of the bars. The sediment may, therefore, be redistributed within the bar system. Waves breaking along the bar crest may induce currents capable of eroding and transporting sediment down the gentle flank of the bar. This sediment may then be deposited in the: (1) bar embayment, (2) transported offshore, or (3) transported over the neighboring bar crest via the rip currents. The transportation of sediment along the transverse bars is, therefore, not a continuous process but rather one that depends on the passage of frontal systems that produce wave heights capable of initiating sediment movement. When such wave conditions occur and when incident wave angles generate eastward moving currents, a steady state condition is set up and the bar morphology is maintained. Furthermore, one may speculate as to the causes of the observed westward bar migration. As stated earlier, fetch is greatest from the east at the study site. Wave heights can, therefore, be greater when wave approach is from the east. Although the ultimate wave height is depth limited in the Mississippi Sound, forecasting curves for shallow water waves in constant water depths for a given set of wind and fetch conditions (U.S. Army Coastal Engineering Research Center, 1977), show that differences in potential wave height from waves approaching the study area from the northwest to waves approaching from the east can vary as much as 0.3 meters. This is a significant difference because the maximum average wave height in the study area is only .39 meters. Wave energy input to the study area is, therefore, greatest from the east. The occurrence of easterly wave approach is also more frequent (Jensen, 1983) than from the northern directions. It is probable that strong frontal passages causing easterly wave approach may generate westward-flowing wave induced currents capable of eroding the gentler stoss side of the

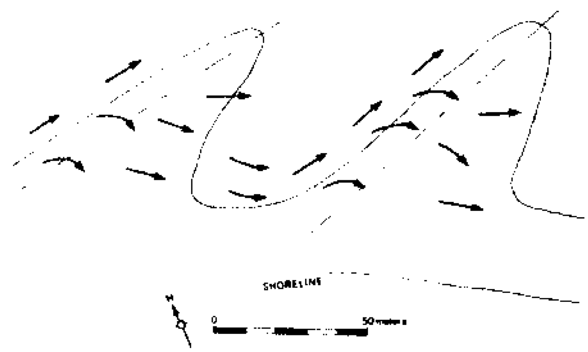

Fig. 6. Sediment transport pattern inferred from fluorescent tracer experiments.

bars and depositing the sediment on the steeper lee side of the bars. The response would be a westward migration of the bars. These processes were not observed during the tracer sand experiments as wave approach was never from the east. However, bar movement was observed by the author immediately after a severe storm in January 1983. This storm generated winds in excess of 30 knots for more than 12 hours (Shabica, personal communication, April 1983). Wave approach was from the east and breaking wave height in the vicinity of the bars is estimated to be one meter. In the wake of this unusually severe storm, movement of the bars to the west was clearly evident with reference to a stationary buoy anchor.

CONCLUSIONS

The mechanisms responsible for the accumulation of sediment into rhythmic bar forms are a direct result of the interactions between the wave climate, current fields and the topography of the nearshore zone. Sediment transport within the transverse bar field is episodic depending on the passage of frontal systems to generate wave heights capable of initiating sediment movement. The magnitude and range of wave energy input to the study area are the limiting factors that result in the persistant transverse bar stage. The wave energy input is never high enough to initiate change to a more dissipative beach stage. The rapid decrease in wave energy following a storm and the absence of swell, prohibit the more accretionary (reflective) beach stages from developing.

The maintenance of the bar morphologies is explained through a current circulation pattern whereby sediment is redistributed throughout the system. Sediment eroded along the gentle flank of the bar may be transported offshore, deposited in the rip current channel or transported over the neighboring bar crest via rip currents. Bar migration is the probable result of westward flowing currents generated by strong frontal passages causing easterly wave approach. Sediment is eroded on the stoss side of the bars and deposited on the lee side. This also explains the asymmetric nature of the bars.

Delineation of the barred back barrier

shoreface of Horn Island into distinct sedimentary facies is impossible. The homogeneity of the sediments that characterize each shoreface environment in the study area is attributed to thorough biogenic reworking and to the clean well-sorted nature of the sands.

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LOUISIANA COASTAL EROSION MONITORING PROGRAM

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ABSTRACT: The coastline of Louisiana is presently experiencing severe erosion. The total coastal barrier island area has decreased from 98.6 Km^2 in 1880 to 57.8 Km^2 in 1980, an overall landloss of 41%. The shoreline has retreated landward 10-20 m/yr in some coastal areas. In response to this problem, the State of Louisiana has developed the Coastal Erosion Monitoring Program of the Louisiana Geological survey to provide a new and comprehensive evaluation of shoreline instability. A systematic beach monitoring network has been developed consisting of 140 beach profile-stations that are monitored every three months.

Shoreline change trends, derived from existing and newly obtained data, are viewed on two levels: (1) short-term changes, and (2) long-term changes. Both types of temporal changes in the shoreline can provide an understanding of the complex interaction of the natural processes responsible for Louisiana's coastal erosion problem. They also provide a more flexible data base for the management of Louisiana's coastal zone and for the analysis and evaluation of proposed shore-stabilization demonstration sites.

INTRODUCTION

Louisiana's coastline is presently experiencing severe erosion. The total coastal barrier island area has decreased from 98.6 Km^2 in 1880 to 57.8 Km^2 in 1980, an overall landloss of 41% (Penland and Boyd, 1981). In response to this problem, a systematic beach profile monitoring network has been established by the Louisiana Geological Survey. The network extends along the 1500 Km (930 mi) irregular shoreline of Louisiana from the Chandeleur Islands west to Sabine Pass, including Lakes Pontchartrain and Borgne (Fig.1). A comprehensive coastal erosion study has never been conducted for the entire coastline of Louisiana. The objective of this program is to provide a new and comprehensive evaluation of shoreline instability for Louisiana.

Due to the complex interaction of relative sea level fluctuations, climate, coastal processes, sediment budget, delta lobe switching cycles and man, Louisiana's coastline has been classified as the most rapidly eroding coastline in the United States (U.S. Army Corps of Engineers, 1971). Average annual rates of shoreline change were determined for the entire coastline by Morgan and Larimore (1957) for the period 1812-1954 based on analysis of 100 different ground and aerial surveys (Fig. 2). Saucier (1963) determined average shoreline retreat rates for Lake Pontchartrain and the western shore of Lake Borgne from aerial photographs and maps averaged over a 14 - 22 year period (Fig. 3). Van Beek and Meyer-Arendt (1982) compiled 31 - 1:50,000 scale littoral habitat maps of the entire Louisiana coast. The maps include the 1955

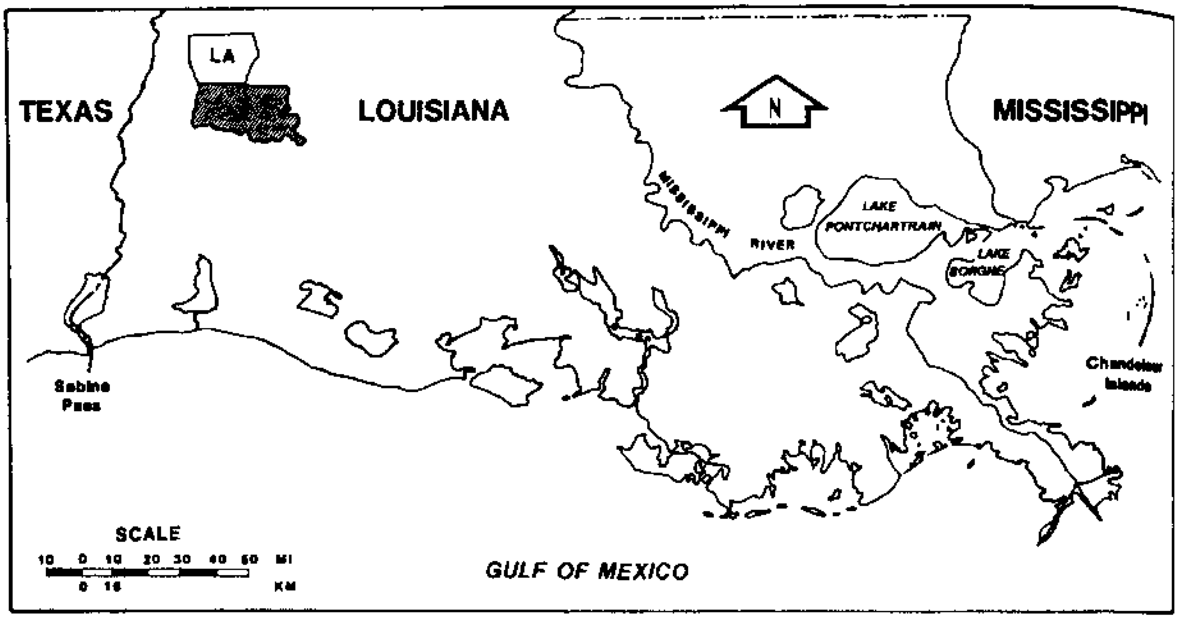

Fig. 1. Location map showing the Louisiana Coastal Zone.

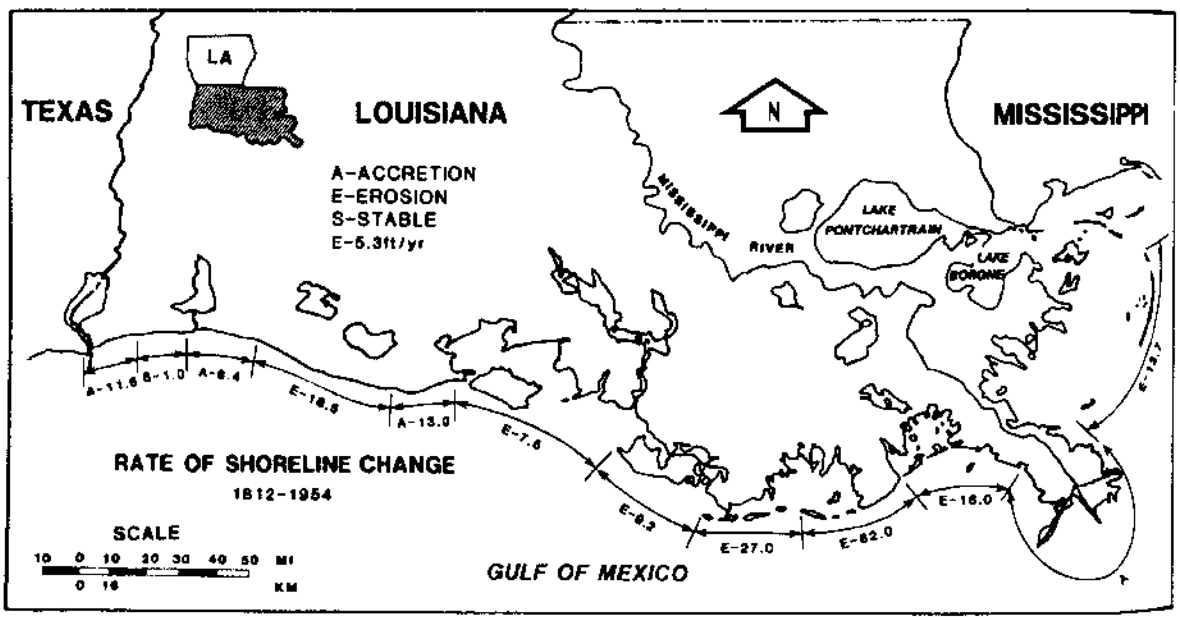

Fig. 2. Average annual rates of shoreline change for the period of 1812 to 1954 Morgan and Larimore, 1957).

and 1978 shoreline. They were constructed from 1955 black and white aerial photography and 1978 color-infrared aerial imagery. Numerous other investigations of limited scope and duration have been conducted on particular sections of the Louisiana coast besides the more comprehensive studies mentioned above (Peyronnin, 1962; U.S. Army Corps of Engr., 1962; Conaster, 1971; Morgan, 1974; Harper, 1977; Adams et al., 1978; Dantin et al., 1978; Penland and Ritchie, 1979; Wells and Roberts, 1980; Penland and Boyd, 1981; Penland et al., 1981). None of these studies have been comprehensive in assessing the present instability of the Louisiana coastline. The Louisiana Geological Survey's Coastal Erosion Monitoring Program will provide the most up-to-date comprehensive assessment of the entire Louisiana shoreline by the analysis of aerial imagery and ground survey data.

DATA ACQUISITION AND ANALYSIS

An assessment of the instability of Louisiana's coastline will be based on three sources of data: (1) the ongoing monitoring of beach profile stations to provide spatial and temporal changes in the position and configuration of the shoreline, including all barrier islands, (2) the evaluation of historic shoreline changes from aerial photographs and a series of

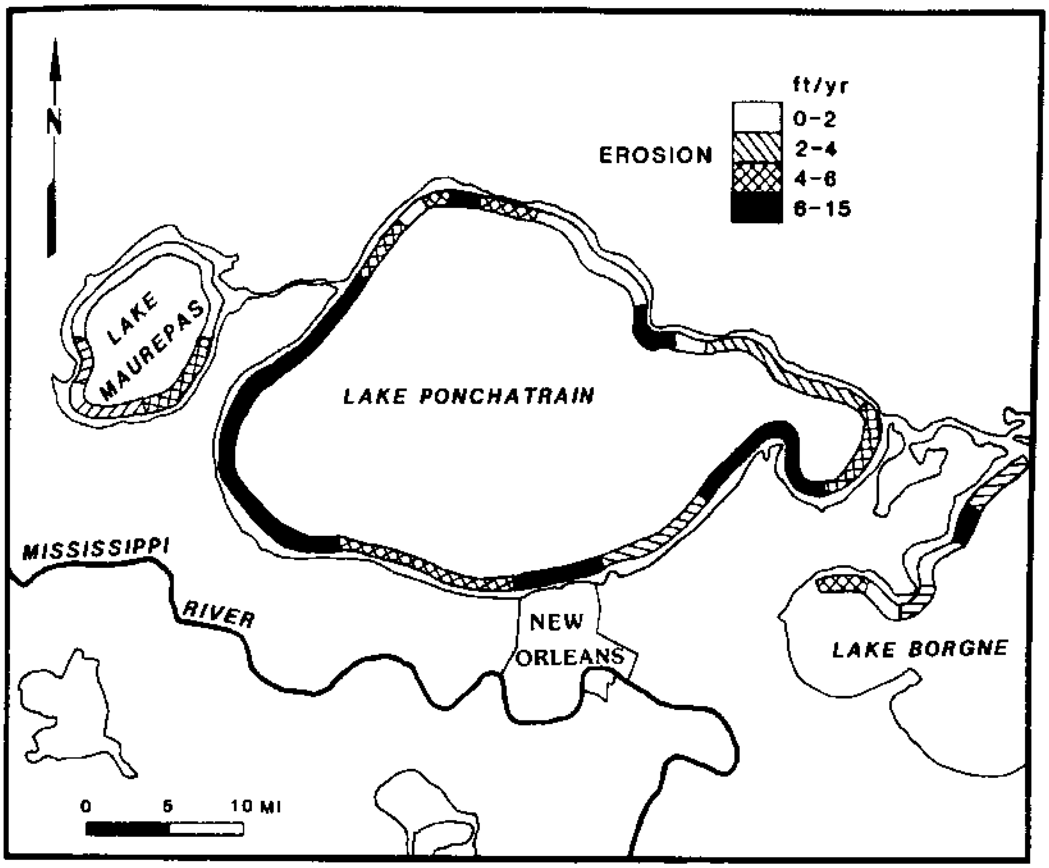

Fig. 3. Average shoreline retreat rates for Lake Pontchartrain and the western shore of Lake Borgne averaged over a 14 - 22 year period (Saucier, 1963).

variously formated maps, and (3) the compilation and reassessment of past investigations.

The shoreline of Louisiana was divided into seven profile districts: (1) Lake Pontchartrain and Borgne, (2) Chandeleur Islands, (3) Sandy Point to West Grand Terre, (4) Grand Isle to Timbalier Island, (5) Isles Dernieres, (6) Point Au Fer to Marsh Island, and (7) Cheniere Tigre to Sabine Pass (Fig. 4). All 140 beach profile stations are monitored every three months. Each survey period was correlated with the conclusion of a major seasonal process cycle. This was done in order to monitor the spatial and temporal (short-term) trends in the coastal erosion and accretion cycles associated with fair-weather, extratropical cyclone, and tropical cyclone processes. Ground truth data was collected at stations by surveying the shore-normal beach profile (Fig. 5), gathering sediment samples from the beach face, photographing notable lines-of-sight and taking intermittent Littoral Environmental Observations (LEO) (Berg, 1969). Each ground survey was enhanced by oblique aerial photographs taken during reconnaisance overflights.

The beach profiles, topographic surveys shore-normal to the trend of the beach, were conducted by a leveling instrument, or by the Emery method (1961). Each survey site consists of two 3/4 in. galvanized stakes cemented into the beach or marsh, landward of the beach crest. The top of either stake (usually the front stake) was used as the permanent origin for successive profiles. The stakes were aligned along a line-of-sight perpendicular to the shoreline trend to insure that future profiles were surveyed along the same line, therefore being more quantitatively valid. After collection in the field, data are edited, plotted and analyzed in various formats on the Louisiana State University computer using the Beach Profile Analysis System (Fleming and DeWall, 1982) provided by the U.S. Army Corps of Engineers Coastal Engineering Research Center.

EROSIONAL TRENDS

The results derived from the combined data base of ground surveys, oblique aerial photographs, historic vertical aerial photographs and various multi-formated maps, are viewed in two different perspectives, both short and long-term change trends. The relative stability of a shoreline should be analyzed on these two levels when planning and developing the coastal zone of Louisiana. This analysis will minimize economic losses resulting from construction in areas of shoreline instability.

Short-term trends

Short-term fluctuations in the position of the shoreline or the configuration of the beach profile are caused by more dramatic storm events

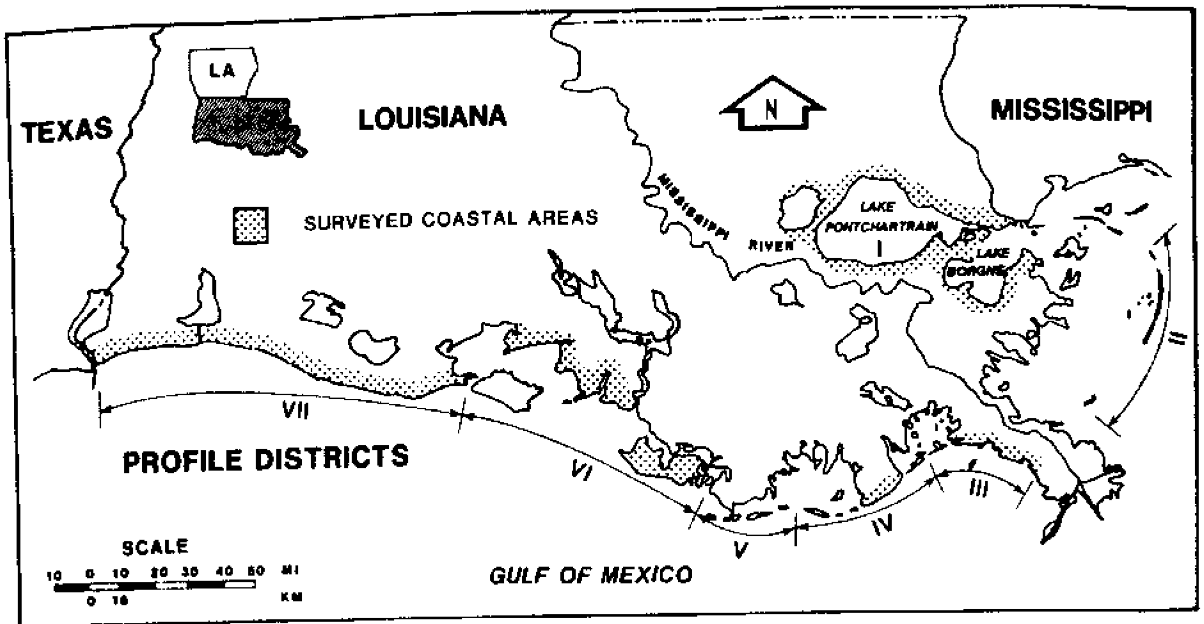

Fig. 4. Beach profile districts: I. Lakes Pontchartrain and Borgne, II. Chandeleur Islands, III. Sandy Point to West Grand Terre, IV. Grand Isle to Timbalier Island, V. Isles Dernieres, VI. Point Au Fer to Marsh Island, and VII. Cheniere Tigre to Sabine Pass.

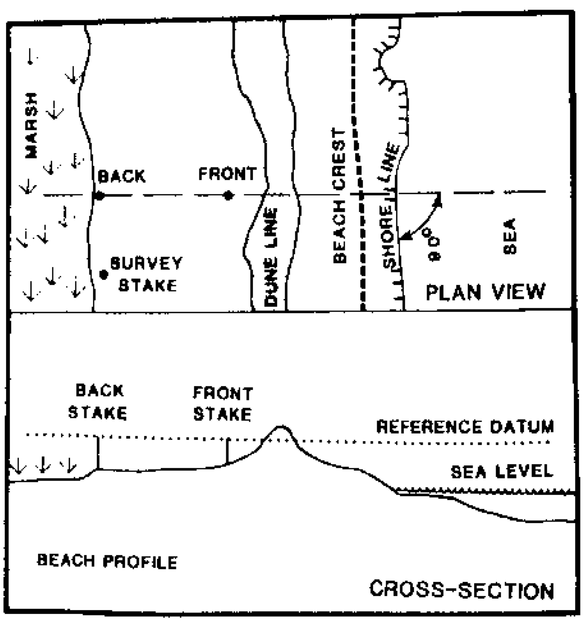

Fig. 5. Schematic diagram showing the plan and cross-sectional views of a generalized beach profile.

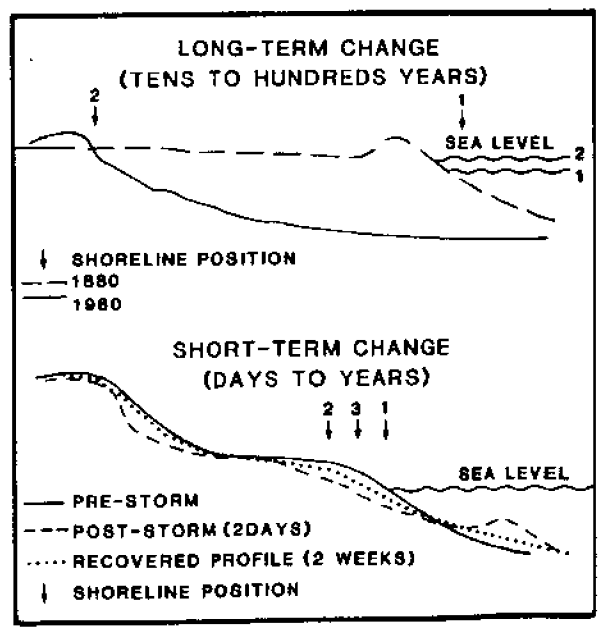

Fig. 6. Illustration of the spatial and temporal magnitude between the long and short-term erosional shoreline trends.

and everyday coastal processes. These types of shoreline changes occur on the order of a few days to several years, and are most important in terms of the construction of residential or industrial facilities. The short-term change in the shoreline is illustrated in figure 6.

Long-term trends

Long-term fluctuations in the position of the shoreline or the configuration of the beach profile represent a net change over tens to hundreds of years. Long-term changes in the coastal zone are the result of the averaging of the short term changes, either accretional or erosional. However these changes don't reflect the individual short-term event.

Attempts at predicting the long-term position of the shoreline is important in the establishment of a reasonable "set-back line" when developing the coastal zone. Long-term changes in the coastal zone usually reflect major changes

Interaction of Major Causes of Shoreline Erosion

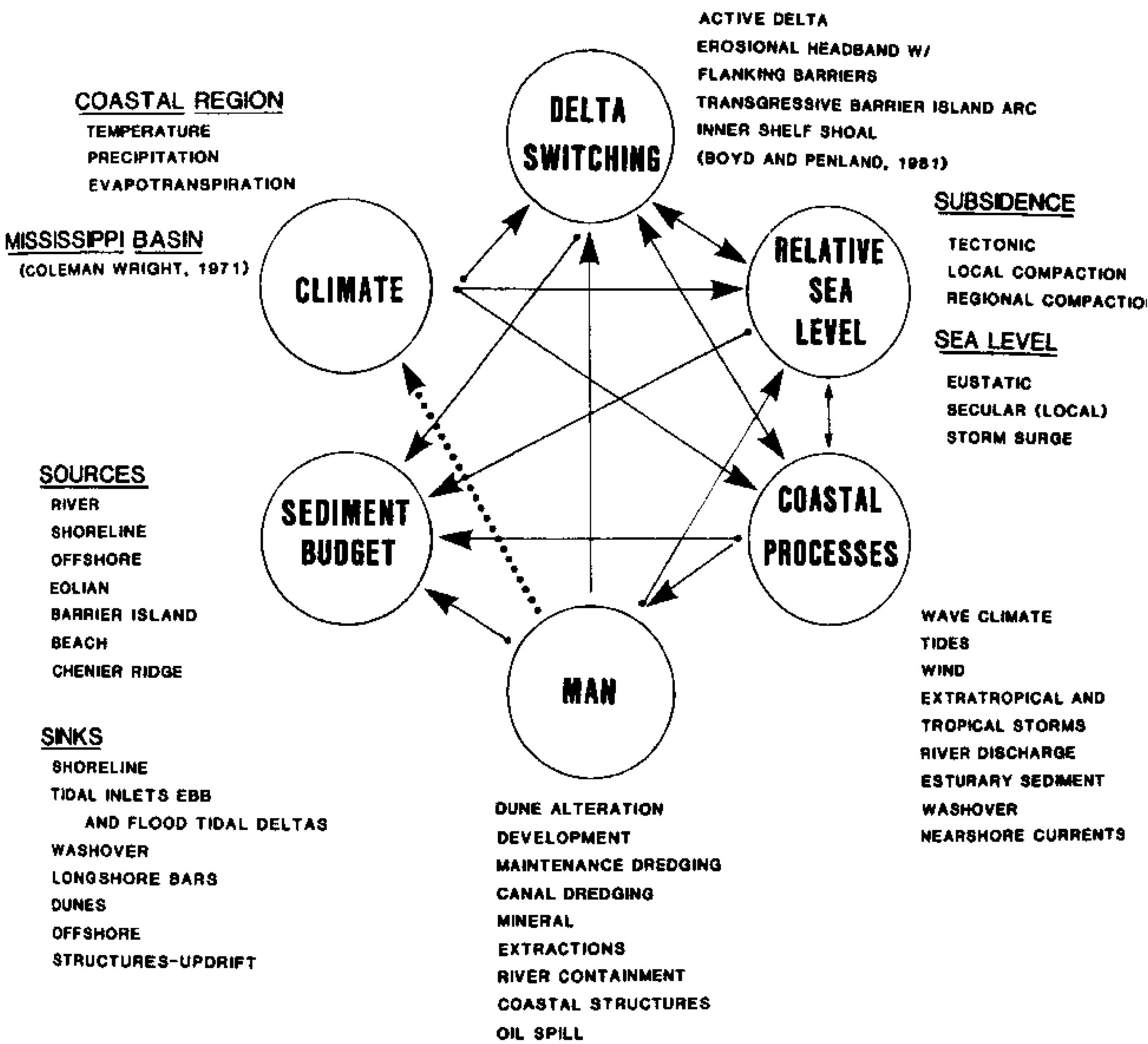

Fig. 7. The interaction of major causes of shoreline erosion along the Louisiana coast. Arrows poin toward the dependent variables. Notice the complexity of the interaction between the causes of shoreline erosion. (modified Morton, 1977)

are caused by the complex interaction of relative sea level change, climate, coastal processes, sediment budget, delta lobe switching cycles and man (Fig. 7).

ACT 41 TEST SITES

In November 1981 legislative act R.S. 30: 313C (Act 41) was passed by the Louisiana State Legislature. This act created the Coastal Environmental Protection Trust Fund, and the appointment of a Governor's Task Force on Coastal Erosion. Due to the passage of Act 41, implementation of coastal erosion control measures such as the proposed beach nourishment projects at Holly-Peveto Beach, Isles Derieres, and Cheniere Ronquille, were authorized. These sar inventory studies and the Coastal Erosion Monit oring Program are presently being investigated and analyzed. All projects funded under Act 4 are designed to inventory and predict future coastal conditions in order to assist in the e tablishment of a baseline upon which Louisiana can guide and measure the success of coastal r toration and erosion-reduction projects in the future. The primary objective of the Coastal Erosion Monitoring Program is two-fold: (1) to

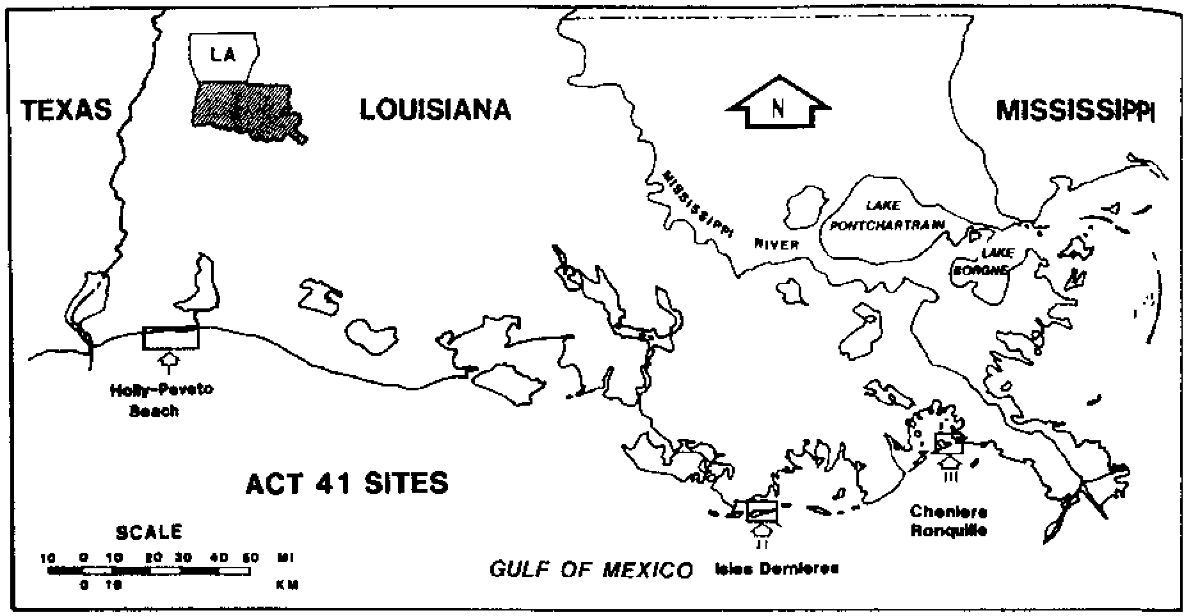

Fig. 8. Location of the Act 41 shore-stabilization projects on the Louisiana Coast.

monitor the effectiveness of the nourishment projects at Holly-Peveto Beach, Isles Dernieres, and Cheniere Ronquille, and (2) to provide short and long-term shoreline stability data that can be used in the management and development of Louisiana's coastal zone.

Holly-Peveto Beach Area

This area is located east of Sabine Pass near the Texas-Louisiana border (Fig. 8). Beachfront communities along this portion of coastline include Holly Beach, Constance Beach, Chaisson Subdivision and Ocean View Beach. Louisiana Highway 82, the Gulf Coastal Highway, hugs the shoreline between Holly Beach and the former beach community of Peveto Beach, and serves as an important hurricane evacuation route. It has been inundated and relocated landward several times since 1930, and with some success, has been protected recently by a three mile long, gobi-block revetment.

For at least the past 150 years (1833 to present), the Holly to Ocean View Beach area has been subjected to both shoreline erosion and increased development (Figs. 8 and 9). The erosion rate along this section of the coast ranges between 3-5 m/yr. The proposed large-scale shore stabilization structures for this area consists of revetment and T-groin construction, supplemented by beach nourishment and replenishment (Fig. 10). The beach nourishment is required in the project to protect the toe of the revetment and to offset the terminal-end scour

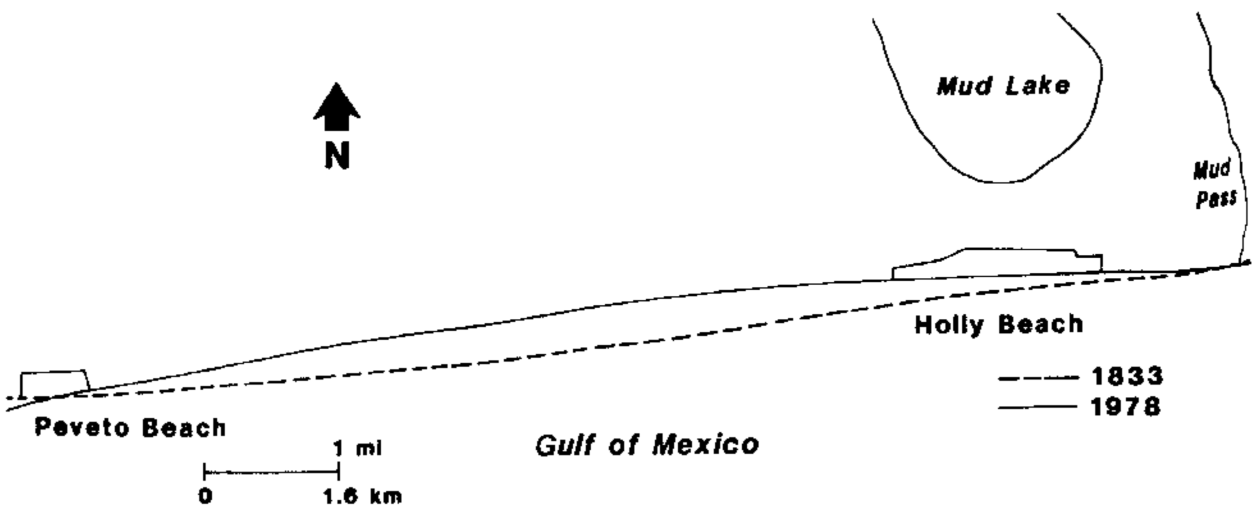

Fig. 9. Shoreline change over the past 145 yrs (1833 to 1978) at Holly-Peveto Beach.

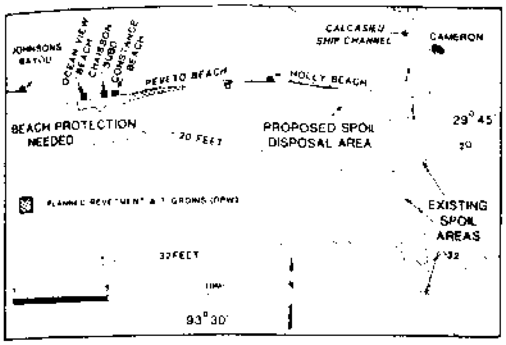

Fig. 10. Proposed shore-stabilization construction at Holly-Peveto Beach area (Van Beek and Meyer-Arendt, 1982).

produced downdrift to the proposed revetment-T-groin field.

Isles Dernieres Area

The Isles Derineres barrier island system is located on central Louisiana and serves to protect important mainland marshes, back-bay oil installation, and commerical vessels from storms (Fig. 8). The islands also serve to establish the controversial and important state-federal baseline from which the three mile mineral rich tidelands territory is measured. The entire Isles Dernieres barrier island system is exposed to high rates of erosion (5-15 m/yr) and island fragmentation (Fig. 11).

The Act 41 demonstration project proposed for the eastern section of the Isles Dernieres includes: (1) the closing of a breach in the island caused by Hurricane Carmen in 1972, utilizing rip rap, and sand nourishment; (2) widening of the back-barrier zone to a minimum width of 200 m; and (3) dune restoration and revegetation in areas of potential storm washover (Fig. 12). Without beach and island restoration, the Isles Dernieres will continue to erode and gradually subside below rising sea level. This event would be devastating to the mainland north of the islands. The mainland would be subjected to increased wave attach and consequently accelerated erosion. Coastal development on the mainland in question would be increasingly vulnerable to waves, storm surge and inland flooding.

Cheniere Ronquille Area

This demonstration project is located along the section of coast from Eastern Grand Terre Island to Cheniere Ronquille (Fig. 8). This segment of the Barataria barrier system has the highest erosion rate (15 m/yr) (Fig. 13) and hence the least potential for protecting the bay's associated brackish esturaries and wetlands from intrusion of higher salinity marine waters. The erosion rate at this section of coast is likely to accelerate in the future due to the shoreline's eminent meeting with a series of pipeline canals paralleling the present beach as the coastline retreats landward. The shoreline in the area in general is sediment deficient.

The proposed demonstration projects for this area include: (1) pipeline-canal filling, (2) back-barrier waterbody infilling, (3) shoreline breach (Ronquille Pass) closing, (4) dune building and revegetation, and (5) beach nourishing and replenishing (Fig. 14).

SUMMARY

Over the past year, the Coastal Geology program of the Louisiana Geological Survey has established a shoreline monitoring network consisting of 140 survey stations located along the 1500 Km (930 mi) irregular coastline of Louisiana. The monitoring network was established in response to the erosion that Louisiana's

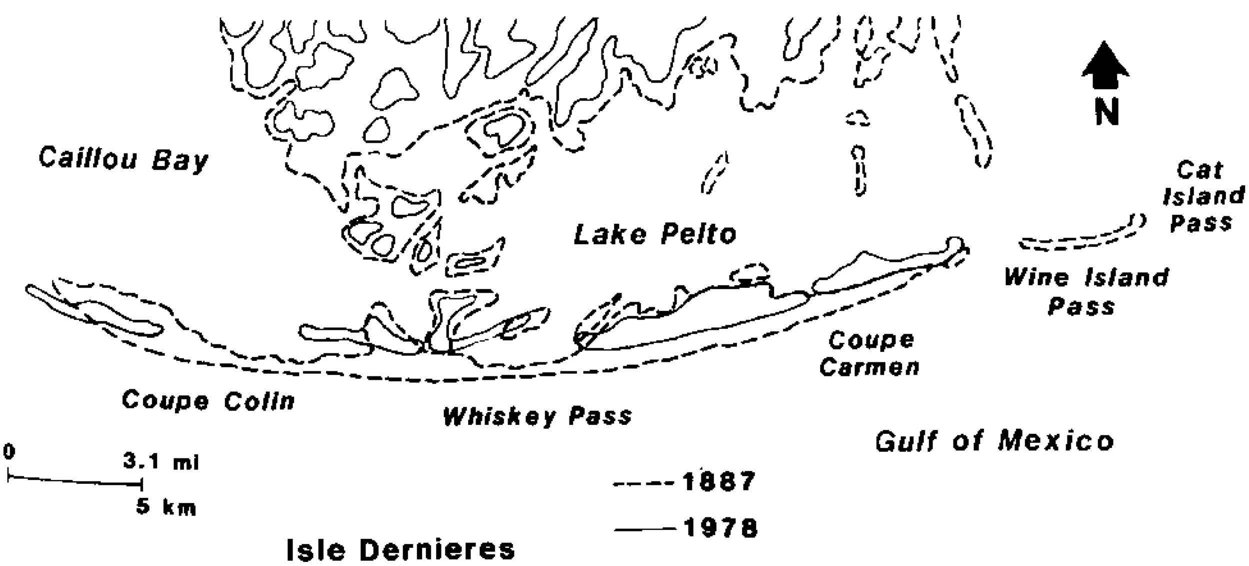

Fig. 11. Shoreline change of Isles Dernieres barrier island system from 1887 to 1978.

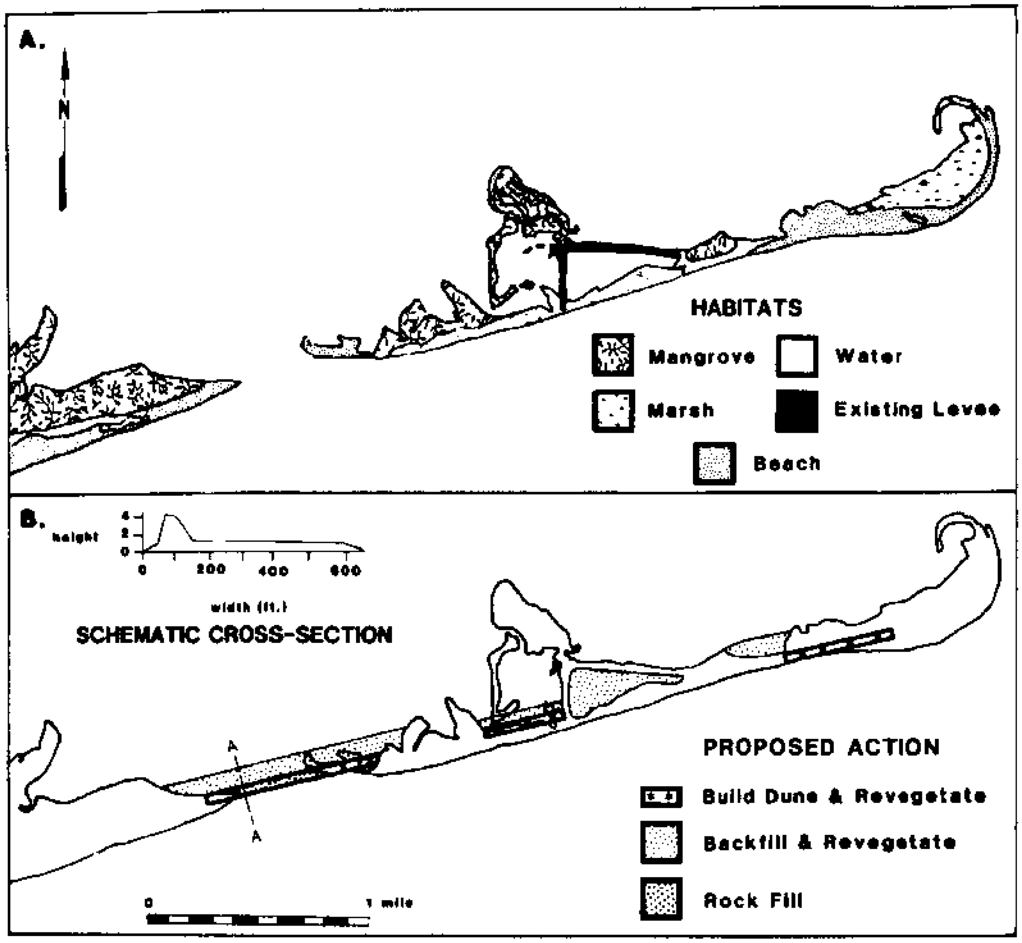

Fig. 12. Proposed barrier Island stabilization at the eastern end of Isles Dernieres (Van Beek and Meyer-Arendt, 1982).

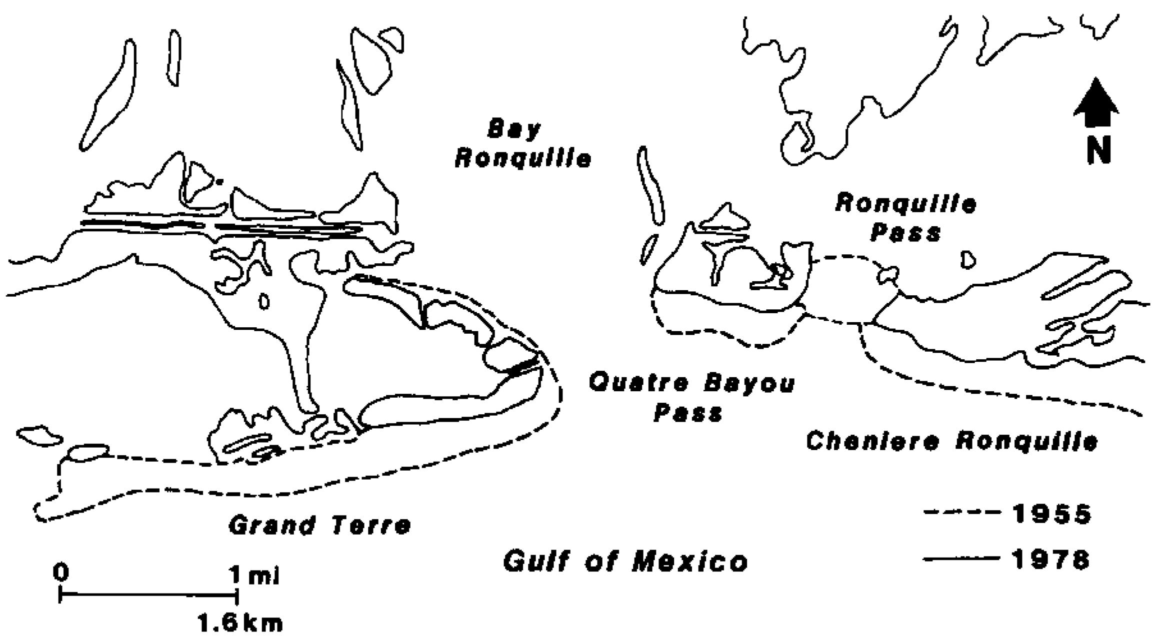

Fig. 13. Shoreline change from East Grand Terre east to Cheniere Ronquille (1955 to 1978).

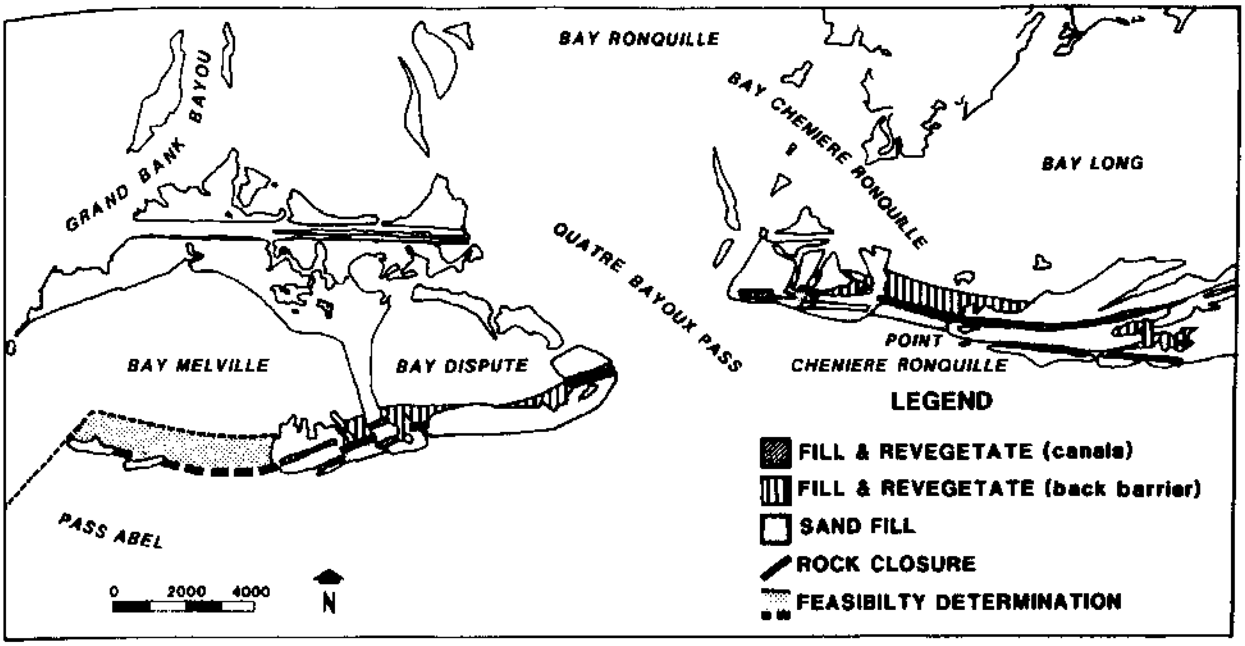

Fig. 14. Proposed barrier beach stabilization at East Grand Terre and Cheniere Ronquille (Van Beek and Meyer-Arendt, 1982).

shoreline is presently experiencing. Analysis of short and long-term temporal shoreline changes will add to the understanding of the complex interaction of the natural processes underlying Louisiana's coastal erosion problem, and provide a more complex systematic data base for the management and future stabilization of the shoreline of Louisiana.

In an attempt to find a solution to the erosion of it's coastline, the State of Louisiana has authourized and is funding the demonstration of these large-scale shoreline stabilization projects. They are located at Holly-Peveto Beach, Isles Dernieres, and Cheniere Ronquille.

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EVOLUTION OF TIDAL INLETS ALONG A TRANSGRESSIVE DELTAIC SHORELINE

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ABSTRACT: Stratigraphic sequences of deltaic and shallow marine origin commonly contain sand bodies transgressively overlying lower delta plain and delta-front deposits. Although generally ascribed to barriers formed during the destructive phase of the delta cycle, most of this sand is probably of tidal inlet origin because of the high preservation potential for sediment deposited below the base of the retreating shoreface in deep migratory tidal channels and their associated tidal deltas. To facilitate the identification of such units, this paper reviews the temporal evolution of the inlet sand bodies found along the rapidly transgressive shoreline of the abandoned Holocene Mississippi River deltas. This study also reveals that tide dominance or wave dominance of a coastline is not simply a function of tide range and wave height; it depends largely on the tidal prism, an inlet parameter which in Louisiana changes rapidly over time.

Three distinct stages can be identified in the evolutionary sequence for Louisiana tidal inlets: (1) wave-dominated inlets with flood-tidal deltas, (2) tide-dominated inlets with large ebb deltas, and (3) wide, "transitional" inlets with sand bodies confined to the throat section.

Stage 1. Tidal inlets ranging in age from 50 to a few hundred years are associated with flanking barrier systems attached to erosional deltaic headlands. The barriers enclose restricted interdistributary bays. Small inlets occur at the entrance to abandoned distributary channels within the headland section proper. The tidal prism being exchanged through either of these inlet types is small; the morphology of the inlets and adjacent coastline is wave-dominated, and most of the inlet sand is associated with a flood-tidal delta. The inlets are generally shallow.

Stage 2. The Holocene Mississippi River deltas are subject to rapid subsidence and consequent local sea level rise. One gage at Grand Isle indicates a sea level rise of 30 cm (12 in.) over the past 20 years; however, the long-term average is somewhat less. Subsidence leads to an expansion of back-barrier open water environments, an increase in tidal prism, and an evolution of the inlet into a tide-dominated morphology with a deep main channel and large ebb-tidal delta. The recent evolution of Pass Abel and Quatre Bayou Pass represents the transition from wave dominance to tide dominance. Sand bodies developed in stage 2 inlets have the greatest preservation potential because they generally lie below the base of the retreating shoreface.

Stage 3. Further subsidence generally leads to the development of an open sound permitting efficient tidal exchange with the gulf along the sound margin (Chandeleur Sound). As a consequence, the inlets play only a minor role in the tidal exchange pattern. At this stage, the inlet sand bodies evolve along two distinctly different paths, apparently controlled by sediment supply. Barriers with adequate coarse sediment produce many small well-defined inlets with large flood-tidal deltas (washover fans) and only transient, post-storm ebb deltas. The island shore is distinctly wave dominated. Along coastal segments where coarse sediment is scarce, one finds rapid island deterioration, shoaling of the inlet channel, and reworking of the ebb-tidal deltas into a "transitional" configuration with the sand tied up in throat section shoals.

As the inlets migrate during the transgression, they will leave behind on the continental shelf tidal sand bodies with a landward succession of facies changing from those characteristic of wave dominance, into tide dominance, and back again to "transitional" or wave-dominated inlets.

SEASONAL SALINITY DISTRIBUTIONS IN A

MULTIPLE-INLET COASTAL PLAINS ESTUARY

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ABSTRACT: Salinity of the Mississippi Sound waters was investigated as part of a multi-year hydrological study of the estuary. Measurements were made at 95 stations at the surface and at intervals of 5 feet from the surface layer to within 1 1/2 feet of the sea bed. The descriptive statistics of mean and coefficient of variability discussed in this paper were derived for surface and bottom salinity from data grouped by seasons. Contour charts of these seasonal statistics show the combined effects of the barrier islands, channels, reefs, and river flow on the circulation patterns of the estuary. Although there is a general decline in salinity from east to west, the locations of points of freshwater inflow and island passes actually create areas of alternating high and low salinities in an east-west direction through the basin. Plots of temporal changes in the salinity structure of the water column at select sites in the study area show that the estuary assumes different hydrological characteristics.

STRATIGRAPHY AND GEOLOGIC EVOLUTION OF ISLES DERNIERES, TERREBONNE PARISH, LOUISIANA

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ABSTRACT: Isles Dernieres, a Holocene transgressive barrier island located off the coast of south central Louisiana, is presently being studied in order to determine: (1) the stratigraphic nature and variability of Louisiana barriers, (2) the geologic history of the island, and (3) the location of sediment sources and sinks. The data will form the basis for a predictive model of barrier island evolution.

Isles Dernieres formed as a result of abandonment of the Caillou distributaries of the Late Lafourche delta lobe approximately 600 to 800 years ago (D. E. Frazier, 1967, Recent deltaic deposits of the Mississippi River: Their development and chronology: Trans. Gulf Coast Assoc. Geol. Soc., v. 16, p. 287-311). Marine processes have reworked distributary mouthbar sands of the delta complex, allowing the formation of barrier spits and islands flanking an early headland. As a consequence of long-term subsidence, the Caillou headland became submerged below sea level. The Isles Dernieres now represent the evolutionary stage of a transgressive barrier island arc separated from the mainland by a wide lagoon.

Field work for this study was accomplished by vibracoring in a variety of subaqueous and subaerial depositional environments throughout the island. Forty cores were taken in locations parallel and perpendicular to the axis of the island in order to determine lateral and transverse facies variation. Cores ranged from approximately 1.5 to 9 meters in length. Analysis of sedimentary structures within the core was achieved by visual examination and through the use of resin peels and x-ray radiography. In addition, the cores were sampled for radiocarbon dating and grain size determination.

Preliminary results indicate a system of regressive and transgressive events during barrier evolution. Thin washover sands of 1 to 2 meters in thickness in the central portion of Isles Dernieres overlie deltaic plain and beach ridge deposits, while thicker sands up to 4 meters thick overlie back barrier marsh deposits at the downdrift ends of the island. Sediment dispersal is attributable to shore-parallel transport into marginal recurved spits and flood and ebb tidal deltas, seaward transport to an innershelf sand sheet, and shoreward transport into large washover deposits.

DUNE BUILDING AND STABILIZATION ON TIMBALIER ISLAND, LOUISIANA

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ABSTRACT: Timbalier Island is a transgressive barrier island formed by downdrift spit accretion resulting from longshore sediment transport away from the Caminada-Moreau erosional headland. During the past century, Timbalier Island has migrated westward via updrift erosion and downdrift accretion. In order to reduce the rate of sand loss from this island and hence retard overall island deterioration, weak points along the island where breaching may occur should be strengthened. In this regard, a dune building and stabilization project was initiated on a low-evaluation washover terrace on Timbalier Island in May 1981.

Sand fencing was arranged in three designs to test sand-accumulation potential, which was compared to control areas without fencing. Straight sand fencing parallel to the beach with perpendicular side spurs accumulated the most sand of the three sand fencing designs tested. Vegetative plantings without the use of sand fencing did not accumulate an appreciable amount of sand. Three plant species, *Panicum amarum* (bitter panicum), *Paspalum vaginatum* (seashore paspalum), and *Uniola paniculata* (sea oats), were evenly planted throughout the 330-m-long test site. After 14 months *P. amarum* exhibited the highest survival rate, averaging 73%. Both *P. vaginatum* and *U. paniculata*, after only ten months, had survival rates of 3% and 23%, respectively. Dune building and vegetative stabilization are possible in Louisiana's sand-deficient coastal environment, although sand accumulation may be from 50% to 80% lower than coastal areas with plentiful sand supplies.

DISCUSSION

SHABICA: Harold, what are the funding levels of the laboratory.

HOWSE: Funding levels? Too low. We have a state appropriation from Mississippi annually, and that takes care of about 60 percent of our operational budget, usually. It probably takes care of more than that now. But we have to get out and scrounge for contracts and grants with federal agencies, private industry, wherever we can find it, just like everyone else, so we bring in about 40 percent of our operational budget.

SHABICA: And what is that per year?

HOWSE: Our next budget is about $5.2 Million for the year which begins July 1st. And if our Budget Commission doesn't cut us again -- we've been going through some of these problems that some of you have in your states, I'm sure the legislature appropriates at one session and the Budget Commission comes in a few months later and takes half of it back. So we have to squeeze and squirm to try to stay ahead. So far, we have been very fortunate. I really can't complain. Mississippi puts in about 60 percent of all of its revenues into the educational process in this state, so we really can't complain about what Mississippi does for its educational system. The problem is, there's just not enough money and they can't get it. But they do a remarkable job with what they do have, I think.

NUMMEDAL: To what extent do storms affect salinity distributions in Mississippi Sound?

ELEUTERIUS: The water column would be completely mixed and also would become very turbid during a surge. It stays mixed for a long period of time. We did conduct a cruise after Hurricane Betsy and after one of the later hurricanes since that time. The water column was well mixed initially, it returns to its normal statification in the Sound. Areas around the Pascagoula freshwater inflow become highly stratified, such as the Pascagoula River outflow in the spring. What we find is a very strong gradient or interface at about 10 to 12 feet down in the water column; over a distance of 1 to 1½ feet you have a jump, an increase in salinity from 12 to 15 parts per thousand, and a corresponding drop in dissolved oxygen levels.

ANONYMOUS: Were any offshore cores taken, Kevin?

NEESE: No, these cores were taken in the winter time and the wave height was too much for us to be able to get offshore cores. Most of the cores were taken on the beach face and in the back barrier lagoon and marsh area. We weren't able to get any on the shoreface.

SHABICA: After a severe storm, do we get migration of the bars, and do stable conditions come back? Do the bars move back to their original position or do they assume their pre-storm shape and form in the new position?

ZAPEL: The bars did migrate westward after the storm. Neither seasonal profile surveys or field observations indicate that the bars return to the original pre-storm position. They maintain an oblique orientation to the shoreline and an asymmetric form at all times.

NUMMEDAL: I'd like to ask you a question following up your last answer. When you look at bars along coastlines of the world, most commonly they are more or less parallel to the beach. Yet these are distinctly transverse. In fact, most bars along the Mississippi Sound margin are transverse. What is overwhelmingly different about the dynamic conditions of Mississippi Sound from other coastlines that would account for this difference?

ZAPEL: Something I planned to investigate further but did not have time to do for this talk, is the amount of energy capable of being generated within the Mississippi Sound. The physical dimensions of the Mississippi Sound limit the amount of energy possible. Maybe the amount and range of energy that causes nearshore bars to change from one form to another as other people have cited in the literature (Shore, and Wright) does not occur in the Mississippi Sound. Maybe the frequency of that energy level is short and it returns immediately to a calmer condition where the bars do not have time to readjust. The bars are always transverse and I have a feeling it is due to the fact that they are limited by the amount of energy that can be produced within the Mississippi Sound and the duration of each energy level.

COUSENS: I wonder if you saw no conflict between your proposed study sites with stabilization and the grand dynamicism of barrier islands that all of your previous studies have shown.

SONNENFELD: Let me try to clarify this question. Are you asking whether I think that the shore stabilization projects will work? Is that what you're asking me?

COUSENS: I guess my question is pejorative in that I wonder, has the Louisiana State Legislature seen the overwhelming evidence from all the studies that you've given that document, the rapid natural change in barrier islands. Do they then have in mind a study that can further document these kinds of results, these kinds of short and long term changes, and then a plan to stop these natural changes at three points which happen to have lots of houses?

SONNENFELD: Previous to the planning of the Act 41 sites, they did historic analysis of the whole coastline of Louisiana and that's how they picked these Act 41 sites. Other than that, I really don't know how to answer your question.

OTVOS: Does your study involve gathering information that will be used in future planning of beach nourishment? Are you going to drill for material to use in beach restoration projects?

SONNENFELD: Yes, there is a study under development right now at the Louisiana Geological Survey to test Trinity and Ship Shoals for a sand resource for the replenishment of the Act 41 test sites. For more details about that study, you can ask Dag Nummedal or Tom Moslow.

MOSLOW: The State of Louisiana has designated three areas for reasons which are both scientific and probably semi-political. Those three Act 41 sites are being analyzed and monitored both in a pre- and post-nourishment study. Part of that nourishment program is to identify nearshore minable sources of sand. The study will begin this summer with vibracoring and high resolution shallow seismic work. The study will not be on the shoals themselves. The shoals are much further offshore, actually. It's going to be within the 3-mile limit of the state, at least to begin with.

ANONYMOUS: Why are you still using 1957 data for erosion and accretion?

SONNENFELD: That data set is a rather good data set in that a lot of the shore protection structures along Louisiana don't have an extensive effect on those rates. The data that you're talking about, we do have. But this is a new program and we haven't yet analyzed it to give you those rates. We'd like to do our own profiles and add that to that study.

RAINEY: How are the Louisiana barriers going to be stabilized?

SONNENFELD: In most of the areas, the state plans large scale fill of tidal inlets and channels that were dug for oil pipelines within the barrier complexes. They will subsequently revegetate them to try to stabilize them in an almost natural way. The only site I know that they are going to use hard structures on are in the Holly-Peveto Beach area where they plan revetments and shore normal groins.

SHABICA: To get to a philosophical question that will bear on some of the talks this afternoon, I assume the public is going to pay for all of this, right?

SONNENFELD: That's a good assumption.

SHABICA: Is it state or federal, Dag?

NUMMEDAL: State.

SHABICA: Would that be from oil revenues to be used for working on structures to protect pipelines.

SONNENFELD: They're not going to try to protect pipelines. They're filling the channels because they have an idea that the channels accelerate the erosion rate

NEMMEDAL: Just let me add something to that. I think it is futile to try to stabilize or stop nature when it comes to sinking of the Louisiana coastal plain. One extreme approach would probably be to tell people who live there and utilize the coastal plain to move out. It is very difficult politically, and probably also from a scientific point of view to go out and play God and tell someone who has lived there for generations to move. Do you say, "Sorry, fella, your property is going to be gone?" So what the state is trying to do to some extent is to buy time. They implemented Act 41, they appropriated $35 million for an initial series of tests to see exactly how effective certain approaches will be. Some of these tests include the stabilzation of these three barrier island sites. Other tests include freshwater diversion and things we talked about yesterday. The economic aspect of the issue is closely related to the petroleum industry because a number of very productive oil and gas fields are very close to the ambulatory border between the state waters and federal waters. As the shoreline moves landward at a rate of a kilometer or two per century -- that's a very rapid rate -- so will that ambulatory border and fields which now produce a revenue for the State of Louisiana will turn over to the federal government. It is based on that overriding economic concern that I think the legislature went ahead with this initial appropriation.

SHABICA: Mark, have you looked at the plantings recently?

HESTER: Yes, we were just out there about two months ago.

SHABICA: How does the Panicum look?

HESTER: The Panicum looks very good. One thing we noticed, that these slides don't really show, was that over this last year the dune essentially moved a little more seaward so that the peak of the dune was more in line with the sand fencing itself, and some of the Panicum there did get buried because of that. But the sea oats which were also interplanted did very well. So right along the sand fence we had mostly sea oats.

SHABICA: So a Panicum and sea oats mixture would be a good plant for that particular area?

HESTER: It seems to be, yes.

ANONYMOUS: How much does a project like this cost?

HESTER: I have some figures on that. In this case, Texaco basically said they would supply the sand fencing and install it and buy all the plants, if LSU'S Marine Science Department would design the experimental layout and provide the labor to do the planting. Texaco estimated that it cost them, I believe, $20,000 for a stretch of beach 381 meters long. However, their estimate included the high cost of installation of the sand fencing by their work crews, and the cost of crew boat usage. If you buy sand fencing yourself it costs about $1.20 per linear foot. The Panicum transplants are about 30¢ each, and the sea oats are about 23¢ each. If you figure 15,000 plants at about a quarter each, that's about $4,000, so the total cost is about $7,000 without labor.

RESOURCES MANAGEMENT

The foregoing bring us to the critical and most important aspect of this conference: MANAGEMENT. How do we put into effect that which our studies show to be the most beneficial for the resource and for the general public? Resource management requires a balance that permits exploitation of a resource without the degradation or destruction of that resource. How do we correctly manage the dwindling, potable water supply? We know that saltwater intrusion is occurring. How do we minimize or reverse this trend? The gap between environmental impact assessment and actual resource management is often quite large. For our abilities to make environmental changes and to predict the effects of those changes is an environmental dilemma that requires that we make the best of what we have, even when the information or data base is minimal. It is possible to integrate assessment and management into one goal-oriented system. The long awaited Coastal Barrier Resources Act of 1982 demonstrates this. In the final analysis, it is this information and data that we as scientists provide that permit resource managers to make decisions. Methods and strategies for correctly or properly managing our resources require that scientists appropriately assist managers and decision makers as they move towards the 21st century.

COASTAL ZONE MANAGEMENT IN MISSISSIPPI

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ABSTRACT: Coastal Zone Management (CZM) in Mississippi comprises several essential aspects of coastal resource management. The first is wetlands protection. Wetlands regulatory procedures are incorporated into CZM as a result of the Coastal Wetlands Protection Law. This law established the public policy of preserving coastal wetlands in their natural state, except where alteration could serve a higher public interest. To carry out this policy, a procedure for permit and review is set up to govern those activities that are regulated by law.

Fisheries management is also an integral part of the overall CZM effort. Needed regulation is accomplished through a series of ordinances which control such things as seasons, catch limits, and areal closures. Monitoring of fisheries stock conditions is another important aspect of the program. By knowing the current status of a fishery, certain affirmative efforts can be implemented to enhance those stocks in short supply or assist those fisheries in need. Prime examples are the establishment of public oyster reefs through the placement of clamshells and other cultch materials and the creation of artificial reefs to increase recreational fishing opportunities.

While fisheries management and wetlands protection are the best known CZM activities, other efforts are also important. Most important is the establishment of plans for special management areas (SMA's). Management plans are developed for specifically designated areas to improve the predictability of permit decisions in these areas and help resolve controversies between environmental groups and industrial interests in advance of development proposals. Three general categories of SMA's have been designated. These include port and industrial areas, urban waterfronts and shorefront access areas. In addition to SMA's, other less known management activities include energy facility siting, shoreline erosion mitigation, and assistance for preservation and restoration of certain areas.

The instrument for maintaining a balance between the perceived values of our coastal area--namely fisheries resources, a pleasant environment including beaches, marshes and barrier islands, and the opportunity for industrial development--is the Mississippi Coastal Program. With its approval in 1980, the program now provides us with a sound, sensible approach to management that strikes a balance between the development of our coastal resources and their preservation.

The Bureau of Marine Resources (BMR) is directly responsible for implementation of the Coastal Program, although many other agencies are involved as well. The Coastal Program organizes the functions of these agencies and assures that their authorities are applied consistently throughout the entire coastal area.

The goals of the program are accomplished through planning, education and mediation, in addition to the necessary regulatory activities of wetlands permitting and fisheries management. The Mississippi Commission on Wildlife Conservation, acting through BMR, is responsible for making the all important decisions that affect all coastal resources below the watermark of ordinary high tide and to enact both wetlands and fisheries regulations.

Because of the increasing demand upon our coastal resources, it is imperative that coastal zone management in Mississippi be continued. Without it, it is apparent that our state's wetlands and other fragile areas plus the fisheries resources which depend on them, will be destroyed by uncontrolled development.

MISSISSIPPI GULF COAST FRESH-WATER: THE FUTURE

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ABSTRACT: The management of fresh-water supplies for the Mississippi Gulf coast, and more specifically Gulf Islands National Seashore, is intimately related to the fresh-water resources available to the entire Mississippi Gulf coast. Extensive development resulting from an influx of moderate to heavy industry, several large governmental facilities, and related increases in population along the coast in the past 40 years have greatly increased the demand for potable water supplies. Numerous rivers and streams located in the area provide billions of gallons of fresh-water to Mississippi Sound and the Gulf of Mexico annually, but this resource is virtually untapped; the preference is for ground-water. Regulation of ground-water resources is almost nonexistant, and wells are designed for economic reasons with little regard for conservation. As a result, most wells located along the Gulf coast extract water from the same narrow zone causing severe reductions in static water levels. Ultimately salt-water intrusion is anticipated. Studies suggest that at deeper levels, thicker, more expansive aquifers containing fresh-water are available. However, these strata are relatively unused for economic reasons. The possibility of contaminants entering the fresh-water streams and aquifers has been reported but no studies have been made, and controls to prevent such occurences are very limited. Apathy on the part of public officials, industrial managers, and governmental agencies has resulted in little attention being given to the problems of fresh-water resources in south Mississippi. Little change in attitude is expected and the prospects for future fresh-water supplies in south Mississippi are poor.

INTRODUCTION

This paper provides an information base to be used by management personnel in maintaining and planning for an adequate supply of potable water on the barrier islands of Gulf Islands National Seashore (Mississippi District). The entire Mississippi Gulf coast will be addressed since the islands are located down dip from the coastal municipalities and will benefit or suffer depending on action taken inland. Included are results of on-site inspections which were made to determine immediate and long range corrective measures necessary to bring existing water systems and wells up to standards established by the National Water Well Association.

LOCATION AND DEVELOPMENT

Gulf Islands National Seashore (Mississippi District) consists of a small mainland area located on Davis Bayou within the city limits of Ocean Springs, Mississippi, and three of the four island groups located on 8 to 12 miles south of the coast of Mississippi (see Fig. 1).

Petit Bois Island does not have any existing water wells and is included in general terms only. Potable water for the mainland park area is obtained from the city of Ocean Springs. Water from a park-owned well is used for the air conditioning system at the Visitor's Center.

The islands can only be reached by boat and, with the exception of the area near the fort on West Ship Island and the ranger station

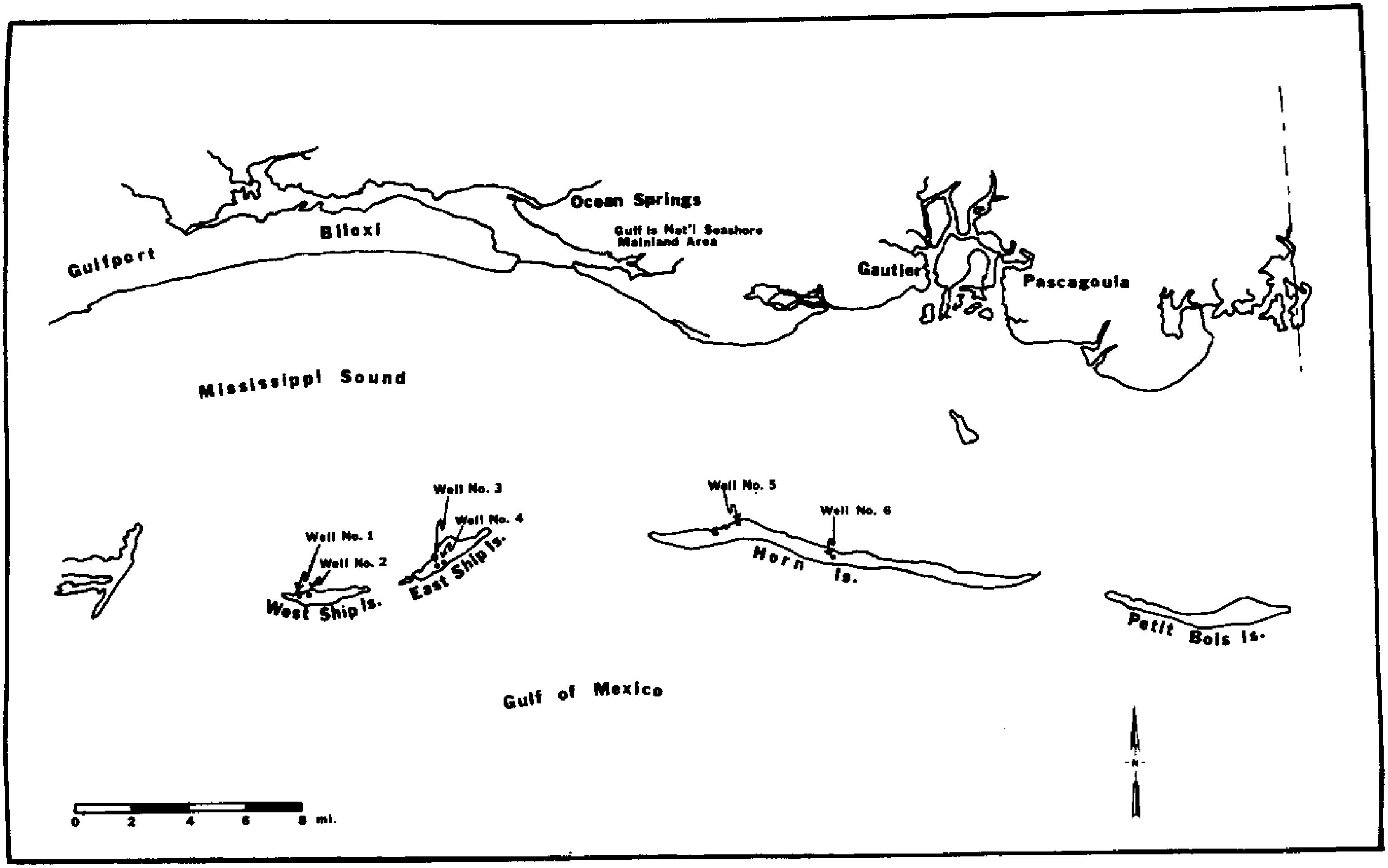

Figure 1. Location map showing study areas and Gulf Islands National Seashore island wells.

on Horn Island, are undeveloped and primitive. Each island except Petit Bois, has two wells. There are two wells north of East Ship Island in Mississippi Sound, below the water's surface, that are not included in this paper.

Municipal development along the Gulf Coast of Mississippi is almost continuous and constitutes the second most populated area in the state. The predominant population centers are the cities of Biloxi, Gulfport, and Pascagoula (see Figure 2). The remainder of the coast is almost evenly populated with slight increases near the larger cities. Heavy industrial developments are located in Pascagoula, Gulfport, and north of Pass Christian, with moderate to small industries found in all communities along the coast. Major governmental complexes are located in Biloxi, Gulfport and north of Bay St. Louis with some smaller units located in Pascagoula and Gulfport (see Fig. 2). The majority of this development and related growth in population has occurred since 1940. This heavy influx of people and industry in such a short period of time has placed a heavy burden on water supplies. Although abundant surface- & ground-water is available, there is a definite preference for the use of ground-water and most of the ground-water used is obtained from a very narrow zone of the fresh-water bearing strata.

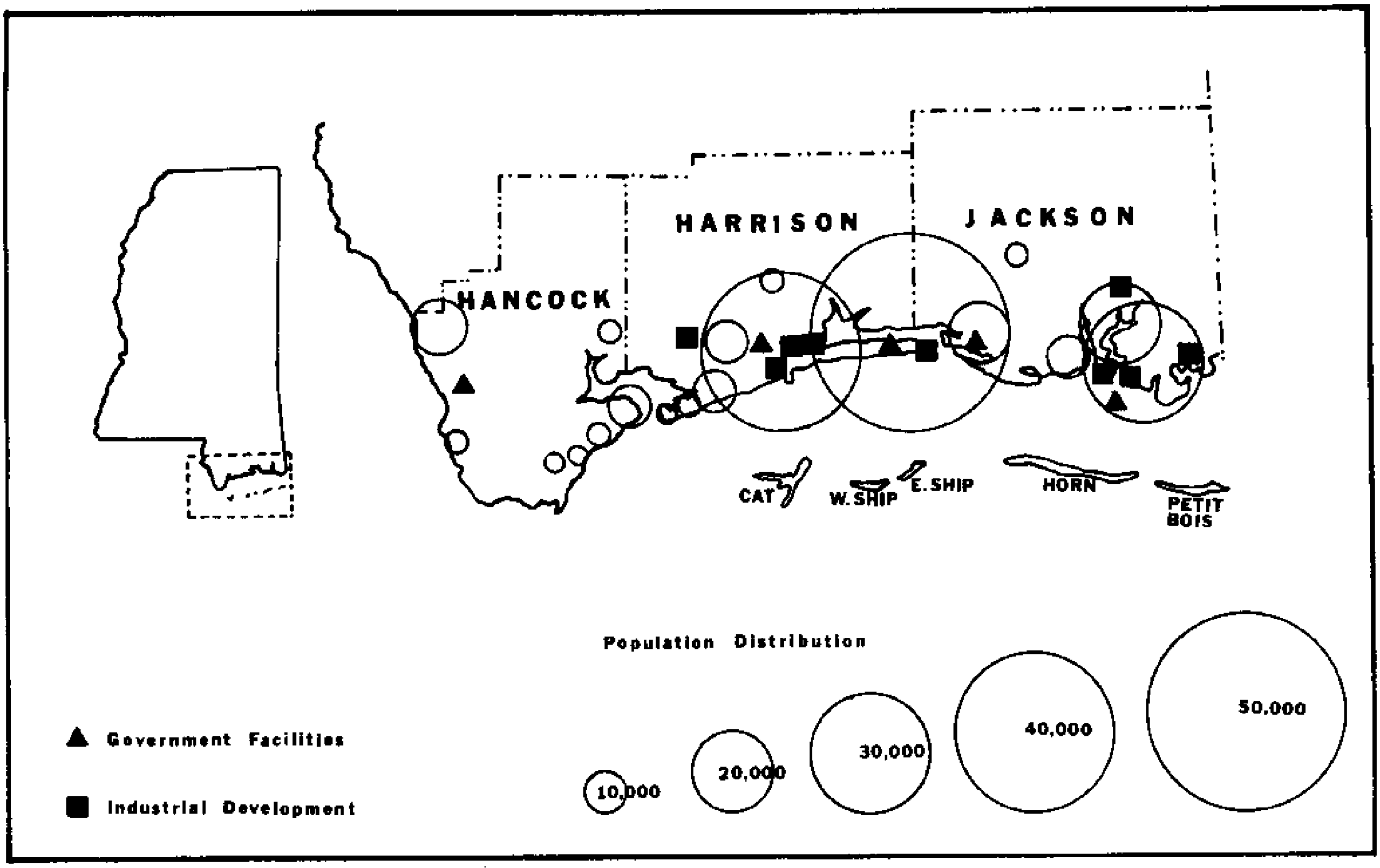

Figure 2. Population centers along the Mississippi Gulf coast.

CLIMATE

The Mississippi Gulf Coast is subject to subtropical climatic conditions, occasional hurricanes and tropical storms, and frequent winter storms. The mean annual air temperature is 68° F., which is also the normal temperature of the shallowest ground water. Average rainfall in the area is about 60 inches per year (Eleuterius and Beaugez, 1979).

LANDFORM AND DRAINAGE

The land surface along the Mississippi coast is slightly rolling, locally marshy, and generally less than 20 feet above NGVD (National Geodetic Vertical Datum). Several miles north of the coast the terrain changes to low rolling hills. The barrier islands that lie about 8 to 12 miles off the Mississippi Gulf coast partially separate the water in Mississippi Sound from water in the Gulf of Mexico. Mississippi Sound is a shallow salt-water basin diluted in varying degrees by fresh-water drainage from several rivers. A more detailed description of the landform and drainage may be found in Bulletin 60, Mississippi State Geological Survey (Brown and others, 1944).

GEOLOGY

The Gulf coast region has been slowly subsiding for millions of years forming a vast sinking trough, or geosyncline. The gradient resulted in the formation of a large drainage basin carrying surface-water from most of the Central Plains area of the United States. A massive network of rivers, streams, and smaller waterways developed and has resulted in large quantities of clay, sand, and gravel being deposited along the Gulf coast where they have accumulated into sediments thousands of feet thick. These circumstances produced the river and stream deposits of deltaic sand and gravel which constitute the principal ground-water aquifers of the Gulf coast region.

The fresh-water bearing beds of sand or sand and gravel in the Mississippi Gulf coast area are of Miocene to Hollocene age, are generally less than 2,500 feet below NGVD, and dip approximately 30 feet per mile to the south, southwest. They tend to be lenticular in shape, differ in thickness and extent, and vary in sediment grain size and sorting; although more than one aquifer may be penetrated by drilling throughout most of the area, they are irregularly distributed and at varying depths. These sediments are not readily separated into stratigraphic units. Detailed examinations of electric logs and water-quality analyses obtained during test drilling failed to reveal mappable horizons in the fresh-water section that could be reliably considered as formation contacts (Newcome and others, 1968, p. 8). Lithology based on mineralogic information, and paleontologic evidence determined by fossils obtained from well-bore cuttings and driller's descriptions are insufficient to make reliable correlations (Brown, 1944, p. 33). The fresh-water bearing sand strata are traceable to their outcrops in the hill areas north of the coast where they are recharged by rainwater. This is based on the premise of interconnection between water bearing aquifers as insufficient data is available for direct correlation.

The principal fresh-water bearing units along the Gulf coast are generally categorized as the near surface Citronelle Formation of Pliocene to Pleistocene age, the Graham Ferry Formation (just below the Citronelle) of Pliocene age, and the deeper Pascagoula Formation of upper Miocene age. Overlying these fresh-water producing strata are Pleistocene to Hollocene terrace and stream valley deposits which are not developed as aquifers. The following geologic formation descriptions are based on those data published by Brown and others (1944, p. 38) as updated by subsequently published papers of the Mississippi and U.S. Geological Surveys (see Figs. 3 and 4).

CITRONELLE FORMATION: Pliocene to Pleistocene Age. Zero to 160 feet thick. Physical Character: Brick-red sand and gravelly sand. The pebbles are mostly brown honey colored chert and milky quartz. Generally cross-bedded, and, in the lower part, contain thin beds and pockets of gray and clayey gravel. Hydrologic Properties: Numerous small farm and yard wells pump water derived from a few feet of saturated sand and gravel in the lower part of the formation. Has high content of iron in solution, subject to salt-water intrusion when extensively pumped.

GRAHAM FERRY FORMATION: Pliocene Age. One hundred and thirteen to 975 feet thick. Physical Character: Silty clay and shale, sand, silty sand, and gravelly sand and gravel in heterogeneous deltaic masses. Various colors, generally dark, carbonaceous clay most abundant in the outcrops, marine fossil casts in the upper beds are common.
Hydrologic Properties: The most intensively developed formation, contained water under artesian pressure in the past but most static levels are 40 to 60 feet below NGVD at this time, water is soft sodium bicarbonate in type and is moderately colored, becomes more highly mineralized with increasing depth and distance from outcrop zones.

PASCAGOULA FORMATION: Upper Miocene age. Eight hundred to 1,300 feet thick. Physical Character: Clay and shale, generally blue-green, silt, sandy shale, gray and green sand, gray silty clay, and dark sandy gravel containing numerous grains and pebbles of polished black chert, of estuarine or deltaic origin, identified for the most part by a brackish water clam (Rangia johnsoni). Hydrologic Properties: Provides approximately 40% of the fresh-water in south Mississippi but is relatively undeveloped along the Gulf coast except in the upper extremities. Contains fresh-water to a depth of 1,700 feet in east Jackson County (Harvey and others, 1965, p. 82), 2,500 feet in west Harrison County (Newcome and others, 1968, p. 55), and 3,000 feet in west Hancock County (Newcome, 1975). Deep wells produce artesian heads up to 100 feet above NGVD. Lower extremities produce brackish water.

PERIOD (SYSTEM)	EPOCH (SERIES)	MISSISSIPPI GULF COAST UNITS	AGE
Quaternary	Holocene and Pleistocene	Alluvium and terrace deposits	2 m.y.
Tertiary	Pliocene	Citronelle Graham Ferry	5 m.y.
	Miocene	Pascagoula Hattiesburg Catahoula Sandstone	23 m.y.

Figure 3. Geological time scale of water bearing formations.

GEOHYDROLOGY

Knowledge of subsurface structural conditions and the various controls which determine the presence and movement of water within geologic formations is the key to understanding ground-water flow. Formations of strata within a saturated zone from which ground-water can be obtained are termed aquifers. To qualify as an aquifer, a geologic formation must contain pores or open spaces which are filled with water (normally referred to as porosity). These openings must be large enough to permit water to move through them at a perceptible rate (this is known as permeability) (Johnson, 1972, p. 21). In the unconsolidated deposits of sands and clays found along the Mississippi Gulf coast, only the sand strata qualify as aquifers. The fine grained clays or muds in this area contain large volumes of water but only the sand strata permit the transmission of water at a perceptible rate.

The amount of water in storage, which is fixed by the total pore volume of the sand strata, and the amount of recharge, which varies with rainfall, extent of outcrops, and runoff are referred to as aquifer potential. Ideally the movement and storage of water in an aquifer is in hydrologic balance, average inflow equals average outflow. Ground-water development subtracts from the natural system. When withdrawal exceeds recharge capability, water tables drop.

Until recent years, coastal water levels in the confined aquifers were above NGVD, and some of the confined water leaked upward into the Gulf and Mississippi Sound. The water in all of the aquifers was at one time salty. The salt-water was displaced by fresh-water entering updip and flowing downdip due to gravity and thus forcing the salt-water toward the Gulf (Newcome, 1975). The present water quality and the position of the fresh-water salt-water interface depends largely on the hydraulic gradient (slope of strata) and permeability of the aquifer. Movement of the salt-water updip or landward is referred to as salt-water intrusion.

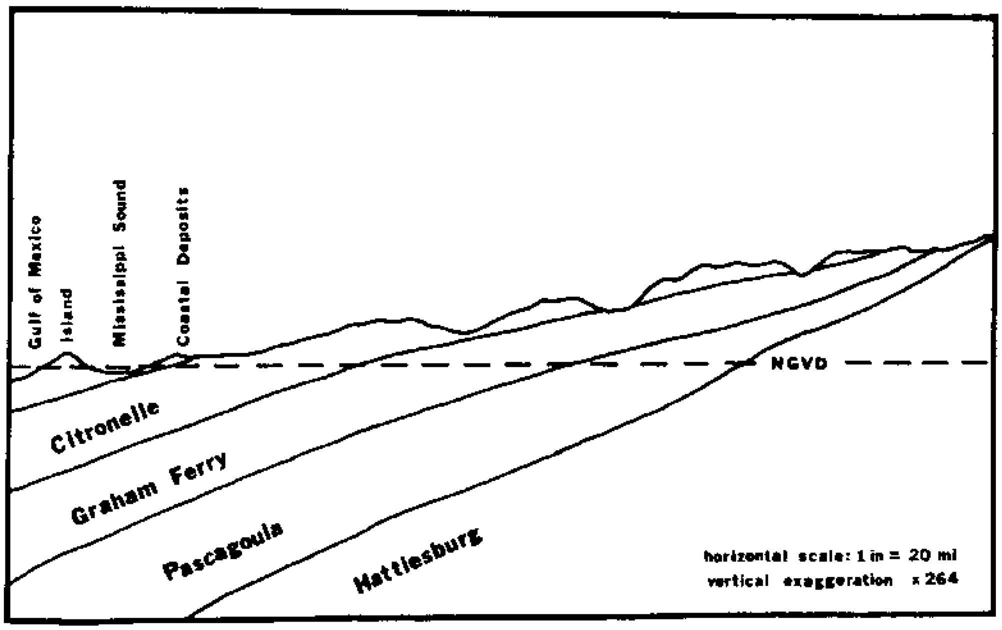

Figure 4. Cross section of water bearing formations of the Mississippi coast.

SALT-WATER INTRUSION

In aquifers exposed below sea level such as many of those found along the Gulf coast, the updip portion (upper part) of the water bearing formation contains fresh-water while the downdip portion (lower part) is saturated with salt-water. The body of fresh ground-water may be considered as floating on salt-water within the aquifer. Because fresh-water and salt-water have different densities, the boundary zone (interface) between the two waters is maintained in hydraulic balance. Roughly speaking, fresh-water extends to a depth of about 40 times the height that the water table is found above mean sea level. This relationship is known as the Ghyben-Herzberg principle (Johnson, 1972, p. 415).

Since the existence of fresh-water at depth requires the water table to be above sea level, it follows that there is also a fresh-water gradient towards the sea. Under the influence of this hydraulic gradient, fresh-water discharges into the sea. Part of the aquifer exposed below sea level is a natural outflow zone for fresh-water. An hydrualic gradient and a fresh-water movement seaward is essential to maintain the position of the contact zone of fresh-water and salt-water at some depth below the land surface. The position and fluctuation of this contact zone depends upon a hydrodynamic (force or pressure) balance of the two water types, not merely the static (standing or stabilized) balance implied by the Ghyben-Herzberg principle (Johnson, 1972, p. 416).

If excessive fresh-water is taken from a coastal aquifer by pumping from wells, the hydrodynamic balance changes, outflow of fresh-water in a seaward direction is reduced, and the water table is lowered. As a result, the salt-water body moves inland some distance as the balance changes, an occurence called salt-water intrusion. If only a part of the normal ground-water flow is pumped out and if the wells are a reasonable distance inland from the sea, the salt-water in the aquifer can be held far enough seaward by the remaining fresh-water flow so that the wells can continue to yield fresh-water. The total ground-water flow in the aquifer is equal to the natural fresh-water recharge occurring on land. Part of this can be taken out by wells but a certain portion must be allowed to flow continuously seaward in order to hold the salt-water interface at a safe distance from the well sites (Johnson, 1972, p. 416).

CONTAMINATION

Safe drinking water has always been a problem for humans and today is of even greater concern than a sufficient water supply. Today, only a few of the more developed countries in the world enjoy relative freedom from worry regarding polluted or contaminated water. Although not a heavily industrialized or populated area, the potential for fresh-water pollution and contamination along the Mississippi Gulf coast is well stated by E.H. Boswell (1979):

> "The characteristics that make the Citronelle Formation a productive aquifer also render it highly susceptible to contamination. A number of abandoned sand and gravel pits in the Citronelle have been converted to landfills that may be sources of contamination. The Citronelle aquifers are now contaminated at many places by industrial and oil-field wastes, sewage, land-fill leachate and other liquid contaminants that move into the water-table aquifers. Fortunately, most of the contaminants probably move toward springs and seeps and are dispersed by streams; however, where the Citronelle overlies confined aquifers the contaminants can migrate into the deep subsurface. These contaminants will affect ground-water supplies. Although the practice of using "evaporation" disposal pits is presumed to have ended, it is likely that "slugs" of contaminated water from old evaporation pits and landfills are today moving down the dip in the aquifers. Other sources of contamination include leaking sewers, sewage lagoons, pipelines, and injection wells."

In addition to the Citronelle Formation, we must also consider the outcrop areas of the Graham Ferry and Pascagoula Formations which cover thousands of acres in the southern half of the state. Much of the outcrop area is farmland which for years has been fertilized and treated with pesticides some of which have been discontinued becuase they were proven to be harmful. While these contaminants and pollutants can devastate rivers and streams, they can in most cases be reasonably flushed and the surface water returned to safe limits, but once they have entered the subterranean fresh-water aquifers, they can remain there for thousands of years. Although some instances of contamination have been found in appreciable amounts in isolated areas, there have apparently been no comprehensive studies made addressing this situation on the Mississippi Gulf coast.

SURFACE-WATER

The largest potential supply of fresh-water in south Mississippi is the numerous rivers and streams located along the Gulf coast. Billions of gallons of fresh-water of good quality and suitable for most municipal and industrial needs flow into the Mississippi Sound annually (see Eleuterius & Beaugez, 1979). This abundant source of fresh-water is virtually untapped, the preference being for well water due to economy and convenience. The extensive development and utilization of ground-water resources have placed a serious burden on the ability of the water bearing formations to maintain hydrologic stability and serious problems are expected.

Utilization of surface-water costs much more when compared to ground-water systems. Convenience is another problem, seldom is the river or stream located ideally, pipe must be run, reservoirs built and filter systems installed. An alternate method for more effectively utilizing surface water, that may be feasible based upon further investigation of subsurface conditions, is water injection. If there is interconnection between aquifers or they are extensive enough, they could be recharged by pumping treated surface-water into them. This would allow continued used of the present ground-water systems. This method should be of particular interest to management personnel for Gulf Island National Seashore as fresh water on the barrier islands is completely dependent on ground-water recharge.

Although abundant and readily accessible along the entire Mississippi coast, surface-water sources also offer some serious challenges that must be considered prior to being accepted as an alternate source of fresh-water supply. During drought periods, the sustained flow of many of the smaller streams will not satisfy large demands, and surface impoundment may be necessary to maintain needed supplies (damming of streams is not implied by surface impoundment, not recommended, and considered detrimental). On-site reservoirs, supplied by feeder lines, are recommended. Flooding is another area that must be considered. During hurricanes and extended period of heavy rain, flooding has caused extensive property damage and loss of life along the Gulf coast. The construction of water systems in or near rivers and streams should take into account potential dangers of damage due to rapid movement of water, waterborne debris, increased introduction of pollutants and excessive concentrations of suspended sediments during high water and subsequent runoff. Planning should include safeguards against encroachment by industrial and urban developments upon flood plains and reclamation of marshes as this greatly increases pollutants and added concentrations of suspended sediments into streams and river systems. Proper planning and wise management will limit property damage, lessen the probability for loss of life, and maintain the ecological and physical environment necessary to protect this important alternate source of fresh-water.

GROUND-WATER

Fresh-water used along the Mississippi Gulf coast is almost exclusively obtained from ground-water resources. All potable water available on the barrier islands is obtained from drilled wells. Abundant surface-water is available on the mainland but not utilized in any appreciable amount. The preference for ground-water is based on abundence and widespread availability at shallow depths. The convenience of being able to ideally locate water systems almost anywhere along the coast, the shallow depth of water bearing aquifers, the excellent quality of ground-water which requires only a minimum of treatment, and the seemingly abundant supply make this the most econmical source of fresh water. Unfortunately, the excessive rate of growth in the coastal area during the past 40 years has placed a heavy burden on ground-water supplies.

Along the Gulf coast extensive pumping of the Citronelle Formation will invite salt-water intrusion in most areas due to its near surface location, the shallow gradient of the strata, and close promimity to Gulf waters (Boswell, 1979). The water contained in this formation has a high concentration of iron in solution and hardness (Harvey and others, 1965, p. 109). Being very close to the surface also subjects water found in the Citronelle to potential contamination by natural and man-made pollutants (Boswell, 1979). Water from this formation is used by some private individuals, a few industries, and one municipality but is considered unattractive by most and as a result is not a highly developed source of fresh-water. It does, however, have some hydrologically important aspects that contribute to the overall availability of fresh-water resources. It is the principal source of water that sustains the low flow of many streams and provides recharge for lower formation aquifers by percolation or direct migration (Boswell, 1979).

The principal source of ground-water utilized along the Gulf coast is from the Graham Ferry Formation. Many geologists doubt the stratigraphic existance of this formation, preferring to assign the strata to the Citronelle and Pascagoula, or simply refer to them as Pliocene deposits (Newcome, 1975). Professional difference regarding stratigraphy noted, Graham Ferry Formation herein is used to designate the narrow geologic zone from which more that 70% of the water systems along the Mississippi Gulf coast extract water. This water is of good quality, a soft sodium bicarbonate type, and requires little treatment other than chlorination (Newcome and others, 1968, p. 102). Aquifers are widespread and available throught the area. High transmissibility is common with most ranging from 50,000 to 100,000 gpd (gallons per day) per foot, and of sufficient thickness of guarantee high yield even with conservative estimates of permeability (Newcome and others, 1968, p. 101).

The vast number of wells and the increasing high volume of water extracted annually from aquifers located in this narrow zone have resulted in the reduction of static water levels. This problem is not restricted to cones of depression near large industrial or municipal developments but is formation-wide. Many of the wells on the coast that originally had artesian flow now have static levels 40 to 60 feet below NGVD (Garland-Wright Well Records). All of the wells located on the barrier islands, which are 8 to 10 miles from any developed areas, originally had artesian flow. Only two of these wells flow at present and both at considerably reduced rates. The continued excessive extraction of water from the aquifers of this formation will undoubtedly adversely affect the hydrodynamic balance of the contained formation waters and imminent widespread occurances of salt-water intrusion is anticipated.

Formation recharge is another factor that must be considered in maintaining hydrodynamic balance of the contained formation waters. Since the turn of the centry, much of the outcrop area where water would normally enter the formation has been cleared of forest and turned into farmland. This allows much of the rainfall to escape as runoff instead of percolating into the soil.

Because of its thickness, areal extent, and permeability, the Pascagoula Formation aquifer system represents the largest potential source of ground-water in south Mississippi, but only the upper few hundred feet of the system have been significantly developed, and many thick aquifers remain untapped (Newcome, 1975). Fresh-water is available to a depth as great as 3000 feet (Newcome, 1967, p. H4). Water contained in aquifers below this depth is usually highly saline. Most of the fresh-water obtained from the Pascagoula Formation is the soft sodium bicarbonate type and except for chlorination requires little treatment. There is an increase in mineralization with depth and much higher water temperatures can be expected as the thermal gradient is about 1° Fahrenheit for each 57 feet of increase in depth (Newcome, 1975). Most wells set in these aquifers still have artesian head, some deeper wells flowing more than 100 feet above NGVD, and with the substantial thickness of many of the sand beds in this formation, transmissivity being considered excellent, at near 13,000 cubic feet per day per foot, efficiently constructed wells could produce several thousand gallons per minute (Newcome, 1975).

The depth of water bearing aquifers in the Pascagoula Formation put them economically out of reach of most individual home owners, small businesses, and is often the motivating factor for rejection by municipalities and industries.

BARRIER ISLAND WELL EVALUATIONS

Each of six wells located on the barrier islands is described in the following paragraphs. Included in this section are: locations and histories from U.S. Geological Survey files, observations based on site visits, recommendations for improving service and longevity, and forecasts of long range production capabilities.

WELL #1: WEST SHIP ISLAND

USGS File # M204
Location: Lat. 30° 12' 42" N, Long. 88° 58' 16" 300' east of Fort Massachusetts, 20' north of Generator Building.
History: Drilled by John A Sutter Co., 1929, for U.S. Coast Guard. Casing is 6" diameter, total depth 750', length of screen and width of sand strata unknown. Well flowed until 1982, rate of flow and level unknown. Park Service restricted use of well to irrigation due to indications of mercury being present, level of contamination unknown. Park Service maintenance personnel replaced top 5' of 6" casing with 8" diameter casing.
Survey: 16 April 1982. 8" diameter casing exposed 3'5" above ground level. Well sealed with 3/8" steel plate with 1" pipe existing at middle. Maintenance records indicate that 21' of pipe with a footvalve is suspended from the adapter plate down into the well. Static water level unknown but should be above the 21' level. A 3/8" hole 10" above ground level on north east side of casing was only opening.
Recommendation: Metal plate welded to top of casing should be replaced by commercially manufactured sanitary well seal. Well should be reworked with air compressor to determine static level, flow and condition. Suggest installation of a diesel powered, right angle drive, irrigation pump. Size of pump would be determined by water quantity needs and well diameter. I would advise caution against over pumping as the well is more than 50 years old and the strainer may be weak.
Forecast: Plans should be made to replace this well, the age is beyond the normal lifespan, continued pumping will probably result in the collapse of the strainer due to deterioration, and sanding will occur. U.S.G.S. is interested in obtaining water samples from this well and will share the information with the Park Service. Utility of this well is probably less than 10 years.

WELL #2: WEST SHIP ISLAND

Location: Lat 30° 13', Long. 88° 58', 600' east of Fort Massachussetts, 400' SSW of Beacon, in fresh water pond.
History: Drilled by Sutter Well Works, Inc., completed August 18, 1974, for Gulf Island National Seashore. Drilled to 900', bore hole was electrilogged, 6" diameter casing was set at total depth of 460', length of strainer unknown, width of strata unknown. Well had artesian flow, head pressure and rate of flow unknown.
Survey: 16 April 1983. Well located in a fresh water pond between dunes, marsh type environment and water is occasionally brackish. 6" diameter casing is 3' above water line, standing water 18" deep at casing. Well was operational at time of survey, with 1 HP, 2 wire, Berkely Submersible pump, depth of pump unknown, rate of flow was 55 GPM and 40 pound pressure. Park personnel indicate that there have been no major problems with water system and that water samples tested have been good. Well still has artesian flow, flow and head pressure unknown, an over flow pipe 3" above water surface exited from 4" tee in well casing. Pump is suspended from 1¼" pipe with metal plate used as seal at top of casing.
Recommendations: The standing water in the marsh represents a potential health hazard to this well even though no problems have been encountered to date. Static drawdown of the water level in the casing due to pumping will create a vacuum in the upper portion of the casing. Suction resulting from this vacuum may draw-marsh water into the well through the overflow pipe or through the course thread of the tee during periods that the marsh-water is higher than normal. Water marks on the outside of casing indicate that this has happened several times.

Extend the casing in height by 4 to 6 feet. Joints should be welded or a permanent type sealant used. Coat the casing with rust type paint to prevent surface deterioration of the casing or overwash to a depth below oxygen level (20') and grout casing. Build an elevated area around the well with a radius of 10' and fill with clay. Sandbags are recommended for the outer edge to maintain the clay in place. Height should be above the high water marks on the casing. The built up area will serve a dual purpose: prevent contaminated water from entering the well and provide a surface to work on when pulling the pump for maintenance.
Forecast: The lifespan of this well is expected to be about 40 years with normal useage. It is anticipated that the static water level will continue to drop at the rate of 1½' per year. This will place a heavier demand on the pump which will have to be lowered further into the well. It is anticipated that the pump is working at or near its capacity now based on the source of electrical power. Lowering the pump and increasing the head it must pump against will increase the load. I believe the generators are producing the maximum now. Some relief could be gained by locating the pressure tank closer to the well. Note: Extreme care should be taken to insure that normal operating tank pressure is maintained and that the pump does not

cycle too frequently. This will damage the pump but more importantly, the resulting milking action on the well can damage the strainer and cause sanding.

For future planning purposes it is suggested that a windmill actuated pump be installed with an elevated tank to provide gravity flow pressure. Many advances have been made in this type application, winds prevail on the islands year around, and the expense of fuel, transportation of fuel, surveillance of generator operation and generator maintenance and drain could be eliminated. The tower could also be used to replace the beacon located NNE of the well.

WELL NO. 3: EAST SHIP ISLAND

USGS File #M1 (Elog #9)
Location: Lat. 30° 13' 45" N, Long. 88° 53' 45" At old Quarantine Station on south shore directly south of rock pile, slightly east of the end of boardwalk.
History: Drilled by Sutter Well Works, Inc., 1958, for the Mississippi Park Commission. Well casing is 6" in diameter, well depth is 727', with 30' of strainer, width of strata unknown. Well flowed until 1980, head pressure and rate of flow unknown.
Survey: 16 April 1983 and 11 August 1983. Well is not in use but according to Rangers it still flows occasionally. Water level was 3½' above surface inside casing, casing extends 5' above surface. Exposed casing is galvanized steel and in good condition. Casing is topped with 6" Tee and a 1¼" pipe extends from the top of the Tee and is not sealed. Well is located 30' from shoreline on beach with no plant growth near.
Recommendations: This well should be cleaned and reworked by air compressor to determine static level and rate of flow. It is very possible that this well would flow again if cleaned out and pumped. It is in good shape from visual inspection and could easily be placed in service.
Forecast: This well probably has utility for another 20 years. It would be an excellent candidate for a windmill operated pump that would provide continuous flow. The location of the well is a favored spot for area sportsmen and campers.

WELL NO. 4: EAST SHIP ISLAND

USGS File #M202
Location: Lat. 30° 12' 18" N., Long. 88° 57' 00" At old Quarantine Station on south shore directly south of rock pile and slightly east of the boardwalk.
History: Well drilled by John A. Sutter, 1901, for the U.S. Coast Guard. Well casing is 4" in diameter, set at a total depth of 730', with 5' of strainer, set in 9' strata of sand. Well originally flowed but head pressure and rate of flow is unknown.
Survey: 16 April 1983 and 11 August 1983. Well casing has deterioriated down to the surface level. A 2½" pipe about 10' long protrudes from the casing. Rangers indicated that the well still flows occasionally.
Recommendations: This well should be grouted closed and the casing cut off below the ground level. It has no utility but does present an avenue where pollutants could migrate into the water bearing aquifers.

WELL NO. 5: HORN ISLAND

USGS File #048 (#112 on some older maps)
Location: Lat. 30° 15' 09" N, Long. 88° 43' 02" Located on north shore near big lagoon approximately 3 miles west of the Ranger Station.
History: Drilled by Layne Central Co., 1943, for the U.S. Army. Casing is 6" in diameter, well set at 819' total depth, 40' screen, set in 60' sand strata. Park maintenance personnel replaced pipe exposed above ground and concreted in the base. No other information available.
Survey: 16 April 1983 and 11 August 1983. Well was not in use. Well casing is sealed with 3/8" steel plate welded to top. Four feet of casing are exposed above ground level, two one inch pipes exit from casing in the concrete base. Static water level was determined to be 11' below the top of the casing. Well casing is being engulfed by a sand dune on the south side.
Recommendation: Replace the steel plate on top of the well casing with a sanitary seal. Well should be reworked with an air compressor. This would be a good observation well for obtaining water samples. Park Rangers indicated that this well flowed until about 1979. It is doubtful that it will flow again.
Forecast: This well probably has reached its normal life expectancy and it is doubtful that it would last more than 10 years if pumped at its normal production capacity. It would be a good prospect for a low yield windmill actuated pump that could provide a continuous flow of water for use by sportsmen and campers.

WELL NO. 6: HORN ISLAND

USGS FILE #049 (#113 on some older maps)
Location: Lat. 30° 14' 05" N, Long. 87° 41' 12", 1000' west by northwest of Ranger Station.
History: Well drilled by Layne Central Company in 1943 for the U.S. Army. Casing 6", total depth 836', with 40' of strainer set in 68' sand strata. Well was abandoned by Army in 1946-47. Well was reworked and put back in operation by the Carland-Wright Water Well Co. in December 1973. Old turbine pump removed, well flowed 80 to 100 GPM at 4" above casing. Eight feet of 2" pipe installed with 800 cu. in. air pressure at 250 pounds, continuous pressure with intermittent back pressure. Approximately 6 cubic feet mix of Scales, rust, black algae, and fine sand (60 to 80) were removed. Head was 8" after air surging 150-160 GPM. Flow topped 2" pipe at 18' with well head blocked. Water was clear and free of foreign particles with strong sulfer smell. Well was reduced to 1' outlet with sanitary seal. Head on 1" line at Rangers' cabin (300 yards east) was 14'.
Survey: 16 April 1983. Well head has been concreted in with a 2" pipe exiting through the concrete. Overflow was cut off and valve

handle removed. Could not estimate pressure or volume of flow. A ½ HP booster pump (electric) was installed in line at Rangers' Area which pumped water into a 500 gallon tank elevated to 30'. Booster pump only runs for a few hours each day to fill water tank.
Recommendation: Concrete plug be removed from wellhead and replace with a sanitary seal. That a windmill and pump be installed at the well site, with an elevated storage tank.
Forecast: This well probably has reached its normal life expectancy and its doubtful that it would last more than 10 years if pumped at its normal production capacity. At present useage it may last 20 to 25 years but plans should be made to replace it.

SUMMARY AND RECOMMENDATIONS

The geology of the Mississippi Gulf coast is complex and poorly defined. There has only been one comprehensive study made of the area (Brown and others, 1944) and much of the information published is out of date due to the intensive build-up in the area. There have been several more recent studies but they are concerned with specific areas such as Pascagoula, NASA, or Harrison County. The heavy influx of people and industrialization of the Gulf coast and the resulting heavy burden placed on water resources make it imperative that attention be given to locating and mapping the available fresh-water strata with special emphasis given to the deeper, undeveloped ones. Personnel at the U.S. Geological Survey, Jackson Office, have indicated an interest in obtaining permission to drill 2,500 foot test wells on the barrier islands. The information gathered from these tests would be of great value because it would considerably enhance the data base need for Gulf coast fresh-water resources. This would be an excellent community relations project between the National Park Service and coastal cities. U.S. Geological Survey personnel readily understand the Park Service's desire to maintain the natural environment and have indicated a willingness to make every effort to prevent unnecessary damage during drilling operations. Arrangements could be made to tap fresh water strata and case wells for use by the Park Service, if desired. Wells set in the Pascagoula strata would flow with an artesian head about 100 feet above NGVD and eliminate the need for pumping water for many years. They have assured that after drilling and testing is accomplished, proper removal of equipment and clean up will leave minimal negative results. Suggested sites for these tests are near the fort on Ship Island, the administrative zone near the station on Horn Island, and near the old building foundations on Petit Bois Island.

For economic reasons most of the wells on the Mississippi Gulf coast extract water from a very narrow zone that extends from about 300 to 800 feet below the surface even though fresh water is available much deeper. The heavy demands on this narrow zone of fresh water aquifers, known as the Graham Ferry Formation, has resulted in an area-wide reduction of static water levels. Continued uncontrolled pumping and removal of high volumes of water from this formation will adversely affect the hydrodynamic balance and widespread occurrences of salt-water intrusion may result. Where possible, large diameter and/or high volume wells should utilize deeper strata which would relieve some of the demand made on the Graham Ferry Formation. Plans should be made to use surface-water resources. Several major streams and numberous smaller ones in the three coastal counties have a potential for sustained fresh-water supplies of hundreds of millions of gallons per day. The water is of good quality and would require very little treatment. Direct utilization of surface-water by injecting the water into aquifers that are being excessively pumped would help maintain hydrostatic equilibrium of formation waters and prevent or forestall salt-water intrusion. Major industrial complexes could reduce demands made on ground water resources by utilizing surface water. On-site reservoirs would offer the best method for guaranteeing adequate supplies.

Without immediate action by Mississippi Legislatures (local, state, and federal) the future of adequate fresh-water supplies for the Gulf coast is in jeopardy. Demands for water have more than doubled in this area since 1960. With current efforts to attract more industry and the increasing immigration of people to this area, requirements may double again in a few years. Strict environmental codes need to be enacted to control the sewage treatment lagoons and dumps that could further pollute the formation recharge areas. The indiscriminate clearing of large tracts of forest for farmland should be curtailed. A study is needed of both ground- and surface-water resources to determine the extent of contamination and a program instituted to closely monitor these resources to insure that they do not become contaminated with insecticides, chemical fertilizers, industrial waste, or other means of pollution.

FORECAST

The crisis of the 1990's will be the lack of water for domestic use according to Eason (1983). While a crisis is not anticipated on the Gulf coast at this early date due to abundant water supplies, it is expected that the lack of action because of official apathy and public ignorance will result in the occurence of serious problems. If the migratory trends of people and industry to this area continue at the same rate as it has for the past 40 years, the demand for fresh-water will more than double near the turn of the centry. Warnings of impending problems were stated by Brown and his colleagues in 1944. These warnings have been reiterated since by almost every author publishing papers regarding the fresh-water situation in south Mississippi, by numerous articles released through the public news media, and repeatedly by local water well contractors. These warnings have been consistently ignored. It is anticipated that municipal and industrial users will continue to extract high volumes of water from the same narrow geologic zone of the Graham Ferry Formation. Water levels in these aquifers will continue to drop with ever increasing rates during the ensuing years until individual home owners in rural areas will be unable to afford private wells. The mineral content of the water will increase and widespread salt-water intrusion will occur. The future of fresh-water availability on the Mississippi Gulf coast is poor.

ACKNOWLEDGEMENT

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Historical and geological data were obtained from documents and studies provided by the Mississippi Geological Survey, U.S. Geological Survey, Gulf Islands National Seashore, park maintenance records, and records of the former Garland-Wright Water Well Company.

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THE MARINE SANCTUARY PROGRAM

TITLE III - THE MARINE PROTECTION, RESEARCH AND SANCTUARIES ACT

16 U.S.C. §§1431 - 1434 (1972, amended 1980)

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ABSTRACT: The Marine Sanctuaries Program was created by Title III of the Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C. § 1431-1432). Title III empowers the Secretary of Commerce to designate recommended marine areas as sanctuaries in order to promote the balanced use of their resources, and to regulate activity within them through the Office of Coastal Zone Management. The purpose of this paper is to analyze the mechanisms and policies of the Program in relation to the criticism which its broad grant of authority to the Secretary of Commerce inspires. This is accomplished by examining the Act's legislative history along with a study of the case law which is a direct product of the Program's implementation.

INTRODUCTION

Legislation which would reauthorize the National Marine Sanctuary Program[1*] passed the House by a vote of 379-38 on June 14, 1983.[2] This bill (H.R. 2062), which attempts to provide the Program with a sounder legislative basis, would reauthorize it for three years at $2.264 million, $2.5 million, and $2.75 million for each successive year.[3] It is expected that before the end of the year, the Senate will pass a reauthorization bill similar to H.R. 2062. Some of the anticipated differences in the Senate version, which would result from a June 23rd U.S. Supreme Court decision,[4] will be discussed later.

*Footnote references may be found at conclusion of article.

The Reagan administration's austere economic policies, coupled with continuing assaults on the eleven-year-old Sanctuary Program, make this a critical time for supporters of its reauthorization. The purpose of this article is to review the Program's legislative history alongside its policies and mechanisms, all in relation to the criticism which it has inspired. Such a review should help to clarify the numerous issues spawned by the Sanctuary Program since its inception, and to identify those which are pertinent to the ongoing reauthorization process.

CURRENT STATUS OF THE PROGRAM

The Marine Sanctuary Program was created by Title III of the Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C. § 1431- 1434). Title III empowers the

Secretary of Commerce to designate recommended areas of ocean and coastal waters as marine sanctuaries in order to preserve or restore them for their conservation, recreational, ecological, or esthetic values to the public.[5] He is further authorized to regulate activity within these areas,[6] a task which is delegated to the Office of Coastal Resource Management.

The original sanctuary designation process was harshly criticized for failing to alert interested parties to the status of potential sanctuary sites. As a result, early in 1982, regulations were proposed to make certain changes in the site selection process according to a new "program development plan" (PDP).[7] The PDP, a result of research and consultation with conservation groups, industry representatives, and federal agencies, defines the means by which the objectives of Title III will be met. The final regulations, which codify the new procedures and refine the PDP, have been published in the Federal Register and are effective as of June 30, 1983.[8]

The first stage of sanctuary designation under the PDP is the one-time establishment of a Site Evaluation List (SEL) by the Assistant Administrator (AA) of NOAA.[9] NOAA contracted with Chelsea International Corporation to provide eight regional teams of local scientists to identify potential marine sanctuary sites which, from a scientific standpoint, represent coastal and offshore areas of high resource value of national significance.[10] It was Chelsea's task to provide a written analysis of each site in relation to the PDP's selection criteria for placement on the draft SEL. These criteria were grouped into four categories: (1) natural resources values; (2) human-use values; (3) potential activity impacts; and (4) management concerns.[11] Public comment was sought regarding the initial sites by mailing to selected parties outlines of the process, descriptions of the preliminary sites, lists of other sites considered, and solicitations of additional site nominations.[12] The original procedure, whereby any person could recommend a site for placement on the List of Recommended Areas, has been abolished.[13]

Of the 29 new sites which were proposed by NOAA on March 1, 1983, neither Alabama nor Mississippi had candidates to be placed on the draft Site Evaluation List.[14] After reviewing the regional site lists with their accompanying documentation, NOAA placed all of the proposed sites on the final SEL and published notice in the Federal Register on August 4, 1983, effectively opening the list to public comment for the first time.[15]

The next stage of designation is selection for Active Candidacy. Sites on the final SEL will be evaluated over a five-year period to determine the feasibility of their becoming active candidates for sanctuary designation. The AA must seek comment from relevant federal and international agencies, state and local officials (the Governor may disapprove a site in state waters), appropriate regional fishery management councils, and the general public. This is accomplished through a series of workshops conducted by NOAA, from which information about the proposed candidate site is obtained. Based on these comments, on the written analysis prepared earlier by NOAA, and on a balancing of relevant considerations (including ecological conditions, immediacy of need, timing and practicality, and public comment), the AA makes a selection. He must publish notice of his decision to select the site as an Active Candidate in the Federal Register within 90 days of initiating preliminary consideration. If the site is not selected, a short statement of the reasons for the determination shall be specified in the notice.[16]

After the site is given Active Candidate status, the AA prepares an environmental impact statement (EIS),[17] a draft designation document, and a draft management plan. A management plan should include goals and objectives, management responsibilities, resource studies, interpretive and educational programs, and applicable regulations. The terms of designation should include the geographic area within the sanctuary, the characteristics of the area that give it conservation, recreational, ecological, or esthetic values, and the types of activities that will be subject to regulation in order to protect those characteristics. Any necessary regulations must be consistent with and implement the terms of designation. To prevent immediate, serious, and irreversible damage to the resources of a sanctuary, activities other than those listed in the designation document may be regulated within the limits of the Act on an emergency basis for an interim period not to exceed 120 days. At least one public hearing must be held in the areas most affected to consider the draft document. The AA's decisions must take into consideration the relationship of a proposed designation to state waters and the consistency of the proposed designation with an approved state coastal zone management program. Furthermore, any portion of the designation package for any site which contains state waters may be vetoed by the Governor of that state.[18]

The final designation and implementing management plan are filed with the Environmental Protection Agency along with an EIS which considers any comments received at the hearings. The document is then submitted to the President for approval. Such designation becomes effective unless both Houses of Congress disapprove through a Concurrent Resolution adopted within the first 60 calendar days of continuous session after publication of the designation.[19] (This procedure will be amended in the reauthorization bill, to accommodate the recent Immigration and Naturalization Service v. Chadha[20] holding that congressional vetos are unconstitutional. See later discussion.)

As a result of the new process, interested parties know much more about individual sites which are being considered for sanctuary designation. By the time any site is designated, it will have undergone review by interested parties and Congress at least four times.

Under a sanctuary's management plan, existing regulatory authorities in the area are incorporated to the maximum extent possible, limited by the purposes for which the sanctuary was designated. New regulations are to be developed by NOAA as necessary, based upon a thorough evaluation of the resources, activity levels, the adequacy of the long-term protection provided by the existing regulatory system, and the economic impacts of new regulations.[21] A 1980 amendment to Title III provides that "all permits, licenses, and other authorizations issued pursuant to any other authority shall be valid unless such regulations provide otherwise."[22] Obviously, the scope of regulation will vary within each sanctuary.

The primary enforcement agency for National Marine Sanctuaries located in federal waters is the U.S. Coast Guard. However, in sanctuaries involving state waters, state enforcement agencies may assume this responsibility.[23] Any person subject to U.S. jurisdiction who has violated any part of the Act may be liable for a civil penalty of up to $50,000. Such person has the right to demand a hearing. Upon failure of the violator to pay an assessed penalty, the Attorney General, at the request of the AA, may commence an action in the appropriate U.S. district court to collect the penalty and seek other relief as may be necessary. Any vessel used in the violation of the Act will also be liable in rem.[24]

As of July 1983, only six marine sanctuaries have been designated in the 11-year history of the program:

(1) The Monitor Marine Sanctuary (1975) was designated to protect the wreck of the U.S.S. Monitor, off the coast of North Carolina;[25]

(2) The Key Largo Coral Reef Marine Sanctuary (1975), to provide protective, comprehensive management of a large coral reef area south of Miami;[26]

(3) The Channel Islands Marine Sanctuary (1980), "to protect and preserve the extraordinary ecosystem including marine birds and mammals and other natural resources of the waters surrounding the northern Channel Islands and Santa Barbara Island and ensure the continued availability of the area as a research and recreational resource;"[27]

(4) The Point Reyes - Farrallon Islands National Marine Sanctuary (1981), to protect and preserve a rich and diverse marine ecosystem off the coast of California;[28]

(5) Gray's Reef National Marine Sanctuary (1981), off the coast of Georgia, "to protect and preserve the live bottom ecosystem and other natural resources of the waters of Gray's Reef and to ensure the continued availability of the area as an ecological, research, and recreational resource;"[29]

(6) The Looe Key National Marine Sanctuary (1981), off the coast of Florida, "to protect and preserve the coral reef ecosystem and other natural resources of the waters at Looe Key and to ensure the continued availability of the area for public educational purposes and as a commercial, ecological, research, and recreational resource."[30]

The existing sanctuaries, then, protect five separate ecosystems and a Civil War wreck. The regulations of activity within the sanctuaries vary in subject matter and scope, according to the resources being safeguarded and the purpose for which the sanctuary was designated.

Four other sites (La Parguera[31] in Puerto Rico, the Humpback Whale Wintering Grounds[32] in Hawaii, Fagatele Bay[33] in American Samoa and Cordell Bank[34] off the coast of Northern California) are presently on the list of Active Candidates under pre-PDP selection procedures.

REAUTHORIZATION ISSUES

Much of the controversy generated by the Marine Sanctuary Program is due to its obscure legislative basis. The language of Title III as finally enacted in 1972 and subsequently amended does little to clarify the intent of Congress in creating the Program. The Act contains ambiguous hints at the Program's goals and philosophies, but even these fail to jibe with portions of its legislative history. Originally, because the sanctuary idea arose in the midst of public clamor over several marine pollution disasters, many perceived the Program as a mechanism for promulgating mineral extraction moratoria and other protective regulations.[35] However, once the Program was underway with a burgeoning list of potential sanctuary sites, it became clear that the prospect of mineral exploitation moratoria had been summarily excluded from the Program's purported goals. The "preserve or restore" purposes soon became confused with a practical emphasis on a "balance of uses within the sanctuaries."

Since then, there has been continuing disagreement as to what Congress really intended to accomplish through the Marine Sanctuary Program. The first two sanctuaries were designated in 1975, and the last four in 1980-81.[36] In 1980, a number of amendments to Title III were passed, in an attempt to restrict the Secretary of Commerce's power to interpret the mission of the Program. These included a means of Congressional veto of any portion of sanctuary designation, and a provision that all permits previously issued under another agency's authority were to remain valid unless specifically prohibited.[37]

However, treating the symptoms did not cure the confusion as to legislative intent. Instead, as has been observed by the Congressional Research Service, "the National Marine Sanctuary Program has undergone a complex evolution of both Congressional intent (evidenced in the original Act and subsequent reauthorization and amendment) and Administrative conduct (evidenced in the variety of statements of goals, purposes, mission, and philosophy of this program)."[38] Not only has this problem tended to hamper the effective implementation of the Marine Sanctuary Program, but it also promotes a great deal of distrust among private interest groups, especially those which never understood the necessity of marine sanctuaries in the first place.

For these reasons, it is imperative that the reauthorization bill include clear language of specific policies and purposes. H.R. 2062 contains such language, providing a guiding theoretical framework for the Program. According to H.R. 2062, the mission of Title III is

> to identify areas of the marine environment of special national significance due to their resource or human use values; to provide authority for comprehensive and coordinated conservation and management of these marine areas which will compliment existing regulatory authorities; to support, promote, and coordinate scientific research on, and monitoring of, the resources of these marine areas; to enhance public awareness, understanding, appreciation, and wise use of the marine environment; and to facilitate, to the extent compatible with the primary objective of resource protection, all public and private uses of the resources of these marine areas not prohibited pursuant to other authorities.[39]

Unfortunately, a clarified theoretical basis is not Title III's ticket to reauthorization; several major procedural changes have also been included in H.R. 2062. These address concerns that there is far too much discretion with the Secretary of Commerce, and too little public participation in the designation process. One adjustment is a requirement that the Secretary send to Congress an annual report on sites receiving active consideration for sanctuary designation. A second alteration requires that in proposing to designate a marine sanctuary, the Secretary shall issue notice of the proposed site, along with reasonable and necessary regulations, in the Federal Register and local media publications, and conduct at least one public hearing in the affected area. In addition, he must submit a prospectus on the proposal to the House merchant marine committee and Senate commerce committee for their evaluation and comment. Otherwise, the previous designation procedures with a mechanism for disapproval of all or part of a Sanctuary by Congress or a Governor, are retained as a major check on the Secretary's power. (It should also be noted that the provision for Presidential approval of a designated site was deleted in H.R. 2062.)[40] This and the aforementioned changes were intended to increase, within reasonable limits, Congressional oversight of the designation process.

Another major procedural change which will be included in the Senate version of the bill is a direct result of the Supreme Court holding in Immigration and Naturalization Service v. Chadha.[41] Chadha struck down the one-House veto of administrative action as being violative of constitutional requirements of bi-cameralism and presentment to the President.[42] The Chadha opinion indicates that this holding extends to the two-House veto as well, so that Title III's provision for congressional disapproval of sanctuary designation through a concurrent resolution would also be unconstitutional.[43] The Senate version, then, is expected to contain a provision for Congressional disapproval through a joint resolution, instead of a concurrent resolution, which requires presentment to the President for approval.

Regarding concern that certain special interests are being regulated out of productive resource areas, few federal programs have been as responsive as the Marine Sanctuary Program. For instance, the oil and gas industry has been highly successful at having its concerns addressed during the designation process; it succeeded in halting consideration of proposed sites at Georges Bank, Flower Garden Banks, and the Beaufort Sea, and in suspending oil drilling prohibitions at two California sanctuaries pending a lengthy and costly regulatory impact analysis.[44]

Fisheries, however, have not had equally effective representation in the designation process, particularly during site selection. This is mainly due to poor communication with the industry.[45] Addressing this problem, certain changes have been made in H.R. 2062. The reauthorization bill requires consultation with appropriate regional fisheries management councils, which are permitted to draft all regulations pertaining to fishing within marine sanctuaries. The councils will be required to follow national standards for fishery conservation and management, to the extent that such standards are consistent with the goals and purposes of the proposed sanctuary. If the council declines or fails to prepare such regulations in a timely manner, the Secretary of Commerce will prepare them.[46]

CONCLUSION

Both the new site selection process (which provides at least four levels of public or Congressional scrutiny) and the changes made by H.R. 2062 (which gives the Program a clear legislative basis and creates several checks on the designation process) should help reinstate public and Congressional faith in the Marine Sanctuary Program. Because there is so little knowledge, and often only speculation, as to the impact of active resource development on certain fragile ecosystems, a carefully monitored balance among uses in such areas is imperative. As awareness increases as to the need for comprehensive, site-specific management of marine areas which contain our more fragile resources, the Marine Sanctuary Program will be recognized as the best system we have for this task. Above all, it must be kept in mind during the reauthorization process of Title III that institutional deficiencies are reversible, while damage to valuable resources oftentimes is not.

FOOTNOTES

[1]H.R. 2062, 98th Cong., 2d Sess. (1983) [hereinafter cited as H.R. 2062].

[2]J. Botzum (ed.), 14 Coastal Zone Management 3-4 (June 23, 1983), Nautilus Press, Washington, D.C.

[3]See H.R. 2062.

[4]See Immigration and Naturalization Service v. Chadha, 41 U.S.L.W. 4907 (U.S. June 23, 1983).

[5]16 U.S.C. § 1432 (1972).

[6]Id.

[7]See 47 Fed. Reg. 39, 191 (1982); See also "National Marine Sanctuary Program: Program Development Plan," U.S. Dept. of Commerce, Washington, D.C. (Jan. 1982), for more detail.

[8]See 48 Fed. Reg. 24,296 (1983)(to be codified at 15 C.F.R. Part 922) [hereinafter cited as PDP].

[9]See PDP at § 922.20.

[10]See PDP at 24,298 for a list of team members; see also Savage, Wayne C., "Marine Sanctuary Site Selection - Continuing," 6 Bulletin 14-16 (Oct. 1982 - Jan. 1983, The Coastal Society), for a procedural description of site selection by Chelsea.

[11]See PDP at § 922.40.

[12]See Savage, supra note 10.

[13]PDP at § 922.20.

[14]See 48 Fed. Reg. 8527 (1983), for list of draft SEL sites.

[15]48 Fed. Reg. 35568 (1983).

[16]See PDP at § 922.30.

[17]An environmental impact statement is required of federal agencies by Section 102(c) of the National Environment Policy Act of 1969 [42 U.S.C. § 4332(c)] in every proposal for legislation significantly affecting the quality of the human environment. It must describe the action's environmental impact, its adverse affects, alternatives to the proposed action, the relationship between man's short-term use and long-term productivity of the area, and any irreversible commitments of resources entailed.

[18]See PDP at §§ 922.31 and 922.32.

[19]Id.

[20]See supra note 4.

[21]See PDP at § 922.31; see also "National Marine Sanctuary Program: Program Development Plan," supra note 7 at 46.

[22]16 U.S.C. § 1432 (as amended 1980).

[23]"National Marine Sanctuary Program: Program Development Plan," supra note 7 at 46.

[24]See PDP § 922.40, referring to codified administrative procedures at 15 C.F.R. 904.100 - 904.273 and 50 C.F.R. Part 219.

[25]See 15 C.F.R. § 924 (1981).

[26]See id. at § 929.

[27]Id. at § 935.2.

[28]See 46 Fed. Reg. 7948 (1981)(to be codified at 15 C.F.R. § 936).

[29]Id. at 7944 (to be codified at 15 C.F.R. § 938).

[30]Id. at 7949 (to be codified at 15 C.F.R. § 937.2).

[31]See 48 Fed. Reg. 9287 (1983) for the proposed designation of this site for the preservation of a representative cross-section of tropical habitat and a coral reef ecosystem in its natural state.

[32]See Re:Act - The Bulletin of the Marine Sanctuaries Coalition, March 4, 1983, p. 3 (Center for Environmental Education, Washington, D.C., 1983).

[33]Id.

[34]See 48 Fed. Reg. 30, 178 (1983).

[35]See "Marine and Estuarine Sanctuaries in the United States: A Comparison of Design and Implementation," abstract prepared by Michael Weber (Marine Habitat Director, Center for Environmental Education, Washington, D.C.) and Laurie Reynolds, 1983.

[36]See supra notes 25-30 and accompanying text.

[37]See 16 U.S.C. § 1431-1432 (as amended 1980).

[38]Congressional Research Service, Study on National Marine Sanctuary Program (1979-80) at 34.

[39]See H.R. 2062.

[40]Id.

[41]51 U.S.L.W. 4907 (U.S. June 23, 1983).

[42]See id.

[43]See id. A subsequent decision, Process Gas Consumers Group, et al. v. Consumers Energy Council of America, 51 U.S.L.W. 3935 (U.S. 1983), affirms this extension of the Chadha holding to the two-House veto.

[44]See "Statement of Michael Weber, Marine Habitat Director, Center for Environmental Education," Committee on Commerce, Science, and Transportation of the U.S. Senate, 28 February 1983, p. 2.

[45]Id. at 3.

[46]See H.R. 2062.

DISCUSSION

SHABICA: Catherine, will 2062 reduce the incredible amount of time that it takes and the amount of money that is spent in proposing and finally seeing a Marine Sanctuary put into the books?

MILLS: I have to say I really don't think so. 2062 wasn't designed solely to cut back on time or effort in designating a sanctuary. On the contrary, its aim is to ensure a carefully monitored selection process--which may actually increase the time and money input. However, the funding levels have been significantly reduced so that will probably take care of that.

SHABICA: That's one way of getting rid of any program, just take its money away, right?

ENVIRONMENTAL ASSESSMENT ON THE NORTH-CENTRAL GULF OF MEXICO COAST

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ABSTRACT: The area to be discussed is dominated by the Mississippi Delta and the estuarine complex of Mobile Bay and the Mississippi Sound. The bulk of the efforts described will obviously be found in Mobile Bay and adjacent waters due to the background and interest of the author.

Classical methods of benthic community analysis have been refined and extended to thoroughly address the technical issues of adequate sample size and experimental design. These methodologies have been integrated with a sophisticated, computer-based statistical analysis system within the context of real-time management applications.

The technical results of this effort will be superficially reviewed and placed within the framework of practical usage and utility. The philosophy underlying the conversion of impact assessment to a predictive/management mode is discussed and the hypothesis presented that management may operate at confidence levels lower than those defined by pure science.

The integrated research plan leading to a possible ecosystem model for Alabama's coastal waters will be described and related to the earlier concepts presented. Finally, the knowledge gaps as currently recognized will be identified.

AN ANALYSIS OF THE CASE LAW UNDER THE CONSISTENCY PROVISIONS OF THE COASTAL ZONE MANAGEMENT ACT

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ABSTRACT: This discussion focuses on the three cases construing the consistency provisions of the Coastal Zone Management Act and regulations. Also discussed briefly is the difference in the consistency provision of CZMA and Section 19 of the Outer Continental Shelf Lands Act. This section provides for acceptance of a governor's recommendations concerning OCS oil and gas leasing if the Secretary of Interior finds that they provide for a reasonable balance between the national interest and the well-being of the citizens of the affected state.

The three cases in question are California v. Watt, Conservation Law Foundation v. Watt, and Kean v. Watt. While all of these cases require a consistency determination for the leasing stage of OCS activity, there is considerable disagreement concerning the meaning of "directly affecting" as intended by Congress in Section 307(c)(1). In Kean v. Watt, the Court found that a consistency determination was necessary, but that the proposed lease sale was not inconsistent because it did not directly affect New Jersey's coastal zone. This decision was based on an examination of consistency with CZMA, not New Jersey's approved coastal zone management program.

The various aspects of consistency determination are discussed, using the analyses of the decisions for guidance to the extent that they provide it. The importance of policies covered by a state CZM program is emphasized in light of the implications in Kean v. Watt.

The discussion concludes with a brief mention of the impact on OCS activities of the National Environmental Policy Act, the Endangered Species Act and the Marine Mammal Protection Act.

BARATARIA AND MOBILE BAYS - COMPUTER ASSISTED ANALYSES FOR ENVIRONMENTAL IMPACT ASSESSMENTS

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ABSTRACT: The U.S. Fish and Wildlife Service (FWS) is obligated by various public laws and Federal regulations to coordinate environmental studies of Federally authorized projects and the analysis of environmental impacts associated with alternatives developed from the studies. A need exists to more effectively address such issues which arise during coordination of studies. Computer software systems developed in recent years offer such capabilities and are oriented toward users with minimal background in the use of computers. The Map Overlay and Statistical System (MOSS) and other related software systems of FWS provide a method to improve efficiency and reliability in analyzing data related to planning of Federal projects. These systems have been adopted and are now being used by some Federal agencies in conducting environmental studies, and identifying and assessing impacts of proposed projects. More widespread use is expected in the future as more agencies adopt such systems.

This paper will highlight the use of the FWS computerized geographic information system to: (1) analyze potential impacts of depositing dredged material in Mobile Bay, Alabama, and (2) conduct habitat (primary wetland) trend and change analysis for Barataria Bay, Louisiana, for the State of Louisiana's Coastal Zone Management Program.

DATA BASE APPLICATIONS: CORRIDOR ANALYSIS IN BALDWIN COUNTY, ALABAMA

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ABSTRACT: A data base was constructed in Baldwin County, Alabama under the aegis of the NASA Test and Evaluation Program. The primary goal of this program is to establish permanent test sites within various physiographic regions for testing new remote sensing technology. Mobile and Baldwin Counties, Alabama were selected as representative of the Gulf Coastal Plain. Objectives of this effort include constructing a standardized digital data base comprised of current remote sensing data (e.g. NOAA-7, AVHRR; Landsat MSS; Landsat 4 Thematic Mapper (TM), Shuttle Imaging Radar (SIR), etc.) and geobased information (soils, topographic, cultural, etc.) which would be available to interested investigators for: (1) testing the capabilities of new remote sensing data against the established state-of-the-art, (2) testing new data analysis or data manipulation algorithms, and (3) addressing specific regional resource management problems.

The data base was first used to test a weighted simulation model and automated corridor selection algorithm developed at the NASA/NSTL Earth Resources Laboratory. This model was comprised of 5 information planes geographically referenced to a 50-meter grid cell size and used to determine the level of trafficability for each cell. The information planes included: (1) Landsat MSS-derived land cover, (2) U.S. Soil Conservation Service detailed soils survey, (3) National Cartographic Information Center (NCIC) topographic data, (4) digitized primary and secondary roadways, and (5) digitized urban boundaries. Variables within each information plan were ranked according to their ability to support traffic. The information planes were then assigned significance values (weights) to vary their impact on corridor placement. Resulting levels of trafficability were used by the automated corridor selection algorithm to compute the most accessible corridor.

COASTAL BARRIER RESOURCES ACT OF 1982

PAST, PRESENT, AND FUTURE STUDIES

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ABSTRACT: This presentation will first describe methodologies used by the U. S. Fish and Wildlife Service for coastal barriers photographic inventory to delineate boundaries for the Coastal Barrier Resources System found in the Coastal Barrier Resources Act of 1982 (CBRA: P.L. 97-348). Secondly, a discussion of how the inventory was used in constructing maps to delineate undeveloped barriers will be presented. Finally, an overview of future study efforts planned by the U.S. Department of the Interior for the Act will be given.

THE COASTAL BARRIER RESOURCES ACT: HISTORY, PRESENT STUDIES, AND RECOMMENDATIONS FOR THE FUTURE

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ABSTRACT: The history behind the Coastal Barrier Resources Act (CBRA) of 1982, the present Department of Interior responsibilities under the Act, and the recommendations to be submitted to Congress in October 1984 for consideration of additional legislation to conserve the natural resources of all of our nation's coasts, are the topics of this paper. A discussion of the definitions and criteria used to delineate the coastal barriers will be emphasized, with particular regard to the Gulf of Mexico coastline's areas.

For decades, public policy both encouraged development and fostered protection of coastal barriers. The Federal government invested millions of dollars to aid private development on some coastal barriers while, at the same time, it acquired other coastal barriers in order to protect their environmentally sensitive resources. Within the last few years, however, policy makers recognized these cross purposes: the costs of development--including the threats to humans and natural resources-- were recognized as being more significant than previously thought.

The Coastal Barrier Resources Act (CBRA), enacted in October 1982, reversed the Federal government's behavior. Leading up to this legislation, however, were five years of intensive work during which large amounts of scientific, technical, and descriptive information on the nation's coastal barriers were amassed; the coastal barrier units were identified and classified; analyses of Federal options for promoting the protection and appropriate use of the areas were prepared; a focus for collaboration among Federal agencies studying the barriers and the Federal policies and programs affecting them was provided; and a draft environmental impact statement was prepared.

During this period, Congress, too, had been considering coastal barrier needs, as well as the need to control spiralling and recurrent Federal expenditures. Legislation introduced in 1979 attempted to deal with these issues, but was not enacted into law. However, in August 1981, Congress did pass the Omnibus Budget Reconciliation Act (OBRA), thereby setting the stage for the passage of CBRA only fourteen months later. Essentially, CBRA established and identified the Coastal Barrier Resources System: a chain of 186 undeveloped and unprotected coastal barrier units on the Atlantic Ocean and Gulf of Mexico coasts which would be ineligible for most kinds of new Federal expenditures or financial assistance. Exceptions were made for defense needs, navigation requirements, energy development research, etc.

The Interior Department was given three specific responsibilities under the Act: (1) to manage the specific set of maps upon which the System is based, and which was adopted as part of the legislation; (2) to establish consultation procedures for the Secretary to deal with those wishing to act upon the exceptions of the Act; and (3) to prepare and submit to Congress by October 1984 a report with our findings of the System and our recommendations.

A number of actions have already been taken with respect to management of the maps and preparation of advisory guidelines and procedures for persons' use in consulting with the Secretary. Presently, we are (1) conducting an inventory of Atlantic and Gulf coasts' barriers that are now identified as protected; and (2) relying heavily on new aerial photography and existing Geological Survey topographic quadrangles as we accumulate data for evaluation, so we can identify coastal barriers on the Pacific coast, Great Lakes, and in the Caribbean, with the purpose of submitting both, this list of areas and the list for (1) above, to Congress for its consideration as additions to the Coastal Barrier Resources System.

Before issuing the October 1984 report to Congress, we will also study the Trust Territories and Alaska; hold a conference in Washington, D.C. in early 1984 whose emphasis will be on significant coastal barrier issues, particularly alternatives for the management of these areas; draw up a list of recommended deletions and/or modifications to the boundaries of the current System; and study the possibilities of changing the definitions of (1) a coastal barrier (so it would include areas of consolidated sediment in high energy areas like the Florida Keys, larger bays like the Chesapeake, and important biological habitats in intertidal zones which do not have a landward aquatic habitat), and (b) the "level of development."

During this process there will be many opportunities for the state and local governments, conservation groups, private citizens, and all others to submit their ideas and recommendations to the Department. We plan to keep everyone informed through the Federal Register and other means; we intend to keep the coastal barrier work a cooperative effort.

AS WE MOVE TOWARD THE YEAR 2000

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Thank you, George. It's a real pleasure for me to be here with you today. I always look forward to the opportunity to share a few ideas. Usually, I'm able to come to conferences and programs such as this at the outset and I'm able to learn something while I am here. Unfortunately, this time I only got to hear a few papers near the end of the conference.

I want to say a word of thanks to Steve Shabica and to June and many of you who have been involved in making this program a success. Steve indicated that over 100 people registered and that there has been good attendance throughout the program. I appreciate your taking time out of your very busy schedules to come and share some ideas on barrier islands in general and about Gulf Islands and concerns that we face, in particular.

My talk today, "As We Move Toward the Year 2000," is one in which I have great interest, but I'm sure you as scientists and resource managers are probably very skeptical of. I think you should be skeptical of anyone who wants to talk about the future as though he has any great insight into what the future may bring. We here today as scientists and as resource managers can be a major part, though, in shaping the direction that we will reach by the decisions that we make today and in the years to come. These decisions will put us in a place where we'd like to be by the year 2000.

My major theme today is to emphasize the importance of professional input into strategic planning if we are to arrive at where we wish to be in the year 2000. As you know, strategic planning is a systematic effort to see beyond the immediate, to look into the future, to predict trends and events that are likely to affect the way we do business, to insure that policies and decisions that we make today will have applicability to the situations that we face in the future. It involves the development of a proactive style rather than one that is reactive to situations.

Historically, people have always tried to guess or to predict the future. The very establishment of this country's first national park, Yellowstone, was a reaction to preserve an area for future generations from the predicted onslaught of timber harvest, wildlife loss, and other types of resource exploitation. Incumbent in predicting the future is often a fear of the future, and this is one area in which professionals have played a major role, that is, trying to deal with laymen and to assure them that the future is not something which needs to be feared. There are some notable examples of our colleagues in the scientific community, however, who have used this fear for their personal gain. Last night, I attended a meeting in Asheville, North Carolina, of the Governor's Task Force that deals with science and technology. It was an open forum for public input and public participation. One of the disturbing things that came out was that the trust on the part of the public was not very high in terms of the value of science. Those people felt that they were told many different things that did not work out to be the exact truths that scientists had indicated them to be at the time.

A couple of examples in our history probably bear some mention. There was a tremendous conflict in this country, as well as in Europe, over the introduction of railroads. Professional papers by some of the most noted scientists in Europe at the time stated that human beings could not withstand travel of 20 miles per hour. It was reported that their blood vessels would burst and that they would be unable to breathe. People would suffocate when passing through tunnels. Cows would drop dead at the sight of these monster-like machines.

The invention of the electric light bulb and the controversy that ensued between Edison and Westinghouse over the use of alternating versus direct current, is another good example. Edison's group believed very strongly in direct current. He funded a group of people to tour this country to publicly electrocute dogs and horses to show the dangers of alternating current. Through Edison's efforts to show the problem of alternating current, on August 6, 1890, William Kemmler became the first person to die in the electric chair. Public opinion was so altered by this public display, that many areas of this country used direct current up into the late 1950's. Unfortunately, there are many such examples carried out by our colleagues in our own community.

People are usually suspicious of change and new ideas, and I think rightly so. But it is this risk that we have to collectively take, if we are going to try to address the future. In 1925, Sir Alfred Whitehead wrote, "It is the business of the future to be dangerous." It is our business, I feel, to come to grips with the future through effective present action. The first step, in my judgment, is to try to understand what we've learned about the past. There is an abundance of pieces and fragments of information. Often, what is lacking is the conceptual overview, the conceptual framework or model that puts the various pieces together in such a way that understanding is possible.

What have we learned about barrier islands in the last 25 or 30 years? As a layman in this particular area, I'll share with you some of the things that I feel we have learned, just in my review of the literature.

We know that barrier islands, the ones that rim the coast from Maine to Texas, are of the Holocene era, about 5,000 years in age. This has been established through all sorts of core borings and carbon dating tests throughout our area.

We know that barrier islands are ephemeral sedimentary deposits that undergo rapid geomorphological and ecological changes. The morphology of beaches and barrier islands, including the inshore bars and the beach faces, the overwash terraces, the inlets and the dunes, are all products of interconnected natural processes that range in intensity from near-zero energy levels to extreme events such as storms. All levels of the process play a very important role in the maintenance of the natural balance of both the physical and the ecological systems. Periodic pulses of salt water serve as important factors in stimulating, retarding, or eliminating elements in coastal ecosystems. Therefore, overwash must occur if natural systems on barrier islands are to be perpetuated. Beaches and barrier islands are products of extreme events. Therefore, storm-caused changes are essential to the maintenance of natural landscapes.

We know that sea level is rising and we know the approximate rate. This long term adjustment is responsible for much of the erosion and barrier island migration that we observe.

One of the most significant developments in coastal science over the last 25 years has been the concerted effort to explain the regular and periodic variations in morphology of barrier islands. This research has now resulted in the conclusion that natural processes on barrier islands vary systematically along the coast, and that the patterns of erosion and overwash along one section of an island may occur at rates five times greater than those at sites just a few miles away.

We now better understand man's impacts on barrier islands. Although the principal agents of change on the beaches and barrier islands are geophysical and biological processes, many of the large scale landscape changes on barrier islands can be traced directly to man's activities. Cape Hatteras National Seashore is an excellent example. The dunes that we built did hold back the storm waves for a while and they did reduce overwash for a while. We're now losing those dunes at a very rapid rate. They also, during the time they were there, prevented the cross-island transport of sediment and salt water, thus preventing accretion on the Sound side of the barriers. They also did not allow for the disruption of the plant communities, so we have a very different vegetation pattern there than we once had.

We've learned a lot about barrier islands in the last 25 or 30 years, and undoubtedly you here in this room could add a great deal to the few comments I've made. But I think the question is, how will we use this information in light of anticipated changes that we can expect by the year 2000? The likely trends concerning economic growth, population and demographic changes, energy consumption rates, recreational demands, and a host of other important trends are well developed. For example, we can expect population growth in our coastal areas to increase at about 1 1/2 to 2 percent per year, which will be one of the highest growth rates of any area in the United States. We know that about 25 percent of our population will be over 65 years of age by the year 2000, and an increasing number of those people will choose to live in coastal areas. Compare that to 1900, when less than 5 percent of our population was over 65.

You probably ask, what difference does it make? It means that an awful lot of different types of services, facilities, and demands will be placed on local coastal communities. About 50 percent of our population growth in the Southeast will come from immigrants. What will be their views of our traditional activities in coastal areas? Will they accept the basic environmental ethic that we've tried to develop over the past 20 - 30 years? Will they accept our cultural heritage in these areas?

Our economic growth will become more global in terms of new markets. What role will harbor development, inlet stabilization, and channelization play in this economic growth period? Throughout the United States, the demand for recreation and leisure will continue to grow. It has grown at a rate of about 10 percent per year since the early 1900's. Undoubtedly, the coastal areas, long known for their recreational value, will experience even higher rates of demand.

We could go on and talk about the political representation that may shift, about how energy development may occur, and what technological innovations may also occur. What I'm suggesting through these few examples is an important second step. We need to get a good understanding of what the likely major trends are that are going to occur to the coast by the year 2000.

The third step, and really the most difficult one, is the coupling of what we know about barrier islands with what we predict will happen by the year 2000, that might impact or impinge on the decisions that we can make now concerning barrier islands. It is obviously the most challenging question of all, but it is in this arena that decisions will be made that will probably shape where we are in the year 2000.

When I started my presentation, I indicated that I would emphasize professional involvement in strategic planning. I'm not advocating plans in the traditional sense. In the Park Service we have great plans: we have shelves full of them. I am suggesting, however, that we as professionals continue, to the greatest extent possible, to engage ourselves in the very important decisions that affect barrier islands, and that we do this in concert with our basic understanding of barrier islands and with a knowledge of the predicted trends. If we don't guide the decisions and the policies with an understanding of the past and a sense of the future, then I'm afraid that the decisions may well be based on other factors. So let me conclude with some points that I think are pertinent in our effort as professionals to try to shape part of this future.

1. I feel that a comprehensive package, that explains what we know about barrier islands, that is in a readable, understandable style, must be made available to decision-makers.

2. I think you have probably done much of this at the conference already: We need to identify the major gaps in information that prevent wise decision-making concerning barrier islands. This needs to include both the generic gaps as well as the site-specific gaps. I would add that I feel these gaps should be identified by as broad a range of interest as possible, if we really hope to receive the necessary funds to be able to address these issues.

3. We need to identify the likely trends in our coastal areas, such as the few that I mentioned, that realistically impact what we are interested in concerning barrier islands.

Armed with an understanding of the past and a sense of the future, I feel professionals such as you here today can truly shape where we'll be in the year 2000. I'm very optimistic. Some of the legislation that Al Green mentioned, some of the decisions that I've seen in recent weeks, have assured me that we are probably moving in the right direction. We had a major issue at Cape Hatteras National Seashore that dealt with an enlargement of an inlet there for fishing purposes. The project has been underway for over 20 years, and about six weeks ago the Secretary denied the permit which would allow construction of major jetties there. It is probably one of the foremost environmental decisions in the State of North Carolina in recent times concerning national park areas. I'm very optimistic about it. I think there is a very bright future for us all, and it's a pleasure for me to be here with you.

Thank you.

DISCUSSION

HERKE: In order to qualify for flood insurance and so on, does the entire island need to be included, or can it be just a portion of the island?

GREENE: The idea of a barrier island was dropped early on. We didn't want to get into a big argument about whether it was a barrier island or not. We just simply used the word "barrier." A barrier, as I described earlier, has other criteria: it has to be at least one-quarter mile of beach length, and it has to be undeveloped, which means less than one structure per five acres, of 200 sq. ft., roofed and walled. But we don't want to talk about barrier islands. We're just talking about a barrier. It's any piece of land one-quarter mile long, that meets those criteria.

CROZIER: Al, I have something of the same question. I'm curious about the Fort Morgan Peninsula in Morgan County, which is an example of what you're talking about. It's not technically a barrier island but it is a coastal barrier. If a developer had begun, if he owns 50 acres of land and has begun his Phase 1, is all his property still eligible?

GREENE: There are some other parts of these definitions that got a little difficult at first, but we worked it out. The area can also be under what is called a "Phased Development." The phased development is an area which has paved roads to the dwelling, plus power, telephone, sewage, etc., which were placed there at the expense of the owner. That rules out a main highway going through or something that's being done by the county and so forth. I didn't want to hurt any individual who had put up a lot of money on something just because he hadn't gotten all the permits and he hadn't gotten around to actually putting the building up. The other part which was just mentioned was the phased development. That became the very difficult part of where somebody, by permit, by intent, brochures, the amount of money spent, had a very large development there, an infrastructure here, and another area which from the aerial photography looked like it was undeveloped, but there was enough money and enough intent and so forth there, that that was in the phase and it was accepted and was excluded as having to come under the law.

HANDLEY: I work for Minerals Management Service. I worked for the National Park Service for about four summers on the Southeast-Southwest Planning Team in Denver. One of the questions that always arose when we were developing General Management Plans, Development Concept Plans, and so forth, for many of these places was, what do you do about the politics? The people in Asheville, North Carolina had been led down the primrose path and had been told a lot of things for quite a while, that were at the time politically feasible to tell them. And so it is with Cape Hatteras. They've been led along; jetties have been put up; their property has been protected, and then all of a sudden it's cut off. You have a conference like this where you develop a lot of ideas and people are getting some sort of an understanding of what is going on. But, what happens to the politics in this situation? We can learn all we want about it, but what do we do when it becomes politically feasible to do something that is completely different like Act 41 for the State of Louisiana?

GOGUE: I'll give it a try. Virtually any major decision that a land management Agency has to try to address has four major components, and you've hit upon a very key one. I think the four components, whether it's the Forest Service or Fish and Wildlife Service or Park Service, that we've had to try to address are: (1) the scientific information or knowledge, (2) the professional judgment and tradition of the agency (its management style), (3) public opinion, and (4) the political arena. The only thing I can say in response to your question is that, depending on the issue that you face, one of those points that I have mentioned will be a larger component of the decision than others. There is no question in my mind that on many decisions, the scientific information carries substantial weight and the decision is made based on that. There are other times in which decisions are made in which public opinion shaped the direction of the decision. In the other case, I'd have to say park management shapes it and in still other cases, the major component is the political arena. I think your question is a good observation. Cape Hatteras received an awful lot of attention, from the 1950's when it became a national park site right on up until the early 1970's when we still built dunes and actually used helicopters to fertilize those dunes and tried to sow grass seed there. And so we went down a direction that we thought would work, and it didn't work. The only thing I can say is that probably because of what we learned in the interim, we changed our mind.

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