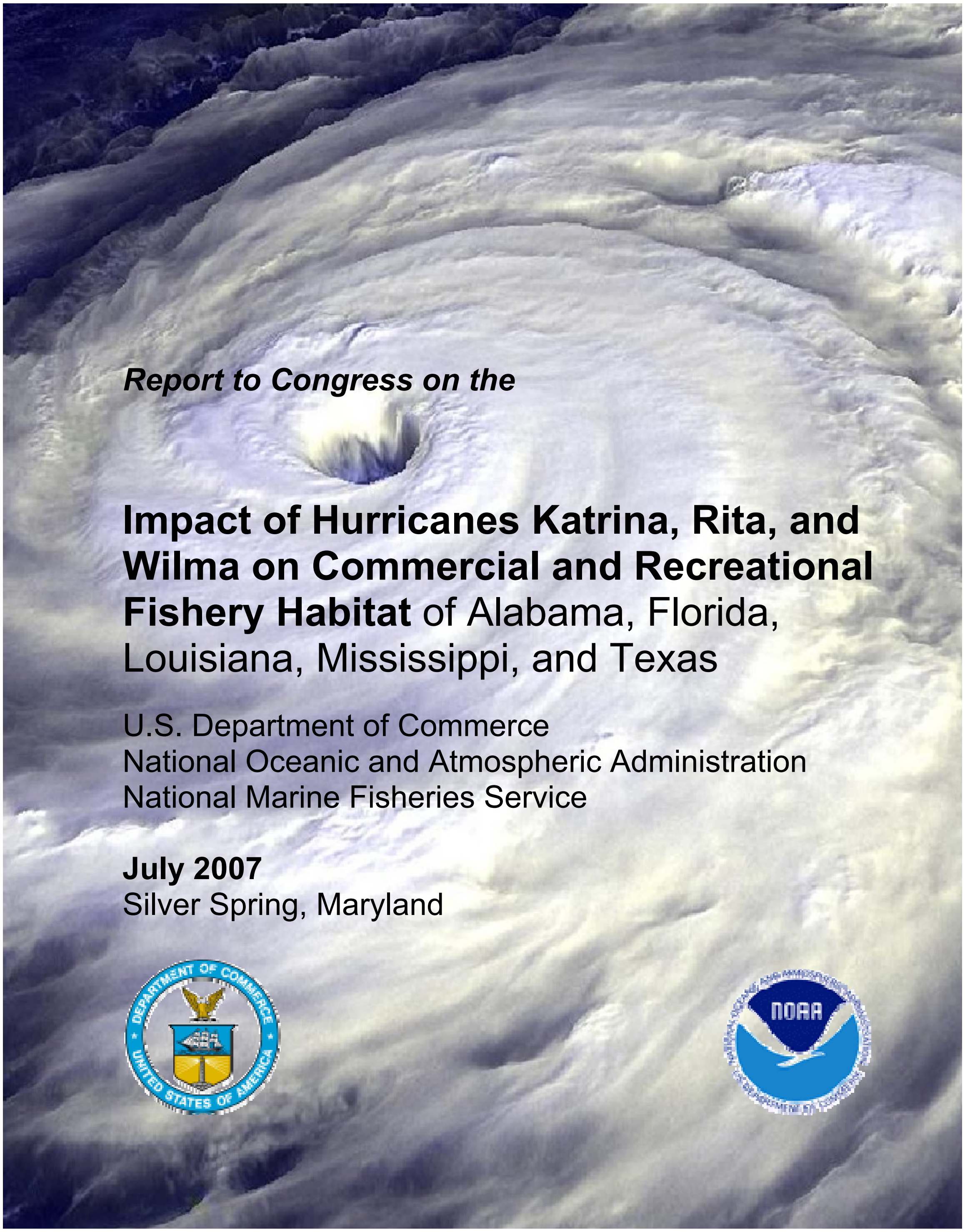

Report to Congress on the

Impact of Hurricanes Katrina, Rita, and Wilma on Commercial and Recreational Fishery Habitat of Alabama, Florida, Louisiana, Mississippi, and Texas

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

July 2007
Silver Spring, Maryland

Errata (8-7-07) – *Report to Congress on the Impact of Hurricanes Katrina, Rita, and Wilma on Commercial and Recreational Fishery Habitat of Alabama, Florida, Louisiana, Mississippi, and Texas* - The third and fourth full paragraphs on page 90 of the report have been corrected below (bold numbers). The error was the conversion of Tiner's 1,925,413 acres of Louisiana wetlands to mi^2.

Hurricanes Katrina and Rita greatly impacted remaining wetlands and may have caused the loss of 217 mi^2 (Barras 2006a, b). This would be a **3** percent loss of the remaining wetland acreage when compared to the **8,023** mi^2 of Louisiana wetlands estimated by Tiner (1991) in 1983. Using Barras' estimates (Barras et al. 2003) of wetland loss (see previous page) an additional 600 mi^2 might have been lost between 1983 and 2007 (a loss rate of 25 mi^2 per year for 24 years) bringing the wetland acreage down to **7,423** mi^2 for 2007. In this case the percent loss due to Hurricanes Katrina and Rita is still at **3** percent.

Turner (1992) using data from the northern Gulf of Mexico has estimated that approximately 1 acre of intertidal vegetation yields about 1 lb per yr of shrimp (Turner 1977). Alternatively, Turner's (1977) relationship between intertidal vegetation quantity and shrimp yield may be restated as an annual 1 percent decline in wetland area is equivalent to a 1 percent decline in fishing yield (GMFMC 2004). Using this estimate future estuarine dependent fish yield might be expected to decline **3** percent (per statements above). As reported earlier, initial reports from a fishery independent survey (November 2005) have not detected any decline and some species (including shrimp) have increased.

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Table of Contents

List of Figures

1.
Executive Summary

This report mandated by the U.S. Congress under Section 213(b) of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act discusses the impacts of the 2005 hurricanes Katrina, Rita, and Wilma on commercial and recreational fishery habitat, including that of shrimp and oysters, for the States of Alabama, Florida, Louisiana, Mississippi, and Texas. There is a companion report, *Report to Congress on the Impacts of Hurricanes Katrina, Rita, and Wilma on Alabama, Louisiana, Florida, Mississippi, and Texas Fisheries*, mandated under Section 213(a).

The U.S. portion of the Gulf of Mexico leads the nation in landings of shrimp, oysters, and blue crab. The habitat that supports these fisheries and coastal economies also supports community resiliency and protects infrastructure (e.g., ports, energy production, fisheries) vital to the Nation. This habitat and its ability to support fisheries and protect vital infrastructure is threatened by natural and anthropogenic factors. Among the threats are those of hurricanes, which exacerbate an already declining overall habitat condition.

Hurricanes Katrina, Rita, and Wilma were Category 3 storms at final landfall after weakening from Category 5 status as they approached the coast. Storm surges penetrated 6 to 29 mi inland and ranged from 4 to 28 ft in height. Winds at the time of landfall ranged from 115 to 127 mph, waves 6 to 12 ft at the beach (offshore up to 55 ft), and rainfall 3 to 15 in.

Hurricane Katrina first came ashore off the Atlantic Ocean between Hallandale Beach and Miami, Florida, as a Category 1 storm and moved westward across the Everglades to enter the Gulf of Mexico. Dade, Broward, and Palm Beach Counties, Florida, were in the northeast quadrant of the storm, considered to be the most destructive quadrant of the hurricane. Hurricane Katrina made a second landfall in Plaquemines Parish just south of Buras, Louisiana, and then impacted the Mississippi coast at Bay St. Louis-Pass Christian. Plaquemines and St. Bernard Parishes, Louisiana, and Hancock, Jackson, and Harrison Counties, Mississippi, were in the northeast quadrant of the storm. Hurricane Rita passed 50 mi. south of Key West, Florida, and veered northward to a landfall between Johnson's Bayou and Sabine Pass at about the Louisiana-Texas border. Monroe County, Florida, and Cameron Parish, Louisiana, were in the northeast quadrant of that storm. Hurricane Wilma first made landfall on the Yucatan peninsula before turning northeastward to make a second and more significant landfall in southwestern Florida near Cape Romano. Monroe and Collier Counties were in the stronger southeast quadrant of that easterly moving storm. These hurricanes impacted fishery habitat on the Atlantic coast of Florida as well as in the Gulf of Mexico. A discussion of impacts by state follows.

Identification of Impacts to Fishery Habitat

Where possible the report describes pre- and post-hurricane habitat conditions. However, much of the information in this report comes only from post-hurricane sampling and some is only qualitative or anecdotal. What follows are summary statements of impacts and important identified non-impacts.

Louisiana (Hurricanes Katrina and Rita)

- Over 100 mi^2 of coastal forests suffered major blow-downs and leaf and bark stripping.
- Freshwater fish and vegetation were killed by saltwater intrusion (via storm surge).
- Coastal freshwater to intermediate marsh vegetation was ripped, lifted, and moved by surge and waves, leaving bare mud, open water, and wracks of debris and vegetation; some freshwater vegetation was replaced on at least a temporary basis by more salt tolerant species. Pore water salinity in southwest Louisiana was abnormally high at least through March 2006 (i.e., 6 mos. after Hurricane Rita).
- Coastal marsh area decreased by 217 mi^2 (i.e., 8 to 10 times the annual rate of loss) according to initial estimates.
- Oyster reefs were buried by sediment and debris or scoured and rutted, resulting in up to a 74 percent loss for the entire state.
- Barrier islands were badly eroded (i.e., they lost area, were reduced in elevation and moved shoreward) (Chandeleur Islands suffered a 50 percent loss in area).
- Offshore habitat was disturbed at specific locations over a wide area (~28,000 mi^2) by debris from oil and gas pipelines and platforms and by huge storm-generated waves. The hurricanes aerated the water column, temporarily relieving low dissolved oxygen conditions in the hypoxic area of the Mississippi River plume.
- Hurricane caused debris gouged, scraped, dragged, covered, crushed, or broke habitat and/or biota upon which it sat or moved.
- Approximately 5,000 acres of habitat in the lower Mississippi River were impacted by 10 major oil spills.
- No significant or long-lasting chemical or biological contamination of seafood (i.e., oysters, shrimp, blue crab, or Atlantic croaker) or habitat occurred.
- Coastal Wetlands Planning, Protection and Restoration Act projects generally maintained their designed function in spite of adjacent severe hurricane damage (i.e., obliteration and removal of houses and dislodging of a large storage tank).

Mississippi (Hurricane Katrina)

- 1,890 acres of coastal marshes and forests (about 5 percent) were severely damaged or destroyed. Thousands of acres were covered with storm debris.
- Massive fish kills occurred in rivers and upper estuarine areas, caused by a combination of saltwater intrusion and low dissolved oxygen.
- Seagrass beds suffered severe impacts in the immediate proximity of the eye of Hurricane Katrina (i.e., lost 100 percent at West Ship Island and along the mainland coast at Waveland; lost 57 percent at East Ship Island). Otherwise seagrass suffered few impacts (i.e., some impact caused by hurricane debris).
- Mortality of oysters exceeded 90 percent for the entire state. Storm related debris impacted oyster reefs.
- About 85 to 90 percent of the nearshore and offshore artificial reefs were destroyed.
- Barrier islands were severely eroded. Their overall size and elevation and vegetative cover were significantly reduced by about 15 percent.
- No significant or long-lasting chemical or biological contamination of seafood or habitat occurred.

Alabama (Hurricane Katrina)

- Oyster reefs were mildly impacted (i.e., 20 percent loss) by Hurricane Katrina. However, they were still recovering from an 80 percent loss caused by Hurricane Ivan in 2004.
- No major loss of seagrass occurred.
- Some erosion of barrier islands occurred along with destruction of sea turtle nests.
- Debris scraped, gouged, covered, and crushed habitat and biota throughout the coastal region (e.g., beaches and shorelines, estuarine bottoms, and wetlands).

Texas (Hurricane Rita)

- The extent of impacts to oyster reefs in Galveston Bay and Sabine Lake is unknown.
- Barrier island shoreline of northeast coast eroded (i.e., lost 1 ft in elevation and retreated landward 98 ft between 2001 and 2005).
- 30,000 acres of freshwater to intermediate marsh in northeast Texas was put at risk because of shoreline erosion allowing more frequent saltwater wash-over and inundation of marsh.
- At Flower Gardens National Marine Sanctuary (more than 100 mi offshore) large coral colonies (10 to 13 ft in diameter) to depths of 236 ft were dislodged, overturned, and deposited in surrounding sand flats. Other coral was fragmented, scoured or detached.
- Of the other shelf edge reefs that were surveyed (i.e., Bright, Geyer, and Sonnier) to the east of Flower Gardens, only Sonnier Banks (about 100 mi. to the northeast of Flower Gardens) were heavily impacted.
- Large amounts of debris were deposited in Texas Point National Wildlife Refuge. Padre Island National Seashore reported tons of hurricane transported debris (including hazardous materials) drifted ashore.

- In November 2005 (nearly 2 mos. after Hurricane Rita), a tank barge struck an underwater obstruction (i.e., drilling rig sunk by Hurricane Rita) and released 1.8 million gallons of heavy fuel oil 30 mi to sea, south of Port Arthur. The impact of the spill on habitat and biota is being determined.

Florida (Hurricanes Katrina, Rita, and Wilma)

- 80 percent of turtlegrass (i.e., seagrass) in Caloosahatchee and St. Lucie Rivers was lost due to freshwater inflow, sediment loading, and nutrient increases from Lake Okeechobee following Hurricane Wilma.
- Northeast Florida Bay to Barns Sound experienced strong algal blooms, probably caused by nutrient runoff.
- Oyster reefs from Cedar Key to Pensacola were impacted by sedimentation and burial caused by the combined effects of Hurricanes Dennis, Katrina, and Rita. Oysters in the Naples area of south Florida experienced short-term impacts (i.e., structural changes, disruption of habitat utilization by mobile organisms, and disruption of reproduction) due to Hurricane Wilma.
- Mangrove forests were extensively damaged (i.e., defoliated and impacted by debris) by Hurricane Wilma. Damage extended from Charlotte Harbor to Everglades National Park and Great White Heron National Wildlife Refuge (WHNWR) in the Florida Keys. In general, higher mortalities occurred closer to the eye of Wilma, where mortalities ranged from 0 to 100 percent.
- South facing barrier islands and shorelines in Dade and Monroe Counties were eroded by Hurricane Katrina. Hurricane Rita eroded the lower Florida Keys from Islamorada to Boca Chica Key. Hurricane Wilma moderately to severely eroded beaches from Lower Matecumbe Key to Key West, and northward to Sea Oat Island in Collier County.
- At Canaveral National Seashore approximately 1,000 of 3,000 sea turtle nests were destroyed.
- Coral was damaged (i.e., displaced, sandblasted, broken, buried by sand and debris) by Hurricane Wilma from Palm Beach County south to Biscayne Bay National Park. Near Key Largo coral was damaged (i.e., reef framework dislodged, elkhorn coral branches broken off) by combined impacts of hurricanes Dennis, Katrina, Rita, and Wilma. In the Florida Keys National Marine Sanctuary coral was damaged (i.e., elkhorn coral branch tips broken off; restoration module dislodged, overturned, and buried in rubble) by the combined impacts of hurricanes Dennis and Katrina.
- Marine debris from Hurricane Wilma impacted seagrass beds, mangrove forests, hard bottoms, and coral reefs by abrasion, smothering, and preventing access to habitat by marine organisms.
- The passage of Hurricane Katrina reversed currents off the southwest coast of Florida (potentially impacting pink shrimp).
- The passage of Hurricane Katrina precipitously decreased salinities (i.e., enough to stress organisms) in Biscayne Bay and other south Florida estuaries. Overall, the passage of the three hurricanes decreased salinity in coastal waters due to rainfall and freshwater runoff.

- Increased nutrient runoff caused by the hurricanes resulted in increased chlorophyll, which likely decreased light penetration, adversely impacting both seagrass and coral.
- With the passage of each of the three hurricanes water temperature decreased about 4^{o} Celsius due to storm caused upwelling, which provided some thermal relief to counter coral bleaching as well as nutrients to enhance phytoplankton blooms.
- Hurricane Wilma suspended bottom sediments off Miami for at least several days, potentially adversely impacting coral.

Significance of Hurricane-Caused Habitat Impacts

The habitats discussed in this report (i.e., coastal forests, emergent intertidal wetlands, seagrass meadows, oyster reefs, mangrove forests, barrier islands and shorelines, offshore soft bottom, coral reefs and shelf edge reefs) provide vital support to fisheries, the coastal ecosystem, and coastal communities of the Atlantic coast of Florida and the Gulf. These highly productive and physically diverse habitats provide food and shelter to fishery species and help determine their distribution, abundance, and health. As such they have been identified and recommended for designation as "essential fish habitat (EFH)" and "Habitat Areas of Particular Concern (HAPC)" by the Gulf of Mexico Fishery Management Council and the South Atlantic Fishery Management Council. Subsequently, these actions were approved by the NOAA National Marine Fisheries Service (NMFS). Certain of these habitats (i.e., coastal forests, emergent intertidal wetlands, oyster reefs, mangrove forests, and seagrass meadows) buffer and improve habitat conditions by filtering and removing water-borne contaminants and suspended material. Coastal habitats (i.e., barrier islands and shorelines, coral reefs, nearshore artificial reefs, mangrove forests, seagrass meadows, oyster reefs, and emergent intertidal wetlands) also contribute to the coastal ecosystem by absorbing energy from storms and hurricanes, thereby protecting more landward habitats, coastal communities, and infrastructure vital to the Nation.

Emergent Intertidal Wetland Habitat
Hurricanes Katrina and Rita greatly accelerated ongoing rates of loss of emergent intertidal wetlands along perhaps 50 percent of the coastline in the region of the Gulf of Mexico, where emergent intertidal wetlands are most abundant (i.e., northern Gulf from Galveston Bay, Texas to Cedar Key, Florida). The loss of these wetlands is thought likely to have direct, negative, and long-lasting impacts on fisheries (e.g., shrimp, oysters, blue crab, etc.). Historically, wetlands lost to open water are not regained.

Oyster Habitat
Oysters are found almost everywhere in the Gulf of Mexico north of Oyster Bay near Cape Sable, Florida. Prior to 2004, Florida had 186,160 acres of oysters. Oyster reefs in the northern Gulf of Mexico were most extensive in Louisiana (40,000 acres), of which nearly 35,000 acres (87.5 percent) were located east of the Mississippi River (LDWF

2002). Texas had about 36,150 acres of oyster reefs. In Mississippi, oyster reefs covered approximately 12,000 acres. In Alabama, oyster reefs covered about 4,700 acres.
The passage of Hurricane Katrina caused mortality of at least 90 percent of the oysters associated with reefs in Mississippi (MDMR/OMF 2005) and, together with Hurricane Rita, caused mortality of 20 to 74 percent of the oysters associated with reefs in Louisiana (50 to 73 percent mortality in southeast Louisiana caused by Hurricane Katrina and 30 to 40 percent mortality in southwest Louisiana caused by Hurricane Rita) (Caffey 2006; Roussel 2006; P. Banks 2007, pers. comm.). Alabama's oysters were still recovering from Hurricane Ivan which struck in 2004 and wiped out 80 percent of the harvest. Hurricane Katrina damaged only about 20 percent of Alabama's oyster beds (Impact Assessment 2007). The extent of injury to oysters in Texas from Hurricane Rita is unknown. Hurricanes Dennis, Katrina, and Rita impacted (i.e., caused sedimentation and burial) oysters between Cedar Key and Pensacola, Florida, but the impacts were not differentiated among the storms. Hurricane Wilma caused some short-term minor impacts to oyster habitat in south Florida near Naples.

Storm surge, waves, and resultant currents from Hurricane Katrina caused scouring of sediment, excavation of gullies in oyster reefs (particularly in western Mississippi Sound), and burial of oysters in both Louisiana and Mississippi (MDMR/OMF 2005; Roussel 2006). Although oysters can tolerate thin layers of sediment or partial burial, complete burial by gradual, natural sediment accumulation or catastrophic events (e.g., a flood or hurricane) will kill them (Britton and Morton 1989). Debris from land, adjacent marshes, and seagrass beds was found covering the reefs in Mississippi. Such debris gouged, broke, and buried live oysters.

Concern for contamination carried by floodwaters from Hurricane Katrina resulted in surveys to measure concentrations of contaminants in oysters. Generally, there was insignificant contamination of oysters from Louisiana, Mississippi, and Alabama. No surveys were undertaken in Texas or Florida.

The long-term locations and abundances of oysters in the Gulf of Mexico have varied due to natural and anthropogenic factors. Because oysters require two or more years to grow to marketable size, full recovery from these hurricanes may take years, and some oyster habitats may be lost permanently. However, oyster reefs have endured on a large scale because they are naturally adaptive and are managed intensively. When they are damaged, individual states reconstruct and rehabilitate the reefs.

Seagrass Meadow Habitat

Seagrass meadows generally were not significantly impacted by the hurricanes except for those in close proximity to the eyes of the storms. Those near to the eyes of hurricanes Katrina and Wilma were destroyed or severely impacted. Hurricane Rita did not impact seagrass meadows, because the storm's track and area of landfall "avoided" areas of significant seagrass.

Mangrove Forest Habitat
Mangrove forests were severely impacted by Hurricane Wilma from the Great White Heron National Wildlife Refuge (in Florida Keys near Key West) and Everglades National Park to Charlotte Harbor, approximately 50 percent of the area over which red mangroves occur in the U.S. portion of the Gulf of Mexico.

Barrier Island and Shoreline Habitat
Barrier islands and shorelines from northeast Texas to Alabama and in south Florida (i.e., from Dade and Monroe Counties through the Florida Keys to Naples, Florida) were moderately to severely eroded by hurricanes Katrina, Rita, and Wilma.

Offshore Soft Bottom Habitat
Offshore soft bottom habitats had no documented impacts from the hurricanes except for the addition of oil and gas platform and pipeline debris (including ~600 pipeline segments of varying length), which may be permanent if the debris is not removed from specific locations over a wide area (~28,000 mi^2).

Shrimp Habitat
Brown shrimp and white shrimp are concentrated in waters and estuaries of the northern Gulf of Mexico (mainly off Texas and Louisiana), and pink shrimp are most abundant near southern Florida. Within estuaries, high densities of all three species are associated with vegetation (either emergent marsh or seagrass meadows). Offshore, adult white shrimp occur to depths of about 130 ft, pink shrimp to about 210 ft and brown shrimp to about 360 ft. Adults of the three species generally live and spawn in waters on the continental shelf; the planktonic larvae are carried by currents to estuarine nursery habitats where postlarvae grow to become subadults over a period of several months. Subadults then migrate offshore.

Hurricanes Katrina and Rita greatly accelerated (i.e., 8 to 11 times) ongoing rates of loss of emergent marsh along perhaps 50 percent of the coastline in the region of the Gulf of Mexico, where emergent wetlands are most abundant (i.e., northern Gulf from Galveston Bay, Texas to Cedar Key, Florida). Strong correlations have been demonstrated between penaeid shrimp yield and wetland area in the Gulf of Mexico. Most juvenile shrimp production occurs along the marsh edge, and this is probably why marsh edge length is the best predictor for inshore shrimp catch. As a marsh begins to break into pieces, the amount of marsh edge increases. At some point, continued wetland erosion will reduce marsh edge as the remaining fragments of marshland convert to open water. At that time or shortly thereafter, a decline in wetland-dependent fisheries (e.g., shrimp, oysters, and blue crab) is predicted. The hurricane-induced loss of wetlands may diminish shrimp production in the future, but the timing and magnitude of the reduction is uncertain.

Seagrasses occur in all states on the Gulf of Mexico, although they are nearly extirpated from Louisiana. Seagrass meadows generally were not significantly impacted by the hurricanes except for those in close proximity to the eyes of the storms. Those near to the eyes of hurricanes Katrina and Wilma were destroyed or severely impacted. Hurricane Rita did not impact seagrass meadows, because the storm's track and area of landfall "avoided" areas of significant seagrass. Seagrass loss from the 2005 hurricanes is unlikely to reduce shrimp production.

Adult shrimp utilize offshore water column and benthic habitats. With the exception of marine debris, hurricane effects on these habitats are believed to have been ephemeral or inconsequential. The effect on shrimp of additional marine debris on benthic habitats is uncertain.

Coral Habitat
A significant area (i.e., from Florida Keys National Marine Sanctuary to Delray Ledge in Palm Beach County, Florida) of the shallow water reef coral in the mainland U.S. was heavily damaged by all three hurricanes. The shelf edge reefs at Flower Gardens National Marine Sanctuary were extensively damaged by Hurricane Rita. Of the other shelf edge reefs that were surveyed (i.e., Bright, Geyer, and Sonnier) to the east of Flower Gardens, only Sonnier Banks (about 100 miles to the northeast of Flower Gardens) were heavily impacted.

Discussion
Ordinarily habitat is thought of only in the positive sense (i.e., the more, the better) as supporting fisheries by supplying food and providing safe and healthy refugia, spawning and nursery areas. As habitat degrades or is reduced in area, such habitat can limit the quantity or quality of fishery resources in three ways – 1) by limiting suitable space, shelter, vital nutrients, or food; 2) by interfering with physiological functioning or reproduction via contamination; or 3) by contaminating the tissues of fishery species so that they are no longer suitable for human consumption as seafood or safe as pet food. There is no evidence that tissues of fishery species in the Gulf of Mexico were made unfit for human or pet consumption by the impacts of Hurricanes Katrina, Rita, or Wilma. Except in areas impacted by oil spills, there is no documentation that the hurricanes caused contamination levels that interfere with the physiological functioning or reproduction of fishery species. However, it appears that as the area of emergent intertidal wetlands decreases and open water increases, a tipping point between wetlands and water is approaching, whereby the quantity of marsh edge ceases to increase and begins to decrease. Based on research it is known that shrimp abundance is dependent, among other factors, on the amount of marsh edge. Hurricanes have exacerbated the loss of emergent intertidal wetlands and are hastening the day marsh edge begins to decrease and reduce the abundance of shrimp in the northern Gulf of Mexico.

Most of the habitats discussed in this report (except oyster reefs, which are intensively managed by the states, and offshore soft bottom habitat) are in broad general decline (due to natural and anthropogenic effects). The ecological services provided by these habitats are declining as well. Hurricanes exacerbate and hasten the general decline of these habitats. Some habitats (i.e., seagrass meadows, offshore soft bottom) appear to be mostly resilient to the impacts of hurricanes. Other habitats (i.e., coral reefs, shelf edge reefs, oyster reefs, mangrove forests, and coastal forests), take several to many years to recover after being impacted by hurricanes. Finally, some habitats (i.e., barrier islands and shorelines, emergent intertidal wetlands, nearshore artificial reefs, oyster reefs, and some coastal forests and mangrove forests), because of physical destruction or burial caused by hurricanes in the absence of natural repair mechanisms (e.g., significant input of freshwater, sediment and nutrients), may not recover within a useful timeframe without human intervention. This leads to a discussion in the next section of the kinds of actions that are being taken or might be taken to: 1) help fishery habitat recover from the impacts of Hurricanes Katrina, Rita, and Wilma; 2) lessen the impacts of future hurricanes on fishery habitat in the U.S. portion of the Gulf of Mexico; and 3) reverse the general decline of fishery habitat of the U.S. portion of the Gulf.

Actions to Mitigate or Prevent Future Injury to Fishery Habitat

The response to habitat effects caused by Hurricanes Katrina, Rita, and Wilma is defined by actions of the Federal Government and the States of Florida, Alabama, Mississippi, Louisiana, and Texas. Some of these actions were in place before the hurricanes struck while the remainder were implemented in response to one or more of the hurricanes. No overarching plan which encompasses or consolidates all of the actions exists.

Presently, no comprehensive, region-wide assessment exists of the successes achieved by implementing the programs described. It has been less than two years since the hurricanes struck, and many efforts have been operational for 15 months or less. Nevertheless, several recovery activities are noteworthy, specifically those relating to the restoration of oyster habitat (e.g., Mississippi planted culch over 175 acres and installed more than 75,000 sacks of seed oysters through March 2007) and the removal of hurricane-generated debris (e.g., Florida removed about 500 derelict vessels from coastal habitats and recovered over 45,000 abandoned or lost lobster traps).

The first three actions below are applicable to the Gulf of Mexico as a region, and cross state boundaries. Following these are the actions that apply to each of the Gulf states.

The Fishery Disaster Recovery Program administered by the National Marine Fisheries Service (NMFS) under Section 312(a) of the Magnuson-Stevens Fishery Conservation and Management Act has provided approximately $127 million to the Gulf States Marine Fisheries Commission to be apportioned to the states for recovery of oyster and shrimp industries and habitat damaged by the 2005 hurricanes. The monies have been transferred to the states, and work is underway on oyster rehabilitation, debris removal, and marsh and artificial reef restoration.

The Coastal Impact Assistance Program (CIAP), administered by the U.S. Department of the Interior's (DOI) Minerals Management Service under the Energy Policy Act of 2005, is providing $250 million per year for fiscal years 2007 through 2010 to oil and gas producing states (i.e., Alabama, Alaska, California, Louisiana, and Texas) that submit a plan of activities for the conservation, protection, or restoration of coastal areas, including wetlands impacted by Hurricanes Katrina and Rita. The planning process for funding projects is underway or nearing completion.

The Gulf of Mexico Fishery Management Council has identified essential fish habitat (EFH) per the Magnuson-Stevens Act and the NMFS subsequently approved the identification. The NMFS is required to provide EFH conservation recommendations whenever a federally sponsored or permitted activity may adversely affect EFH. Since implementing regulations for EFH conservation were promulgated in January 1997, NMFS has acted on thousands of projects to help avoid, minimize or mitigate the losses on EFH that would otherwise have resulted from federal actions. Over the years, the EFH conservation program has contributed to the protection and conservation of thousands of acres of habitat in the Gulf of Mexico that supports commercially and recreationally important fish stocks. This on-going activity by NMFS will continue to provide a layer of oversight and protection for these important fishery habitats.

Louisiana

- Projected to receive up to $523 million in CIAP funds over four years to manage Mississippi River water and sediment, protect and restore critical land bridges, restore and protect barrier and interior shorelines, create marsh, conserve coastal forests, and mitigate Outer Continental Shelf oil and gas activity impacts onshore.
- The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) of 1990 has provided about $643 million in federal funds administered by the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service (FWS), NOAA National Marine Fisheries Service (NMFS), Natural Resources Conservation Service (NRCS), and the State of Louisiana for the restoration and protection of coastal wetlands. The program has funded 78 projects and constructed 70 of them re-establishing or protecting approximately 70,616 net acres and enhancing an additional 320,354 acres of wetlands. These projects generally maintained their designed function in spite of the hurricanes. NOAA-NMFS is serving as lead agency on 25 projects.
- The Louisiana Coastal Area (LCA) Ecosystem Restoration Study to reverse the current trend of degradation of the coastal ecosystem is overseen by the USACE. Fifteen critical restoration projects have been identified to help counter long-term habitat loss as well as offset the fishery habitat impacts caused by Hurricanes Katrina and Rita. The USACE expects to develop nine beneficial use of dredged material projects in the first three years of the program to help rebuild barrier islands. During FY07, the USACE expects to develop project management plans and cost share agreements for the Myrtle Grove Freshwater Diversion, the Mississippi River Delta Management Study, and the Chenier Plain Freshwater and Sediment Management Study all aimed at actions to counter habitat loss. At this time they have planning dollars, but no construction funding. NOAA Fisheries is cooperating with the USACE.
- Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006 (4th Supplemental) for Flood Control and Coastal Emergencies:
    - Directs the Secretary of the Army through the USACE to reduce the risks of storm surge and storm damage to the greater New Orleans area by restoring the surrounding wetlands ($20.2 million); modifying the Caernarvon Freshwater Diversion ($10 million) to create marsh; and

developing a plan (at full Federal expense) to deauthorize (i.e., plug and/or reduce deep draft channel to 12 ft.) the Mississippi River Gulf Outlet to cut storm surge, protect channel-side wetlands from wake-induced shoreline erosion, and prevent saltwater intrusion into freshwater habitats (interim report to Congress submitted December 2006; Final Technical Report due December 2007).
    - Directs NOAA-NMFS through the Fisheries Disaster Recovery Program to provide assistance for recovery of oyster, shrimp and other fishery habitat. Louisiana is receiving $52.9 million from this fund for surveys, rehabilitation, restoration, and monitoring of oyster grounds.
    - The U.S. FWS is authorized under Chapter 5, 120 STAT. 460 additional funding for expanding an existing rock dike on Lake Ponchartrain to protect tidal brackish marsh from wind-wave shoreline erosion (cost unknown) and conducting associated wetland plantings to restore and enhance tidal marsh ($161,000 for plantings).
    - The NRCS is authorized under Chapter 5, 120 STAT. 444 and Public Law 109-148 (119 STAT. 2748) funding to remove and dispose debris and animal carcasses in order to restore water conveyance to pre-storm conditions (e.g., salinity, water quality). Over 200,000 carcasses have been removed.
- The Louisiana Coastal Protection and Restoration Project (LaCPR), overseen by the USACE under the Energy and Water Development Act of 2006 and the Department of Defense, Emergency Supplemental Appropriations to Address Hurricanes in the Gulf of Mexico, and Pandemic Influenza Act of 2006, as part of both the 3rd and 4th emergency supplements of the Defense Appropriations Act, is to develop a hurricane protection plan at full federal expense for flood control, coastal restoration, and hurricane risk reduction. Funding has not been authorized for constructing restoration projects under the LaCPR. A final report is due December 2007.
- The NOAA-NMFS Community-based Restoration Program (CRP) in Louisiana has partnered with industry and landowners to build projects that not only restore marine fisheries habitat, but help protect critical infrastructure as well. In Louisiana 35 projects have been funded (12 after the 2005 hurricanes), directly benefiting over 4,500 acres. These projects have leveraged an average of $3.20 for every federal dollar spent and have accumulated over 30,000 volunteer hours.
- The Louisiana Regional Restoration Planning Program (LRRPP) is designed to expedite the restoration of Louisiana's marine habitats injured by frequent oil spills, including those caused by hurricanes. Natural resource trustees, including NOAA-NMFS, the U.S. Department of the Interior, and the State of Louisiana, developed the statewide program. Under the LRRPP the state is divided into nine regions and for each region a Regional Restoration Plan will describe the resources and services likely to be injured, suitable restoration types for various injuries, and available projects that can be implemented at the local level to compensate for these injuries.
- The Coastal Protection and Restoration Authority (CPRA) created by Act 8 (signed by the Governor of Louisiana) is charged with developing a Master Plan

(submitted to the State Legislature April 30, 2007, and unanimously approved on May 30, 2007) to coordinate the efforts of local, state, and federal agencies to achieve hurricane protection and coastal restoration needed to provide for a safe and sustainable Louisiana.

Mississippi

- Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006 (4th Supplemental), directs NOAA through the Fisheries Disaster Recovery Program to provide $37.1 million to survey, map, rehabilitate, restore, and monitor oyster grounds, marsh areas, and artificial reefs. Oyster reef surveys, mapping, rehabilitation and restoration are well underway. As of March 2007, 240 pyramid reefs have been installed under Mississippi's Artificial Reef Program since Hurricane Katrina. Additionally, over 9,600 derelict crab traps have been removed from the fishing grounds.
- Under the Department of Defense Appropriations Act, 2006 (P.L. 109-148; enacted December 30, 2005), the U.S. Congress designated $10 million to the USACE to expedite studies of flood and storm damage reduction, prevention of saltwater intrusion, preservation of fish and wildlife, and prevention of erosion related to the consequences of hurricanes on the coastal area of Mississippi (i.e., Mississippi Coastal Improvements Program). The Act also requires the USACE to provide an interim report by June 30, 2006, and a final report by December 30, 2007. NOAA-NMFS is coordinating with the USACE in the planning process.
- The CIAP, administered by the Minerals Management Service (MMS) under the Energy Policy Act of 2005, is providing $30.39 million per year for FY07 and FY08 for the conservation, protection, or restoration of coastal areas, including wetlands, and mitigation of damage to fish, wildlife, or natural resources.
- The report of the Governor's Commission on Recovery, Rebuilding, and Renewal notes activities already underway (i.e., debris removal and oyster reef rehabilitation) and recommends restoration of coastal wetlands and forests, riverine floodplains, nearshore areas, and a barrier island. It supports a survey of habitat types, development of an estuarine habitat restoration plan, examination of potential long-term restoration efforts, and the use of rubble for creating reefs and wave attenuation structures. It also recommends rebuilding the Seatrout Hatchery and developing aquaculture. Projected costs are estimated to be about $158 million; the State of Mississippi has not identified a funding source.

Alabama

- Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006 (4th Supplemental) directs NOAA through the Fisheries Disaster Recovery Program to provide $29.6 million to Alabama to identify and map oyster, shrimp and other marine fishery habitat, restore oyster habitat, and control shoreline erosion.
- The CIAP, administered by the MMS under the Energy Policy Act of 2005, is providing $25.55 million per year for FY07 and FY08 for the conservation,

protection, or restoration of coastal areas, including wetlands, and mitigation of damage to fish, wildlife, or natural resources.

Texas

- Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006 (4^{th} Supplemental) directs NOAA-NMFS through the Fisheries Disaster Recovery Program to provide $3.2 million to the State of Texas to purchase vessel and side-scan equipment to determine the condition of oyster reef habitat in Sabine Lake and Galveston Bay. Data are to be collected during the winter seasons 2008 to 2010.
- The CIAP administered by the Minerals Management Service under the Energy Policy Act of 2005, is providing $48.59 million per year for FY07 and FY08 for the conservation, protection, or restoration of coastal areas, including wetlands, and mitigation of damage to fish, wildlife, or natural resources. More specifically, Texas plans to survey and rehabilitate oyster habitat damaged by Hurricane Rita, restore the upper coast beaches in Jefferson County, conduct stabilization of shoreline in Orange County, and conduct topographic profiles of selected coastal beaches.
- The National Wildlife Refuges (NWR) along the Texas coast recommended a list of projects (i.e., shoreline protection, dune restoration, marsh restoration, and debris removal) to protect marsh habitat behind the barrier shorelines. A source of funding has not been identified for these projects.

Florida

- Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006 (4^{th} Supplemental), directs NOAA-NMFS through the Fisheries Disaster Recovery Program to provide $4.2 million to the State of Florida to restore damaged oyster reef habitat.

Recommendations

The data collected and analyzed for this report clearly reflect the ferocity of Hurricanes Katrina, Rita, and Wilma, the devastating and far reaching effects on habitats of the winds, flooding waters, and waves generated by the storms, and the collateral damage inflicted by debris scattered by the storms. The data also show that existing programs of large-scale conservation and restoration provide some hazard protection benefits but more such work is needed. It is clear that:

> *Restoration and protection of coastal wetlands and barrier islands will assure critical habitats for estuarine-dependent seafood species, and will act as a first line defense for the protection of coastal communities from a range of hazards* (NMFS 2006a).

Recommendations are grouped into two categories. Many significant government actions have been on-going since well before Hurricanes Katrina, Rita, and Wilma; other actions have been initiated in the wake of the storms. Several are singled out because of their value for short-term habitat protection and restoration and/or long-term re-establishment of natural ecosystem functions that support the valuable fisheries of the region. In addition, a series of actions is highlighted if the Nation is to: (1) more effectively manage fisheries habitat and associated fish stocks, (2) reduce impacts from future devastating tropical storms in the region, and (3) better respond to and learn from future events.

NOAA supports the listed programs in their stated goals and objectives. These address fishery-related habitats along portions of the northern Gulf of Mexico:

- The Louisiana Coastal Area Ecosystem Restoration (LCA) study, its components and recommendations that would rebuild or enhance living marine resource habitats.
- The Louisiana Coastal Protection and Restoration Project process.
- The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) projects and the adoption of the CWPPRA governance approach for other restoration programs in Louisiana and other states. The latter would enable federal partners to work with the USACE and the states cooperatively to protect and restore vital wetland habitats.

> *Stemming and then reversing the loss of coastal wetlands and barrier islands of the region will require a substantial increase in the number of projects currently funded or proposed. Because NOAA administered CWPPRA projects survived Katrina and Rita so well, these investments in wetland rebuilding, if replicated on a larger scale, could contribute to a more resilient coastal wetland network in the Gulf. These projects are a model for wetlands rebuilding should funds become available to scale-up protection programs consistent with the magnitude of the problem* (NMFS 2006a).

- The Coastal Protection and Restoration Authority process to achieve long-term and comprehensive coastal protection and sustainability for the coastal ecosystem, including fishery habitat in the State of Louisiana.
- The Mississippi Coastal Improvement Program process and continued coordination with the USACE on the projects as they advance through plan formulation, implementation, and post-construction monitoring.
- The Mississippi Governor's Commission Report as it advances beyond the conceptual stage and moves into the planning process.
- The Louisiana Regional Restoration Planning Program to expedite remediation and restoration of marine habitats injured by frequent oil spills, including those caused by hurricanes.

The above programs provide a solid foundation upon which to build a comprehensive, system-wide strategy for coastal habitat protection and restoration. As was reported in the Plan for Recovering Gulf of Mexico Fisheries Using an Ecosystem Approach (NMFS 2006a):

> *Rebuilding the coastal wetlands is a key component of improving community protection and restoring ecological function. While damage can never be*

prevented fully, restoration of these natural areas can mitigate a considerable amount of coastal inundation from storm surge, and protect vulnerable man made structures at the water's edge. Levees should be viewed as the ***last*** *line of defense for coastal communities, not the first and only. Barrier islands, coastal wetlands and levees working together can provide a tiered approach to defending coastal towns and cities in the Gulf region* (NMFS 2006a).

The analyses underlying this report underscored several issues that deserve action:

- Rebuilding and maintaining the extensive system of wetlands historically nourished by the Mississippi delta are essential for the health of estuarine-dependent fish populations, enhancement of Gulf water quality in areas influenced by the Mississippi River plume, and heightened storm protection for natural and human systems in the coastal zone. A key element is re-establishing freshwater and sediment supplies to deltaic wetlands of the area. Approaches should be implemented that allow predictable and regular deliveries of water and sediment to deteriorating coastal marshes while protecting human settlements, economic interests, and vital infrastructure.
- Barrier islands offer demonstrated protection against the effects of major storms on coastal wetland systems; however, geological processes that naturally create these features presently are hampered by insufficient sediment supply. Human restorations of barrier islands, such as those undertaken under the aegis of the Coastal Wetland Planning, Protection and Restoration Act, are effective as partial solutions but come at high cost. Re-establishing permanent freshwater and sediment delivery to re-nourish barrier islands is likely to be a more efficient and cost effective option over the long run. In the interim, a combination of restoration and sediment and water flow enhancements will be needed.
- Programs which identify and reverse key wetland losses inflicted by the 2005 hurricanes and which protect and restore wetland habitat deserve robust support (e.g., at the McFaddin complex in Texas, restoring dune and beach areas would support wildlife and marine fishery production and protect interior wetlands from future hurricanes).
- Greater efforts must be made to conserve Essential Fish Habitat as a means to preserve the long-term vitality of coastal wetlands and related habitats that sustain healthy fish stocks, diminish storm impacts, and protect coastal communities and critical national infrastructure. Such actions to conserve existing habitat, taken in advance of storm events as opposed to after-the-fact restoration, would diminish the need to invest future resources for restoration and enhancement of habitat and for repair or replacement of infrastructure. Proactive efforts must engage stakeholders to identify and implement needed protection and conservation measures.
- Baseline assessments are required against which to compare the effects of future hurricanes and major storms along the Gulf and Atlantic coasts. No such comprehensive data set and analyses were available in the aftermath of the 2005 hurricane season, making assessments of the extent, severity, permanence, and implications of damage difficult or impossible to undertake.

- Federal agencies in partnership with the states must develop and implement plans to respond to future storms to collect a pre-determined suite of data using commonly-accepted protocols. Such plans should identify sites to which data will flow for analyses. Such sites must have the capability to produce region-wide analyses on time frames of weeks to months instead of years.
- A complementary mechanism is needed to assure the information from the above analyses is disseminated to on-the-ground managers in readily usable formats on a scale of weeks to months. Such analyses might target areas most in need of restoration and advise local and state governments on reconstruction that maximizes future protection, while avoiding past mistakes or harming remaining habitats. Such analyses might also be useful in identifying needs and opportunities for focusing conservation and protection efforts, so as to maximize the amount of habitat set aside from other uses that impair that habitat's capacity to provide storm protection services as well as beneficial ecosystem functions.
- The linkage between habitat (quality and quantity) and fisheries production must be mathematically defined to produce more precise estimates of the effects of habitat loss on fisheries and apply an ecosystem approach to the management of fisheries. This will require significant enhancements of research, assessment and monitoring. While this will be a costly undertaking, failure to make this investment will foreclose options for future generations. For the first time in history, society has the computational tools, the ecological understanding, and the observational capabilities to significantly enhance the precision of fishery and habitat management approaches.

2. Introduction

Background

In 2005, three major hurricanes struck the Gulf Coast of the United States. All three made landfall as Category 3 storms after weakening from Category 5 status as they approached the coast.

- Hurricane Katrina crossed the southern tip of Florida on August 25, 2005, causing significant flooding as a Category 1 storm, and then entered the Gulf of Mexico. Katrina made landfall in southeastern Louisiana on the morning of August 29, 2005, with sustained wind speeds of 127 miles per hour (mph). It caused a maximum storm surge of 24 to 28 feet that penetrated at least 6 miles inland and up to 12 miles along bays and rivers along the Mississippi coast. A large portion of southeastern Louisiana and southwestern Mississippi received 8 to 10 inches of rain, with some areas receiving 12 inches, which contributed to significant flooding.

- Hurricane Rita passed south of Key West, Florida, on September 20, 2005, causing a 3- to 5-foot storm surge in this area. After crossing the Gulf, it made landfall on the Louisiana–Texas border on September 24, 2005, with sustained winds of 115 mph. The storm surge here was difficult to determine due to the associated destruction, but it is believed to have been as high as 15 feet. Rainfall totals of 5 to 9 inches were common, with some isolated maxima of 10 to15 inches.

- Hurricane Wilma crossed the Caribbean Sea to strike Mexico's Yucatan Peninsula before turning northeastward to make landfall on the southwestern coast of Florida on October 24, 2005. Wilma had sustained winds of 121 mph and crossed the Florida peninsula in 4.5 hours to enter the Atlantic Ocean as a Category 2 storm. It caused a storm surge of 4 to 8 feet for coastal Collier County and 15 feet in Everglades National Park (Smith et al. unpubl. report), and surges of 4 to 5 feet throughout the Florida Keys. Rainfall associated with Wilma ranged from 3 to 7 inches.

Mandate

With the signing of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act by the President on January 12, 2007, the Secretary of Commerce is required under section 213 of the Act to submit within 180 days two reports to the United States Congress on the impacts of Hurricane Katrina, Hurricane Rita, and Hurricane Wilma. This report describes the impacts of the hurricanes "on commercial and recreational fishery habitat, including that of shrimp and oysters, for the States of Alabama, Florida, Louisiana, Mississippi, and Texas." The other report describes the impacts of the hurricanes on "(1) commercial and recreational fisheries in the States of Alabama, Louisiana, Florida, Mississippi, and Texas; (2) shrimp fishing vessels in those States; and (3) the oyster industry in those States." Under the Magnuson-Stevens Act, the Secretary also is required to carry out activities to restore fishery habitats, including shrimp and oyster habitats in Louisiana and Mississippi.

Rationale and Purpose

Outside of Alaska, the Gulf of Mexico region has the largest expanse of wetlands and the largest fishery landings in the United States. Louisiana leads the nation in production of blue crab, with 25 percent of all landings. The Gulf region leads in production of oysters, with 61 percent of all landings, and in domestic shrimp production, with 84 percent of all landings (NMFS 2007a). The productive habitat in this region supports Gulf fisheries that provide livelihoods for fishermen and a steady supply of safe, wholesome seafood for the Nation.

The wetlands that are so important to fisheries are being degraded and lost at a significant rate (projected by Barras et al. [2003] to be 10 square miles per year between 2000 and 2050). Sea level rise, in combination with subsidence, has resulted in relative sea level changes in Louisiana of approximately 3 feet per century (Day et. al. 1995; USGS 2002). According to glaciologists cited in *The Times-Picayune* (New Orleans, March 21, 2005), "…the combination of melting ice and ice flowing into the ocean could increase the world-wide sea level by between 2 and 3 feet [by 2100] [Church and Gregory 2001] . . . that means the [Louisiana] coast could be facing the equivalent of a 4-foot to 6-foot rise in sea level over the next 100 years." This potential sea level rise increases the vulnerability of the Gulf Coast to hurricanes (Fig. 2-1).

The habitat that supports fisheries in the Gulf of Mexico and its coastal areas also supports and protects infrastructure (i.e., ports, energy production, and fisheries) vital to the Nation. The largest port in the United States, New Orleans–Baton Rouge, is located here and handles 24 percent of the Nation's exports. The region has more than 30 percent of the Nation's oil refining capacity and all four of the National Strategic Petroleum Reserves, and provides 21 percent of the Nation's natural gas. In short, it is the most important energy-producing region in the United States. The loss of Louisiana wetlands could make much of this critical infrastructure vulnerable through exposure. It would be threatened by storms in the near term and put at greater risk by a combination of sea level rise and subsidence in the long term. Many of the fishery habitats discussed in this report play a significant role not only in supporting fisheries, but also in protecting infrastructure critical to the Nation.

Hurricanes are natural occurrences, and the ecosystems of the Gulf of Mexico, and their natural recovery processes have developed within this context. However, system response has been altered by the cumulative effects of humans and development, which have tended to increase vulnerability and reduce resiliency. Thus, on top of the increasing impacts of human-induced ecological change are the impacts of storms. Hurricanes exacerbate long-term trends in fishery habitat structure and function. This report not only identifies the impacts of three hurricanes on fishery habitat in the Gulf of Mexico and assesses the significance of these impacts, but also discusses actions that might be taken with a long-term perspective to mitigate or prevent future injury to fishery habitat by such storms.

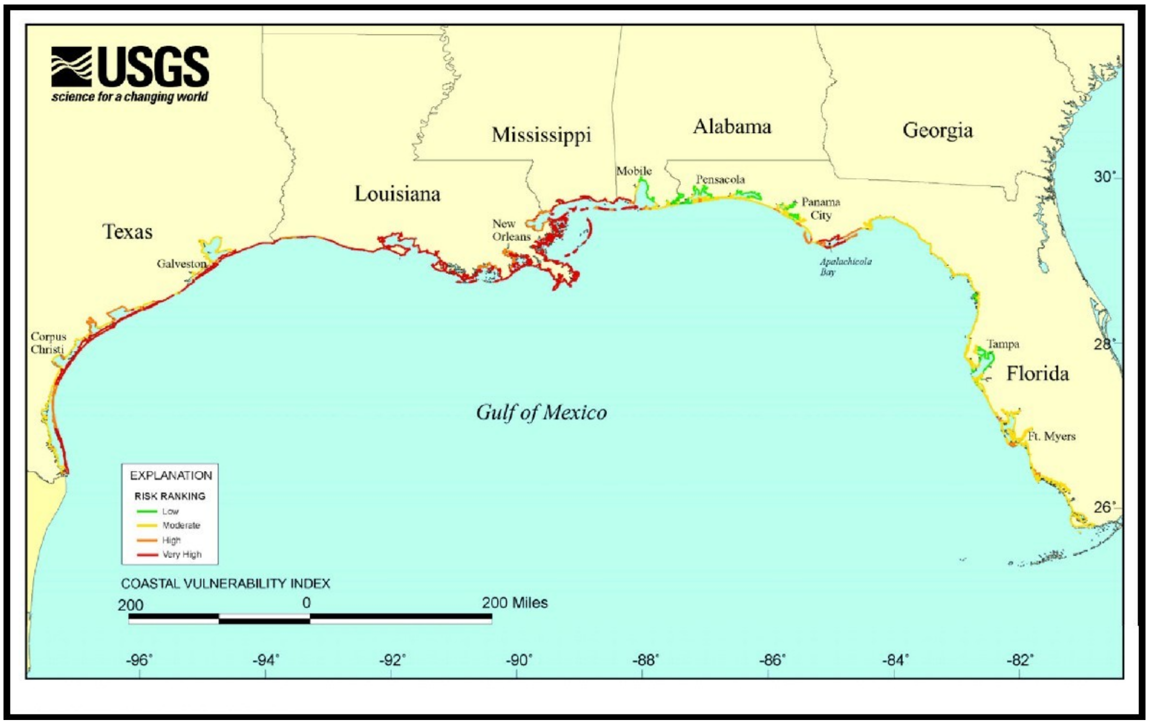


Figure 2-1. Map of the Coastal Vulnerability Index (CVI) for the U.S. Gulf Coast. The CVI shows the relative vulnerability of the coast to changes from future rise in sea-level. Areas along the coast are assigned a ranking from low to very high risk, based on the analysis of physical variables that contribute to coastal change. Source: Thieler and Hammar-Klose (2000).

Scope

The scope of this report includes identified habitat losses and habitat changes (i.e., impacts) to commercial and recreational fishery habitat for the States of Alabama, Florida, Louisiana, Mississippi, and Texas that have occurred as a result of Hurricanes Katrina, Rita, and Wilma. This report also assesses the significance of these impacts to biota (i.e., oysters, shrimp, crab, and fish, and the services they provide) and the ecosystem, and identifies the actions that might be taken to mitigate or prevent similar injury in the future. As part of the discussion on significance, impacts are placed in perspective to habitat losses or degradation occurring over extended time periods from a combination of issues including saltwater intrusion and erosion, sediment starvation, sea level rise, and subsidence in concert with these hurricanes. Geographically, the habitats considered extend from the open Gulf of Mexico to those associated with the furthest inland impacts affecting marine fisheries along the paths of the hurricanes. The scope includes all fishery organisms, their forage, and habitats within the region. In the context of this report, habitat is defined as the place where an organism lives (Odum 1971) and includes its physical, biological, and/or chemical characteristics (Peters and Cross 1992).

Approach/Methods

Personnel with NOAA's National Marine Fisheries Service (NMFS) Office of Habitat Conservation, Southeast Region, and Southeast Fisheries Science Center cooperated in preparing this report. Given the short congressional deadline for completion of the report, the drafters drew upon data and information available at the time the report was developed. No independent data gathering was undertaken for the report.

The report focuses on the impacts of the 2005 hurricanes on fish habitat of the Gulf Coast. It does not address the impacts of the storms on Gulf Coast fisheries, because that information is being provided in a separate report to Congress. The two reports were developed simultaneously but independently. They are intended to be complementary but not redundant.

NMFS contacted over 40 organizations (see Appendix 1) for available information. We take this opportunity to thank all who responded. The project team also searched for additional information through traditional web-based data and literature.

We have made every effort to verify all information and to present it fairly and accurately. Where possible the report describes pre- and post-hurricane habitat conditions. However, much of the information in this report comes only from post-hurricane sampling and some is only qualitative or anecdotal. Not all field data were collected at the same time. Certain areas were so devastated that information gathering to assess impacts to habitat was delayed. In other cases, surveys were accomplished shortly after the 2005 hurricane season (i.e., October and November 2005) at a time of naturally declining biological activity or before systems could adequately respond to the impacts (e.g., for the flood waters to recede, for salt burn to fully take effect), perhaps resulting in over- or underestimated impacts. Some data collected the following growing season in 2006 provided a clearer interpretation of the initial impacts (e.g., regrowth of seagrass, new deposition of wetlands). Much of the data and information presented represent only a snapshot in time, but several datasets allow interpretation from the perspective of a longer timeframe. In spite of the patchwork of data and problems presented, a picture emerges of the impacts of the 2005 hurricanes on fishery habitat in the U.S. portion of the Gulf of Mexico. These are presented and evaluated in Chapters 3 and 4 of this document, respectively.

Chapter 3 documents the impacts of Hurricanes Katrina, Rita, and Wilma on fishery habitat of the U.S. portion of the Gulf of Mexico. The chapter begins with a time-course description of the three hurricanes as background, elucidating the far-flung nature of the impacts from Florida to Texas. The chapter then presents the impacts by hurricane and by state (i.e., Louisiana, Mississippi, Alabama, Texas, and Florida) for all habitats for which there is information.

Chapter 4 focuses on the significance of the impacts by habitat type (i.e., coastal forest, emergent intertidal wetlands, oyster reefs, seagrass meadows, mangrove forests, barrier islands and shorelines, offshore soft bottoms, coral reefs, and shelf edge reefs). For each habitat type the discussion begins with a statement of the importance of that habitat to fisheries and the ecosystem, the impacts received by that habitat type from all three hurricanes, the significance of the impacts (i.e., distribution of that particular habitat type in the U.S. portion of the Gulf of Mexico versus geographic extent of the impacts, duration, and severity of injury to that habitat type), and, where known, the broader perspective of the status and change in that habitat type over many years.

Chapter 5 identifies actions being taken to mitigate (recover, rebuild, restore, rehabilitate, renew) or prevent (conserve against, protect against) future impacts of hurricanes on the coastal areas (including fishery habitats) of the U.S. portion of the Gulf of Mexico impacted by the hurricanes of 2005. Regional Action Plans are presented first, followed by plans affecting each of the states (Louisiana, Mississippi, Alabama, Texas, and Florida).

Chapter 6 discusses recommendations for repairing damage to fishery habitat caused by the hurricanes of 2005, as well as preventing similar or worse damage from future hurricanes.

Chapter 7 contains cited references.

Appendix 1 is the list of agencies and institutions contacted for information for this report.

Appendix 2 contains instructions for operating the source documents CD. Source documents not under copyright are contained on a companion CD in the back of the report. For those without a CD, the following web site may be used to access the same information as on the CD: http://ecowatch.ncddc.noaa.gov/nmfs-report
For assistance please call the NOAA National Coastal Data Development Center (228-688-2936).

Appendix 3 is a list of source documents contained on the CD.

Appendix 4 is a list of several websites related to this report.

Appendix 5 is a table (referred to in Chapter 5) providing post-storm evaluation for each NOAA Community-based Restoration project.

Appendix 6 is a table (referred to in Chapter 5) providing information about coastal habitat restoration, enhancement, and/or protection projects under consideration for Mississippi's Comprehensive Plan.

3.

Identification of Impacts to Fishery Habitat

Overview of Impacts

Major Hurricanes of 2005: Katrina, Rita, and Wilma

Hurricane Katrina

Hurricane Katrina moved southwest across the tip of Florida on August 25, 2005, making landfall as a Category 1 storm between Hallandale Beach and North Miami Beach at 6:30 pm. In addition to wind damage, the storm caused significant flooding before it entered waters of the Gulf of Mexico during that night. Most of southeastern Florida received about 5 inches of rain. However, some areas experienced over 15 inches of rain associated with the storm. A storm surge of 2 to 4 feet was reported at Key West. Over the next several days the storm moved westward over the warm waters of the Gulf, attaining major hurricane status (Categories 3–5) on August 26 and reached Category 5 on August 28, 2005. At that time sustained tropical storm force winds were already affecting the southeast Louisiana coastline as the storm turned northward (Fig. 3-1).

At approximately 6:00 am on Monday August 29, the storm made landfall in Plaquemines Parish just south of Buras, Louisiana, as a strong Category 3 storm with wind speeds of 127 mph. Katrina continued to weaken as it moved northward the rest of the day, but remained at tropical storm strength that evening when it was centered 30 miles northwest of Meridian, Mississippi, approximately 240 miles from its landfall location.

The storm surge accompanying Hurricane Katrina was estimated along the Mississippi coast as 24 to 28 feet across a path of about 20 miles, tapering to a height of 17 to 22 feet along the eastern Mississippi coast. The maximum high water mark observation was 27.8 feet at Pass Christian, Mississippi. The surge appears to have penetrated at least 6 miles inland in many portions of coastal Mississippi, and up to 12 miles inland along bays and rivers. Alabama’s coast experienced surges ranging from as high as 10 feet in the east to

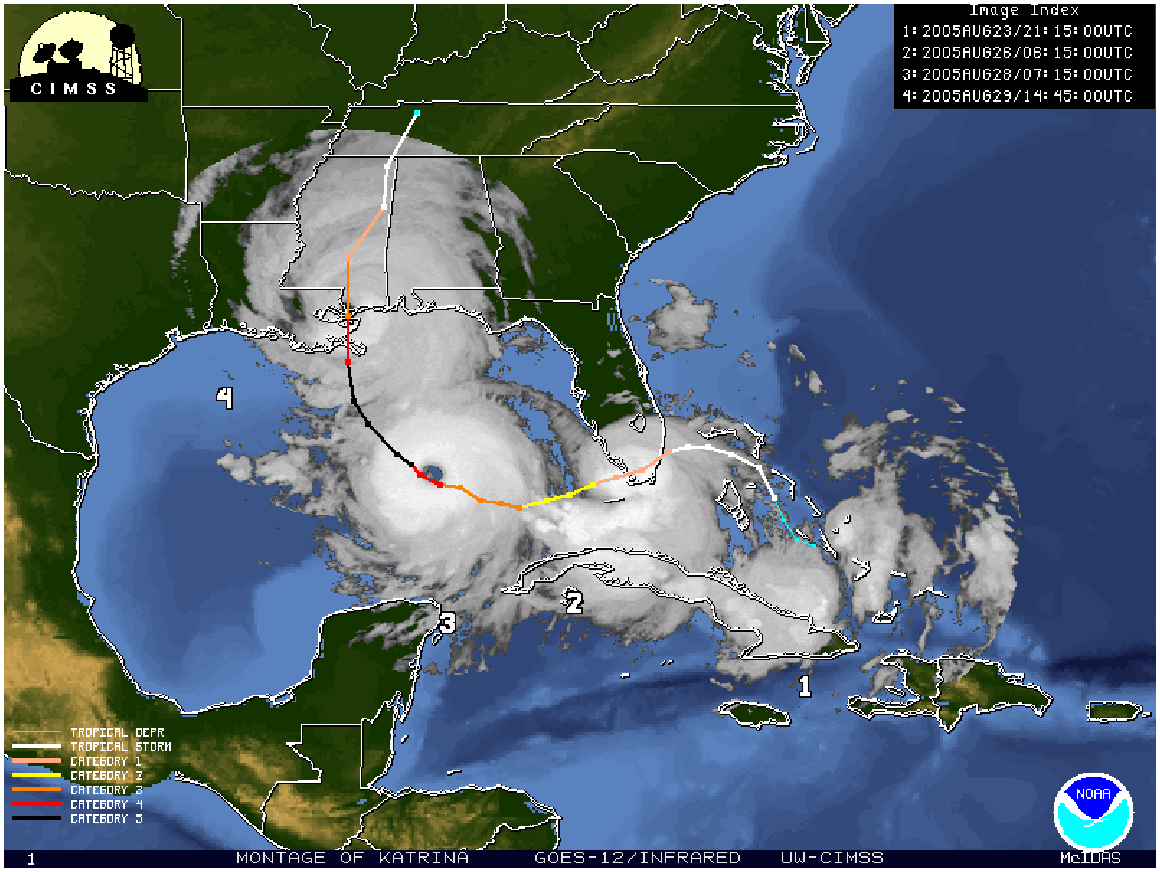


Figure 3-1. Hurricane Katrina storm track. Source: NOAA and Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin

15 feet in the west. Surges in eastern Louisiana generally ranged from 10 to 19 feet causing levee failures and flooding. New Orleans and other populated areas along the Louisiana, Mississippi, and Alabama coasts were flooded. Flood waters pumped from New Orleans to the near-shore habitat of the Northern Gulf of Mexico were severely polluted with both chemical and microbiological contaminants giving rise to concern for human health and safety of seafood. The storm surge in Florida ranged from 6 feet along the western panhandle to 1 or 2 feet along most of the west-central coast of Florida. A large portion of southeast Louisiana and southwest Mississippi received 8 to 10 inches of rain, with localized measurements up to 12 inches (Knabb et. al. 2006b).

Hurricane Rita

Rita attained tropical depression status on September 18, 2005, while still east of Grand Turk in the Turks and Caicos (Fig. 3-2). It passed about 50 miles south of Key West, Florida during the evening of September 20; associated storm surge caused floods in portions of the Florida Keys. Visual estimates suggest the maximum surge along the south-facing shores of Key West and the lower Keys was 4 to 5 feet, while the surge along the Atlantic portions of the middle and upper Keys was 3 to 4 feet.

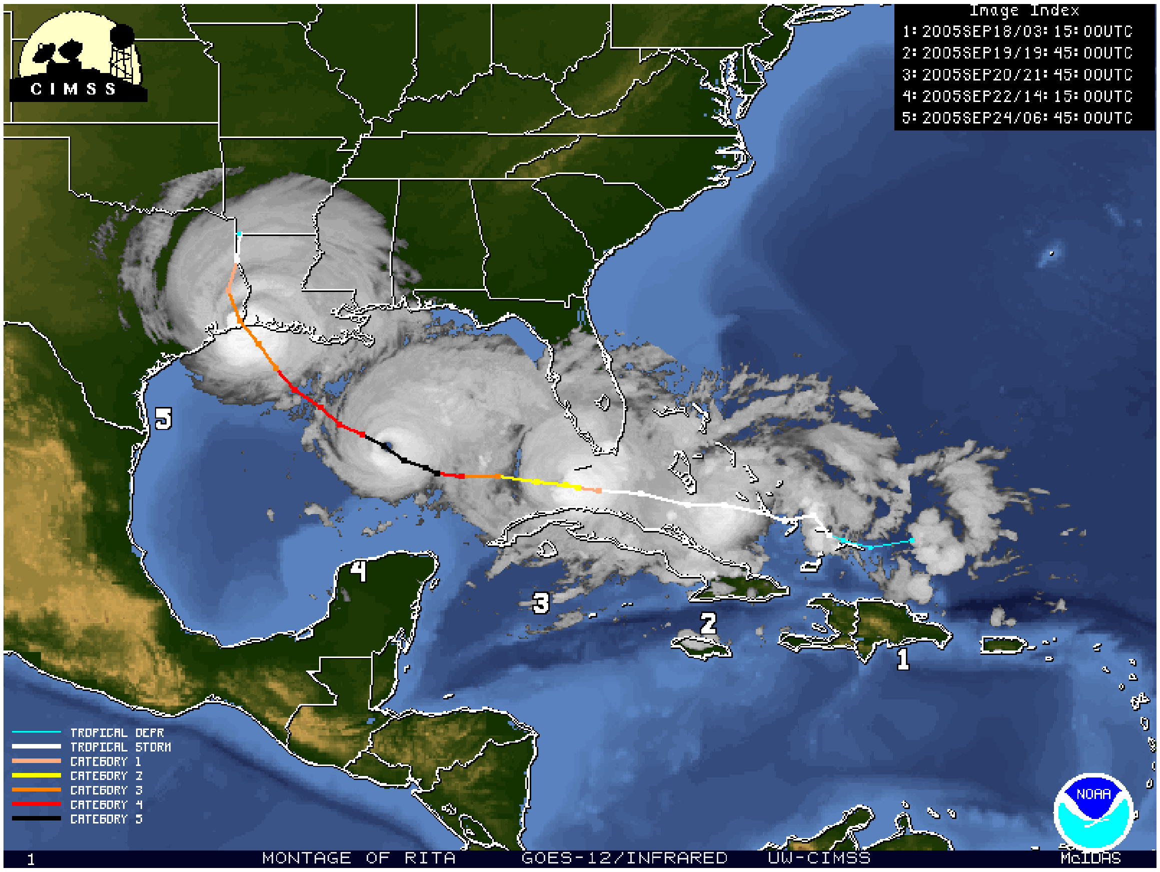


Figure 3-2. Hurricane Rita storm track. Source: NOAA and Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin

Rita reached Category 5 strength when it entered the Gulf of Mexico on September 21, but weakened to a Category 3 when it made landfall on the morning of September 24 in extreme southwest Louisiana, just west of Johnson's Bayou and just east of Sabine Pass. Rita remained at hurricane strength, proceeding northward into Texas, for about 68 miles before weakening to a tropical depression and turning northeastward.

The storm surge in southwest Louisiana has proven difficult to determine due to the destruction of many structures and equipment. A few high water marks were collected and analyzed suggesting a storm surge in portions of Cameron, Louisiana, as high as 15 feet. Water was pushed into Calcasieu Lake (community of Grand Lake) with a storm surge of at least 8 feet. The surge then propagated up the Calcasieu River and flooded portions of the Lake Charles area to depths of 6 feet. The surge reached Interstate 10 (29 miles from the Gulf Coast). Farther east, most or all of Vermilion, Iberia, and St. Mary Parishes south of Highway 14 and U.S. 90 were inundated by the surge, estimated at 8 to 12 feet in some areas.

Rita also produced a storm surge, generally 4 to 7 feet based on gage data, in coastal areas of southeast Louisiana, reflooding some areas that were impacted by Hurricane Katrina approximately 1 month earlier. A storm surge of at least 5 feet occurred in

Sabine Pass, reaching Sabine Lake. Storm tides measured along much of the Texas coast were generally in the 3- to 5-foot range on September 23, the day prior to landfall.

Storm rainfall in the lower and middle Florida Keys was generally 2 to 4 inches, with 6 inches estimated in the upper Keys. Rita produced very heavy rainfall in Mississippi, Louisiana, and extreme eastern Texas. Rainfall totals of 5 to 9 inches were common, with some isolated maxima of 10 to 15 inches. Portions of Arkansas received 3 to 6 inches of rain from Rita. Flash floods occurred in several areas, including the Big Black River basin of west-central Mississippi (Knabb et. al. 2006a).

Hurricane Wilma

Wilma formed over the northwestern Caribbean Sea and is estimated to have become a tropical depression on October 17, 2005 (Fig. 3-3). It strengthened to a Category 5 hurricane by early morning on October 19 as it approached the Yucatan peninsula. After making landfall there, the storm turned northeastward over the Gulf of Mexico and made

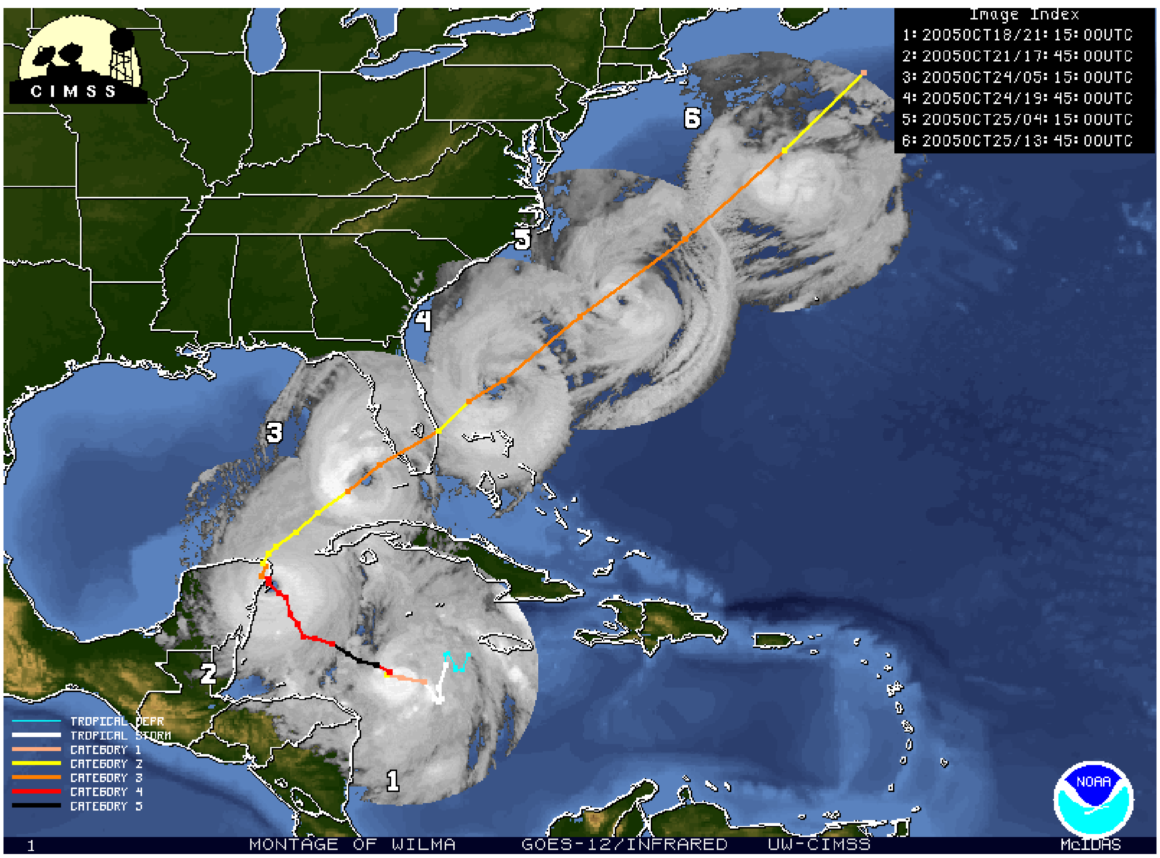


Figure 3-3. Hurricane Wilma storm track. Source: NOAA and Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin

landfall in southwestern Florida near Cape Romano as a Category 3 storm on October 24. Wilma crossed the southern Florida peninsula in 4.5 hours and was still a Category 2 hurricane when it entered the Atlantic Ocean. It did not make landfall again.

A storm surge of 4 to 8 feet was reported for coastal Collier County, Florida, and may have been larger in the uninhabited areas of southwestern Florida, south of its landfall location. The Everglades National Park reported a storm surge of 13 feet. Storm surges of 4 to 5 feet were observed over much of the lower, middle, and upper Florida Keys, with some locations near 7 feet. Storm surges of 12 feet or more were measured along the southwestern coastal area of Grand Bahama Island.

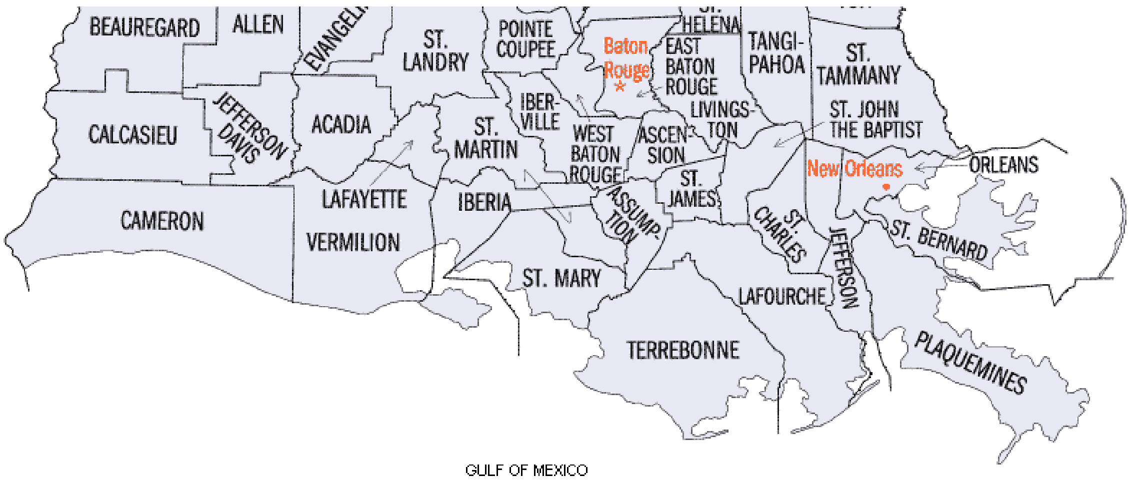
Because Hurricane Wilma moved quickly across the southern Florida peninsula, it did not produce exceptionally large rainfall totals. Rainfall generally ranged from 3 to 7 inches. Some locations in southeast Florida only received 1 to 2 inches or less (Pasch et. al. 2006).

Impacts of Hurricanes on Fishery Habitat

The three hurricanes contributed directly to the impact on fishery habitat via their high winds, large waves, huge storm surges, and heavy rainfalls along their paths from the open Gulf of Mexico to coastal and inland areas. The strong winds not only destroyed structures (i.e., created debris) and blew over, uprooted, and stripped vegetation, but also produced waves, swell, and currents that roiled waters, broke and overturned reefs, stirred and moved sediments and debris, eroded wetlands and other shorelines, and caused releases of oil and potentially other contaminants, including pathogenic microbial organisms. The huge storm surges penetrated as far as 29 miles inland in some cases. These surges brought saltwater to an otherwise freshwater environment, crushed and moved structures off their foundations, and carried sediment (Turner et al. 2006) and debris many miles inland. Debris in the inland areas clogged water channels, disrupting the flow of storm surge water back seaward, leading to extended flooding in localized areas. In the offshore area, debris scraped, crushed, and buried habitat and obstructed its use by biota. Salt burn (caused by the intrusion of saltwater into areas of freshwater plants) resulted in the death of plants and their replacement with more salt-tolerant species. With the retreat of the storm surges, floatable land debris and oils and other contaminants from broken and flooded structures were carried seaward. The heavy rains accompanying these hurricanes flooded streams and rivers and lowland areas, further moving debris and contaminants, causing algal blooms, and precipitously lowering salinity in estuarine areas. Decaying plant material in these streams and rivers caused depletion of oxygen, leading to fish kills.

Identified Impacts from Hurricanes Katrina, Rita and Wilma: Louisiana, Mississippi, Alabama, Texas, and Florida

Louisiana



Coastal and Southern Parishes of Louisiana

Coastal Land Cover Change

In Louisiana, land cover changes observed by NOAA's Coastal Change Analysis Program (C-CAP) using remotely sensed imagery highlight several of the impacts caused by the 2005 hurricanes (N. Herold and J. McCombs 2007, pers. com.). Most notable of these changes is the dramatic loss of emergent wetlands and areas of unconsolidated shore, and the subsequent increase of over 200 mi^2 of open water (Figure 3-4). The most prominent of these changes was the loss of over 150 mi^2 of estuarine emergent marsh. These changes were seen in the areas surrounding Plaquemines and St. Bernard Parishes.

Losses of hardwood forests and scrub cover were also observed throughout the state, resulting in a large increase in the amount of grassland mapped. Over 100 mi^2 of forest land (primarily evergreen) was lost or converted to grasses. This was also true of the bottomland forested areas (though on a much smaller scale), as these areas were lost and are now dominated by palustrine emergent species and/or their scrub/shrub under stories. Salvage logging, debris removal, and repair/rebuilding of the constructed environment will likely be the dominant force of change in these formerly forested areas, over the next several years.

Also of note, is the small loss of high and medium intensity areas of development. In several cases the destruction of the hurricanes causes the damage or loss of these properties. The resulting piles of debris and building material, or those remaining foundations, have been captured as lower intensity area of development.

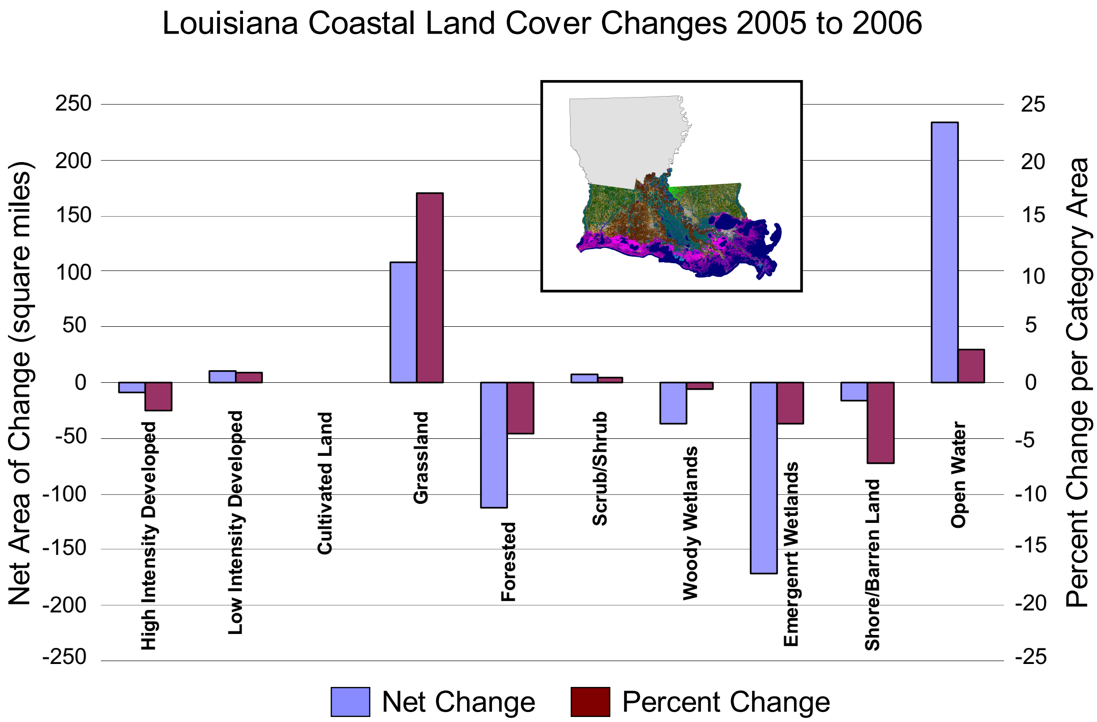


Figure 3-4. The land cover changes depicted above occurred between August 2005 and March 2006. The inset map shows the area (in color) used for the change analysis.

Coastal Forests

Hurricane Katrina greatly impacted forest resources, particularly hardwoods in the path of the storm (Smith 2005). These forests suffered major blowdowns of canopy trees and leaf and branch stripping of standing survivors. Knocked down and defoliated trees affect water quality and timing of runoff to fishery habitat (Smith et al. 1993). Forests act as one of the best purifiers of runoff and hold water to limit floods and release it during low water periods (Omernik 1977; Chamberlin et al. 1991; Smith et al. 1993).

Fresh Water Habitat

Impacts of the 2005 hurricanes to some species associated with freshwater marshes were immediate (Roussel 2006). Fish kills caused by storm-related flooding from Hurricane Katrina followed by the death and decomposition of vegetation and low dissolved oxygen concentrations were documented for the Pontchartrain basin including Lake Maurepas (Roussel 2006). Surveys of the Lower Pearl River found that freshwater fish were no longer present in the area immediately after Hurricane Katrina because of increased salinity (Smith 2006). Hurricane Rita also pushed saltwater into fresh marshes, killing freshwater fishes and invertebrate species (U.S. Fish and Wildlife Service 2005c; Smith 2006) (Fig. 3-5).

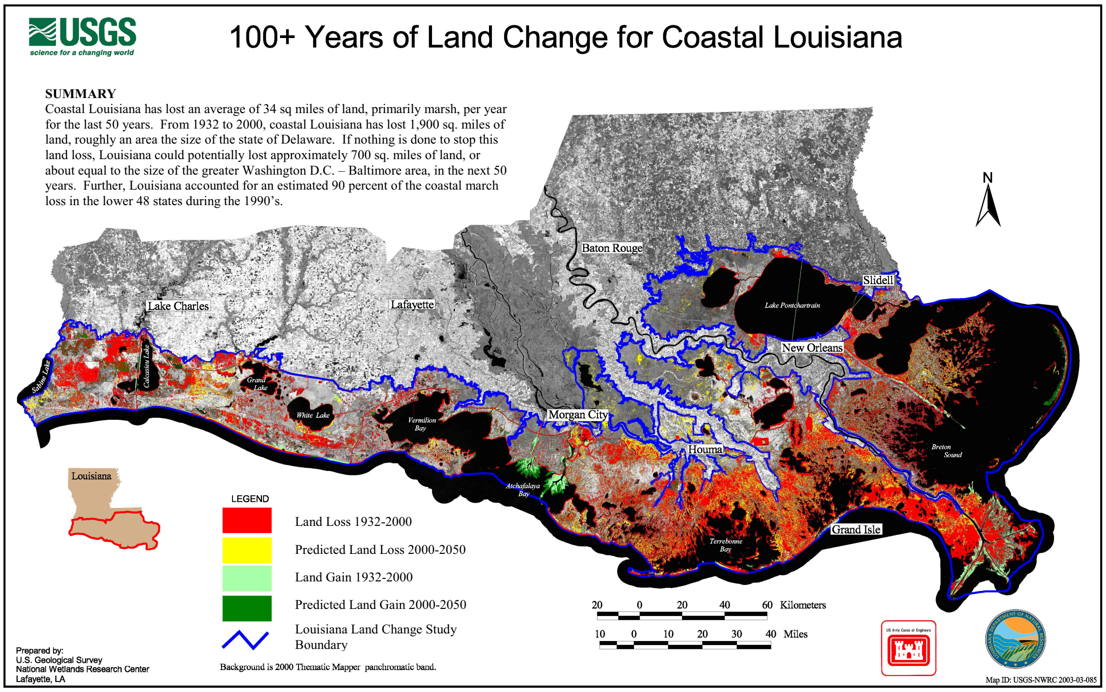


Figure 3-5. History of land change in coastal Louisiana. Source: U.S. Geological Survey.

Wetland Impacts

The 2005 hurricanes impacted coastal marshes in Louisiana in at least three ways: (1) the force of the tidal surge removed or rearranged marsh, (2) saltwater pushed inland by the hurricanes killed vegetation in freshwater marshes, and (3) water pushed in by the hurricanes became trapped, flooding some marshes for extended periods (Smith 2006; USACE 2006a; Weifenbach and Sharp 2006). Extensive areas of marsh appear to have been pushed against firm barriers (for example, levees and firmly grounded marsh), resulting in a ridge and trough pattern (USACE 2006a). Many new areas of open water were created when storm-generated waves sheared or ripped the vegetation from the marsh surface down to the root zone or firm substrate of clay (Smith 2006). Remnant marsh balls (large mats) and other debris littered some of these sheared areas, but other areas appear as exposed mud flats or shallow ponds (Smith 2006). Groups of small, interconnected ponds coalesced when waves removed intervening marsh (Smith 2006). The surge lifted and moved areas of floating fresh marsh in the western Terrebonne basin (USACE 2006a). Damage to floating marsh and shrub/scrub vegetation located near the

Louisiana–Mississippi border was extensive (Smith 2006). Areas of wrack (i.e., uprooted vegetation and other debris) completely buried vegetation in some areas (USACE 2006a).

Gulf waters pushed inland by the hurricanes also damaged freshwater marsh vegetation. Monitoring stations located in the upper Barataria Basin showed that salinity increased from 0.2 to over 10 parts per thousand (ppt) following passage of Hurricane Katrina (Smith 2006). Hurricane Rita's storm surge pushed inland more than 20 miles, overtopping the cheniers (i.e., Louisiana French term for the oak tree belts that mark the former beach ridges; see Visser et al. 2000) of southwestern Louisiana by as much as 10 feet (USACE 2006a). Storm surge estimates and surface salinity measurements confirm that the hurricanes pushed saltwater well into freshwater marsh and swamp areas across the state (Steyer et al. in press). Even areas outside the direct paths of the hurricanes were affected. For example, a continuous recording station in a freshwater marsh of Terrebonne Parish recorded a peak salinity of 17 ppt following Hurricane Rita, and salinity levels remained above 6 ppt into December 2005 (Steyer et al. in press). The freshwater marshes associated with Calcasieu Lake, Sabine Lake, White Lake, and Grand Lake were damaged by this saltwater intrusion (Roussel 2006).

Prolonged flooding of marshes by saltwater was a major problem in southwest Louisiana. Saltwater became trapped by cheniers, flooding the fresh marshes behind them (USACE 2006a). Marsh areas under structural marsh management (i.e., surrounded by earthen levees with structures to control water levels) also remained flooded with saline water for an extended time as floodwaters could not be drained off fast enough (Boesch et al. 2006).

Prolonged flooding by saline waters may have damaged these fresh marshes (Boesch et al. 2006); USACE 2006a; Weifenbach and Sharp 2006). Weifenbach and Sharp (2006) evaluated wetland plant health, vegetative coverage, and species diversity at over 300 sampling stations in project areas in southwestern Louisiana. They found an increase in the cover and occurrence of salt-tolerant species and commensurate decrease in fresh marsh species when comparing pre-storm and 1-year post-storm data (Fig. 3-6). This indicates that at least a temporary shift in habitat occurred. Analysis further revealed an increase in unvegetated, open water areas that do not appear to be recovering, indicating an overall loss of vegetated wetlands. Less than 3 percent of sampling stations were unvegetated in 2004, but open water areas increased to about 10 percent of the total stations in both immediate post-storm and 2006 sampling events.

Louisiana was in an extended drought before the hurricanes, and the drought continued well into 2006. Therefore, saltwater was not immediately flushed from freshwater systems inundated by Gulf waters during the hurricanes. Pore water salinity measurements taken 30 cm below the sediment surface at 30 locations within the Sabine basin in December 2005 and again in March 2006 were still outside the normal range for the marsh plant species that occur there, and these relatively high salinities have limited the recovery of some plant species (Steyer et al. in press).

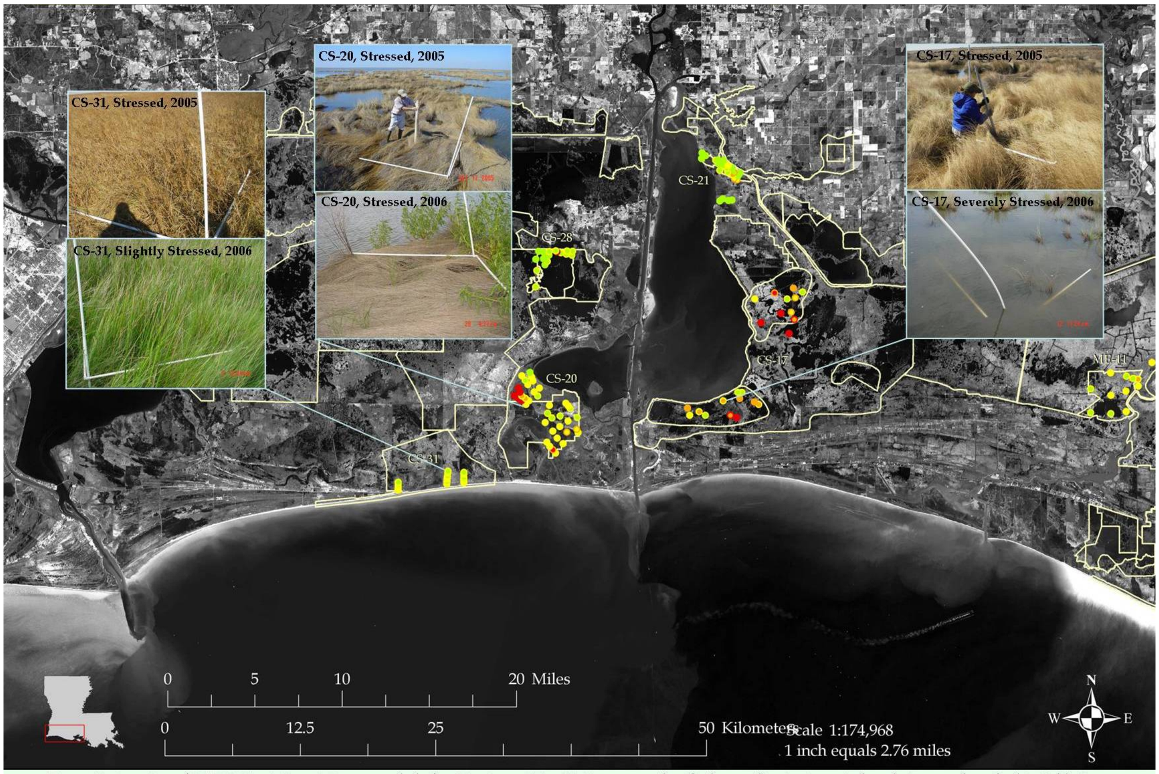


Figure 3-6. Vegetation surveys in southwest Louisiana (from Weifenbach and Sharp 2006).

The U.S. Geological Survey (USGS) estimated changes in land and water coverage in coastal Louisiana within 2 months of the passage of Hurricanes Katrina and Rita by comparing 2004 and 2005 Landsat images using GIS (Barras 2006a). The analysis showed that coastal marsh area had decreased (and water area increased) by 217 mi^2 following passage of these storms. Of this total, 98 mi^2 were lost in southwestern Louisiana and 119 mi^2 were lost in southeastern Louisiana (Barras 2006a). The water area increase of 79 mi^2 from the 2005 hurricanes estimated for the area east of the Mississippi River exceeds the projected 50-yr (2000 to 2050) marsh loss (61 mi^2) that was based on recent trends (Barras et al. 2003). In this one hurricane season, as much land loss took place as was predicted to occur over more than 21 years (Barras et. al. 2003) and as much as 8 to 11 times the annual rate of loss between 1990 and 2000. The extent of marsh decrease varied across the coastal area, but occurred in areas that had experienced high marsh loss rates in the past as well as in historically stable areas where loss rates had been relatively low.

Land area changes in coastal Louisiana could be related to a specific storm in some cases by comparing imagery acquired after Hurricane Katrina but before Hurricane Rita (Barras 2006b). Open water increased by 82 mi^2 in areas primarily affected by Hurricane Katrina (Mississippi River Delta, Breton Sound, Pontchartrain, and Pearl River basins) and by 99 mi^2 in areas impacted mostly by Hurricane Rita (Calcasieu/Sabine, Mermentau, Teche/Vermilion, Atchafalaya, and Terrebonne basins). The Barataria Basin, where open water increased by 18 mi^2, was affected by both hurricanes.

The degree of impact varied by marsh community type. Fresh and intermediate marsh types located near to or east of the hurricane landfalls appeared to experience extensive shearing, and estimates of the decrease in marsh area in these communities (fresh = 122 mi^2, intermediate = 90 mi^2) accounted for 71 percent of the coast-wide water area increase. Intermediate and fresh marshes received most of the hurricane damage because their highly organic soils were ripped apart by the storm surge and waves (Boesch et al. 2006). Most (72 percent of the total) water area increase occurred on the Chenier Plain in the interior marshes located between Freshwater Bayou and Calcasieu Lake (Barras 2006a). The decrease in intermediate marsh was greater on the Deltaic Plain primarily in the upper Breton Sound basin (Barras 2006a).

Most saline marshes appeared physically intact after the storms, although some shorelines along open bays were eroded by storm-generated waves (Boesch et al. 2006). The brackish marsh turned brown from exposure to saline waters but appeared physically intact (Boesch et al. 2006). Estimates for the decreases in brackish and saline marshes by Barras (2006a) were 33 mi^2 and 28 mi^2, respectively.

The storm deposited sediment, marsh vegetation, and organic debris in the remaining wetlands and shallow ponds. Debris from homes, businesses, and industries also was pushed into coastal marshes. Approximately 1,400 potentially hazardous items (mostly propane, antifreeze, and gasoline tanks) were identified on Sabine National Wildlife Refuge alone following Hurricane Rita (USFWS 2006). In some cases, substantial sediment deposition associated with the passage of the storm buried the pre-storm surface and smothered vegetation (USACE 2006a). The amount of inorganic sediments deposited on the wetlands of coastal Louisiana by Hurricanes Rita and Katrina has been estimated at more than 133 million tons (Turner et al. 2006).

These recent changes in land and water coverage also were compared with historical (1956 to 2004) changes. Net decreases in land area occurred in all basins except the Atchafalaya over the 48-year historical period and in every basin between 2004 and 2005 following the hurricanes of 2005. Estimates of these recent decreases in land area were relatively high when compared to historical losses for the Mermentau and Breton Sound basins. Pre- and post-hurricane images of the north shore of Lake Pontchartrain and the Biloxi marsh southeast of New Orleans show what appear to be large areas of wetlands converted to open water by Hurricane Katrina (Lake Pontchartrain Basin Foundation 2006). In the Pontchartrain Basin, approximately 40 mi^2 of wetlands may have been converted to open water by Hurricane Katrina—more than was lost in the basin between 1990 and 2000 (Lake Pontchartrain Basin Foundation 2006).

The results of the Barras (2006a) study are considered preliminary because the classification of some areas may be transitory. For example, marshes that were still deeply flooded from the hurricane surge when the 2005 images were acquired would have been classified as water even though these areas may have since recovered. Persistently high water levels made classification particularly difficult for areas in the Chenier Plain of southwest Louisiana. The U.S. Fish and Wildlife Service (2005b) reported that the Sabine National Wildlife Refuge (a coastal marsh refuge) was still underwater nine days after the end of Hurricane Rita. Transitory water area changes may also have been caused by the removal of aquatic vegetation, scouring of marsh vegetation, and water-level variation attributed to normal tidal and meteorological variation between satellite images (Barras 2006a). Barras (2006a) indicates the permanent losses caused by these storms can be estimated only after several growing seasons have passed when the transitory impacts of the hurricanes can be documented.

Effects of Hurricanes Katrina and Rita on Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) Projects

Post-Storm Assessments of Impacts to Fishery Habitat. Immediately post-storm, and acting under the program's established Hurricane Contingency procedures, the Louisiana Department of Natural Resources (LDNR) coordinated project inspections for all authorized CWPPRA projects, with an emphasis on assessment of constructed projects. Each of the program's 70 constructed projects was visited via small plane, boat, or ground to evaluate the condition of constructed project features and identify both short-term remedial actions and long-term repair needs.

In contrast to non-project wetland areas, many of which suffered major damage, 36 CWPPRA projects had some type of damage, but most was minor and limited to features such as navigation and safety signage, pumps, and other attendant structures such as handrails. Only about 19 projects were in need of repair sufficient to warrant application for Federal Emergency Management Agency (FEMA) funding (LDNR 2007b and 2006).

NOAA (2006b) also conducted a qualitative assessment of the majority of its Louisiana restoration projects implemented under various authorities and programs including CWPPRA. The assessment focused on damages to restored habitats. Eighteen constructed CWPPRA projects were analyzed using aerial photography and on-site inspections. The assessment indicates that 44 percent of the reviewed projects experienced no damage to restored habitats, 39 percent sustained minimal damage, and only three projects (17 percent) had significant damage. The assessment suggested the majority of the constructed projects sustained little damage as a result of the 2005 storms and appeared to be functioning as intended.

Ongoing monitoring is beginning to suggest some vegetated wetlands are recovering from storm impacts, while others remain damaged or were converted to open water. Even though extensive quantitative data are not currently available, qualitative observations suggest areas with substantial restoration projects generally fared better than those without. For example, LDNR (2007b) found that restored barrier islands and back-barrier saline marshes in the Terrebonne Basin fared substantially better than a similar, largely unrestored barrier island chain in Barataria Basin. Undoubtedly, some of the inter-basin differences were attributable to storm track, but both air and ground inspections clearly revealed a more intact barrier island system in the Terrebonne Basin, potentially because of the major restoration efforts accomplished in the area.

Case Study: A Closer Look at Higher Resolution

Selected NOAA-Sponsored Restoration Projects
Additionally, NOAA (J. Thomas, unpublished data) undertook detailed monitoring of nine of its 25 NOAA-sponsored, CWPPRA restoration projects in order to verify their status (see Fig. 3-7). Monitoring was accomplished using boats, aircraft, and U.S. National Imagery Systems (1 m resolution) between 1998 and the present to track shoreline change. All nine projects have continued to function as designed in spite of nearby impacts to human infrastructure from the passage of Hurricanes Katrina and Rita. For the nine restoration projects monitored, impacts ranged from no or little observable change to significant change in shoreline and area for one project (i.e., East Timbalier Island, Terrebonne Parish, Louisiana). Here we focus on four of those projects—Delta-wide Crevasse (in the path of Hurricane Katrina), Pecan Island (approximately 80 miles east of Hurricane Rita's landfall), Big Island Mining in the Atchafalaya Delta (an accretion area due to plentiful sediments delivered by the Atchafalaya River and impacted by Hurricane Rita), and East Timbalier Island (a sediment-starved barrier island impacted by both Hurricanes Katrina and Rita).

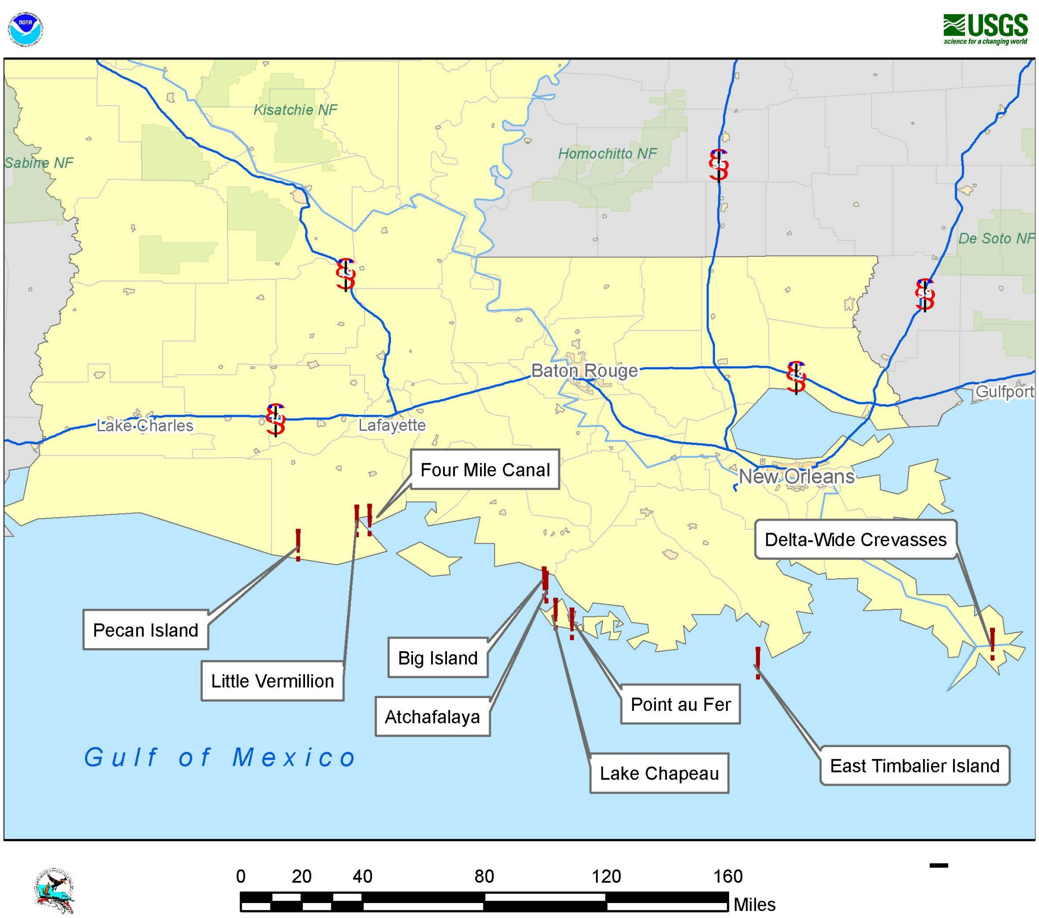


Figure 3-7. NOAA CWPPRA sites in southern Louisiana.

NOAA Delta-wide Crevasse Project. Hurricane Katrina passed just west of the bird's foot delta of the Mississippi River on August 29, 2005. The bird's foot delta contains the NOAA sponsored Delta-wide Crevasse project, whose purpose is to build new wetlands behind existing natural levees. This is done by breaching the natural levees located there with a series of crevasses to allow sediment- and nutrient-laden Mississippi River water to flow through the crevasses to the wetland areas behind the levees. As can be seen in pre- (March 2005) and post-Hurricane Katrina (September 2005) imagery for one of the crevasses artificially cut in the delta (Fig. 3-8), the crevasse remained open and continued to function as designed. All of the artificially cut crevasses in this project remained open and functioning.

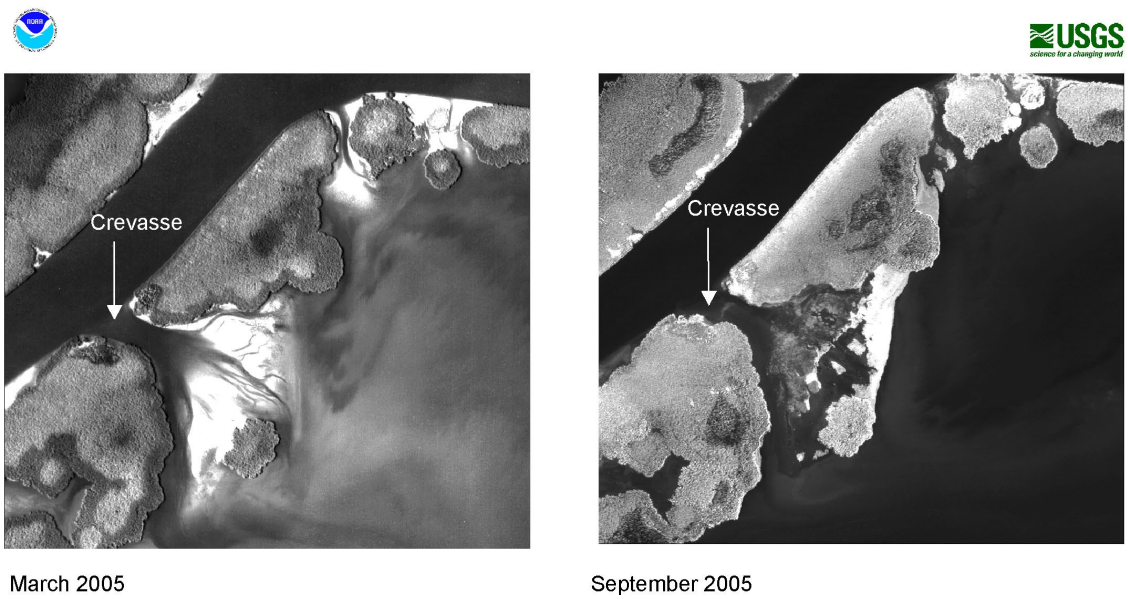


Figure 3-8. Mississippi Delta Crevasse (MR-09). Source: NOAA and USGS.

NOAA Pecan Island Terracing Project. Hurricane Rita came ashore September 24, 2005, at the Louisiana–Texas border. The town of Pecan Island, Louisiana, located about 80 miles east of the Texas border, experienced significant flooding and structural damage. The nearby NOAA-sponsored Pecan Island project, even though overrun by the storm surge of Hurricane Rita, exhibited no or little observable change between pre- (October 2004) and post-Hurricane Rita (October 2005) imagery (Fig. 3-9). The Pecan Island project is a terracing project of nearly 5-mile-long terraces (which appear in Fig. 3-9 as dashed lines within the white border, project delineated area). The terraces are bottom material dredged and deposited to form a berm about 2 to 3 feet above the water. The berms are planted with appropriate vegetation to prevent erosion. The purpose of the terraces or berms is to protect the adjacent coastline from usual wave erosion and to make a quiescent area in the water for sediment deposition. In spite of the destructive forces of Hurricane Rita on the human structures of Pecan Island (i.e., Highway 82 and the town of Pecan Island immediately above the project area), no or little change is observed between pre- and post-Hurricane Rita on the terraces.

October 2004

October 2005

Figure 3-9. Pecan Island Terracing in October 2004 (left) and October 2005 (right). From NOAA and USGS.

NOAA Big Island Mining Project. In the east-west middle of the state, along the coast, is the Atchafalaya River Delta, site of the NOAA-sponsored Big Island Mining project. The purpose of this project, completed in September 1998, is to build new wetlands by capturing some of the sediment brought by the Atchafalaya River. Wetlands in the delta tend to grow naturally in spite of subsidence and sea level rise, because of this steady supply of sediments (Fig. 3-10). However, when hurricanes pass wetlands are lost, as can be seen in the table in Figure 3-10 (i.e., Hurricane Lili of October 2002 caused decrease in 2003, and Hurricanes Katrina and Rita of 2005 caused decreases in 2005 and 2006). The system returns to building new wetlands after the passage of each hurricane, as exhibited by the increase in wetland area for 2004, and 2006.

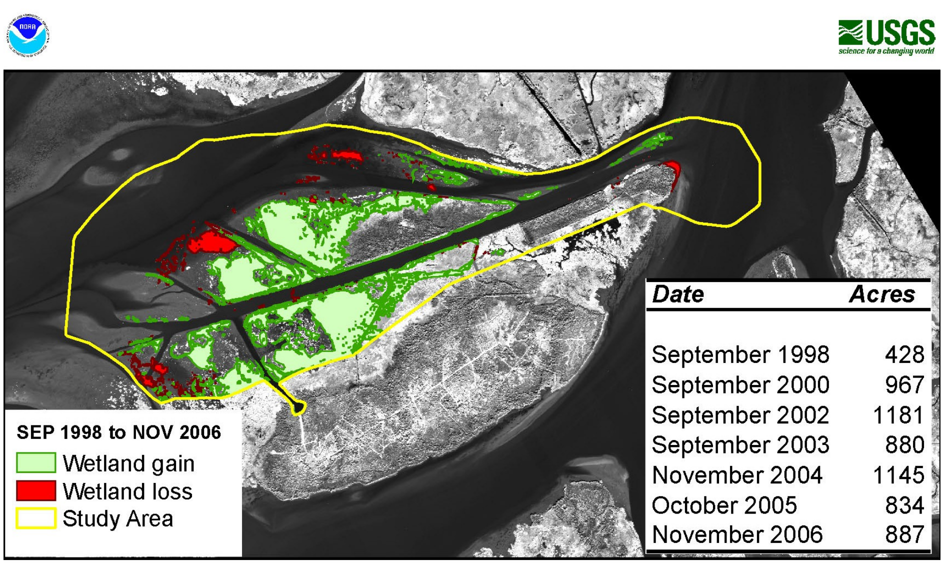
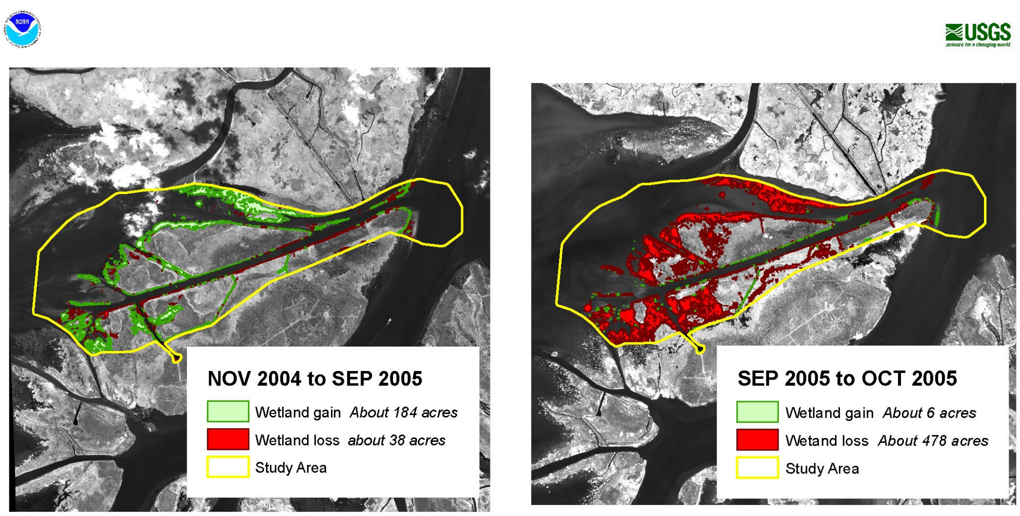


Figure 3-10. Big Island Mining (AT-03). Source: NOAA and USGS.

November 2006 Imagery

To further elucidate the impacts of Hurricanes Katrina and Rita on the Big Island Mining project, imagery taken before Hurricane Katrina (October 2004), between Hurricanes Katrina and Rita (September 2005), and after Hurricane Rita (October 2005) were compared. Hurricane Katrina caused little immediate loss, whereas Hurricane Rita caused a much larger immediate loss in the wetlands of the Big Island Mining project (Figure 3-11). Additionally, based on Louisiana Department of Wildlife and Fisheries data (T. Blair 2007, pers. comm.), the salinity of the waters near the Big Island Mining project (i.e., Wax Lake Outlet Delta) went from zero parts per thousand (ppt) to almost 20 ppt with the passage of Hurricane Rita storm surge and remained above 2 ppt for at least several days (Figure 3-12). Such a salinity increase would be expected to cause a die-back of many of the mostly freshwater plants of the Big Island project area and exacerbate additional erosion.



September 2005 October 2005

Figure 3-11. Big Island Mining (AT-03). Source: NOAA and USGS.

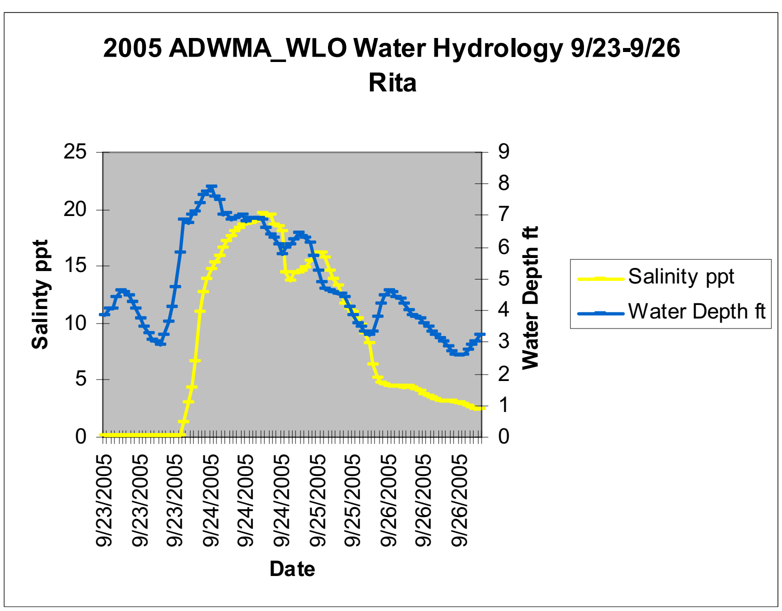
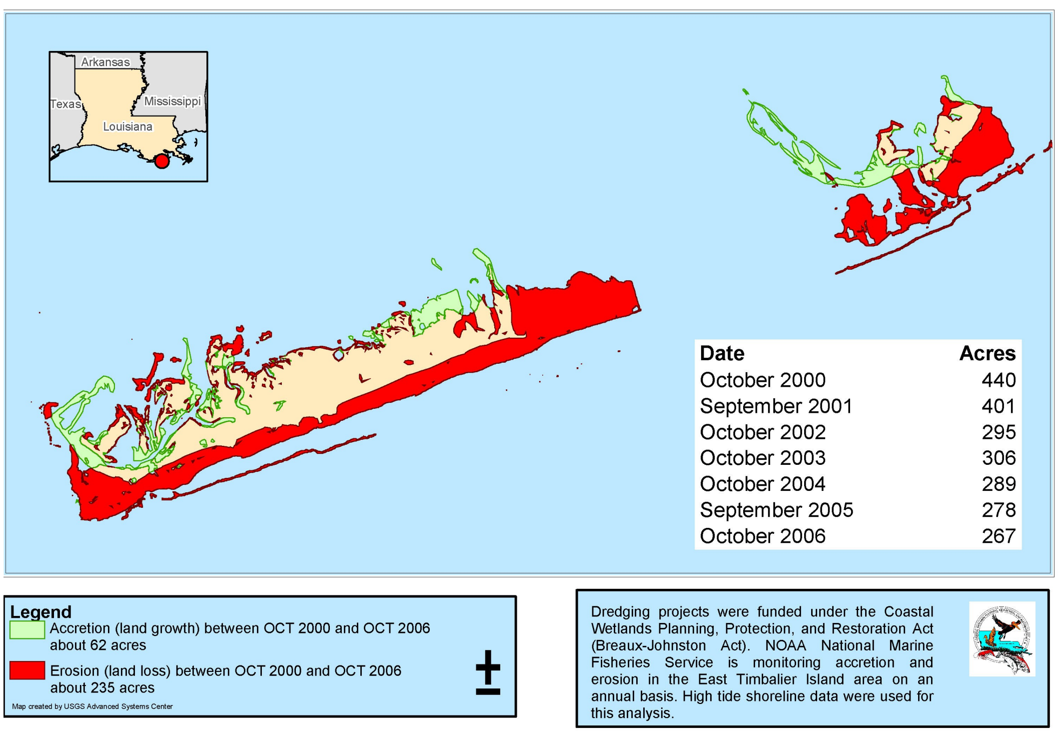


Figure 3-12. Salinity and water depth changes at the Wax Lake Outlet Delta (near the Big Island Mining Project) with the passage of Hurricane Rita. Source: Louisiana State Department of Wildlife and Fisheries

NOAA East Timbalier Island Project. Further east, in a sediment-starved part of the coast, is the NOAA-sponsored East Timbalier project, a barrier island that protects wetlands and other more landward fishery habitat. The project reinforced the island, which had been cut into two sections in 1992 by Hurricane Andrew (Fig. 3-13). Reinforcement included dredged material added to the front and back sides of the island, addition of wetland and dune plants to help stabilize the island, installation of a sand fence to cut down on movement of sand, and addition of a stone revetment to armor the foreface of the island against the Gulf of Mexico. NOAA has been monitoring the island since 2000, when reinforcement activities were concluded. In spite of this reinforcement the island continues to erode at a dramatic pace. This loss shows the island eroding from both ends as well as from the Gulf side of the island. Some of the eroded sediments have been deposited on the back side of the island. The net effect is that the island (both sections) is decreasing in size and moving landward without the influence of hurricanes. Its protective potential, although still there, is decreasing with time. The combined effects of Hurricanes Katrina and Rita on East Timbalier Island are shown in Figure 3-14. These hurricanes caused additional erosion on both ends of the island and continued to move the island landward at an accelerated rate. For comparison note the impact of Hurricane Lili in September 2002 (table in Figure 3-13). Also note that the island continued to erode in 2006, even though no major storms occurred. Hurricanes Katrina and Rita exacerbated the rate of existing erosion of barrier islands along this part of the coast. Such enhanced erosion increases the threat to more landward wetlands and infrastructure protected by these wetlands.

Figure 3-13. East Timbalier Island change, 2000 - 2006. Source: NOAA and USGS.



Date	Acres
October 2000	440
September 2001	401
October 2002	295
October 2003	306
October 2004	289
September 2005	278
October 2006	267

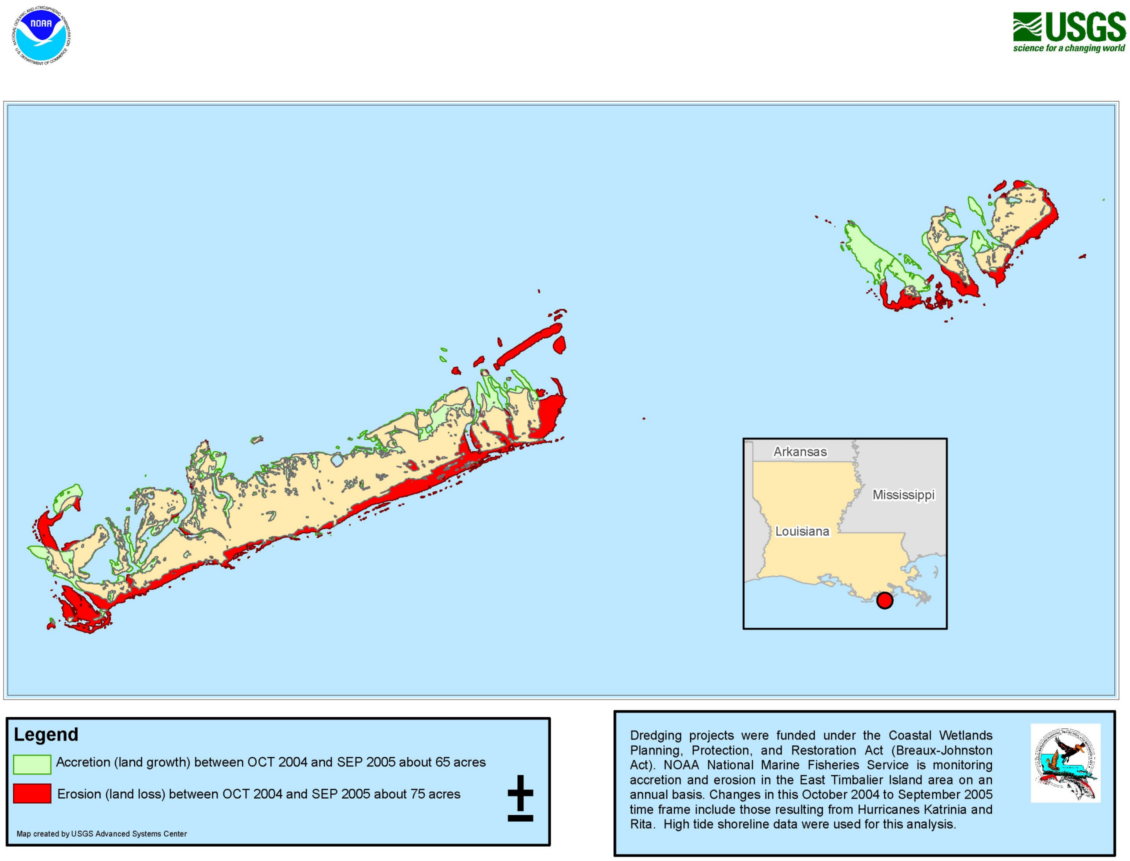


Figure 3-14. East Timbalier Island change, October 2004 – September 2005. Source: NOAA and USGS.

Oyster Reefs

Productive oyster reefs were buried by sediment and vegetation or were scoured by waves and currents, resulting in their destruction. The LDWF estimated seed and sack (market size) oyster mortality rates on the state's public oyster reefs as 74 percent and 53 percent, respectively (Roussel 2006). These estimates were based on samples collected by LDWF biologists in September, October, and November 2005. No data were collected on private oyster leases in the state, but Roussel (2006) speculated that mortality rates were similar. Oyster mortality was documented on public grounds across the state, and the highest rates occurred in the southeast. Combined (seed and sack) mortalities were as high as 72 percent east of the Mississippi River and 73 percent in upper Barataria Bay (P. Banks 2007, pers. comm.). The central part of the coast experienced the lowest rates of mortality, and rates in the southwest were intermediate in severity between the southeast and central areas (Roussel 2006). Caffey (2006) presented preliminary estimates of 20 to 30 percent mortality in the central portion of the state and 30 to 40 percent in the southwest portion. The range presented for the most heavily impacted area was 50 to 70 percent, in agreement with the data presented by Roussel (2006). The high mortality rates documented after the hurricanes were partially offset by a high spat set observed in fall 2005 (P. Banks 2007, pers. comm.). Despite this, the available oyster stock on the public reefs decreased by 18 percent from July 2005 to July 2006 (LDWF 2006a). These high mortality rates also were reflected in the oyster fisheries. Oyster landings decreased by 60 percent and gross dockside revenue decreased by 56 percent following the hurricanes (LDWF 2006b), although infrastructure damage was also a contributing factor to these findings.

Barrier Islands

The Chandeleur Islands serve as an important barrier for Louisiana's wetlands. Already badly eroded by several hurricanes between 2002 and 2005 (i.e., Lili, Ivan, and Dennis), these islands were nearly destroyed by Hurricane Katrina (Graumann, et. al. 2005; Knabb et. al. 2006b). Landsat and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery for the Chandeleur Islands acquired before and just after Hurricane Katrina were obtained from a U.S. Geological Survey website (Figure 3-15).

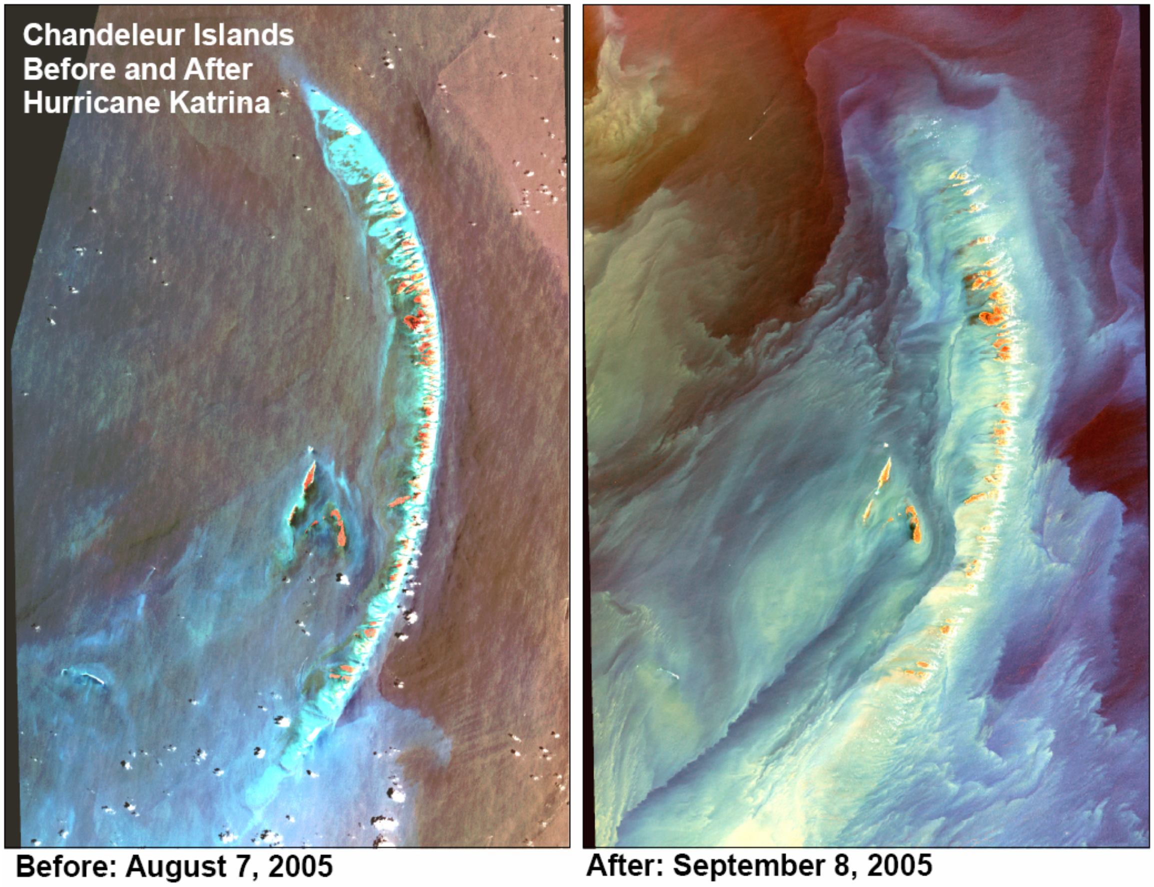


Figure 3-15. Chandeleur Islands, Louisiana. Source: USGS.

Image datasets were registered to each other and classified into four broad categories; water, bare soil, vegetation, and cloud. These were merged into a single file depicting the differences in land cover between the imagery dates. The area for the depicted categories were totaled and converted to acres (Table 3-1). The Chandeleur Islands suffered a nearly 50 percent permanent loss to both unvegetated and vegetated areas. It is likely that seagrass habitat adjacent to the Chandeleur Islands also was severely impacted by scouring and burial. The U.S. Fish and Wildlife Service (2005a) reported that the Breton National Wildlife Refuge had been reduced by about half its previous size.

Table 3-1. Barrier Island Land Loss

Location	Approx Total Land Pre-Katrina (acres)	Percent Loss of Soil and Vegetation to Water	Percent Loss of Vegetation to Soil
Chandeleur Islands (LA)	2434.33	0.487 (1185.53 acre loss)	0.075 (181.75 acre loss)

Source: Miller 2007, pers. comm.

Offshore Habitat

The Minerals Management Service (MMS) of the U.S. Department of the Interior estimates that 3,050 of the Gulf's 4,000 platforms and 22,000 of the 33,000 miles of Gulf pipelines were in the direct path of either Hurricane Katrina or Hurricane Rita, resulting in the destruction of 115 platforms, extensive damage to 54 others, and damage of more than 600 pipeline segments (MMS 2007a). In terms of drilling rigs, 11 were destroyed and 44 (one platform rig and 43 mobile rigs) were extensively damaged. Of the 43 extensively damaged mobile rigs, 15 were torn loose from their moorings and sent adrift. Some of these rigs drifted northwest toward the coast, periodically making contact with and scraping the seabed and damaging pipelines until the rigs grounded in shallow water (Figure 3-16). The broken pipelines and destroyed platforms became a form of debris that disturbed the seabed at specific locations within a widespread area (Figure 3-17) (MMS 2007a).

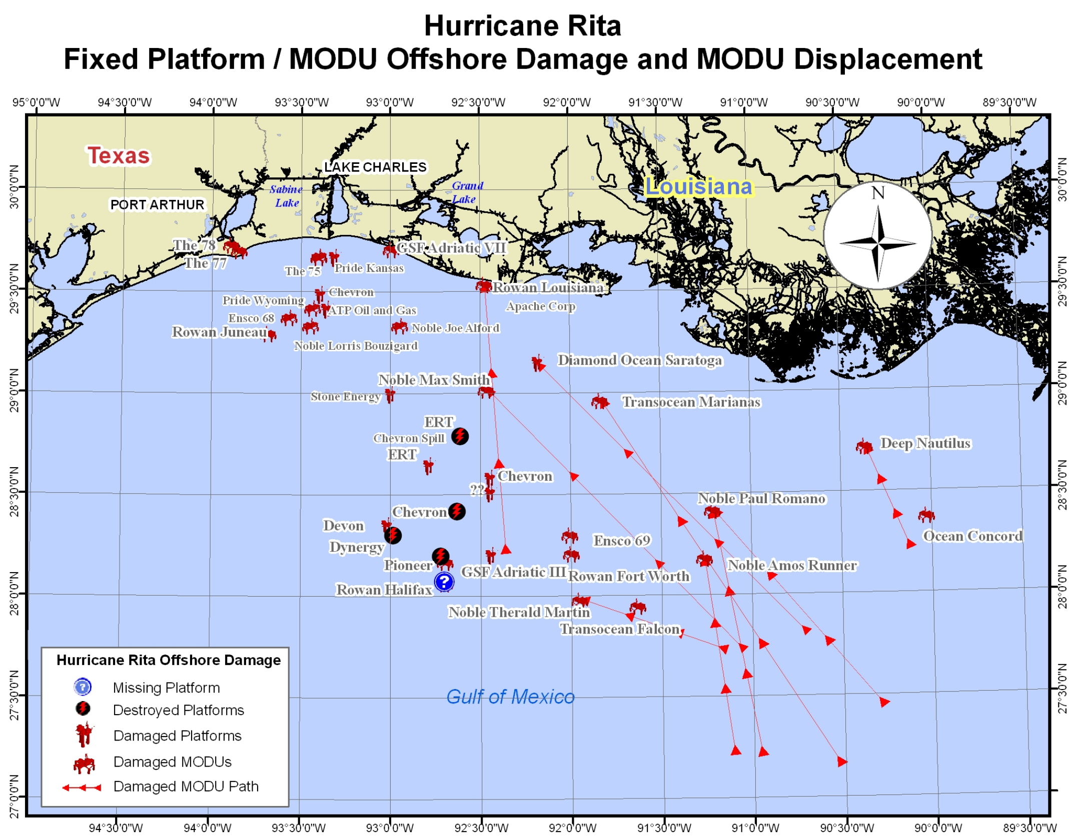


Figure 3-16. Hurricane Rita Fixed Platform/MODU Offshore Damage and MODU Displacement. Source: Minerals Management Service.

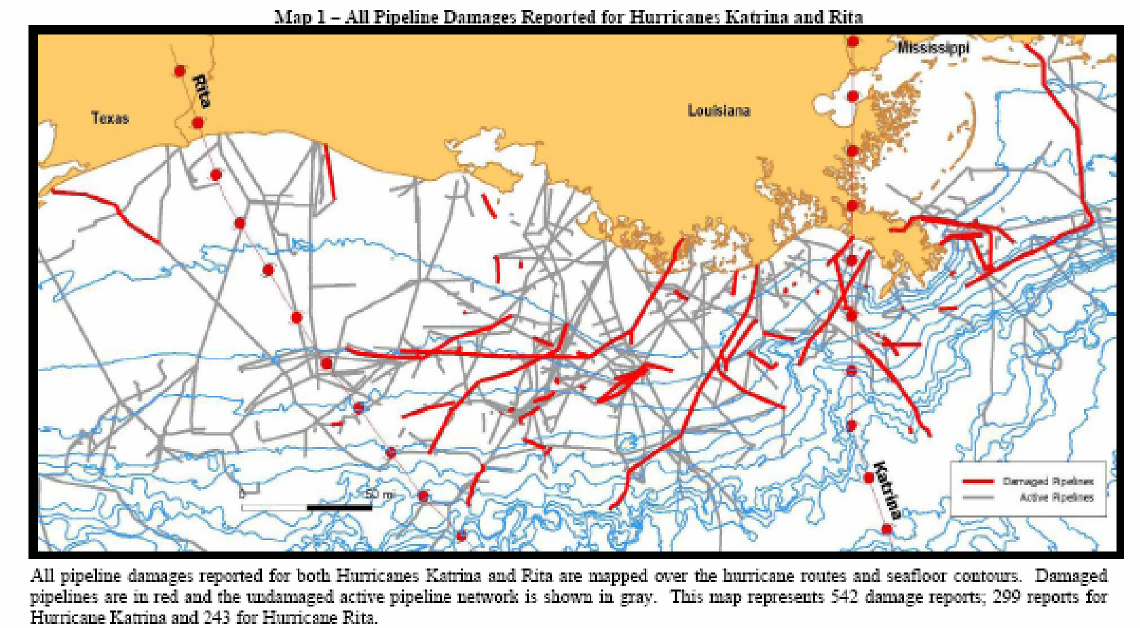


Figure 3-17. Outer Continental Shelf pipeline damage from Hurricanes Katrina and Rita. Source: MMS.

Because the offshore oil and gas facilities were shut down for both hurricanes, oil losses were mostly limited to the oil stored on damaged structures or contained in the individual damaged pipeline segments (125 spills amounting to 16,032 barrels, or 673,344 gallons, of petroleum products). Using the U.S. Coast Guard size classifications for offshore spills, 112 of the spills or 90 percent were minor in size (less than 238 barrels), and 13 of the spills or 10 percent were medium in size (238 to 2,380 barrels). There were no accounts of spills from these facilities on the Federal Outer Continental Shelf that reached the shoreline, oiled birds or mammals, or involved any discoveries of large volumes of oil to be collected or cleaned up (MMS 2007b).

Large hurricanes in the Gulf of Mexico generate waves large enough to trigger submarine slope failures, commonly referred to as "mudslides," which disturb the seabed. Coleman et al. (1982) examined sediment instabilities in the offshore Mississippi River Delta region of the Gulf of Mexico and identified a large area (~300 to 800 mi^2) of instabilities and mudslide activity. During Hurricane Ivan in 2004, offshore pipelines were damaged by mudslides (Figure 3-18). During Hurricane Katrina only one mudslide was identified 8 to 10 mi. south of the bird's foot delta in about 200 ft. of water (MMS 2007a; J. Mathews 2007, pers. com.).

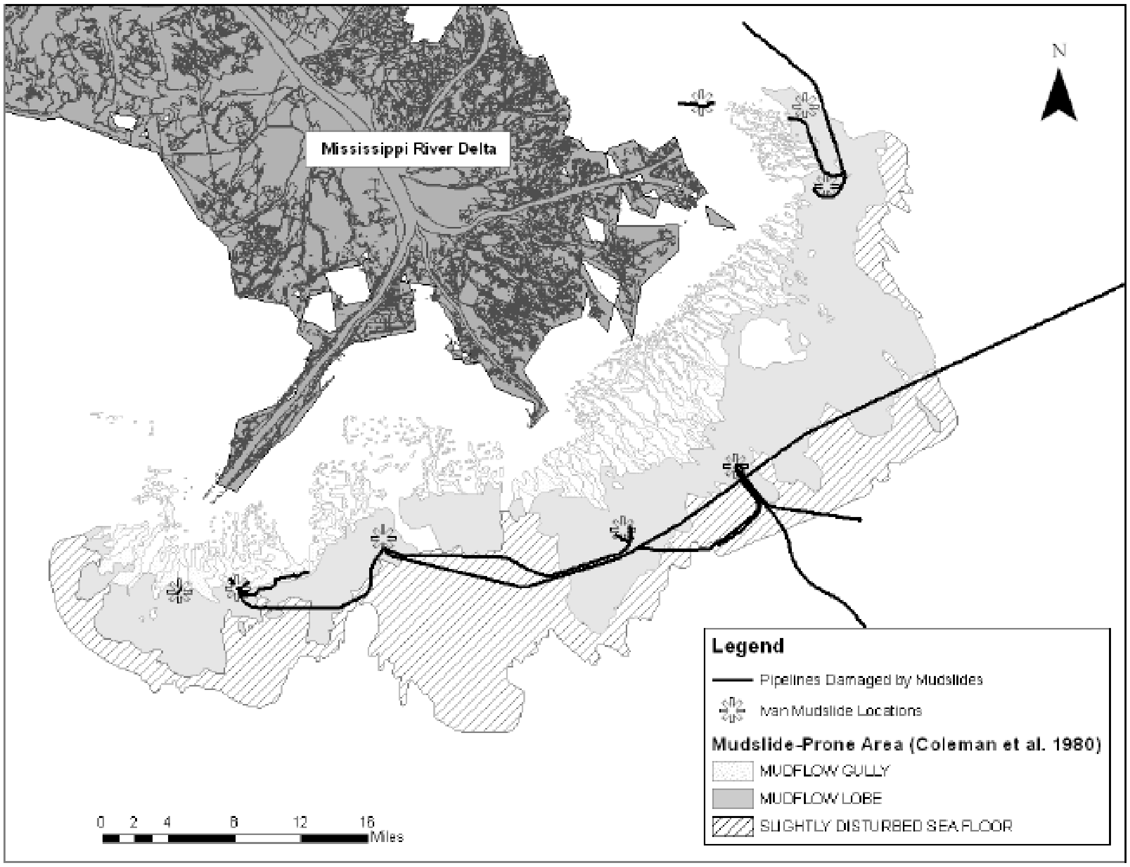
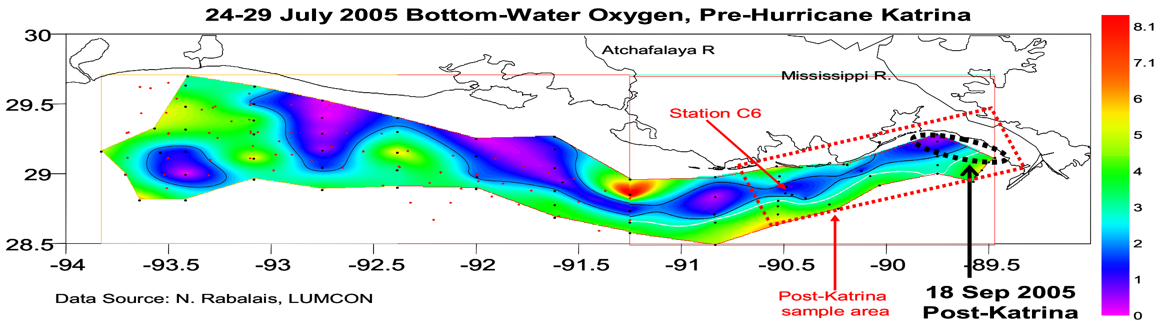


Figure 3-18. - Locations of pipelines damaged by mudslides during Hurricane Ivan and inferred mudslide locations superimposed on map of mudslide prone areas from Coleman et al.1982. A smaller area was impacted during Hurricane Katrina.

The MMS contracted with Oceanweather, Inc. (Cardone 2006) to do a hindcast on the wind, waves, and currents for the northern Gulf of Mexico during Hurricanes Katrina and Rita. They used a series of models that were validated using independent data. For Hurricane Katrina, wave heights of 52 to 55 feet with a wave period of 13.7 seconds occurred. For Hurricane Rita, wave heights of 46 to 49 feet with a wave period of 12.9 seconds occurred. Sverdrup et al. (1942) indicated that waves with such periods begin increasingly to “feel” bottom between 520 and 325 feet. Thus, the waves from these hurricanes disturbed the entire water column and likely the seabed as well along a 300-mile-wide swath (waves greater than 33 feet) from the outer Continental Shelf all the way to the coast. Based on findings for Hurricane Georges (DiMarco 2004), it is believed a zone of upwelled water occurred along the tracks of both Hurricane Katrina and Hurricane Rita. Recent studies (Michaels 2007; Benitez-Nelson et al. 2007; McGillicuddy et al. 2007; Sriver and Huber 2007) now have confirmed that cyclones (i.e., hurricanes) cause upwelling of subsurface, colder, nutrient-rich waters to the sunlit surface of oceans and resultant phytoplankton blooms.

Offshore Hypoxic Zone

Most years a hypoxic (i.e., generally defined by dissolved oxygen below 2 mg/l) area forms in patches in the bottom water under the Mississippi River plume between May and September (e.g., Figure 3-19a). During hypoxia trawlers record little or no catch within the area. According to Rabalais (2006) tropical storms and hurricanes, although devastating to coastal communities, temporarily alleviate low oxygen conditions in this area (Fig. 3-19a) as they mix and aerate the water column. With the approach of Hurricane Katrina, bottom water dissolved oxygen began to increase from 0 mg/l on August 24, 2005, to in excess of 3 mg/l by August 27, and 4 mg/l by August 29 (Figure 3-19b), when transmission of data was lost. However, given sufficient calm weather following the storm, low oxygen conditions redeveloped within a week or so. Two weeks after passage of Hurricane Katrina, the Mississippi River Bight was surveyed (September 2005, before Hurricane Rita) and a small area of low oxygen was found. While the storm had mixed and aerated the water column in the hypoxic area, the re-suspended sediments and organic carbon again consumed the oxygen within the bottom water and re-established low oxygen conditions. A similar survey following Hurricane Rita in late September found no hypoxia in the area (Rabalais 2007, pers. com.).



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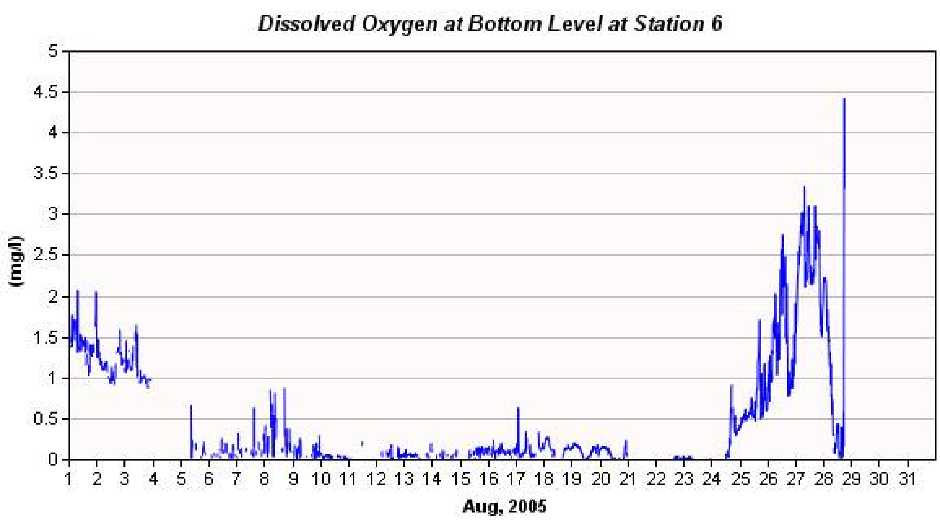


b

Figure 3-19. (a) Hypoxic zone in the Mississippi River Bight July–September 2005 and (b) dissolved oxygen levels as Hurricane Katrina approached in late August 2005. Source: Rabalais (2006).

Marine Debris

Hurricanes Katrina and Rita caused large amounts of debris to be widely deposited in nearshore waters and within the coastal wetlands of Louisiana. Marine debris consists of vessels, vegetation, construction debris, and various hazardous materials. Debris impacted fishery habitat in several ways. It gouged, scraped, dragged, covered, crushed, or broke the habitat and/or biota upon which it was deposited or moved. The impacts of deposited debris continue until the debris is physically removed.

Lost crab traps also were noted as a marine debris impact in Louisiana and they present a different long-term impact to fisheries. In addition to gouging or covering habitat, lost or abandoned traps can remain functional (i.e., can continue to fish) for many years, depending upon their composition and the amount of damage they sustained. They continue to impact organisms attracted to the trapped and/or decaying organic matter (i.e., other organisms) already present in the trap. The traps, like other debris, were widely scattered by the storms (Fig. 3-20).

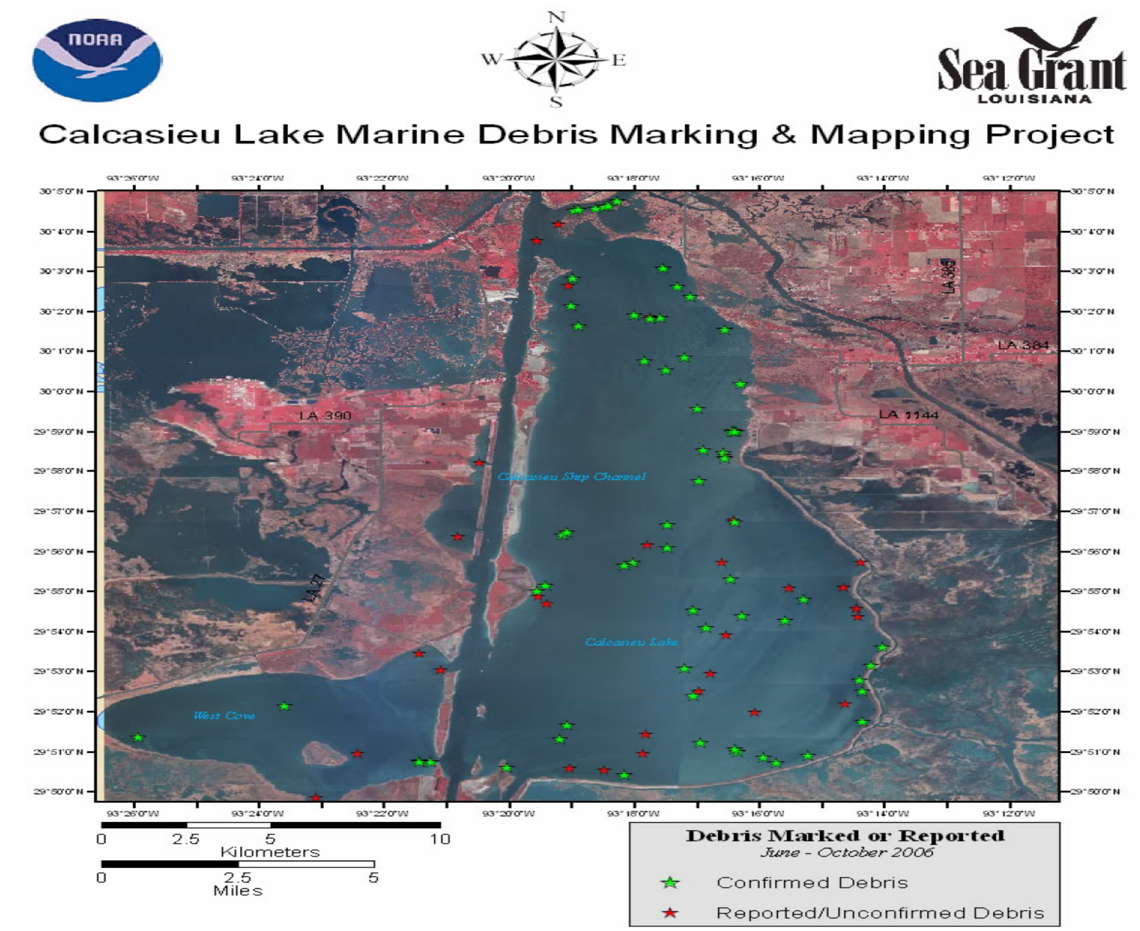


Figure 3-20. Marine debris in Calcasieu Lake. Source : NOAA and Louisiana Sea Grant.

Chemical and Biological Contamination Caused by Hurricanes Katrina and Rita
In the wake of Hurricanes Katrina and Rita, NOAA's NMFS and National Ocean Service (NOS)—in cooperation with the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), U.S. Food and Drug Administration (FDA), and coastal states of the northern Gulf of Mexico—initiated a comprehensive interagency effort to assess human-health and environmental impacts (Christensen 2007). The study was

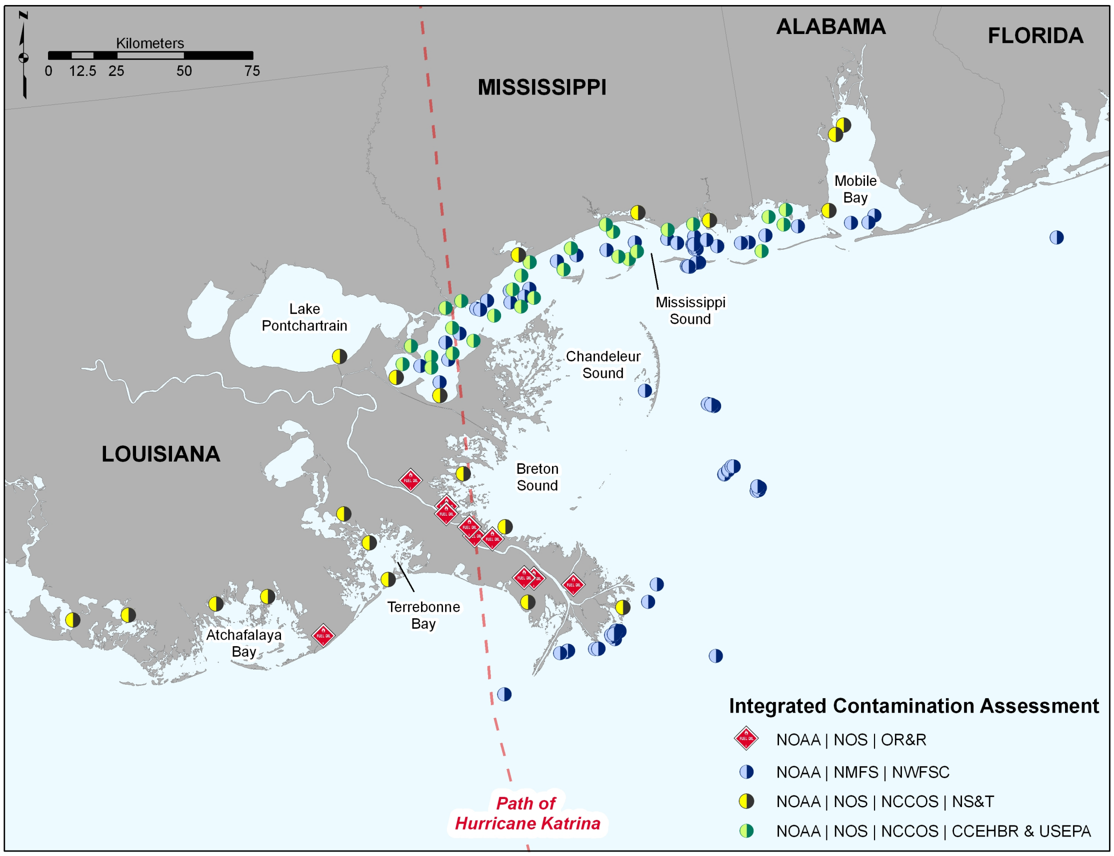


Figure 3-21. Chemical and biological contaminant sample locations collected by NOAA and partners in response to Hurricanes Katrina and Rita. Dashed line indicates the path of Hurricane Katrina. Blue markers indicate locations of NOAA|NMFS activities, green and yellow markers indicate joint EPA – NOAA|NOS|NCCOS activities, and red markers indicate NOAA|NOS|OR&R activities. Source: Christensen 2007.

designed to quantify the magnitude and extent of coastal contamination, and associated human-health and ecological effects resulting from these unprecedented storms (see DVD for full report).

NOAA Response. NMFS led a series of missions focused on Atlantic croaker (*Micropogonias undulatus*) and white shrimp (*Litopenaeus setiferus*) as the primary target species. Reports generated are available online at http://www.st.nmfs.noaa.gov/hurricane_katrina/water_sediment_survey.html, and are listed in Krahn et al. 2005a, b, c, d; Krahn et al. 2006a, b; Peterson et al. 2005a, b, c, d; and Peterson et al. 2006a, b. Sampling commenced on September 13, 2005, within 1 week after floodwater pumping from New Orleans began, and continued through the fall (Figure 3-21, blue symbols). Samples were analyzed for a suite of organic pollutants, including organochlorines (OCs), polybrominated diphenyl ethers (PBDEs), and polycyclic aromatic hydrocarbons (PAHs). Samples were also tested for bacterial contamination, including fecal contaminants such as *Escherichia coli* and potentially pathogenic species of *Vibrio*. Seafood samples from additional cruises in November–December 2005 and April 2006 were collected and analyzed for chemical and bacterial contaminants to evaluate temporal trends over a period spanning 7 months.

Organic Pollutants. Low levels of chemical contaminants were measured in muscle tissue of fish and shrimp. Concentrations of PCBs, DDTs, and chlordanes were well below the FDA regulatory guidelines, but concentrations of some contaminants did fall within EPA fish consumption advice (Christensen 2007). PBDEs—flame retardant compounds thought to be associated with urban runoff—generally were not detected in fish or shrimp, suggesting that the detected contaminants were not derived from recent urban runoff. Concentrations of PAHs in white shrimp were low (25 ng/g or less) compared to levels measured in other marine seafood species. Bile analysis of fish collected post-Katrina indicated that they were not exposed to increased levels of PAHs compared to fish collected from the region in 1990.

With respect to temporal trends, NOAA found initial increases in petroleum-related PAHs in shrimp from Lake Borgne and Mississippi Sound between the periods September 13–19 and October 27–31, but this increasing trend had moderated by December and had declined by April 2006. No significant temporal trends were found for urban runoff–related PAHs for any of the regions over the 7-month period. Although the initial increases in petroleum-related PAHs may be attributable to petroleum released following Hurricane Katrina, concentrations of PAHs in shrimp samples collected during April had returned to background levels found in samples in September. Statistically significant increases in PCB concentrations in shrimp from Mississippi Sound also were found initially, but, again, the highest concentrations were quite low (<5 ng/g) and had decreased by April 2006 to levels at or below those from the same region in September 2005.

Bacterial Contamination. No indication of fecal contamination was found in fish or blue crab (*Callinectes sapidus*) tested in fall and early winter 2005. Levels of *E. coli* and *Enterococcus* measured in water collected in the region post-Katrina were below the EPA guidelines for recreational waters. Low levels of *E. coli, Enterococcus*, non-toxigenic *Vibrio cholerae*, and *V. vulnificus* were measured in sediment samples. Although there are no standards for the presence of fecal indicators in marine sediments, NMFS recommended limited contact based on the presence of *E. coli.*

With respect to temporal trends in microbial pathogens, samples examined in 2005 showed no significant differences. In 2006, sampling of fish and shrimp species showed extremely low levels of fecal contaminant indicators (*E. coli and Enterococcus*). During survey cruises (Christensen 2007), the presence of *Salmonella* was also examined as an indicator of fecal contamination, and was found only in one sample. In addition, only 4 of 134 positive isolations of *V. parahaemolyticus* were strains considered to be pathogenic if present in oysters destined to be consumed raw. Because other seafood is generally cooked, there is no health risk associated with the presence of these bacteria in other species. A more detailed summary that includes pathogen data related to human health risks can be found in the report appendices.

Status and Trends Sampling. In coordination with the NMFS response, NOS' National Centers for Coastal Ocean Science (NCCOS) sent a team of National Status and Trends Program (NS&T) scientists to the region to collect chemical and microbiological samples from its long-term nearshore and intertidal habitat monitoring sites. NS&T is the longest running coastal contamination monitoring program that is national in scope, and has made annual collections throughout the impact zone since 1986 (Figure 3-21, yellow symbols), including a mission to the region in 2006. As such, NS&T data provide a unique perspective on storm impact and recovery for persistent organic pollutants (POPs), metals, and major trace elements (http://ccma.nos.noaa.gov/data/katrina/welcome.html). In addition, NCCOS mobilized staff to work in partnership with the EPA and USGS to assess sediment and water quality throughout subtidal waters of Lake Pontchartrain, and coastal waters from Dauphin Island, Alabama, to the western side of Lake Borgne, Louisiana. Surveys in Lake Pontchartrain were conducted with the USGS from October 11–14, 2005, using small boats, and in Mississippi Sound/Lake Borgne from October 9–15, 2005, using boats staged from the EPA ship OSV *Bold* in Gulfport, Mississippi (Figure 3-21, green symbols; stations in Lake Pontchartrain not shown).

Median concentrations of organochlorine compounds (OCs) in the tissues of oysters (*Crassostrea virginica*) collected from shallow and intertidal habitats were lower for PCBs and DDTs immediately after the storm when compared to the 20-year NS&T historical record. Within 5 months of landfall, most OCs returned to pre-storm levels, with the exception of dieldrins (the sum of similar compounds), which statistically exceeded pre-storm conditions. These differences are not statistically significant when results of the region are considered as a whole. On average, median PAH levels in oyster tissues also were lower immediately after the storm when compared to the 20-year historical record. This reduction—and return to near-pre storm concentrations—was not statistically significant, although Biloxi Bay did experience a significant increase in PAH levels after the storm. An analysis of POPs in the sediments collected from NS&T sites suggested that no significant changes in contamination levels occurred as a result of Hurricane Katrina.

Concentrations of metals in oysters after the storm were generally elevated when compared to the 20-year historical record for each site. When considered collectively, 45 percent of the sites had concentrations above the 75th percentile of the preceding 20-year record, and 23 percent of measured concentrations for this group of contaminants were record highs. Selenium exhibited elevated concentrations at all but one site, and showed record highs at all but five sites. Similarly, elevated concentrations were evident for copper, nickel, and zinc when compared to the 20-year record. On average, increased nickel concentrations were statistically significant in the study area, with an equally significant decrease 5 months after landfall. Levels of lead decreased significantly from pre-storm and immediate post-storm conditions throughout the region, and 2006 measurements of mercury exhibited a significant decrease in the region when compared to the historical record (Fig. 3-22).

Elevated concentrations of trace metals have been documented by NS&T before and after U.S. coasts have been impacted by large storm events. There are at least two possible sources of increased metals available to biota as a result of the Gulf Coast hurricanes: (1) large rain events can wash trace metals into coastal environments (because the metals are a natural component of coastal soils); and (2) trace metals are also a natural component of coastal sediments (once sediments settled out of the water column, oyster metal concentrations began to return to their historical levels).

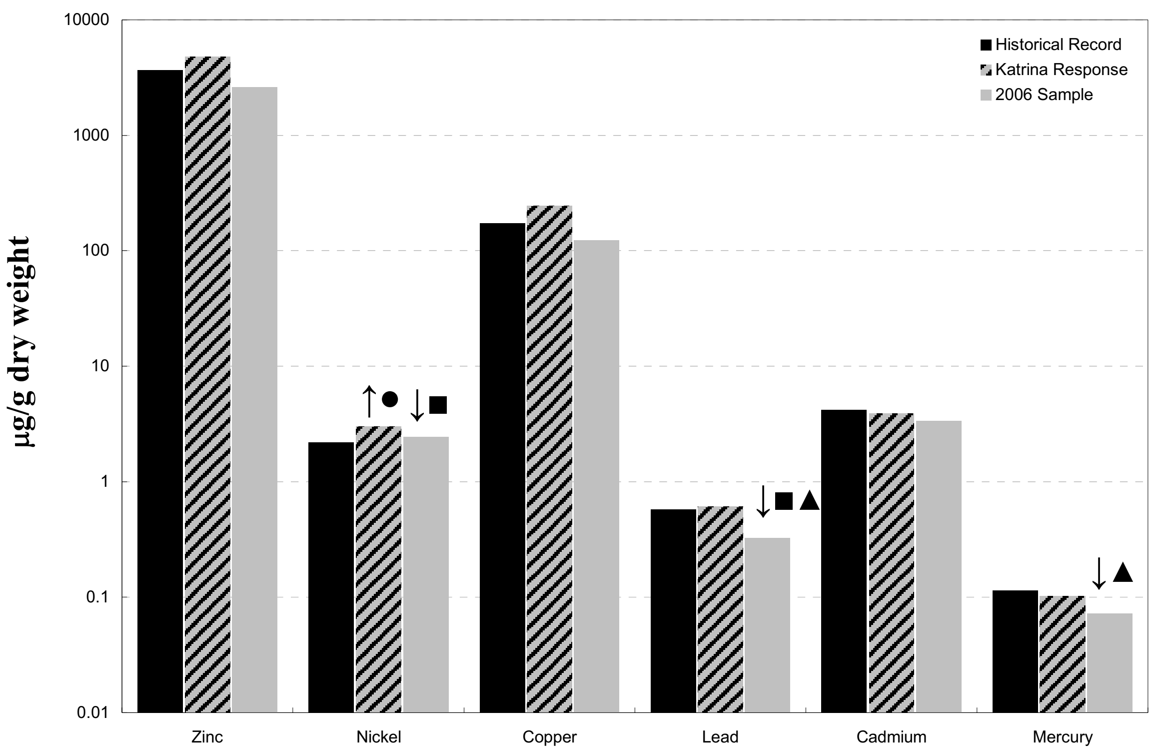


Figure 3-22. Levels for select metals and major trace elements measured in eastern oyster tissues before and after the passage of Hurricane Katrina. ● indicates a significant difference between pre-storm and immediate post-storm conditions, ■ indicates a significant difference between immediate post-storm and 2006 conditions, and ▲ indicates a significant difference between pre-storm and current (2006) conditions. Source: Christensen 2007.

Oil Spills. NOS's Office of Response and Restoration (OR&R) began assessing fuel/oil and other contamination spills resulting from the hurricanes on November 15, 2005

(Figure 3-21, red symbols). Follow-up site visits occurred in 2006 and 2007 to evaluate injuries to natural resources and habitat recovery rates.

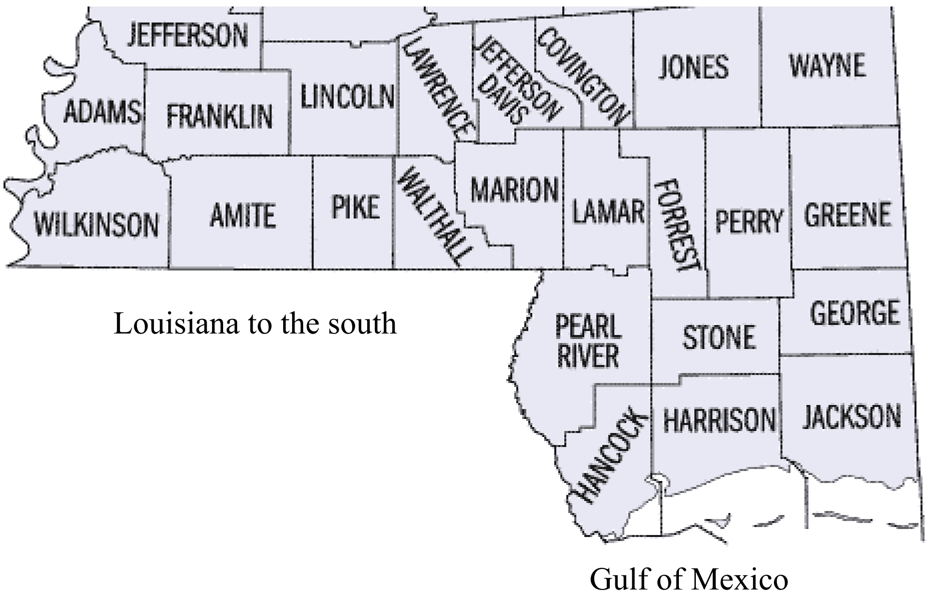
Information on the spatial extent and degree of oiled habitat was collected during surveys, as well as information on habitat recovery. Approximately 5,000 acres of habitat were injured from 10 major oil incidents in southeast Louisiana. Oil sheening in coastal waters also was observed at the 10 major oil incidents and many of the 300+ incidents that have not been assessed in detail. It is projected that heavy and moderate habitat oiling observed at the 10 major oil incidents likely will result in longer-term (months to years) fishery habitat impacts, such as adverse changes to ecological processes and functions and adverse changes to fishery and non-fishery habitat quality and structure.

US EPA. The U.S. EPA's Offices of Water and Research & Development (Regions 4 and 6) mobilized the OSV *Bold* and key scientific personnel to the affected region to characterize impacts throughout Lake Pontchartrain, its drainage waters, coastal waters from Dauphin Island, Alabama, to the western edge of Lake Borgne, Louisiana, and the Mississippi River Delta and plume waters. Parameters measured and evaluated include the EPA's National Coastal Assessment indicators (sediment quality, water quality, and benthic condition), chemical and microbial/pathogenic contaminants in water, sediment, and fish and shellfish tissues. This effort was closely coordinated with NOAA, USGS, FDA, and the States of Louisiana, Mississippi, and Alabama.

Concentrations of POPs in sediment samples taken by EPA throughout Lake Pontchartrain and the Mississippi Delta and Sound were unremarkable, and none exceeded the NOAA "effects range low" guidelines for potential biological effects. Findings from the September 2005 survey showed few detectable priority pollutants, including POPs, in the studied bays and rivers. In general, pollutants present were detected in acceptable concentrations when compared to EPA's water quality criteria and the NOAA NS&T Program's published effect levels for sediment. During the October mission, there was no single indication of contaminant release, or detected contaminant concentrations were below levels of concern. In addition, EPA's conclusions regarding the potential impact of the hurricane proximal to National Priorities List (NPL) and non-NPL Superfund sites indicated no apparent contaminant impacts at any of the studied sites.

Dissolved oxygen concentrations were determined to be above the minimum criteria at all but two of the 39 surface water locations. Bacteriological densities at the study locations were less than EPA's promulgated enterococci criteria for coastal waters. Overall, the data collected by EPA show that few water quality criteria were exceeded during the study.

Mississippi



Coastal and Southern Counties of Mississippi

Coastal Land Cover Change
In Mississippi, land cover changes observed by NOAA's Coastal Change Analysis Program (C-CAP) highlight several of the impacts caused by the 2005 hurricanes (Figure 3-23) (N. Herold and J. McCombs 2007, pers. com.). Much less notable than in Louisiana, is the loss of emergent wetlands and areas of unconsolidated shore, and increase in area of open water. The total area that changed to water is less than 5 mi^2. The losses occurred primarily in the area surrounding Hancock County.

The most dramatic changes seen in the coastal areas state were the losses of hardwood and bottomland forests and scrub cover, and resulting increase in the amount of grasslands and palustrine emergent marsh. Over 70 mi^2 of forest land (primarily evergreen) was lost or converted to grasses, and 10 mi^2 of bottomland forests were seen changing to the palustrine scrub or emergent categories. There was also a conversion of approximately 40 mi^2 of evergreen forest to scrub/shrub cover.

Also of note, is the small loss of high and medium intensity development caused by the 2005 hurricanes. The resulting piles of debris and building material and remaining foundations have been captured as lower intensity development.

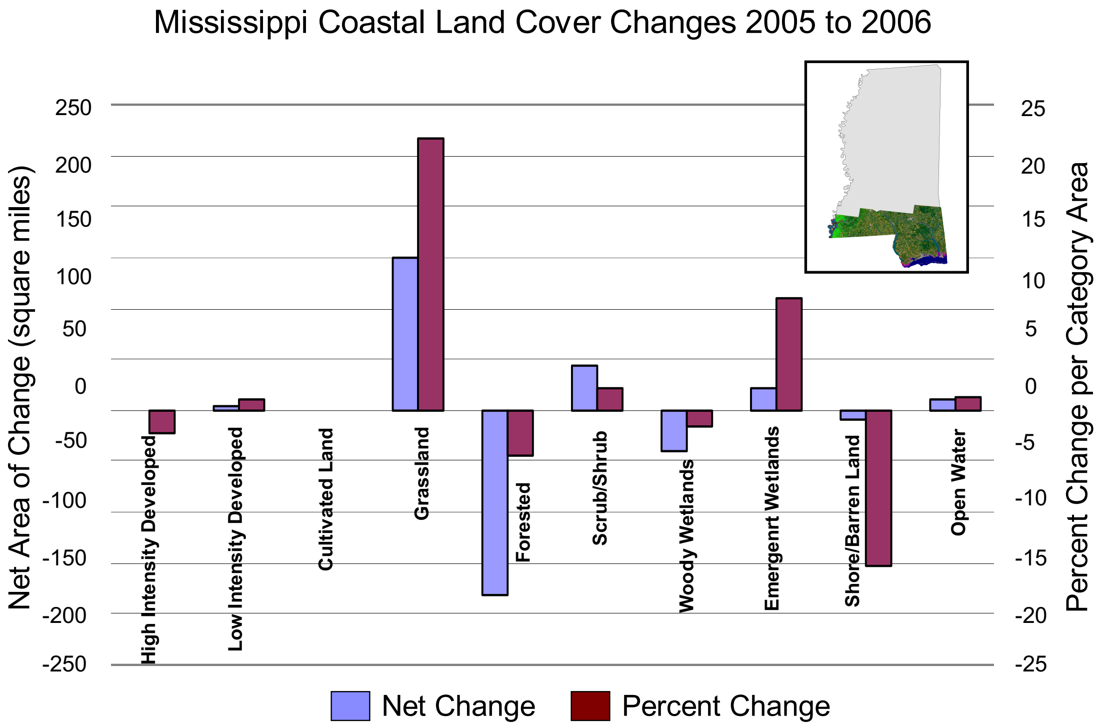


Figure 3-23. The land cover changes depicted above occurred between August 2005 and March 2006. The inset map shows the area (in color) used for the change analysis.

Coastal Forests and Wetlands

Estuarine marsh and wetlands suffered extensive damage from Hurricane Katrina (Mississippi Department of Marine Resources 2005; Barbour 2006). An estimated 1,890 acres of coastal marshes and forests were severely damaged or destroyed. Landward, the storm surge from Hurricane Katrina scoured the bottom of Mississippi's bays and river systems, suspending large amounts of organic anoxic sediments. The resulting drop in dissolved oxygen caused massive fish kills in Mississippi's rivers and upper estuarine areas. Thousands of acres of were covered with storm debris, inhibiting the ability of these areas to function as essential habitat for important commercial and recreational species.

Seagrass

P. Biber (2007, pers. comm.), using a semi-automated classification approach on aerial imagery of Mississippi's barrier islands in 2003 and 2006, found little impact on seagrass due to Hurricane Katrina (Table 3-2). Approximately 90 percent of Mississippi's seagrass is associated with these barrier islands (P. Biber 2007, pers. comm.). There are only two locations of seagrass along the mainland Mississippi coast—Grand Bay National Estuarine Research Reserve at the eastern end of Mississippi, and Waveland near the Louisiana border. During the 2006 seagrass growing season following

Hurricane Katrina, the seagrass beds at Grand Bay National Estuarine Research Reserve appeared healthier and more extensive than any time since monitoring began in 2003 (C.A. May 2007, pers. comm.). However, the extensive bed of seagrass *(Ruppia)* off Waveland, Mississippi, in 2004 was gone in 2006, probably due to the landfall of Hurricane Katrina (P. Biber 2007, pers. comm.).

Table 3-2. Seagrass associated with the Mississippi barrier islands (acres).

Island	2003	2006	Difference
Petit Bois Island	16.911	37.591	20.680
Cat Island	81.111	62.957	–18.154
Ship Island	34.233	41.543	7.310
Horn Island	62.915	163.403	100.488

Source: P. Biber, University of Southern Mississippi, Gulf Coast Research Laboratory (pers. comm.)

Heck and Byron (2006), in their post–Hurricane Katrina assessment of November 2005, concluded that Hurricane Katrina had locally significant negative impacts on seagrass but did not devastate the majority of seagrass beds along the Mississippi Gulf Islands National Seashore. They compared the 2005 distributions and abundances of seagrasses in the Gulf Islands National Seashore against a previous assessment in 1992 using aerial imagery that was updated with groundtruth and monitoring through 1996 (Heck et al. 1996). Comparison of the 2005 survey to the survey conducted in 1996 showed 100 percent loss of seagrass along West Ship Island, a 57 percent decrease in seagrass coverage at East Ship Island, a 14.8 percent increase at Horn Island, and a 72.5 percent increase in seagrass occurrence at Petit Bois Island (Heck and Byron 2006). The dramatic losses (over 50 percent) at West and East Ship Islands are likely the result of their proximity to the eye of Hurricane Katrina as the storm made landfall at Waveland, Mississippi (Heck and Byron 2006). Overall, Mississippi has experienced a loss of nearly half of the seagrass acreage that was present in 1967–1968 because of declining water quality (Moncreiff et al. 1998).

Oyster Reefs

The worst immediate damage to Mississippi fisheries habitat was to the State's approximately 12,000 acres of oyster reefs. On September 14, 2005, Mississippi Department of Marine Resources/Shellfish Bureau personnel conducted an initial assessment of the impact of Hurricane Katrina on Mississippi oyster reefs. Dredge samples were taken on the public oyster reefs in western Mississippi Sound (MDMR 2005). In all samples, a large amount of new shell was found, indicating recent mortalities. Anthropogenic debris was found in many samples, comprised mostly of housing material. Organic materials such as branches, leaves, seagrass, and marsh grass were also found. All samples were covered in a slimy, foul-smelling mud. Dredging proved very difficult because of the amount of debris in the water and because reef contours had changed. The hurricane appeared to have created gullies over much of the area. The initial assessment indicated a vast majority of the public oyster resource and substrate may have been scoured away, buried by sedimentation and debris, or moved (MDMR 2005).

Preliminary mortality estimates of harvestable oysters exceeded 90 percent. Because oysters are a long-term crop, full recovery may take years and some oyster habitats may have been lost permanently (Barksdale 2005). Although officials have found active beds, they do not expect oysters to be harvestable for at least another 2 years (Barksdale 2005; Hogarth 2005). However, a good spat set occurred following the hurricane, and spat were present in most of the areas surveyed (MacKenzie 2006; B. Randall 2007, pers. comm.). Over the next 5 years, at least 75 percent of the lost reef habitat is expected to be restored (Barksdale 2005).

Nearshore Artificial Reefs

About 85 percent of the nearshore low-profile reefs and 90 percent of Mississippi's offshore reefs were scoured and/or buried and no longer function as reef habitat. These reefs were essential habitats for a variety of marine animals for feeding, spawning, and cover.

Barrier Islands and Shorelines

Mississippi's offshore barrier islands include Petit Bois, Horn, Ship, and Cat Islands. This island chain, located 12 miles south of coastal Mississippi, provides a natural first line of defense against hurricanes and other tropical storm systems. Unfortunately, these natural barriers have suffered a series of onslaughts—first by Hurricane Camille in 1969, which created a major cut through Ship Island; then by Hurricane Georges, which breached Horn Island; and several years later by Hurricanes Ivan and Katrina, which caused further damage. Hurricane Katrina alone destroyed more than 2,000 acres on these four islands and drastically reduced the functionality of the remaining acres (Barbour 2006). Importantly, their elevations have in many instances been reduced to near sea level and vegetative cover has been greatly reduced. (Figure 3-24.) The majority of permanent land loss (conversion to open water) occurred from what appears to be bare to slightly vegetated soil, with the exception of Petit Bois Island, which lost mostly denser vegetation (Table 3-3).

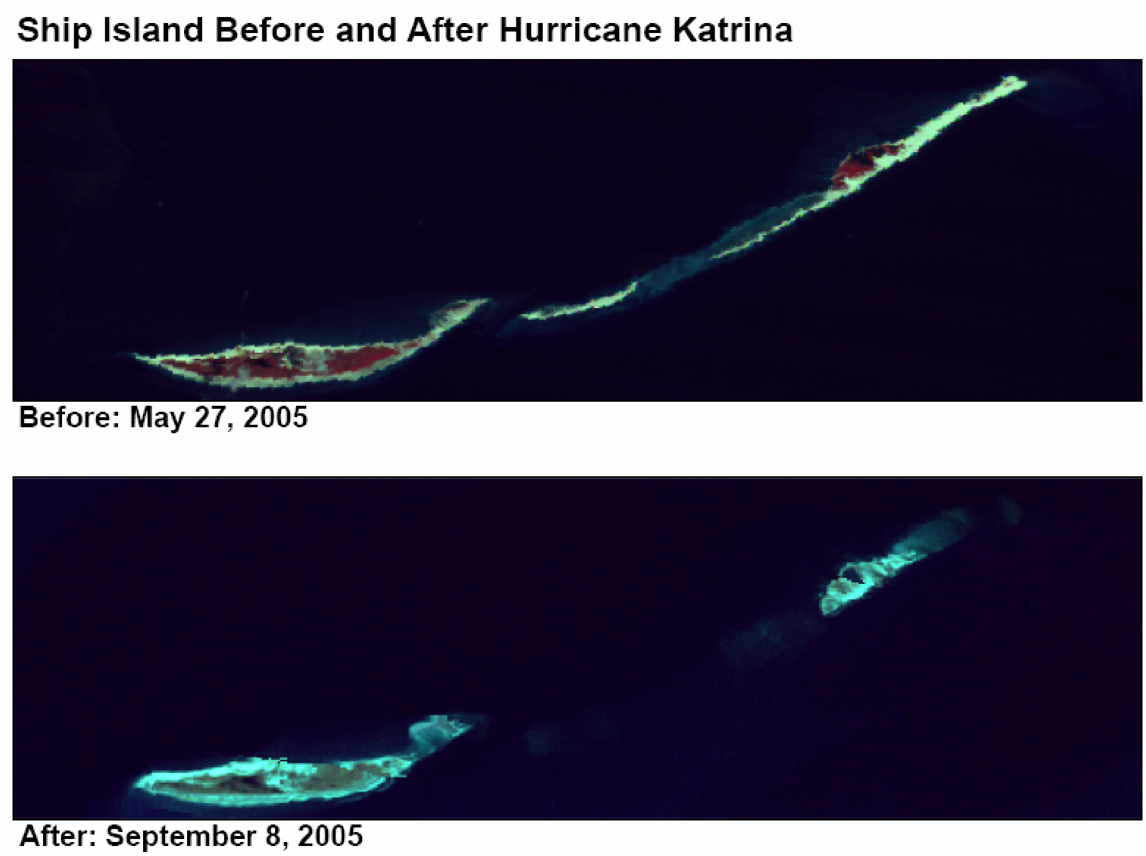


Figure 3-24. Ship Island, Mississippi, before and after Hurricane Katrina.

Table 3-3. Barrier Island Land Loss in Mississippi.

Location	Approx Total Land Pre-Katrina (acres)	Percent Loss of Soil and Vegetation to Water	Percent Loss of Vegetation to Soil
Cat Island (MS)	1,994.544	0.022 (43.09 acre loss)	0.016 (32.2 acre loss)
Horn Island (MS)	3,083.17	0.053 (163.85 acre loss)	0.030 (91.18 acre loss)
Petit Bois Island (MS)	1,017.67	0.046 (47.16 acre loss)	0.264 (268.88 acre loss)
Ship Island (MS)	816.412	0.375 (306.02 acre loss)	0.085 (69.61 acre loss)

Source: Miller 2007, pers. comm.

Marine Debris

Mississippi has a large amount of marine debris affecting habitat as a result of Hurricane Katrina, and Mississippi's oyster habitat was particularly impacted, as noted above. The debris can be moved by tides and storms and can scour and uproot emergent and submerged vegetation. Much of this debris will need to be removed in order to restore the oyster habitat. To date 9,862 derelict crab traps have been removed from coastal Mississippi marine habitats. Figure 3-25 illustrates the extent of the debris problem near an urbanized area. Concentrations of debris seem to generally decrease away from developed shoreline areas.

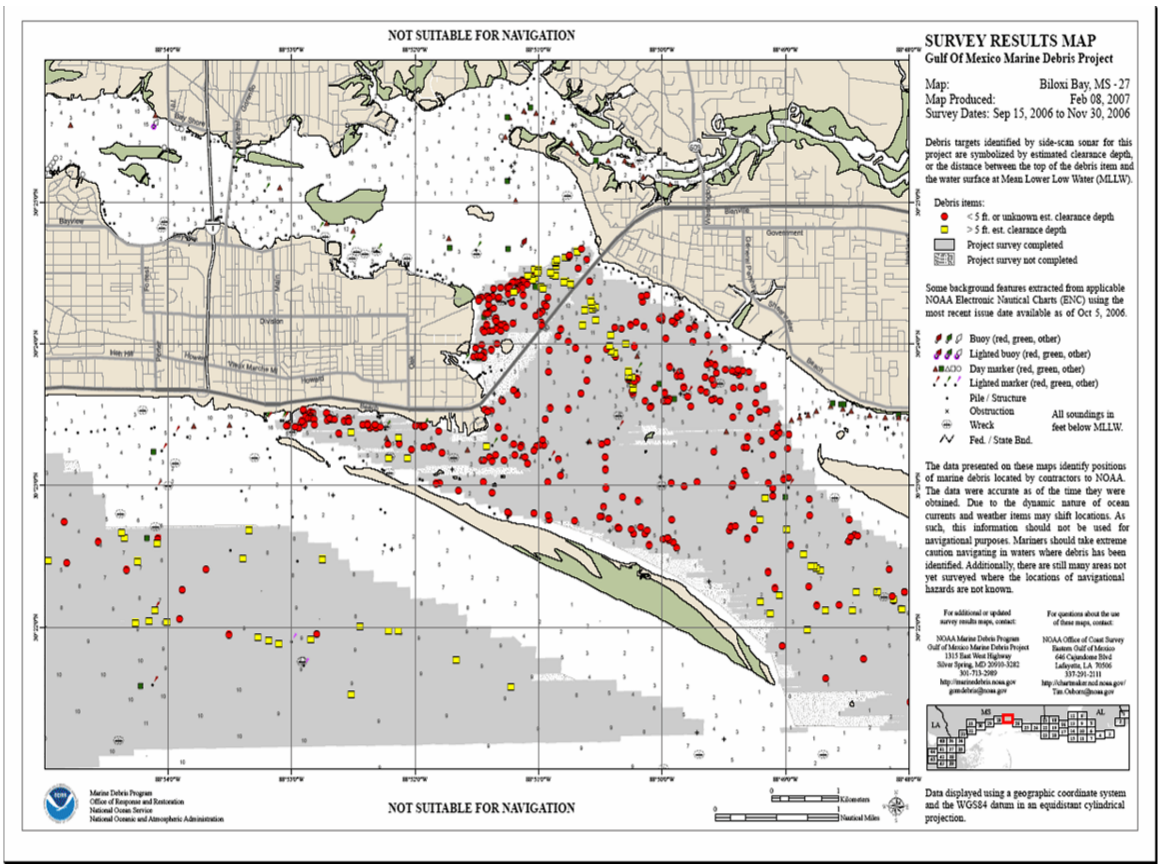


Figure 3-25. Biloxi Bay, Mississippi – Gulf of Mexico Marine Debris Project. Source: NOAA.

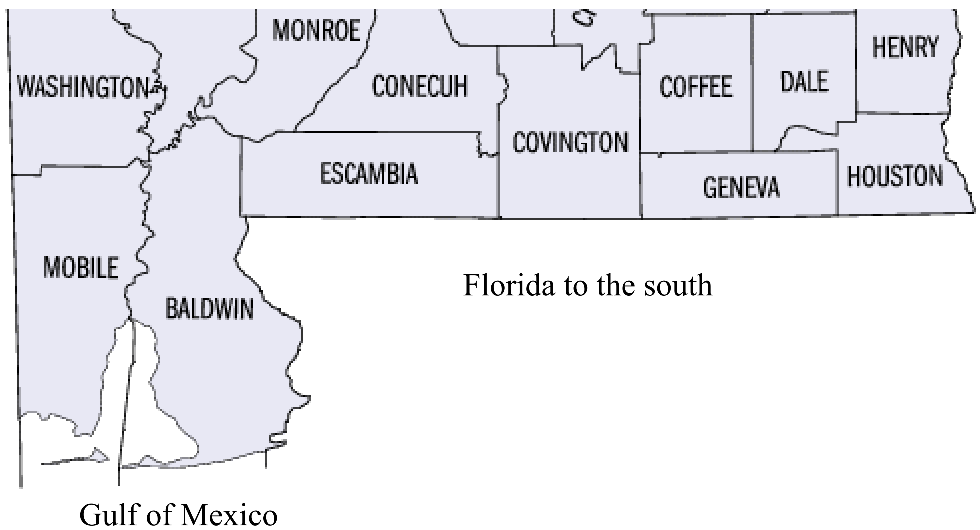
Chemical Contamination Caused by Hurricane Katrina

EPA's Region 4 Science and Ecosystem Support Division, along with the Mississippi Department of Environmental Quality, conducted a water quality study in the rivers and bays along the Mississippi coast following Hurricanes Katrina and Rita. The study was completed during September 2005, and encompassed major bay systems on the Mississippi coast including Bangs Lake, Bayou Casotte, the Pascagoula and West Pascagoula River systems, the Back Bay of Biloxi, St. Louis Bay, and the Pearl River. The objective was to collect sediment and water quality data in each major bay system along the Mississippi Sound (http://www.epa.gov/region4/sesd/reports/2005-0926.html).

During the week of October 3, 2005, the EPA collected soil and sediment samples near facilities in the affected areas in Mississippi to determine whether flooding from the storm surge released hazardous constituents and materials (http://www.epa.gov/region4/sesd/reports/2005-0928.html). Later that month, EPA scientists collected sediment, surface water and groundwater samples in the vicinity of nine National Priorities List (NPL) and two non-NPL Superfund sites in the potentially affected region to determine whether storm-related releases occurred. The NPL sites investigated were located in Alabama and Mississippi and included Ciba Geigy, Stauffer-Cold Creek, Stauffer-LeMoyne, Perdido Groundwater Contamination, Redwing Carriers (Saraland Apartments), American Creosote Works, Davis Timber, and Picayune Wood Treating. The non-NPL sites were Chemfax, Inc., and Sonford Products (http://www.epa.gov/region4/sesd/reports/2006-0139.html). Overall, the data collected by EPA showed that few water quality criteria were exceeded during the study. An exception was algal growth results in Back Bay of Biloxi and Bayou Casotte that exceeded 5 mg/l (dry weight).

Alabama

Because Alabama was further off the path of Hurricane Katrina, and because of the complicating factor of Hurricane Ivan impacts from 2004, it was difficult to identify and quantify impacts associated with Hurricane Katrina.



Coastal and Southern Counties of Alabama

Coastal Land Cover Change
In Alabama, land cover changes observed by NOAA's Coastal Change Analysis Program (C-CAP) highlight the loss of forested land, and related increase to grassland area, which was likely caused by the 2005 hurricanes (Figure 3-26) (N. Herold and J. McCombs 2007, pers. com.). There was a loss of approximately 50 mi^2 of hardwood forests. The areas that were primarily evergreen stands were either damaged by Hurricane Katrina or intentionally harvested and now are dominated by scrub/shrub (approximately 15 mi^2) or grassland (approximately 17 mi^2).

Alabama Coastal Land Cover Changes 2005 to 2006

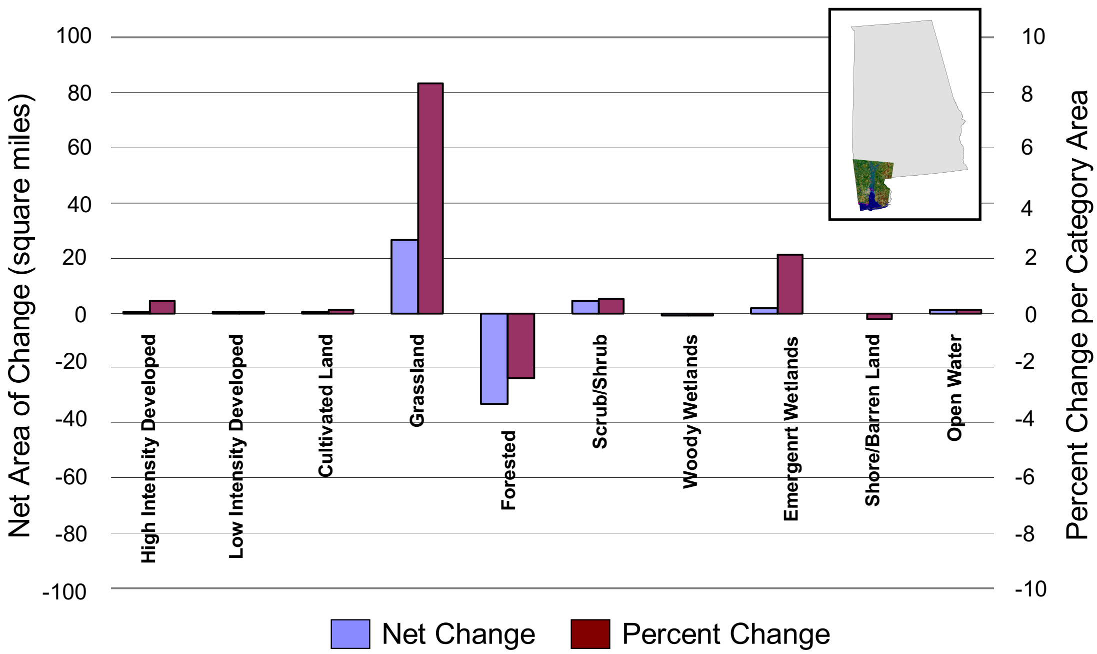


Figure 3-26. The land cover changes depicted above occurred between August 2005 and March 2006. The inset map shows the area (in color) used for the change analysis.

Seagrass

A resurvey of the western half of Alabama's coastal waters in October 2005, after Hurricane Katrina, found no loss of seagrass; all sites that supported seagrass in 2004 still contained seagrass in 2005 (Byron and Heck 2006). In November 2004, Byron and Heck (2006) evaluated the effect of Hurricane Ivan on seagrass meadows in Alabama by surveying all coastal locations known to support seagrass prior to Hurricane Ivan's landfall in September 2004. They found that 82 percent of the sites containing seagrass in 2002 still supported seagrass in 2004. There was no major loss of Alabama's seagrass resources due to Hurricanes Ivan or Katrina, even though both Category 3 hurricanes severely affected the northern Gulf Coast. As in Louisiana and Mississippi, debris was a problem in coastal waters and wetlands (Fig. 3-27.)

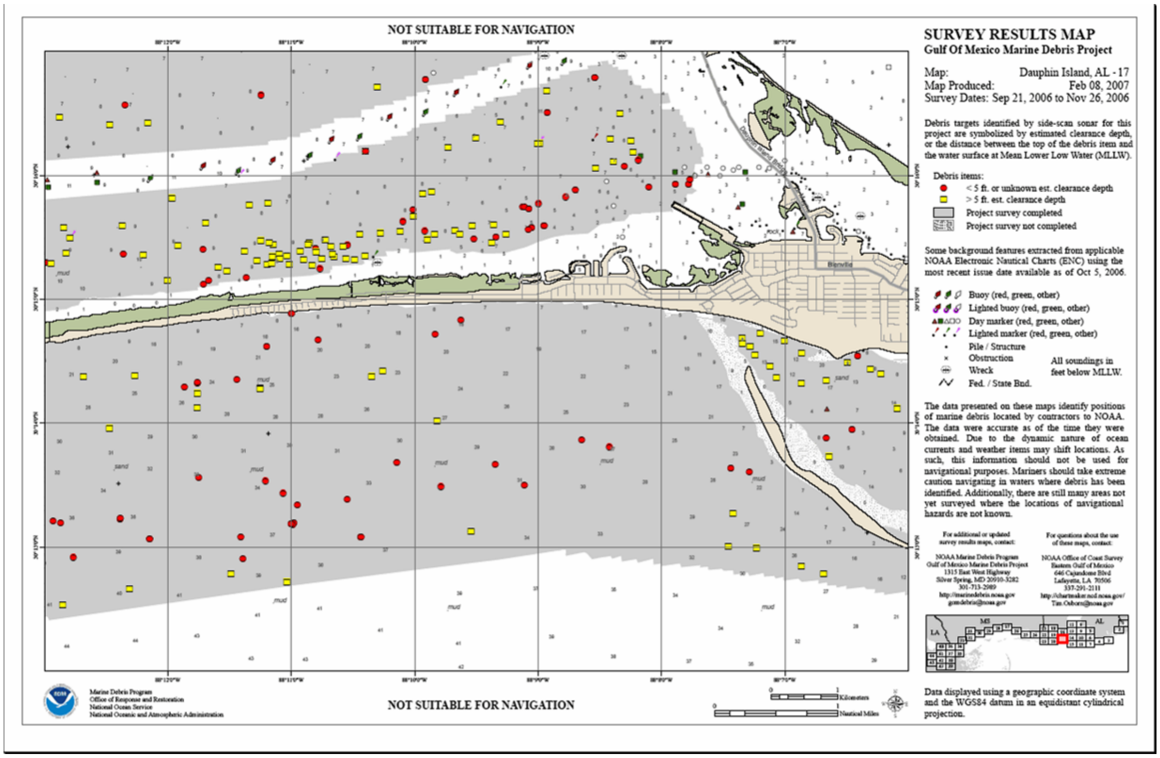


Figure 3-27. – Dauphin Island, Alabama – Gulf of Mexico Debris Project. Source: NOAA.

Oyster Reefs

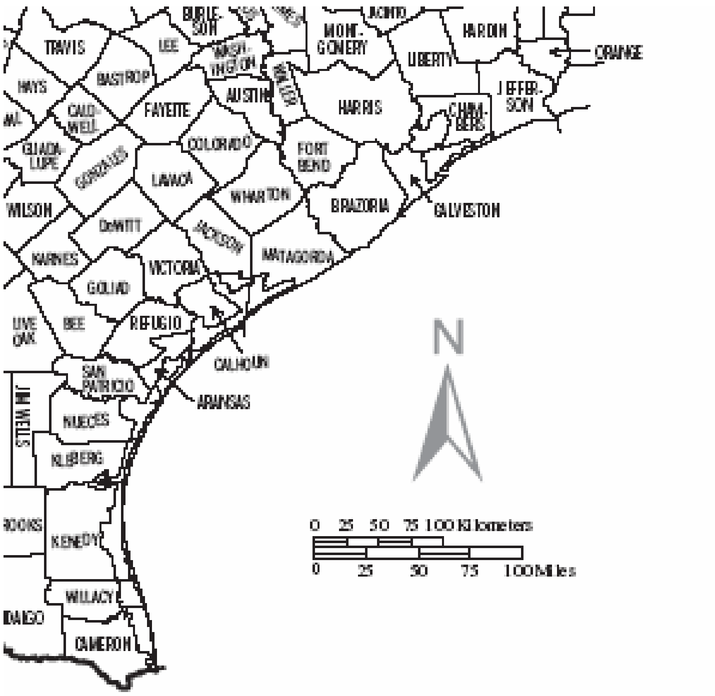
Although Alabama's oysters are still recovering from 2004's Hurricane Ivan, which wiped out 80 percent of its harvest, these beds came through Hurricane Katrina with relatively little damage (Impact Assessment 2007). Biologists estimate that perhaps only 20 percent of state oyster beds were damaged, with an 80 percent survival rate in the Cedar Point reefs surrounding the Dauphin Island Bridge (Raines 2005).

Barrier Islands and Shorelines

A report prepared for the Mobile Bay National Estuary Program (2006) provides a detailed biological description of Isle aux Herbes, a barrier island in Mississippi Sound off the southwest coast of Alabama. The biological survey was completed following Hurricane Katrina, and the resulting report indicates some land loss occurred through shoreline erosion and vegetative debris from the storm event was piled on some areas of the island. The U.S. Fish and Wildlife Service (2005a) reported that about 50 sea turtle nests were lost along the Alabama coast. All 10 nests at the Bon Secur National Wildlife Refuge were destroyed.

Texas (Hurricane Rita)

Texas was on the western side of Hurricane Rita's landfall, where winds and waves were diminished compared to areas to the east of the eye.



Coastal and Southern Counties of Texas

Oyster Reefs
Major oyster-producing areas of the upper Texas coast are located in Galveston Bay. Within the area impacted by Hurricane Rita, a small area of oyster habitat also exists in the southeastern portion of Sabine Lake. The extent of impacts to oyster reefs in Texas is unknown (J. Mambretti 2007, pers. comm.). However, the Texas Parks and Wildlife Department reported that secondary impacts resulting from increased harvest pressure (i.e., effort displaced from Louisiana and Mississippi reefs) did occur. Assessment of hurricane-related impacts is planned.

Barrier Shorelines
The Texas General Land Office used Lidar data from July 2001 and October 2005 (post-Hurricane Rita) and performed change analysis of the Jefferson County shoreline by subtracting the 2001 data from the 2005 data (R. Newby 2007, pers. comm.). The general trend as seen on the profiles is a loss of beach elevation and a landward retreat of the beach ridge. The retreat in some areas is as much as 98 feet in four years. Figure 3-

28 shows the elevation gains and losses. Some areas show a shore-parallel strip of elevation gains. In these areas the material from the beach was over-washed landward of the beach ridge with sediment deposited into low-lying areas. There are some anomalous areas of beach accretion in the vicinity of Sea Rim State Park that may be a function of a circulation gyre created by the Sabine Ship Channel jetties.

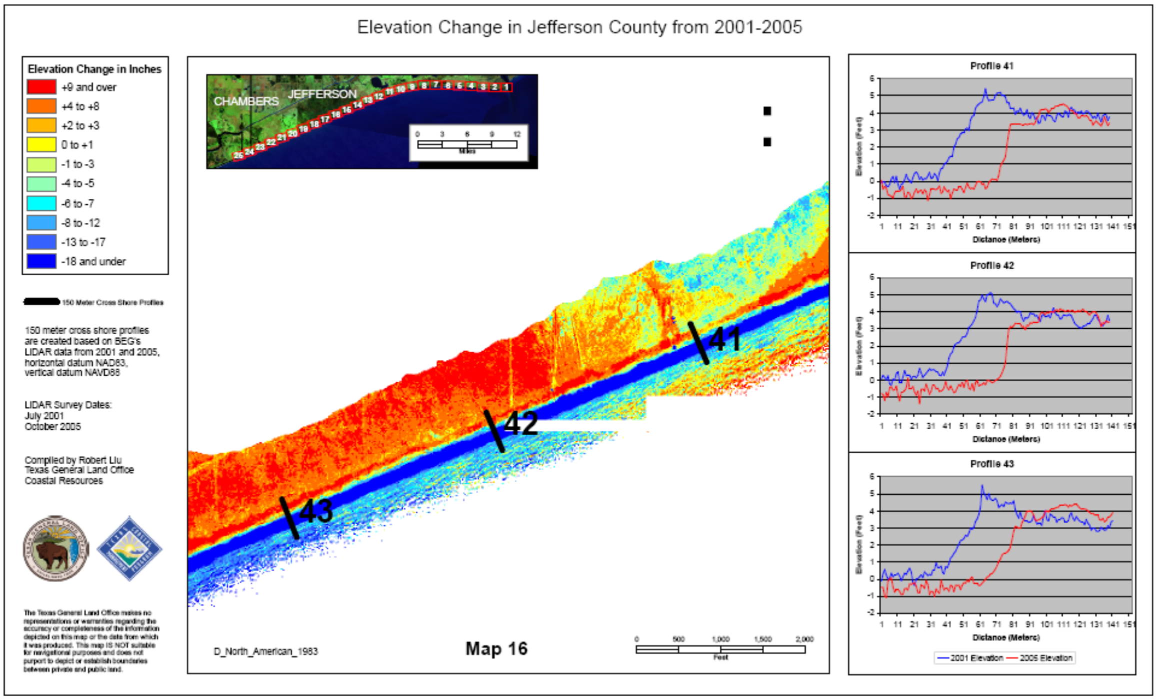


Figure 3-28. – Lidar Image showing elevation change along northeast Texas coast. Source: Texas General Land Office.

Loss Impacts Wetlands. McFaddin National Wildlife Refuge (NWR), Texas Point NWR, Sea Rim State Park, and J.D. Murphree State Wildlife Management Area (the McFaddin Complex) comprise approximately 60,000 acres of coastal marsh (fresh, intermediate, brackish), coastal prairie (non-saline and saline), coastal woodlands, and beach/ridge habitats in Jefferson and Chambers counties in southeast Texas (R. Swafford 2007, pers. comm.). The McFaddin Complex is composed primarily of low-lying coastal marsh (lying below the 5-foot above mean sea level contour) (A. Loranger 2007, pers.comm.). The Complex's southern boundary consists of over 15 mi. of Gulf of Mexico shoreline, which was adversely impacted by Hurricane Rita. The marsh habitats protected by a low elevation beach dune ridge represent a portion of the largest contiguous coastal marsh complex in Texas, and are a major component of the natural storm buffer protecting the industrial, commercial, and residential infrastructure in Southeast Texas. Historical erosion rates along the Gulf shoreline of the McFaddin Complex are on the order of 5 to 7 ft per year. A remnant dune/beach system still exists post-Rita, although much has been lost through erosion and shoreline retreat, leaving only a low-lying washover terrace. Loss of the existing beach dunes and lowering of beach ridge elevations along the Gulf shoreline of the McFaddin Complex from Hurricane Rita imperils approximately 30,000 acres of nationally significant wetlands due to the increasing frequency of saltwater inundation from the Gulf of Mexico.

Ongoing shoreline retreat along the Gulf of Mexico, which was exacerbated by Hurricane Rita, is resulting in a rapid loss of valuable coastal habitats, including emergent estuarine marshes and coastal prairies. The wetlands in the Salt Bayou portion of the McFaddin Complex range from fresh/intermediate to brackish marsh habitats. Historically, saltwater inundation occurring from storm surges during landfalling tropical storms and hurricanes periodically flooded the wetlands. However, relative sea level rise (eustatic sea level rise and regional subsidence) and erosion of the Gulf of Mexico shoreline's beach and dune system (most recently by Hurricane Rita), is allowing saltwater inundation to occur more frequently and at lower Gulf wave heights during minor tropical systems and prior to the passage of cold fronts. The increased volume of salt water entering the wetlands is negatively impacting wetland water quality and is contributing to the conversion of fresh to intermediate marsh to more brackish habitats. The overall result is a loss of native biological diversity and productivity. The long-term health and stability of the coastal marshes of the refuge requires restoring the beach ridge elevation to reduce the frequency and impacts of seawater over-wash into tidal marsh habitats.

The McFaddin Complex wetlands protected by the eroded dune ridge are important habitats for many species of fish and wildlife. The coastal marshes also serve as nursery areas for many important commercial and recreational fish and shellfish species, including white and brown shrimp, blue crab, red drum, flounder, and spotted sea trout, and a variety of other living marine resources. In addition, these wetland habitats provide important wintering and migration stopover habitat for migratory birds, including Central Flyway waterfowl, shorebirds, wading birds, and marsh waterbirds.

In summary, the NWRs in southeast Texas suffered wetland habitat loss, primarily as a result of wave erosion, during Hurricane Rita. Impacts to three federal refuges were estimated to include marsh loss of more than 75 acres, approximately 15,000 acres of marsh under increased threat by future storms, and erosion losses along 20 miles of shoreline.

Outer Shelf Coral

Flower Gardens National Marine Sanctuary research teams conducted routine monitoring at East and West Bank in June and August 2005, prior to Hurricanes Katrina and Rita, and again approximately 2 weeks after passage of Rita to evaluate impacts of the storm (Hickerson and Schmahl 2007). Hurricane Rita passed within 30 mi of East Flower Garden Bank, with wave heights estimated at over 30 ft. Large colonies of coral, up to 10–13 ft in diameter, as well as large pieces of reef rock were dislodged from the reef framework, overturned, and deposited in surrounding sand flats (Fig. 3-29). Other corals and barrel sponges were fragmented, scoured, and detached, and 21 tagged colonies that had been photographed in June 2005 were lost (Figures 3-30a and 3-30b). An extensive field of the branching coral, *Madracis mirabilis,* was flattened by storm waves associated with Rita, with branch fragments and debris accumulating in large piles at the edge of the reef. As much as 1 meter of sand was scoured from the sand flats and redeposited elsewhere on the reef, including onto corals where it will interfere with their growth and survival. Physical damage associated with the hurricanes was observed to depths of 236 feet.

Figure 3-29. Example of coral impacted by Hurricane Rita. The lack of fouling on the underside of the coral indicates this was a recent break. Photo credit: Joyce and Frank Burek.

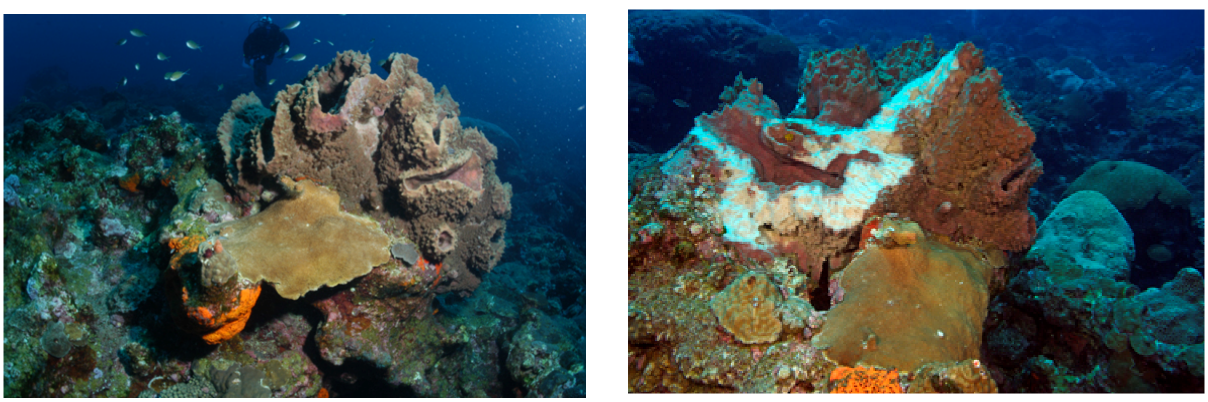


Figure 3-30. At left, Elkhorn coral and barrel sponge at WFGB#2, May 2005, pre-hurricanes. Photo credit: FGBNMS/Schmah. At right, Elkhorn coral and barrel sponge at WFGB#2, October 2005, post-Rita. Note how the barrel sponge has been broken and twisted. Photo credit: Joyce and Frank Burek

An enormous plume of turbid water formed along the Texas–Louisiana coastline shortly after Hurricane Rita's landfall and rapidly progressed from shore to the Flower Gardens, more than 100 mi offshore. The plume persisted for several weeks, and eventually dissipated as it progressed further west and south. Passage of Hurricane Rita was also associated with a slight drop in temperature (~1.5º Celsius) and salinity (1 ppt), with a more dramatic decline in salinity recorded at Stetson Bank (75-ft depth) between September 22 (35.5 ppt) and September 25, 2005 (33 ppt) (Flower Garden Banks NMS 2006). These observations likely were caused by upwelling along the storm track

(Michaels 2007; Benitez-Nelson et al. 2007; McGillicuddy et al. 2007; Sriver and Huber 2007) An unusual outbreak of coral disease was observed during the March 2006 research cruise that affected a mean of 8 percent of all colonies examined at both East and West Flower Garden Banks, including multiple colonies of *Montastraea annularis*, *M. franksi, M. faveolata*, *Diploria strigosa, Porites astreoides, Colpophyllia natans,* and *Stephanocoenia intersepta*. Although this outbreak cannot be conclusively linked to the unusual environmental conditions associated with the 2005 hurricanes, this event was unprecedented. With extensive monitoring undertaken for over two decades, coral disease has rarely been observed on these banks. Furthermore, disease prevalence and mortality rates rapidly declined during the spring and summer, as water temperatures increased. Similar disease signs have been observed in other locations throughout the western Atlantic, but outbreaks typically occur during periods of high sea water temperature.

Other Shelf Edge Reefs

Sixteen other banks are located closer to the track of Hurricane Rita. These other banks are important habitat for reef fish and reef organisms. Sonnier, Geyer, and McGrail Banks are three of the more developed bank habitats in this area. The banks have all been studied in the past. They are populated by lush assemblages of sponges, fire coral, star coral, pencil coral, brain coral, and numerous other invertebrates.

A post-Hurricane Rita impact assessment survey of Geyer, Bright, and Sonnier Bank was conducted April 29 to May 3, 2007, by PBS&J under contract to MMS (G. Boland 2007, pers. com.). Other than the Flower Garden Banks (shallowest point is about 55 ft.) and Stetson Bank (shallowest point about 55 ft.), these three banks are the shallowest of the shelf-edge or mid-shelf Gulf of Mexico topographic features, and therefore, the most likely to sustain bottom impacts from large waves caused by hurricanes. The shallowest point on Geyer bank is about 110 ft, Bright Bank about 115 ft, and Sonnier Bank about 60 ft. McGrail Bank (about 140 ft.) was visited on a later cruise where only the ROV was used.

Sonnier Bank (or Banks) is a collection of isolated peaks within a diameter of several miles. It is a sponge-algae habitat with significant cover of fire coral and some scleractinian coral (mostly *Stephanocoenia*). Only two of the peaks come to less than 100 ft of the sea surface. Two dives were made to 80 ft. on May 1. The bottom community was radically different from the previous visit on May 9, 2002. The percent cover of sponge and algae had been reduced from 80 to 90 percent to about 20 percent. The physical structure of the underlying siltstone also was noticeably altered. Very little of underlying substrate was visible before 2005 and now it was exposed almost everywhere. It appeared as if major chunks of the siltstone substrate had been torn lose from the bottom and removed from the area. There also was evidence of a great deal of erosion and abrasion. Valleys between elevated outcrops were eroded as much as several feet in some places. The giant barrel sponges observed in previous visits were completely gone. There were very few large sponges anywhere on top of the 80 ft peak. Some medium size *Ircinia* sponges survived. The sponge, *Neofibularia*, in areas where it had been near 100 percent of the cover, was gone. Areas on top of the peak where 40 to

50 percent cover of *Neofibularia* had occurred were now reduced to less than 5 percent. There were large expanses of substrate with virtually nothing growing on it but a thin film of filamentous algae.

A single dive to between 115 and 122 ft on Geyer Bank was made on May 2, 2007. Geyer Bank appeared to look the same as it did in 2001. The bottom habitat was covered nearly 100 percent by algae, sponges and some corals. Reef butterflyfish were present in large numbers (hundreds seen in a few minutes), but not quite as many as in 2001. Live Sargassum attached to the bottom was common. Numerous big sponges that appeared undamaged also were present.

Bright Bank was visited May 2, 2007. The bottom habitat observed on this dive between 105 and 117 ft. seemed quite undisturbed and there was a very diverse community of sponges, algae and scleractinian coral. There were no observable impacts from 2005 hurricanes.

A formal report, *Post-Hurricane Assessment of Sensitive Habitats of the Flower Garden Banks Vicinity,* presently being drafted will include extensive quantitative analysis. The web link is:
http://www.gomr.mms.gov/homepg/regulate/environ/ongoing_studies/gm/GM-06-x11.html

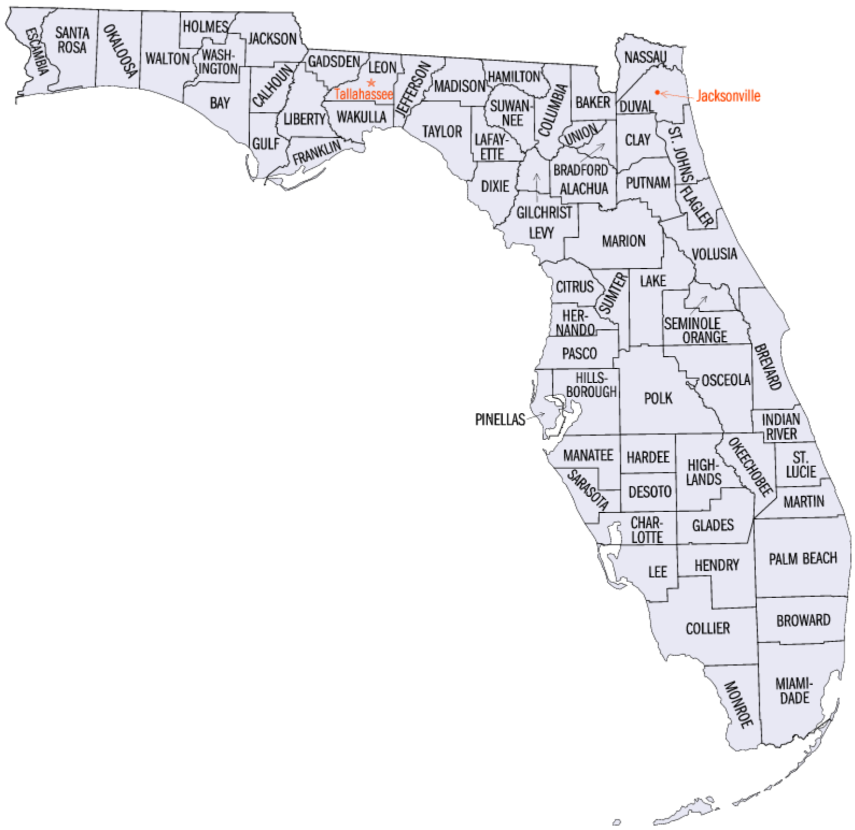
Marine Debris

As was the case for other states discussed in this report, debris deposition is a noted impact of Hurricane Rita in Texas. The Texas Point NWR reported a large amount of debris deposited in the refuge marshes. The Padre Island National Seashore reported tons of hurricane-transported debris drifted ashore, requiring an extensive cleanup by the park's hazardous materials team. The debris may have impacted habitat during transport and it is likely that more debris remains in the Gulf waters nearby.

Offshore Habitat Contamination

On November 11, 2005, a tank barge, *DBL-152,* being pushed by the tug *Rebel,* collided with a drilling rig that had sunk during Hurricane Rita some 30 miles to sea, south of Port Arthur, Texas,. The result was a tear in the starboard forward tank and sinking of the barge, with the release of approximately 1.8 million gallons of heavy fuel oil (i.e., oil that is denser than the receiving water). Based on an understanding of the chemical and physical characteristics of the oil and over a year of on-scene observations, experienced physical scientists from NOAA's Emergency Response Division believe the oil is slowly migrating to deeper waters and dispersing into ever smaller droplets. However, this conclusion is unconfirmed due to an inability to detect and track sunken and submerged oil (S. Lehmann 2007, pers. comm.)

Florida



In 2005, the State of Florida was impacted by Hurricane Dennis (July 10) (not considered in this report), Hurricane Katrina, Hurricane Rita, and, most importantly, Hurricane Wilma (Figure 3-31). Hurricane Katrina passed across the southern tip of Florida (August 25) on its way to the Gulf of Mexico and ultimately Louisiana-Mississippi (August 29). While there is no scientific evidence to support the claim, some believe that Hurricane Katrina pushed an offshore red tide bloom into the nearshore waters of northwest Florida. Hurricane Rita (not shown in Figure 3-31) passed 50 mi south of the Florida Keys (September 20). Hurricane Wilma crossed the southern tip of Florida later in the season (October 24), from southwest to northeast.

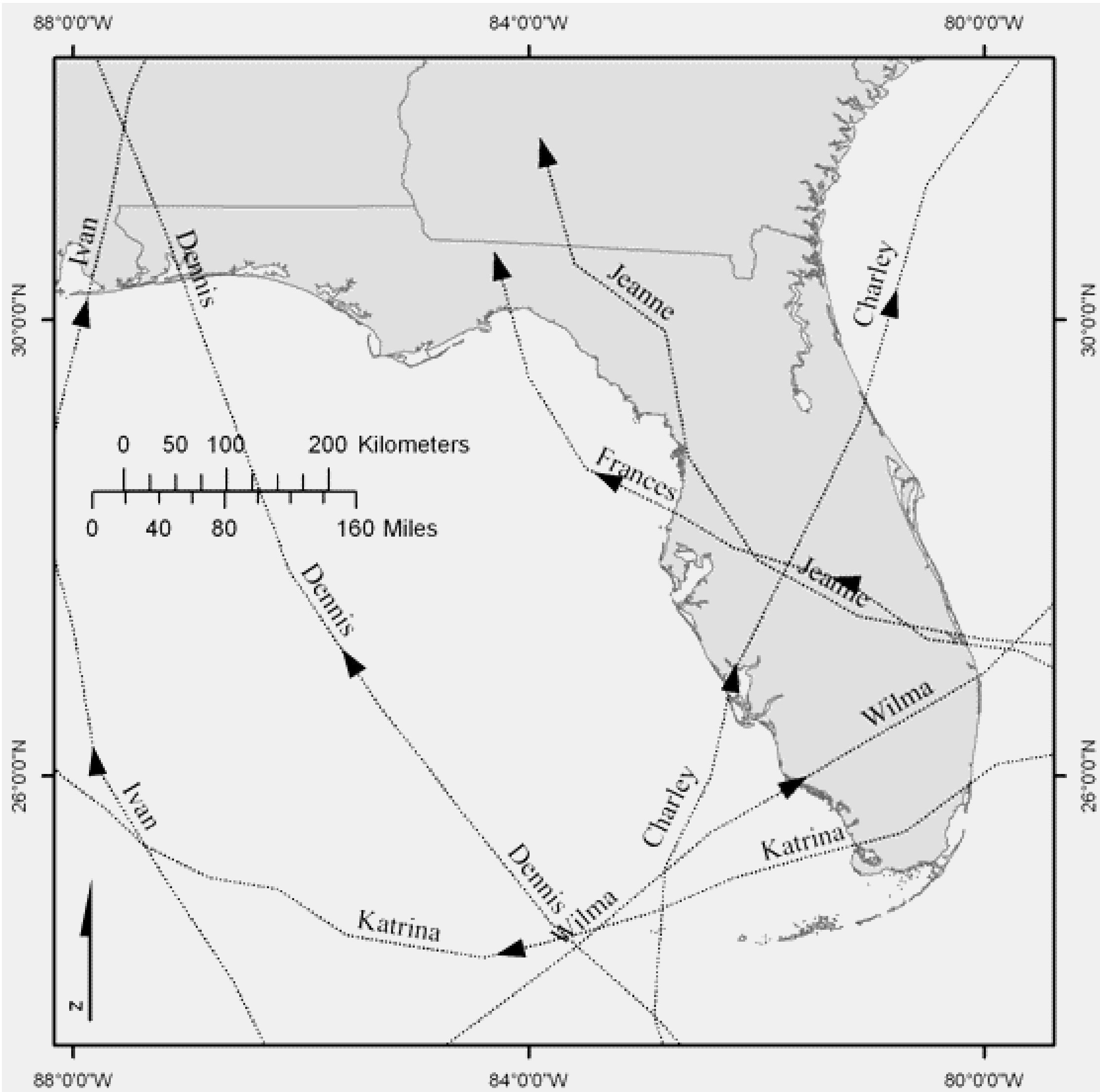


Figure 3-31. Overview of 2004–2005 hurricane paths across the State of Florida (courtesy of USGS). Hurricane Rita's storm track (not shown) occurred mostly beyond the bounds of this figure.

Seagrass
The Sanibel Captiva Conservation Foundation indicated that 80 percent of turtlegrass resources in the Caloosahatchee and St. Lucie rivers were lost because of Hurricane Wilma. Increased freshwater inflow, sediment loading, and nutrients from Lake Okeechobee following storm events are factors affecting the decreases in submerged aquatic vegetation.

Following Hurricane Wilma, seagrass habitats were assessed in the Florida Keys Tidal Restoration area, located on the Atlantic and Florida Bay sides of Curry Hammock State Park in Marathon (J. Hunt 2007, pers. comm.). Only minor impacts were observed and they were confined to Florida Bay. Turtlegrass was most affected, with areas of the seagrass torn from sediments and observed growing with overturned rhizome structures following the storm event. Hardbottom communities in the region were minimally affected. Since the fall of 2005, the area from northeast Florida Bay to Barnes Sound has experienced an extended and strong algal bloom. Hurricane Katrina also may have contributed to this event, although Hurricane Wilma most likely influenced the algal bloom through increased nutrient runoff from storm surge and rainfall. The bloom has reduced seagrass cover in Blackwater Sound and may have caused seagrass losses in other areas. Quantification of seagrass and hardbottom impacts is not available.

Oyster Reefs

Oysters from Cedar Key to Pensacola, Florida were impacted by sedimentation and burial caused by Hurricanes Dennis, Katrina, and Rita. The impacts of individual storms were not differentiated (M. Berrigan 2007, pers. comm.).

Hurricane Wilma caused some structural changes, some short-term disruption of habitat utilization for mobile fauna, and some short-term disruption to oyster reproduction in the greater Naples area on the southwest coast of Florida (A. Volety 2007, pers. comm.). These impacts were not quantified. Hurricane impacts to oyster reefs in this area may be of small ecological consequence. Oysters in southwest Florida are near the southern end of their range and small populations existed in the area both before and after the storm.

Mangroves

The extensive damage caused by Hurricane Wilma to mangrove systems in the Charlotte Harbor area was thought to affect the occurrence and distribution of the endangered smalltooth sawfish (*Pristis pectinata*) in southwest Florida. Damage to shallow mangrove tidal creek systems (one of the sawfish's primary habitats) and the susceptibility of this species to entanglement in debris prompted studies to determine the effect of the hurricanes on sawfish distributions in southwest Florida. Preliminary results indicate that sawfish are still present in affected areas (P. Stevens 2007, pers. comm.).

Mangrove shorelines in the Marco Island area were significantly damaged, with some areas stripped of their substrate. This may lead to a secondary die-off of the mangrove vegetation, similar to what happened in 1992 as a result of the passage of Hurricane Andrew. Hurricane Wilma also hit Big Cypress National Preserve, which sustained widespread, though not severe, damage to natural resources. In particular, Loop Road was devastated. The poor condition of the Loop Road culverts prevented proper sheet flow. Freshwater sheet flow is important in maintaining estuarine salinity regimes.

Hurricane Wilma's 15-foot storm surge, winds, and waves damaged an extensive area of coastal mangroves in Everglades National Park (i.e., from Flamingo to Everglades City, Florida) that had been damaged by Hurricane Andrew 13 years earlier (Figure 3-32). Mangrove trees were blown over. The defoliation was so severe that mangroves were expected to continue to die for months after the storm (Smith et al., in press). Mangrove mortality from Hurricane Wilma was highly variable and dependent on location. Initial estimates ranged from 0 to 98 percent mortality (Smith et al., in press). Trees closer to the eye wall of the storm and trees closer to the coast tended to have higher mortalities.

Figure 3-32. Two views of Hurricane Wilma's impacts on the mangrove forests of the coastal everglades. At left, a permanent plot at Highland Beach that suffered 98 percent mortality. At right, a plot where initial tree mortality was less than 10 percent. From Smith et al. 2007.

The Mangrove Islands portion of the Great White Heron National Wildlife Refuge (in the Florida Keys between Big Pine Key and Key West) also reported severe damage from Hurricane Wilma. On all islands nearly all red mangroves were defoliated, with resulting mortality ranging from very low to severe. However, with notable exceptions, on most islands recovery of the defoliated trees is well under way. Notable exceptions include Little Crane Key (1 acre), which was nearly obliterated and now contains only a few scattered dead trees, and Upper Harbor Key (about 5 acres), where nearly all trees were killed. (T. Wilmers 2007, pers. comm.).

Barrier Islands and Shorelines

Hurricane Katrina subjected the south-facing shorelines of Dade and Monroe Counties to storm surge and minor beach erosion (FDEP 2005). A second landfall at the Louisiana–Mississippi border resulted in minor to no impact on beach erosion in the Florida Panhandle (FDEP 2006a). Minor beach erosion is defined as loss of small scarp on beach (Condition I) and loss of 1 to 3 feet of vertical scarp in beach or dune profile (Condition II) (FDEP 2005).

Hurricane Rita caused storm surge floods and minor to moderate beach erosion in the lower Florida Keys from Islamorada–Lower Matecumbe Key to Boca Chica Key (FDEP 2005). Beach erosion from Broward County to Key Biscayne was minor (FDEP 2005). Moderate beach erosion is defined as the lowering of the beach profile and loss of 3 to 10 feet of dune vertical scarp (Condition III) (FDEP 2005).

Hurricane Wilma, in addition to impacting the state directly, exposed the Florida Keys' north-facing beaches—from Key West to Lower Matecumbe Key and Curry Hammocks State Park—to storm surge, flooding, and moderate to major beach erosion (FDEP 2005).

Major beach erosion is defined as the lowering of beach profile with recession of dune vertical scarp greater than 10 ft or that the dunes are totally removed (FDEP 2005). The island at Pelican Shoal Critical Wildlife Area (5 miles south of Boca Chica Key) washed away. At Cape Sable, Hurricane Wilma devastated carbonate and shell beaches (FDEP 2005). From Cape Sable northward along the west Florida coast to Sea Oat Island in Collier County, beach erosion also was major (FDEP 2006b).

The Florida Gulf Coast National Estuarine Research Reserves reported damage to Marco Island, where the eye of Hurricane Wilma made landfall. Most beaches in the area were stripped of sand, indicating heavy scour of the nearshore area. The beaches at the Caxambas Pass Critical Wildlife Area (on Marco Island) and Little Estero Island Critical Wildlife Area (further north near Ft. Myers) experienced erosion. From Sea Oat Island to Park Shore, north of Naples in Collier County, beach erosion was moderate (FDEP 2006b), and farther north beach erosion was minor (FDEP 2006b). Beach erosion was generally minor in Dade and Broward Counties on the east coast of Florida, with little or none in Palm Beach County (FDEP 2006b).

At Canaveral National Seashore, approximately 1,000 of 3,600 sea turtle nests were lost to erosion, and several sections of the coast were washed over or experienced 3 to 5 ft of dune erosion due to Hurricane Wilma.

In Dry Tortugas National Park, notable changes to park geography were observed. Some islands gained elevation as a result of the storms while others eroded. East Key was breached briefly, and in July, Hurricane Dennis reopened a channel between Bush and Garden Keys, which was later made deeper by Hurricanes Katrina, Rita, and Wilma.

Coral Reefs

Passing hurricanes can affect coral reefs and neighboring habitats in several ways: (1) enhanced sediment resuspension can scour and bury corals (Rogers 1990); (2) altered surface wave spectrum impinging on reefs can affect the structure of the reef (Hughes and Connell 1999); (3) altered direction and magnitude of ambient current field can affect the transmission and dispersal of eggs and larvae; (4) reduced ambient light for a prolonged time period can adversely affect the algae associated with coral; (5) upwelling of cold, nutrient-rich, deeper ocean water can provide nutrients to coral and their algae as well as provide thermal relief in coral bleaching (i.e., a process characterized by the loss of symbiotic zooanthellae algae from coral tissues) (Lesser and Lewis 1996); (6) enhanced runoff and water flows through inlets and cuts can decrease salinity levels to stress coral and other organisms; and (7) direct mechanical stress (i.e., waves) can break, damage, detach, and relocate corals (A. Bruckner 2007, pers. comm.; J. Proni 2007, pers. comm.). It is clear from the information submitted that the coral reef resources of Florida were impacted by several of these effects during the 2005 hurricane season.

On the Atlantic coast of Florida, in Palm Beach County, new limerock corridors at Governor's River Walk Reef were sandblasted by Hurricane Wilma. Regrowth on the exposed hard surface was primarily bryozoans, hydroids, and algae. Delray Ledge octocorals also experienced damage from Hurricane Wilma, including an overall reduction in height—from 4 to 5 ft to only 1 to 2 ft—and reduction in density of colonies (Palm Beach County 2006).

To the south, in Broward County, Florida data from long-term monitoring at the Broward Shore Protection Project found that 12 of 200 coral monitoring sites were buried and several other monitoring sites were damaged by tires, lobster traps, and other debris.

Further south, Biscayne National Park staff observed that in the course of about 3 hours, winds from Hurricane Wilma nearly emptied shallow Biscayne Bay, which took an estimated 10 hours to fill following the storm. It is thought this caused subtidal organisms to be exposed, subjected to breaking waves, desiccation, and low salinity shock. Farther from shore, branching corals were flattened and boulder corals were displaced; however, whether coral mortality can be attributed to the storm is unclear because corals were suffering from widespread bleaching (a sign of stress) before any of the 2005 storms hit.

Continuing southward along the Atlantic coast of Florida, Gleason et al. (2006) studied the combined impacts of four 2005 hurricanes—Dennis (July), Katrina (August), Rita (September), and Wilma (October)—on a population of elkhorn coral (*Acropora palmata*) at Molasses Reef, near Key Largo. Hurricane damage and coral diseases have been identified as the main sources of mortality to elkhorn and similar corals (Bruckner 2003; Oliver 2005; Precht et al. 2005). In Gleason et al. (2006), a total of 19 elkhorn coral colonies were identified from May 2005 until prior to the onset of the 2005 hurricane season, and 17 of these colonies remained, in the same location, in the study plot in February 2006. The two colonies that were removed from the plot were located on one of the sections of the reef framework that was dislodged during Hurricane Rita. These two colonies remained attached to the dislodged reef section but were in contact with bottom sediments and died shortly after this storm. Hurricane damage to the Molasses Reef study area caused a 14 percent loss of live coral tissue on the dislodged reef area and, for those colonies that remained, the net tissue loss was about 10 percent. Tissue loss was mainly attributed to the removal of branches of the elkhorn coral. One of the most significant impacts of the 2005 hurricanes was the damage caused to the reef framework. Within the study area, a large section of the reef was broken off and deposited on the sand at the bottom of the reef spur. The dislodged coral colonies were smothered and buried by sand and the exposed reef framework may be further weakened by biological and physical forces (Glynn 1988).

Further south and west, the physical breaking and scouring of coral resources was noted at several sites examined after the hurricanes. The status of the M/V *Connected* coral reef restoration site in the Florida Keys National Marine Sanctuary was examined in July 2004, 3 years after the initial restoration, and again in September 2005 after passage of Hurricane Dennis and Hurricane Katrina (Schittone et al. 2006) (Figure 3-33). Physical damage to the restored colonies attributed to the hurricanes included breakage of *Acropora palmata* branch tips and tissue loss associated with sand scouring. One of the 20 restoration modules (reef crowns) was dislodged and overturned. Sediment and *A. palmata* debris were eroded from the bases of three reef crowns, and two reef crowns were completely buried by unconsolidated reef rubble. Living coral cover on the reef crowns declined by 36 percent (from approximately 36 to 22 percent). In the reference site and neighboring unrestored control area, living coral cover declined by 88 percent due to burial of the site by translocated sediment and rubble (Table 3-4).

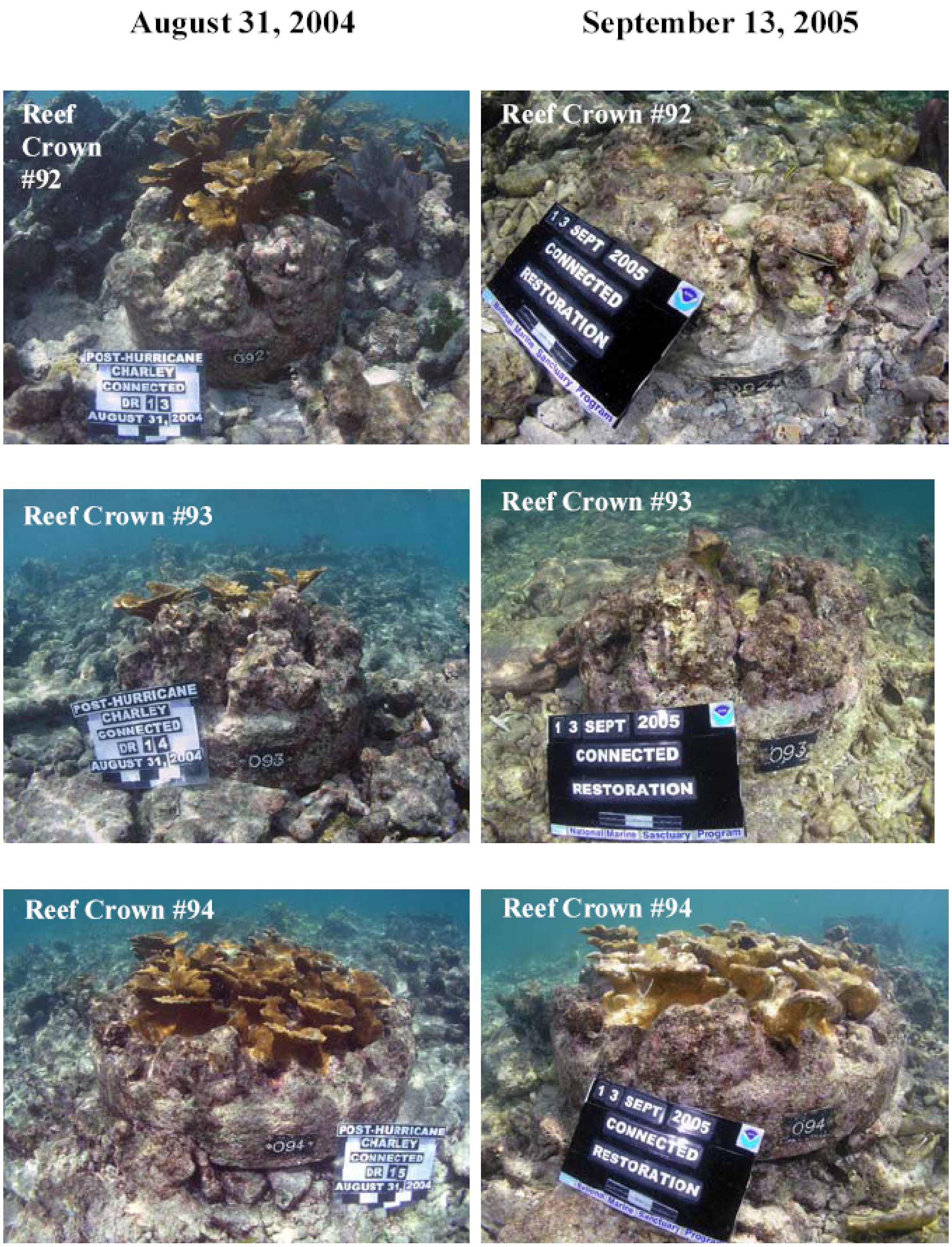


Figure 3-33. Examples of damage to coral reef restoration after Hurricane Katrina at the M/V *Connected* site. From Schittone et al. 2006.

Table 3-4. Reductions in coral cover at M/V *Connected* site before and after Hurricane Katrina.

(All values are percentages)	Reef Crown Coral Cover	Unrestored Area Coral Cover	Reference Site Coral Cover
2004	34.7	8.7	19.7
2005	22.2	1.0	2.2
Reduction (relative)	36.0	88.0	88.6
Benthic Coral Cover Decrease (absolute)	12.5	7.7	17.5

From Schittone et al. 2006

Marine Debris

Impacts to fishery habitat from marine debris were noted throughout the information submitted for this report. Monroe County Division of Marine Resources—in concert with the Florida Fish and Wildlife Conservation Commission's Division of Law Enforcement, the Florida Keys National Marine Sanctuary, and FEMA—reported an impressive marine debris recovery effort after the 2005 hurricane season. The focus was on removing derelict vessels that had moved as a result of the storms, as well as lobster traps that were relocated due to storm energy. The vessels removed were as large as 80 feet in length. These vessels broke from their moorings or from their resting places and moved with the wind and water forces. Impacts to the fishery habitats such as corals and seagrass have been noted but have not been quantified. Final resting locations included seagrass, hard bottom, and sand as well as nearshore communities such as red and black mangroves. Approximately 500 vessels were removed.

In addition 45,129 abandoned and lost lobster traps were recovered. Each lobster trap is approximately 18" by 36" and can weigh up to 50 pounds. Some traps were reported to have moved over 15 miles. The traps were found on coral reefs, causing damage by abrasion, smothering, and filling spaces used by marine organisms (Fields 2006). Traps impact seagrass resources if dragged across bottom habitat by storms and hurricanes or if left in place for more than 6 weeks (Uhrin and Fonseca 2005) as debris.

Water Quality Changes

There may have been some positive effects to fishery habitat from Hurricane Wilma. The *New York Times* published an article reporting the hurricane removed filamentous algae that had covered sections of reef in Broward County (Lyman 2006). The article also reported “Hurricane Wilma dragged cooler, life-saving water into the region.” The appearance of cooler water over the Florida reef tract also was observed by the NOAA Atlantic Oceanographic and Meteorological Laboratories (AOML), which reported that hurricane-caused upwelling of cooler water dropped temperatures by about 4^o to 5^o Celsius or more in the vicinity of the reefs (C. Kelble 2007, pers. comm.) (Fig. 3-34). The effect of hurricanes bringing colder subsurface water to the surface also has been observed by others (Michaels 2007; Benitez-Nelson et al. 2007; McGillicuddy et al. 2007; Sriver and Huber 2007). Some researchers suspect Hurricane Wilma provided some relief to corals subject to warm water bleaching events (i.e., a process characterized by the loss of symbiotic zooanthellae algae from coral tissues) (Lesser and Lewis 1996).

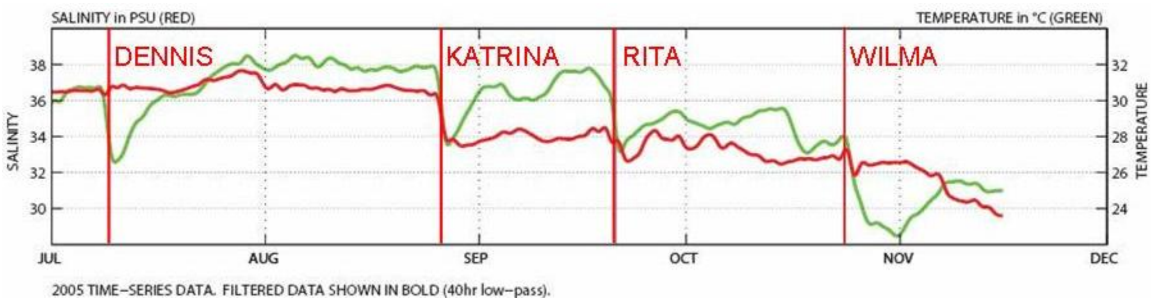


Figure 3-34. Temperature and salinity data for a mooring located just west of Florida Bay shows the effect of the four hurricanes of 2005 on oceanographic conditions on the southwest Florida shelf. Source: C. Kelble, AOML, Miami.

AOML also observed significant changes in the direction of currents on the southwest Florida shelf adjacent to Florida Bay. Atypical oceanographic conditions were visible in drifter trajectories, where during Hurricane Katrina the drifter moved rapidly to the northwest before drifting offshore (Fig. 3-35). This change in current direction may have affected the migration of pink shrimp post-larvae from the area of the Dry Tortugas to their nursery habitat in the Florida Bay area (Criales et al. 2003).

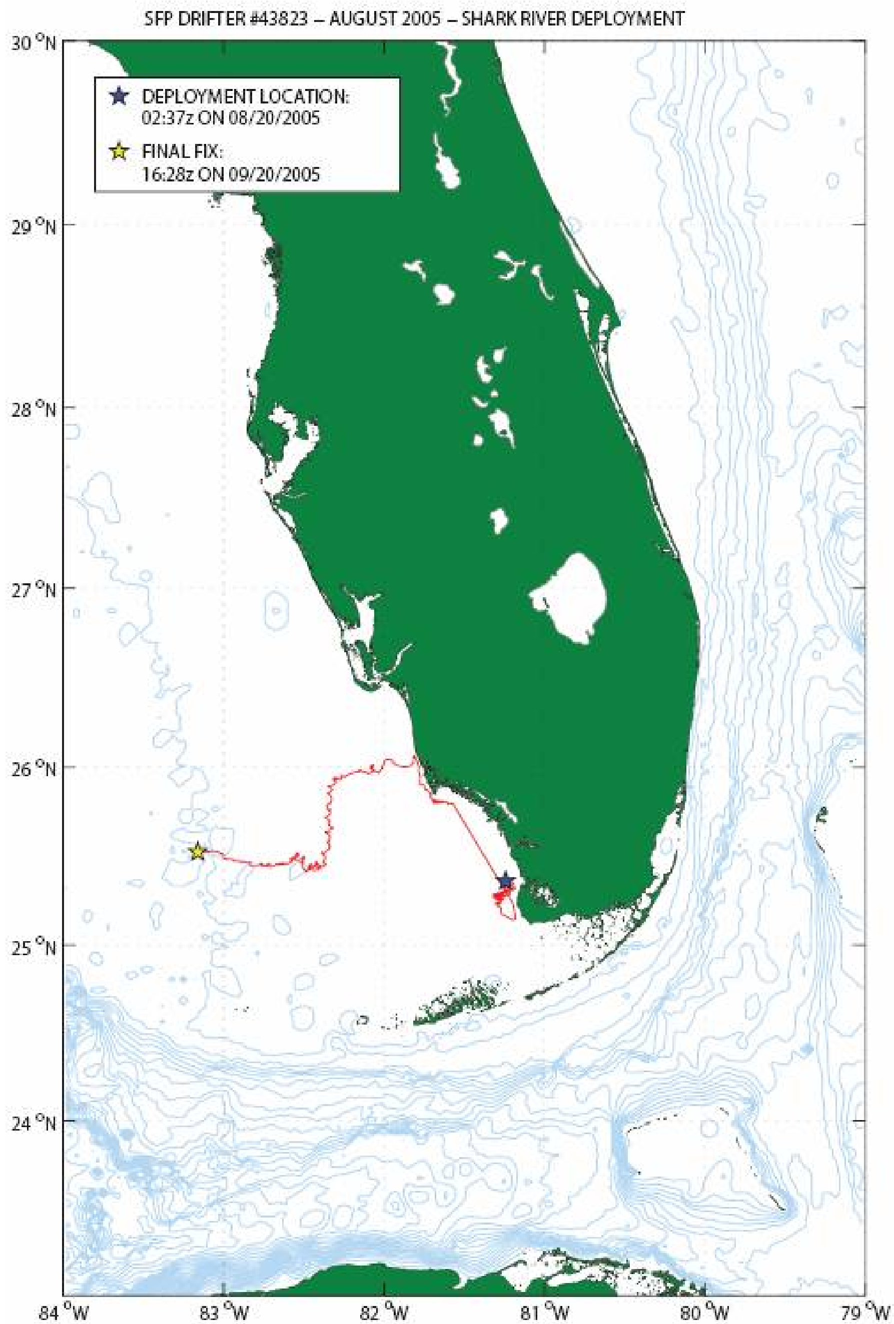


Figure 3-35. The trajectory of a drifter along the southwest Florida shelf showed a rapid northwesterly movement during the passage of Hurricane Katrina on August 26, 2005. Source: C. Kelble, AOML.

The passage of Hurricane Katrina dramatically altered the salinity distribution in Biscayne Bay, as illustrated by the salinity distributions for two cruises separated by a mere 2 weeks (Figure 3-36). The second cruise was conducted 4 days after Hurricane Katrina; the salinity reduction must have been rapid and likely caused significant stress to many sessile organisms in the region. The salinity effect was not as well pronounced in Florida Bay immediately after Katrina; however, the cumulative effect of the hurricanes still resulted in a large enough salinity response to warrant consideration as a potential stress to organisms (Figure 3-37). The large-scale surveys indicated the active hurricane season resulted in decreased salinities and increased chlorophyll *a* throughout large portions of south and southwest Florida (Figure 3-38). The increased chlorophyll likely decreased sunlight needed by the coral and their algae.

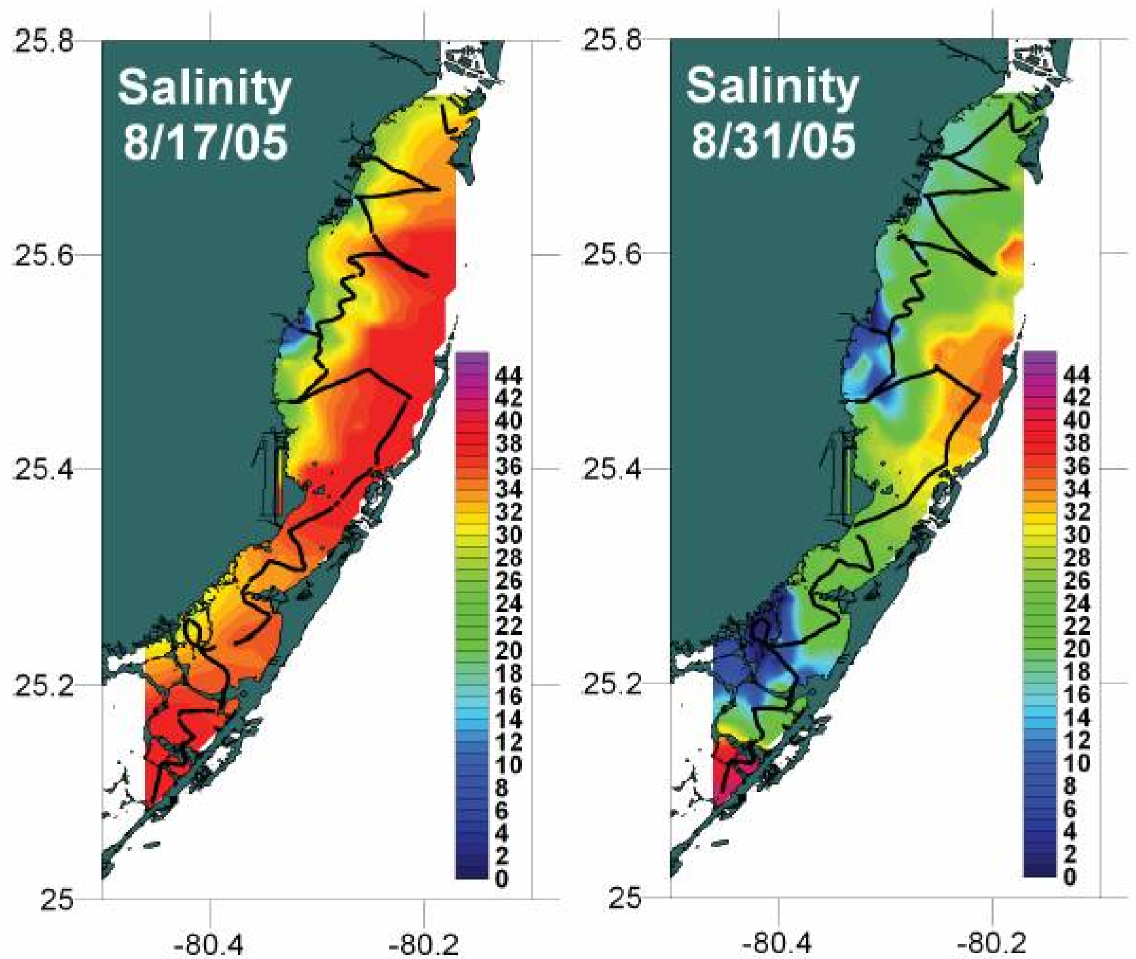


Figure 3-36. Contour maps depicting the salinity distribution in Biscayne Bay show a dramatic decrease in salinity after the passing of Hurricane Katrina. Source: C. Kelble, AOML.

The AOML moorings located near the reef tract from Looe Key up to Jupiter on the Atlantic coast of Florida also observed a consistent decrease in temperature with the passage of Hurricane Katrina. This was accompanied by an increase in acoustic backscatter, indicating an increase in the concentration of suspended particles over the reef tract. These observations could be indicative of a large-scale upwelling or an enhanced mixing event on the reef tract that occurred with the passage of Katrina and that may play an important role in the supply of nutrients to coral reefs in the region.

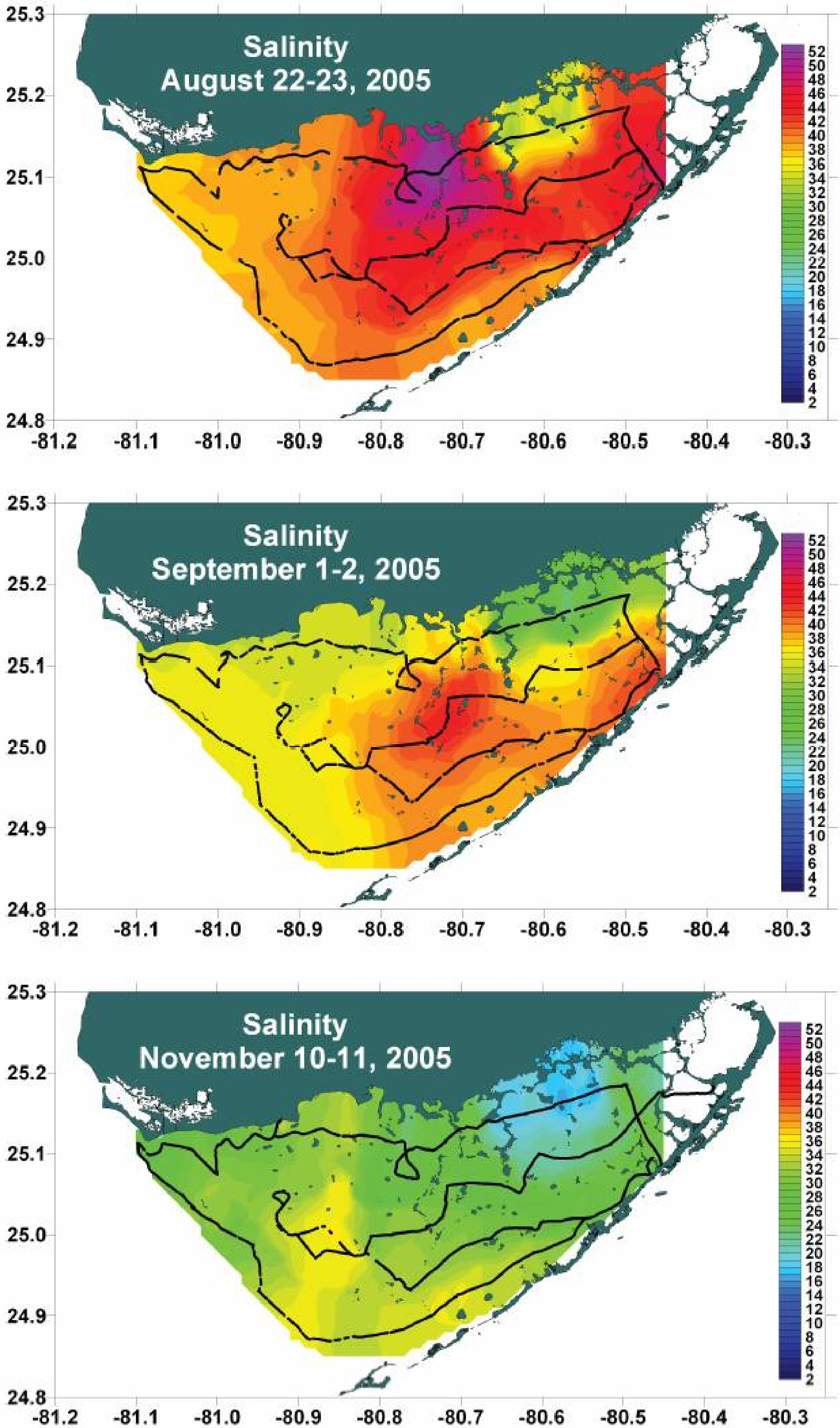


Figure 3-37. Sequential contour maps depict the changes in salinity distribution for Florida Bay during the 2005 hurricane season. Source: C. Kelble, AOML.

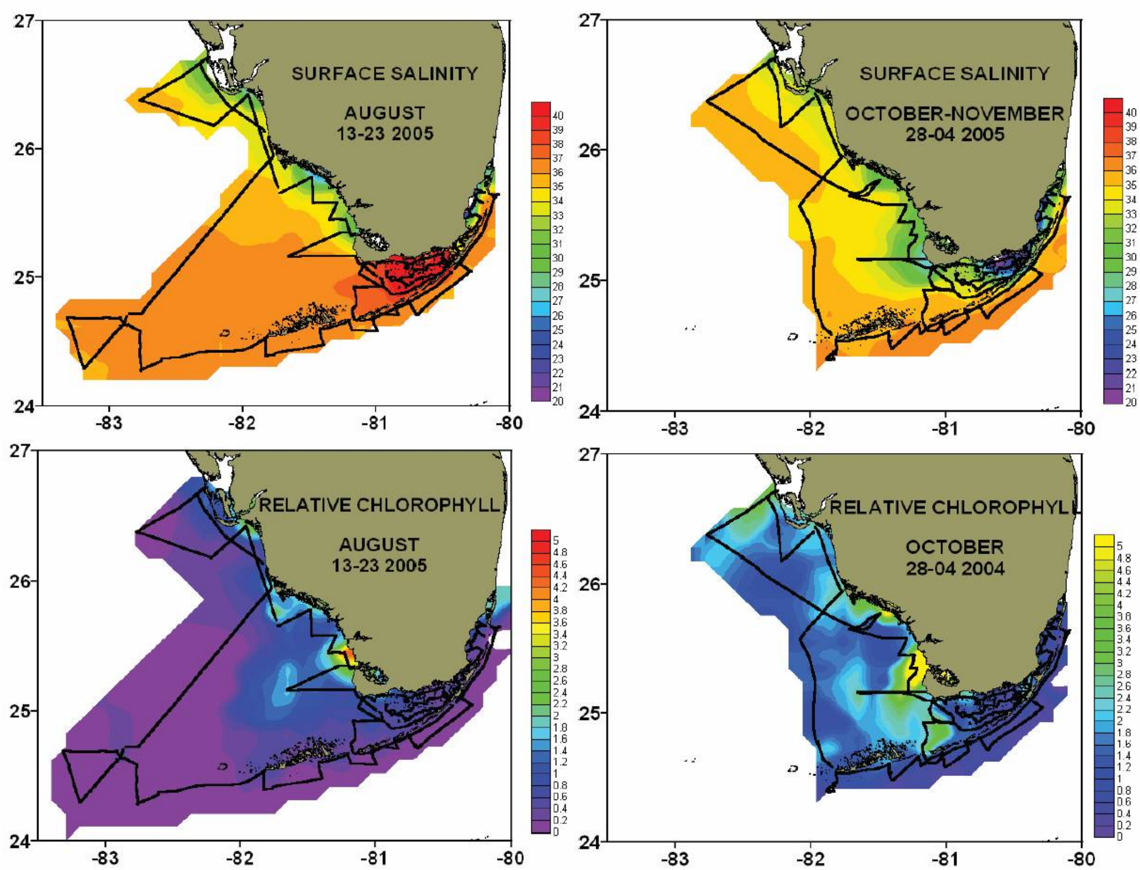


Figure 3-38. Contour maps of salinity and chlorophyll distribution show the effect of the 2005 hurricane season on salinity and chlorophyll *a* throughout south Florida. Source: Kelble, AOML.

AOML also generated backscatter measurements using a bottom-mounted Acoustic Doppler Current Profiler (ADCP) mounted in 55 ft of water off Miami (J. Proni, pers. comm.). The information presented in Figure 3-39 is an approximate measurement of sediment resuspension that results in the scouring of fishery habitat and eventually the settling of the sediments onto substrates such as corals. Physical smothering may be the most obvious effect of sedimentation (Rogers 1990). Sedimentation also can impair photosynthesis, feeding, and sexual reproduction (Kojis and Quinn 1985). Even 4 days after passage of Hurricane Wilma, the backscatter levels had not returned to pre-hurricane levels. The extended period of elevated backscatter levels is coincident with the appearance of long-period (16 second) surface waves radiated from Wilma after it had left the reef environment.

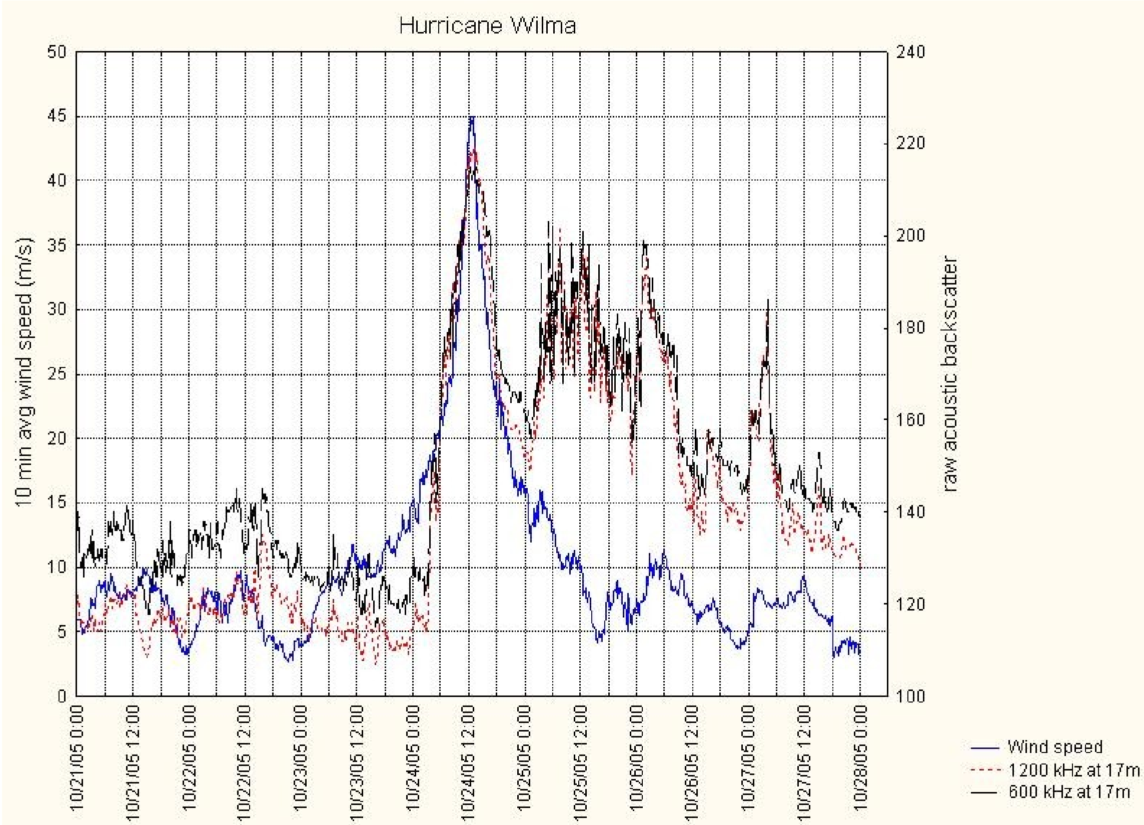


Figure 3-39. Acoustic backscatter (red and black) and wind speed (blue) during passage of Hurricane Wilma from a mooring located offshore of Miami, Florida. Source: J. Proni, AOML.

In summary, the intense Hurricane season of 2005 had an effect on the physical and biological environment (i.e., habitat) of south Florida that could have resulted in significant impacts to the upper trophic level biota, including fisheries. These effects could be seen on a large scale, indicating they were ecosystem-wide; however, the magnitude of the effect (e.g., salinity response) was variable throughout the region. The response to hurricanes could be observed immediately after their passage and, at least with respect to salinity, the response persisted for several months.

4. Significance of Hurricane-Caused Habitat Impacts in the Gulf of Mexico

Chapter 4 focuses on individual habitats—their importance to fisheries and the ecosystem; the impacts received from all three hurricanes (rather than, as in the previous chapter, impacts received by a mix of habitats by state and hurricane); the significance of these impacts (i.e., distribution of that particular habitat type versus geographic extent, duration, and severity or magnitude of injury to that habitat type); and, where known, the broader perspective of the status and change in each of the habitat types over many years. Portions of the text of this chapter are adapted from GMFMC (2004) and other sources to identify the importance of these habitats in supporting fisheries and, more broadly, ecosystem services that also contribute to fisheries.

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 highlights habitat related to oysters and shrimp. While oyster reefs are a habitat unto themselves and effects on this habitat are described below, shrimp are dependent on a suite of habitats, most notably wetlands and seagrass. In addition to discussions of the hurricane effects on wetlands and seagrass, an integrated discussion of the likely effects of the 2005 hurricanes on shrimp is provided in a "Shrimp Habitat" section.

Coastal Forests

Importance

Although not a marine fishery habitat, coastal forests provide important ecological services that affect adjacent fishery habitat. They act as one of the best purifiers of runoff and they hold water to limit floods and release it during low water periods (Omernik 1977; Chamberlin et al. 1991; Smith et al. 1993).

Impact of Hurricanes
Coastal forest was the predominant type of land cover lost in Mississippi and Alabama from Hurricane Katrina. For Louisiana loss of coastal forest was second after that of emergent wetlands. Hardwood forests in Louisiana and Mississippi suffered major blowdowns of canopy trees, and leaf and branch stripping of standing survivors, with the passage of Hurricane Katrina (MDFR/OMF 2005; Smith 2005; Barbour 2006). Storm surge brought saltwater that killed vegetation and caused extensive debris that inhibited the ability of adjacent fishery habitat to function. As a result, many birds and other wildlife were displaced or killed (Smith 2005). Decomposition processes led to declining water quality, including low dissolved oxygen and fish kill events in freshwater (Roussel 2006). Various degrees of these impacts may continue until the functional attributes of the forest once again dominate. Although Hurricane Rita's storm surge pushed more than 20 miles inland in southwest Louisiana and northeast Texas, reports of impacts to coastal forests were not submitted for this report. There are no reports of damage to coastal forests by Hurricane Wilma other than to mangrove forests, which are discussed later.

Long-Term Perspective
Unknown at this time.

Estuaries

Estuaries exist along the coast, where freshwater runoff from the terrestrial environment mixes with seawater from the ocean. Common habitat types within estuaries in the impact area include tidal wetlands, mangrove forests, lagoons, oyster reefs, and seagrass beds. Generally, estuaries in the impact area occur behind barrier islands.

In eastern Florida the estuaries are typically shallow, lagoon systems. On the west coast of Florida, estuaries are more expansive and are characterized by tidal channels, wetlands, and vast mangrove islands south of Tampa. In Alabama and Mississippi, the estuaries are shallow and characterized by mud, sand, and silt. The estuaries of Louisiana are extraordinarily expansive, principally because of the massive estuarine building capabilities of the Mississippi River. Large bays, expansive lagoons, and barrier islands characterize the estuaries of Texas. These are typically bordered by broad tidal marshes and mud-sand flats. In south Texas, embayed water in combination with low rates of runoff and high evaporation lead to hypersaline conditions, particularly in the summer months (GMFMC 2004).

Importance
The estuaries in the area covered by this report support some of the most productive and commercially valuable fishery species in the United States. The estuaries also contribute to the productivity of reefs and other offshore habitats and their fisheries. The intertidal wetlands and seagrass meadows found in estuaries produce large quantities of organic

detritus that is exported to both nearshore and deeper water habitats (outwelling) (Odum 1980; Williams and Heck 2001), and this source of nutrients and organic material is an important determinant of productivity in many offshore habitats. Wetlands, mangrove forests, seagrass meadows, and oyster reefs also provide complex habitat that serves as a refuge and nursery habitat for juveniles of many marine species, as well as foraging habitat for adults (Day et al. 1989). Fisheries of the Gulf of Mexico depend heavily upon species that spend a considerable portion of their life cycles in nearshore coastal areas and estuaries. These estuarine-dependent species include the main species of shrimp (brown, white, and pink), American oyster, menhaden (an industrial fish used in chicken feed and for oils for many purposes), red snapper, sea trout, and countless other species of commercial and recreational importance. Because of the dependence on estuaries and brackish marshes as nursery areas, losses in these coastal habitats will affect the reproductive success of these species (NMFS 2006a). In addition, the close coupling between the estuarine/nearshore zone and offshore habitats opens the possibility that coastal habitat degradation, habitat loss, or loss of habitat function may impact productivity in offshore fisheries.

Emergent, Intertidal Wetlands

Importance

The vegetated wetlands found in estuaries are among the most productive ecosystems on Earth (Teal and Teal 1969; Odum et al. 1982). These wetlands serve as refuge and nursery habitat for larval and juvenile invertebrates and fish of many species, and as foraging habitat for adults of some species (Day et al. 1989; Zimmerman et al. 2000; Minello and Rozas 2002). They are also the source of much of the organic material needed to sustain the detrital food webs that dominate energy flow in both estuarine and marine ecosystems. As a consequence, degradation and/or loss of wetlands may threaten productivity not only in estuarine fisheries, but also in offshore fisheries. In addition, marshes remove contaminants from water. The wetland benthic community recycles and regenerates nutrients useful to primary producers that dominate these habitats and make them so productive. Emergent, intertidal wetlands reduce erosion and buffer inland areas from storm damage by absorbing wave energy and controlling floods (Farber 1987).

Strong correlations have been demonstrated between penaeid shrimp yield and wetland area in the Gulf of Mexico (Turner 1977, 1979, 1992; Turner and Boesch 1988; Zimmerman et al. 2000; Minello and Rozas 2002). Most biological activity is confined to the marsh edge, and this is probably why marsh edge length is the best predictor for inshore shrimp catch. The brown shrimp (*Farfantepanaeus aztecus*), a species managed by the Gulf council, is a notable example of a fishery species that is intimately linked to the salt marsh. Its life cycle is typical of estuarine-dependent organisms (Gosselink 1984). Brown shrimp are spawned offshore and the eggs, larvae, and postlarvae are carried into the estuaries by currents. Once in the estuaries, shrimp move deep into the marsh, where they spend their early juvenile stages in protected marsh ponds and bayous. As their size increases, they move out of the shallow areas of the marsh and into progressively deeper water. The deeper waters are used as staging areas from which shrimp migrate back into the Gulf during late spring and summer.

Other notable species that use marsh habitats extensively include white shrimp (*Litopanaeus setiferus*), blue crab (*Calinectes sapidus*), mullet (*Mugil cephalus*), spotted seatrout (*Cynoscion nebulosus)*, and many forage species in both juvenile and adult life stages. Several shallow water reef fish species occupy marsh areas for a time. The majority of these fish feed on the benthic and epibenthic invertebrates that are abundant throughout the marshes.

Impact of Hurricanes

Emergent intertidal wetlands were the predominant type of habitat lost in Louisiana. Hurricane Katrina extensively and severely damaged freshwater and intermediate emergent, intertidal marshes near the Louisiana–Mississippi border (Smith 2006). Hurricane Rita's storm surge caused salt water intrusion and flooded Louisiana's freshwater marshes from Terrebonne/Barataria Parishes westward to Texas (Roussel 2006; Smith 2006; T. Blair 2007, pers. comm.; Steyer et al. in press). The surge and waves from both storms ripped apart highly organic soils (Smith 2006), removed or rearranged marsh (USACE 2006a), lifted and moved floating marsh and shrub/scrub vegetation (Smith 2006), pushed saltwater more than 20 miles inland (USACE 2006a; Steyer et al. in press), killed or damaged freshwater vegetation, and buried parts of the wetlands under debris (USACE 2006a). Approximately 5,000 acres of habitat, mostly wetlands, were injured by 10 major oil releases caused by Hurricane Katrina in southeast Louisiana (NOAA/NOS/OR&R 2007, pers. comm.). These releases might be expected to have adversely affected survival, growth, and reproduction of aquatic organisms, but no detailed assessment was made. Prolonged flooding of marshes by saltwater was a major problem in southwest Louisiana (Boesch et al. 2006; USACE 2006a). In southwest Louisiana, pore water salinity was still above the normal range six months after Hurricane Rita (Steyer et al. in press). This led to an increase in salt-tolerant plant species and a commensurate decrease in freshwater species (Weifenbach and Sharp 2006). Groups of interconnected ponds coalesced when waves removed intervening marsh (Smith 2006). Overall, Louisiana lost 217 mi^2 of coastal (mostly freshwater and intermediate) marsh with the passage of Hurricanes Katrina and Rita. This amounted to approximately 8 to 11 times the annual rate of loss between 1990 and 2000 (Barras 2006a). In this one hurricane season, as much land loss took place as was predicted to occur over more than 21 years (using the rate of loss for the years 2000 to 2050 as predicted by USGS [Barras et al. 2003]). In contrast to the freshwater and intermediate marshes, most saline marshes remained physically intact, although some shorelines were eroded (Boesch et al. 2006).

In contrast to the injuries described above, most of the 70 Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) projects experienced little or no damage due to Hurricanes Katrina and Rita. A high-resolution look at the CWPPRA Delta-wide Crevasse project, located in the bird's foot delta of the Mississippi River and just to the east of the track of Hurricane Katrina, showed that following the storm the artificially cut crevasses remained open and functioning as designed (Thomas 2007, unpubl. data).

Likewise, the CWPPRA Pecan Island Terracing Project, located about 80 miles east of the landfall of Hurricane Rita, experienced little or no injury, even though the adjacent town of Pecan Island was severely damaged.

In Mississippi an estimated 1,890 acres of coastal marshes and forests were severely damaged or destroyed by Hurricane Katrina (MDFR/OMF 2005; Barbour 2006). Thousands of acres were covered with storm debris, inhibiting the ability of these areas to function as essential fish habitat. Alabama's emergent, intertidal wetland losses were associated with losses to barrier islands (Mobile Bay National Estuary Program 2006), although no statewide acreage documentation was available for this report. Texas lost more than 75 acres of coastal marsh from wave erosion at the McFaddin National Wildlife Refuge (MNWR). An additional 30,000 acres of wetlands at McFaddin National Wildlife Refuge are becoming increasingly imperiled due to erosion of barrier beaches and increasingly frequent saltwater inundation, which is converting fresh to intermediate wetlands to more brackish habitat.

Distribution of Habitat versus Extent, Duration, and Severity of Injury

More than half of the wetlands in the coterminous United States are found in the Gulf of Mexico region. Salt marshes are found primarily within coastal bays and deltaic areas throughout the Gulf of Mexico. They dominate in the northern Gulf, from Galveston Bay, Texas, to Cedar Key, Florida—the portion of the Gulf where freshwater inflows are greatest.

Hurricanes Katrina and Rita greatly accelerated the rates of loss (8 to 11 times the annual rate) of these marshes along perhaps 50 percent of the coastline (planimetric determination by M. Westington, NOAA, Coast Survey) in the region of the Gulf where they are most abundant (i.e., Galveston Bay, Texas, to Cedar Key, Florida). The loss of these coastal wetlands is likely to have direct, negative, and long-lasting impacts on fisheries. Historically, wetlands lost to open water have not reestablished themselves.

Fishery-independent stock assessments immediately following the hurricanes (November 2005) found no significant immediate impact on populations of shrimp and finfish in offshore areas of the Northern Gulf of Mexico (Hogarth 2005; NOAA 2006a). In fact, red snapper populations were higher than their long-term average (1972–2004). Shrimp and bottom fish increased about 30 percent from the 2004 level. This may have resulted from decreased fishing pressure (Lautenbacher 2006) or to the surveys being conducted immediately after the storm, which would not capture any life-stage, wetland-dependent delayed impacts. Further study is required.

Long-Term Perspective

Historically, the Mississippi River changed course every 1,000 to 2,000 years and balanced Louisiana delta lobe deterioration with new delta lobe formation—i.e., natural wetland loss was exceeded by natural wetland gain. With increased settlement in the 1700s, people began building flood protection levees to shield homes and property. As the levees grew larger, the "wild" nature of the river was restricted. This ultimately reduced the frequency of alluvial flooding and new delta lobe formation so critical to the creation and maintenance of wetlands in coastal Louisiana. After the Great Flood of 1927, Congress authorized funding for major Mississippi River flood control projects, including a system of continuous, reinforced levees that allowed for increased settlement and development along the river and its distributaries (Caffey 2005).

Levees provided needed flood protection but prevented vital land-building sediments and nutrients from replenishing and elevating deteriorating marshes. The result was increased marsh loss, larger and more prevalent areas of open water, and higher rates of erosion and subsidence. Additional alterations to the landscape have compounded the problem. The dredging of thousands of miles of access canals for petroleum extraction and navigation accelerated saltwater intrusion and erosion and impeded even further cross-marsh sediment migration.

Combined with natural causes, such as subsidence and hurricanes, the loss rate for Louisiana's coastal wetlands in the 1970s was as high as 39 mi^2 per year (USACE 2004). The rate decreased to between 20 and 25 mi^2 per year between 1990 and 2000 (Barras et al. 2003), and the USGS (Barras et al. 2003) projected a net land loss rate of 10 mi^2 per year for the years 2000 to 2050, under the assumption there would be land gains from Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) projects, the Caernarvon and Davis Pond diversions, and land building in the Atchafalaya and Mississippi River Deltas.

[1]Hurricanes Katrina and Rita greatly impacted remaining wetlands and may have caused the loss of 217 mi^2 (Barras 2006a, b). This would be a **3** percent loss of the remaining wetland acreage when compared to the **8,023** mi^2 of Louisiana wetlands estimated by Tiner (1991) in 1983. Using Barras' estimates (Barras et al. 2003) of wetland loss (see previous page) an additional 600 mi^2 might have been lost between 1983 and 2007 (a loss rate of 25 mi^2 per year for 24 years) bringing the wetland acreage down to **7,423** mi^2 for 2007. In this case the percent loss due to Hurricanes Katrina and Rita is still at **3** percent.

Turner (1992) using data from the northern Gulf of Mexico has estimated that approximately 1 acre of intertidal vegetation yields about 1 lb per yr of shrimp (Turner 1977). Alternatively, Turner's (1977) relationship between intertidal vegetation quantity and shrimp yield may be restated as an annual 1 percent decline in wetland area is equivalent to a 1 percent decline in fishing yield (GMFMC 2004). Using this estimate future estuarine dependent fish yield might be expected to decline by **3** percent (per statements above). As reported earlier, initial reports from a fishery independent survey (November 2005) have not detected any decline and some species (including shrimp) have increased.

Strong correlations have been demonstrated between penaeid shrimp yield and wetland area in the Gulf of Mexico (Turner 1977, 1979, 1992; Turner and Boesch 1988; Zimmerman et al. 2000; Minello and Rozas 2002). Most juvenile shrimp production

[1] The bold numbers in the third and fourth full paragraphs above (page 90) are corrected values as of August 7, 2007. The original values were the result of an incorrect conversion of acres to mi^2.

occurs along the marsh edge, and this is probably why marsh edge length is the best predictor for inshore shrimp catch. As a marsh begins to break into pieces, the amount of marsh edge increases. At some point, continued wetland erosion will reduce marsh edge as the remaining fragments of marshland convert to open water. At that time or shortly thereafter, a decline in wetland-dependent fisheries (e.g., shrimp, oysters, and blue crab) is predicted (Browder et al. 1989; Smith 2006).

The inability to precisely describe the linkage between habitat (quantity and quality) and fishery production is the primary impediment to applying an ecosystem approach to the management of fisheries. Resolving this shortcoming will require significant enhancements of research, assessment and monitoring. While this will be a costly undertaking, failure to make this investment will foreclose options for future generations. For the first time in history, society has the computational tools, the ecological understanding, and the observational capabilities to significantly enhance the precision of fishery and habitat management approaches. It is essential this opportunity to see meaningful advances in fishery management is not overlooked.

Oyster Reefs

Importance

Oyster reefs serve as fish habitat by providing structure, protection, and trophic support to juveniles and adults (SAFMC 1998). In the northern Gulf of Mexico (north of Galveston Bay, Texas, to northwest Florida), in areas where seagrasses are not abundant, oyster reefs may function similarly to submerged vegetation. Oyster reefs provide structural complexity in soft mud and sand environments that lack complexity by increasing available surface area for use by other organisms. The spaces between and among the oysters and other sessile organisms (e.g., mussels) provide hiding places for fish larvae and juveniles. The eggs, embryos, and larvae provide food for a variety of invertebrates (particularly the stone crab) and forage fish that in turn provide food for predatory fish. Several offshore reef fish species—including gag (*Mycteroperca microlepis*), mahogany snapper (*Lutjanus mahogoni*) and gray snapper (*L. griseus*)—are transients in oyster reefs during some portions of their life cycle, as are pinfish (*Lagadon rhomboides*) and pigfish (*Orthopristis chrysoptera*)(species of finfish preyed upon by reef fish). As many as 303 species have been documented on intertidal and subtidal oyster reefs (Wells 1961). As islands of hard substrate in areas where soft sediments predominate, oyster reefs help prevent erosion of intertidal wetlands, baffle water currents, regenerate nutrients useful to primary producers, and provide food and shelter for a variety of organisms (Day et al. 1989). These reefs also play a role in filtering suspended matter from the water column.

The eastern oyster (*Crassostrea virginica*) is itself an important commercial food species and is found throughout the Gulf of Mexico in intertidal and subtidal areas where salinities are above 7 ppt and winter air temperatures are moderate (Britton and Morton 1989; Day et al. 1989). Optimal temperatures and salinities for oysters range from 10^{o} to 26 ºC and 9 to 25 ppt (SAFMC 1998). Although oysters can tolerate thin layers of sediment or partial burial, complete burial by gradual, natural sediment accumulation or catastrophic events (e.g., a flood or hurricane) will kill them (Britton and Morton 1989). Because reefs are located at the ecotone between wetlands and open water, wetland loss can result in loss of oyster reefs, through decreased macrophytic detritus as food for oysters. Both sharply increased (i.e., flood) and decreased (i.e., drought) freshwater flow negatively impact oysters. Poor water quality due to contaminants (e.g., heavy metals, hydrocarbons, and pesticides), nutrient enrichment (e.g., sewage and fertilizers) or turbidity reduces habitat quality for oysters. If concentrations of these materials are excessive, they can result in the demise of oysters. On the positive side, oysters may be able to ameliorate algal blooms associated with eutrophication through their ability to filter particulates, thus affecting the distribution and abundance of phytoplankton (Coen et al. 1999).

The value of a mature oyster reef lies in its contribution to the function of the estuary as a whole, rather than just in its value for harvest (Bahr and Lanier 1981). It plays a substantial role in the energy flow dynamics of the estuaries in which it is found. The effects of reef loss may be both obvious and subtle, but will certainly result in reduced estuarine productivity (Bahr and Lanier 1981; Britton and Morton 1989) that may affect productivity in offshore fisheries. Much of the value of the reef lies in its stability as an island of complex intertidal habitat in otherwise soft sediment and its stabilizing influence on erosion processes. The suspension and deposit feeding fauna associated with the reef provide trophic support for higher consumer levels through the conversion of detritus to animal biomass and to the primary producers through mineralization of organic carbon and release of nutrients like nitrogen and phosphorous (GMFMC 2004).

Impact of Hurricanes

The passage of Hurricane Katrina caused mortality of at least 90 percent of the oysters associated with reefs in Mississippi (MDMR/OMF 2005) and, together with Hurricane Rita, caused mortality of 20 to 74 percent of the oysters associated with reefs in Louisiana (50 to 73 percent mortality in southeast Louisiana presumably was caused by Hurricane Katrina and 30 to 40 percent mortality in southwest Louisiana presumably was caused by Hurricane Rita) (Caffey 2006; Roussel 2006; P. Banks 2007, pers. comm.). Alabama's oysters were still recovering from Hurricane Ivan in 2004, which wiped out 80 percent of the harvest. Hurricane Katrina damaged only about 20 percent of Alabama's oyster beds with an 80 percent survival rate in the Cedar Point reefs surrounding Dauphin Island Bridge (Impact Assessment 2007). The extent of injury to oysters in Texas from Hurricane Rita is unknown. Hurricanes Dennis, Katrina, and Rita impacted (i.e., caused sedimentation and burial) oysters between Cedar Key and Pensacola, Florida, but the impacts were not differentiated among the storms. It is possible that the 2005 Hurricane Dennis (not addressed in this report) damaged oysters in the Florida Panhandle. Hurricane Wilma caused some short-term impacts (i.e., structural change, disruption of habitat utilization by mobile biota, and disruption of reproduction) to oysters in south Florida near Naples (about 60 mi. north of Oyster Bay, the southern limit in the Gulf for oysters).

Storm surge, waves, and resultant currents from Hurricane Katrina caused scouring of sediment, excavation of gullies in oyster reefs (particularly in western Mississippi Sound), and burial of oysters in both Louisiana and Mississippi (MDMR/OMF 2005; Roussel 2006). Debris (mostly housing material and vegetation) from land, adjacent marshes, and seagrass beds was found covering the reefs in Mississippi. Samples of broken and killed oysters were covered by a slimy, foul-smelling mud (MDMR/OMF 2005), suggesting decaying organic matter and perhaps low dissolved oxygen conditions.

Concern for contamination carried by floodwaters from Hurricane Katrina resulted in surveys to measure concentrations of contaminants in oysters. Generally, there was insignificant contamination of oysters from Louisiana, Mississippi, or Alabama. With the passage of Hurricane Katrina, there was a temporary (less than 5 months) increase of heavy metals in oysters in southeastern Louisiana, Mississippi, and western Alabama compared to 20-year historical averages for each site (Christensen 2007). Once sediments settled, all metal concentrations in oysters returned to historical averages or below (Christensen 2007).

Distribution of Habitat versus Extent, Duration, and Severity of Injury

The southernmost oysters in the United States are found in Oyster Bay, near Cape Sable, Florida Bay; north of that point, oysters grow almost everywhere in the Gulf of Mexico (McNulty et al. 1972). Oyster reefs in the northern Gulf of Mexico are most extensive in Louisiana (40,000 acres) and Florida (186,160 acres). In Louisiana the majority of public ground reef acreage is found east of the Mississippi River, where nearly 35,000 acres (87.5 percent) are located (LDWF 2002). This is the area most heavily damaged (50 to 74 percent mortality) by Hurricane Katrina. In Mississippi, oyster reefs cover approximately 12,000 acres. About 97 percent of the commercial harvest comes from western Mississippi Sound, mostly from Pass Marianne, Telegraph, and Pass Christian reefs, areas heavily damaged (over 90 percent mortality) by Hurricane Katrina. In Alabama, oyster reefs cover about 4,700 acres (20 percent mortality attributed to Hurricane Katrina). In Florida there are about 186,160 acres of oyster reefs, but only about 14,000 acres are open to shell fishing. Of the open area, most (63 percent) is in the panhandle estuaries of Apalachicola Bay and St. George Sound (some sedimentation and burial impacts noted above from the combined effects of Hurricanes Dennis, Katrina, and Rita). Hurricane Wilma had a short-term impact on relatively sparse oysters near Naples, Florida. Most of the 186,160 acres of oysters in Florida were unaffected by the hurricanes, and thus, are providing ecological services to the coast despite being unavailable for harvest because of closures related to pathogen (i.e., coliform bacteria) contamination. Texas has about 36,150 acres of oyster reefs, but extent of mortality attributed to Hurricane Rita is unknown.

Because oysters are a long-term crop, full recovery may take years and some oyster habitats may be lost permanently (Barksdale 2005). Although officials have found active beds in Mississippi, they do not expect oysters to be harvestable for at least another 2 years (Barksdale 2005; Hogarth 2005). Apparently, a good spat set occurred following Hurricane Katrina and spat were present in most of the areas surveyed in Mississippi (B. Randall 2007, pers. comm.). Over the next 5 years, it is expected that at least 75 percent of Mississippi's lost reef habitat will be restored (Barksdale 2005). There is no comparable documentation for the oyster reefs of Louisiana, Alabama, or Florida. The status of oyster reefs in Texas is unknown.

Because hurricanes cause repeated catastrophic injury to oyster reefs (i.e., Ivan in Alabama in 2004, Katrina in Mississippi in 2005), because the documented injury to oyster reefs caused by Hurricanes Katrina and Rita ranged from 20 percent to over 90 percent mortality, and because the area impacted was approximately one-third of the coastline of the U.S. portion of Gulf of Mexico, the combined impacts of Hurricanes Katrina and Rita on oyster reef habitat are considered severe. The damages to or the permanent losses of these reefs resulted in a significant decrease in the ecological services provided. The impact of Hurricane Wilma on oyster reefs is considered minimal. Hurricane Dennis, which impacted the Florida panhandle in 2005, is not considered in this report.

Long-Term Perspective

The long-term locations and abundances of oysters in the Gulf of Mexico have varied due to fluctuating periods of floods and droughts and also sporadic hurricanes. Occasional floods bringing freshwater have killed oysters, and drought conditions have produced high salinities (above 15 ppt), which have permitted disease and oyster drills to spread into the beds and kill many oysters before they reach harvestable size. However, oyster reefs have endured on a large scale because they are managed. When they are damaged, individual states reconstruct and rehabilitate beds, including spreading new shell or other growth substrate (e.g., limestone gravel). Following drought, with the return of wet weather and continued plantings of shell, the oysters return in abundance (Dugas et al. 1997). The Gulf states probably always will have substantial oyster resources. Some oysters on Mississippi's reefs did survive, and heavy sets of spat were observed on the remnants of Mississippi's reefs (MacKenzie 2006). This, along with ongoing and anticipated reef rehabilitation, bodes well for the long term.

Seagrass Meadows

Importance

Seagrass meadows are highly productive submerged habitats that are extremely valuable because of the multiple roles they fill (McRoy and Helfferich 1977). Seagrass meadows provide nursery and foraging habitat throughout the Gulf for red drum (*Sciaenops ocellatus*) and penaeid shrimp (white, pink, and brown). In South Florida, gray (*Lutjanus griseus*) and mutton snapper (*L. analis*), and gag (*Mycteroperca microlepis*) also make extensive use of seagrass meadows as nursery habitat (Thayer et al. 1978), and these species, along with other coral reef fish, may migrate from reefs into meadows at night to forage (Zieman 1982). Large offshore or oceanic fish such as mackerels and jacks are present in seagrass habitats from time to time, as are juveniles of several shark species. The large meadows off the west coast of Florida are in close association with productive live bottom habitats, and may provide important foraging grounds for commercially and recreationally important fishes such as grunts, snappers, grouper, and flatfish (NMFS 2000a). Invertebrate abundance is much higher in seagrass beds than in adjacent unvegetated habitats. Seagrass meadows provide a rich nursery with safe refuge and abundant food resources for juvenile invertebrates and fish, as well as prime foraging habitat for adults of many fish species (Zieman and Zieman 1989). Seagrass beds also support some species of sea turtles and manatees.

Most seagrass meadows include many species of algae. Both seagrasses and macroalgae have been found to be important nursery habitats for numerous fish species (Rydene and Matheson 2003). The meadows baffle waves, reduce erosion, and promote water clarity (Fonseca 1996). Large quantities of detritus are exported out of meadows to adjacent communities and even far offshore to deep-sea habitats. Low-energy, shallow-water areas with restricted circulation are prime areas for seagrass meadow development. Salinity tolerances vary, although optimal salinities for the species found in the Gulf range from 20 to 40 ppt.

Impact of Hurricanes

The seagrass beds associated with the Chandeleur Islands were severely impacted by scouring and burial due to Hurricane Katrina (Graumann et al. 2005; Knabb et al. 2006b). Hurricane Katrina also is thought to have caused the 100 percent loss of an extensive seagrass bed in Mississippi Sound off Waveland, Mississippi (P. Biber 2007, pers.comm.), and along West Ship Island, Mississippi (Heck and Byron 2006). Except for East Ship Island (57 percent loss of seagrass), seagrass beds associated with the other barrier islands of Mississippi, including the Mississippi Gulf Islands National Seashore, suffered little injury (Heck and Byron 2006; P. Biber 2007, pers.comm.). There was no loss of seagrass in Alabama (Byron and Heck 2006). Because southwest Louisiana has no apparent seagrass (seagrass only in Lake Pontchartrain and Chandeleur Sound) (L. Handley 2007, pers. comm.), Hurricane Rita had no identified impact.

Hurricane Wilma caused an 80 percent loss of turtlegrass in Caloosahatchee–St. Lucie Rivers (Sanibel Captiva Conservation Foundation), and an unquantified amount in Florida Bay, Blackwater Sound, and Barnes Sound (Curry Hammock State Park). For both Hurricanes Katrina and Wilma, it is believed the losses were due to storm surge and waves that scoured or buried plants. This same action stirred sediment into the water column, limiting light needed by the plants for photosynthesis. The wind, the surge, and the waves generated large quantities of debris, including crab pots (Caffey 2006) and lobster traps (Florida Keys National Marine Sanctuary). This debris scraped, crushed, and settled on top of grassbeds. Such debris is likely to be a nearly permanent feature unless physically removed.

Heavy rain and freshwater runoff washed nutrients into coastal waters, causing algal blooms that “shaded” the grass, and effectively limited the light available to sustain the seagrasses in the Florida Bay–Blackwater Sound–Barnes Sound area (Curry Hammock State Park). Additionally, the heavy rains associated with the hurricanes resulted in runoff that precipitously decreased the salinity in seagrass meadows, in particular killing turtlegrass in Florida in the Caloosahatchee–St. Lucie Rivers region (Sanibel Captiva

Conservation Foundation). All of these impacts combined to kill or decrease the amount of seagrass in coastal areas of the Gulf.

Distribution of Habitat versus Extent, Duration, and Severity of Injury
Seagrasses occur in all states on the Gulf of Mexico, although they are nearly extirpated from Louisiana (seagrass remain only in Lake Pontchartrain and Chandeleur Sound). Severe injury appears to have occurred along the direct path of Hurricane Katrina (i.e., Chandeleur Islands, Louisiana, and West Ship Island and off Waveland, Mississippi). Areas off the direct path (i.e., Mississippi's barrier islands) reported no or little loss in acreage of seagrass. Alabama reported no damage to seagrasses. No damage to seagrass beds was documented for Hurricane Rita. Hurricane Wilma damaged turtlegrass in south Florida (up to 80 percent loss) in an area from Captiva Island–Sanibel across the state to St. Lucie (i.e., Caloosahatchee–St. Lucie Rivers), and from Sanibel south to Florida Bay and east to Key Largo (Blackwater and Barnes Sounds).

Hurricanes Katrina and Wilma are likely to have caused effects beyond the actual limits of the seagrass meadows. With the loss of wave baffling, enhanced erosion almost certainly took place along adjacent landward (often wetland) habitats used by fishery species. With the loss of seagrass beds, a concomitant loss occurred in shelter and food for many species, including many reef species. These losses may have affected penaeid shrimp, snappers, gag, and grouper, among many other species. Even sea turtles and manatees that use seagrass beds may have been negatively affected, although the degree of impact is unknown.

Long-Term Perspective
Seagrass coverage has declined in almost all areas of the Gulf of Mexico since the 1950s due to anthropogenic and natural effects (Robblee et al. 1991; Zieman et al. 1994; Carlson et al. 1998; Moncreiff et al. 1998; C.A. May 2007, pers. comm.). In most instances, declining water quality has been blamed for seagrass die-off (Moncreiff et al. 1998). Estimates of losses range from about 25 percent in the lower Laguna Madre (Pulich 1998) to nearly 100 percent in parts of Louisiana, Mississippi, and Alabama (Eleuterius and Miller 1976; Moncreiff et al. 1998; Handley, no date). Heavy wave action associated with Hurricane Camille in 1969 destroyed approximately 58 percent of the seagrasses in Mississippi Sound (Eleuterius and Miller 1976). Seagrasses are resilient to the acute effects of hurricanes (Steward et al. 2006), but if their habitat is destroyed recovery is rare (Byron and Heck 2006), which may have long-term consequences for sediment stability and economically important fish and shellfish (Williams and Heck 2001).

Mangrove Forests

Importance
Mangroves serve as nursery areas and habitat for commercially and recreationally important fisheries such as shrimp, snook *(Centropomus undecimalis)*, tarpon *(Megalops*

atlanticus), gray (mangrove) snapper *(Lutjanus griseus)*, red drum *(Sciaenops ocellatus),* and numerous other estuarine fish species (Manson et al. 2005; Faunce and Serafy 2006). They protect seagrass flats and coral reefs from sedimentation and eutrophication. Mangrove forests accumulate, stabilize, and cause sediments to settle out before they reach critical shallow water habitats (Wolanski and Chappell 1996; Wolanski et al. 1997; Wolanski et al. 1998). Mangrove forests also sequester dissolved nutrients from the estuarine environment (Rivera-Monroy et al. 1995), thereby limiting the development of asphyxiating algal blooms in the vicinity of seagrass flats and coral reefs. Mangrove biomass is a source of energy for the food chain within the forest ecosystem. This biomass also is exported from the forest as plant and animal matter, which stimulates productivity within the larger coastal environment.

Red mangroves, which grow intertidally, function as fish habitat by providing shelter within the complex prop root system, and by providing abundant detritus to fuel the detrital food web on which fishes and invertebrates depend (Odum et al. 1982). In particular, the prop roots of red mangroves provide a source of hard substrate in an otherwise soft sediment system and can be heavily populated with a diverse assemblage of both sessile and motile invertebrates as well as algae. Many animals use mangrove habitats in Florida (Mitsch and Gosselink 1993), including at least 220 species of fish (Odum et al. 1982). The invertebrate fauna is composed primarily of filter or suspension feeders and detritivores (sponges, ascidians, oysters, barnacles, isopods, gastropods, polychaetes, amphipods, and crabs) (Ellison and Farnsworth 2001). Goliath grouper (*Epinephelus itajara*), red grouper (*E. morio*), Nassau grouper (*E. striatus*), gag (*Mycteroperca microlepis*), bluefish (*Pomatomus saltatrix*), cobia (*Rachycentron canadum*), mutton snapper (*Lutjanus analis*), gray snapper (*L. griseus*), dog snapper (*L. jocu*), lane snapper (*L. synagris*), red drum (*Sciaenops ocellatus*), Spanish mackerel (*Scomberomorus maculatus*), king mackerel (*S. cavalla*), and gray triggerfish (*Balistes capriscus*) all use mangroves as juveniles, subadults, or adults, often as foraging habitat. In addition, mangroves remove contaminants from water and recycle inorganic nutrients. Physically, they reduce erosion and buffer inland areas from storm damage by absorbing wave energy and controlling floods.

Impact of Hurricanes

Hurricanes Katrina and Rita had little impact on south Florida’s mangrove forests. Hurricane Wilma severely damaged the mangroves in Everglades National Park. Defoliation was so severe that mangroves died for months after Hurricane Wilma (Smith et al. 2007). After the mangroves died, their roots rotted, leaving empty spaces in the peat layer in which they were growing. The peat collapsed into these empty spaces, lowering the elevation of the growing surface and preventing growth of new mangroves. Smith et al. (1994) have observed this phenomenon with Hurricanes Andrew, Donna, and now Wilma.

Hurricane Wilma also caused severe damage to the red mangroves on the Mangrove Islands portion of the Great White Heron National Wildlife Refuge. Nearly all of the mangroves were defoliated, with resulting mortality ranging from very low to severe. On two of the islands (Little Crane Key and Upper Harbor Key), all of the mangroves were killed. However, on most other islands in the refuge, recovery is well under way (T. Wilmers 2007, pers. comm.). Hurricane Wilma caused extensive damage to the mangroves of the Charlotte Harbor area in southwest Florida. Damage there is threatening the endangered smalltooth sawfish (*Pristis pectinata*)(P. Stevens 2007, pers. comm.), but preliminary studies indicate the sawfish is still present in the affected area. Finally, debris (80-foot vessels in some cases) from Hurricane Wilma impacted red and black mangrove areas of Monroe County and the Florida Keys National Marine Sanctuary. In some cases this debris broke, crushed, or killed mangroves.

Distribution of Habitat versus Extent, Duration, and Severity of Injury
Distribution of mangroves, particularly the red mangrove, is limited by freezing temperatures. In the Gulf of Mexico they are found in south Florida north to Cedar Key, Florida, and along the estuarine intertidal zone of the Mexican coast (Odum et al. 1982). Black mangroves, which grow in the upper intertidal to supratidal zone, are found along the south Texas coast (Corpus Christi to the Rio Grande) and in scattered patches throughout much of the northern Gulf coast (Odum et al. 1982). The extent of severe impact occurred from the Great White Heron National Wildlife Refuge (Florida Keys near Key West) and Everglades National Park to Charlotte Harbor, Florida, approximately 50 percent of the area over which red mangroves occur in the U.S. portion of the Gulf of Mexico.

Hurricanes can destroy entire mangrove populations (Jimenez et al. 1985), causing significant long-term effects to the ecosystem. Mangroves are particularly sensitive to storms and hurricanes because of their exposed location within the intertidal zone, their shallow root systems, and the noncohesive nature of the forest soils. Hurricanes can also affect the long-term sustainability of mangroves with primarily organic (i.e., peat) soils located far from terrigenous sources of sediment. In these soils, continual addition of new organic matter is required to maintain mangrove sediment elevation because the peat is constantly decomposing (Middleton and McKee 2001). When the catastrophic winds and flooding associated with a hurricane cause mass mortality of mangrove forests (Jimenez et al. 1985), the sediment elevation of the forest collapses without renewed tree growth (Cahoon and Hensel 2002). In the absence of forest regeneration, the mangrove sediments eventually become submerged as sea level rises and the once intertidal forest is converted to subtidal open water habitat.

In evaluating the effects of Hurricane Mitch (November 1998), which struck Naples, Florida, Hensel and Proffitt (2002) determined that recovery of red mangrove had not occurred to any significant degree 27 months after the hurricane. Ward and Smith (in press) predicted recovery from Hurricane Wilma could take six years in an area where the mangroves had lost 99 percent of their biomass. Without live mangrove cover, the highly organic soils in this area would rapidly decompose and lose elevation. Some form of active restoration would be needed to repopulate the area with mangrove seedlings (Cahoon and Hensel 2002). This pattern of destruction and limited or no regrowth seems to be reappearing in some areas of Florida impacted by the 2005 hurricanes (Smith, in press). Impacts in these areas may be permanent without intervention, making the impact level severe and the duration permanent.

Field studies of hurricane impacts on mangrove-associated fish communities are few and generally short-term. Adams and Wolf (in press) compared fish communities in natural and degraded creeks before versus immediately after passage of Hurricane Charley, which struck Charlotte Harbor, Florida, in August 2004. They found fish density and species richness values for both creek types were reduced following the hurricane, but returned to pre-hurricane levels within a month. Natural creek fish assemblages appeared to be more resilient than degraded ones. Greenwood et al. (in press) also examined impacts of Charley on Charlotte Harbor mangrove fishes, with a focus on economically important species that were at least 4 inches standard length. They failed to detect a significant pre- versus post-hurricane difference in fish community structure within two months of the hurricane's passage. Bortone et al. (in press) also examined pre- versus immediately post-Charley impacts on mangrove fish assemblages. In their examination of Sanibel Island mangrove–fish assemblages, changes in fish community structure were detected, but these appeared short-lived and relatively small compared to the effects of a red tide event that occurred several months later.

Collectively, studies suggest that fishes are resilient to hurricane-induced mangrove damage. However, the major limitation of these investigations is that they address only short-term effects. Moreover, they do not address cases in which mangrove habitats are transformed to mudflats (Silverman et al., in press) or open water. In the former case, community changes have been found to be dramatic. As noted by Greenwood et al. (in press), the effects of mangrove habitat damage may be delayed if prop-root structure remains in a non-living state. Upon prop-root deterioration, impacts at the community and species-specific level are likely to be substantial.

Long-Term Perspective

Mangrove forests are in a long-term decline across the Gulf and southern Florida, both from impacts of hurricanes and development. However, restoring appropriate hydrology, which may include adding sediment to reestablish proper elevation, usually results in natural re-colonization absent other impacts.

Barrier Islands and Shorelines

Importance

Barrier islands and beaches protect landward habitats (i.e., wetlands, oyster reefs, seagrass meadows, and lagoon systems) used as nursery areas by many fishery species and their prey. They also protect coastal forests and upland areas where people and critical infrastructure (e.g., oil and gas, ports, and fisheries) are located. Barrier islands and beaches provide suitable habitat for wetlands and seagrass and their associated biota on their landward side, and habitat for nesting turtles and other biota (e.g., shore birds and numerous invertebrates) on their seaward side.

Impact of Hurricanes
Barrier shorelines were second after forested habitat in terms of the predominant type of habitat lost in Mississippi from Hurricane Katrina. More barrier shoreline was lost in Mississippi than in Louisiana or Alabama from Hurricane Katrina. Barrier islands and beaches in Louisiana, Mississippi, Alabama, and Texas in and adjacent to the paths of Hurricanes Katrina and Rita experienced severe erosion. In many cases, their elevations were reduced to near sea level and their vegetative cover was greatly diminished. Already badly eroded by several hurricanes between 2002 and 2005 (Lili, Ivan, and Dennis), the Chandeleur Islands were nearly destroyed by Hurricane Katrina (Graumann et al. 2005; Knabb et al. 2006b). Hurricane Katrina destroyed over 2,000 acres on Mississippi's four barrier islands (i.e., Cat, Horn, Petit Bois, and Ship Island) (Barbour, 2006). These islands also had been eroded by previous hurricanes—Camille in 1969, Georges in 1998, and Ivan in 2004. In Alabama, Isle aux Herbes experienced some shoreline erosion and land loss. About 60 turtle nests were lost along the Alabama coast (U.S. Fish and Wildlife Service 2005a).

East Timbalier Island, a barrier island in the sediment-starved portion of the Louisiana coast, lost about 10 acres from the combined effects of Hurricanes Katrina and Rita (J. Thomas 2007, unpubl. data). In the process, 75 acres were eroded from the front and ends of the island and 65 acres were deposited on top and the back side of the island. In Jefferson County, Texas (on the border with Louisiana), Hurricane Rita caused a loss in beach elevation and the landward retreat of the beach ridge (R. Newby 2007, pers. comm.).

In south Florida, Hurricane Wilma stripped the sand off most of the area beaches as it moved onshore at Marco Island. Major beach erosion occurred from the Florida Keys (i.e., Lower Matecumbe Key to Key West) to north of Marco Island (Sea Oat Island) on the west coast of Florida (FDEP 2006b). Moderate beach erosion extended north to Naples in Collier County, Florida (FDEP 2006b). Hurricane Wilma caused the disappearance of the island at Pelican Shoal Critical Wildlife Area (5 miles south of Boca Chica Key) and eroded the beaches at Caxambas Pass (Marco Island) and Little Estero Island Critical Wildlife Area (near Ft. Myers). On the Atlantic side of Florida, at the Canaveral National Seashore, Hurricane Wilma caused beach erosion that led to the loss of 1,000 of the 3,000 sea turtle nests. Otherwise, beach erosion in Dade, Broward and Palm Beach Counties, Florida, was minor (FDEP 2006b).

Qualitative observations suggest that areas with substantial restoration projects generally fared better than those without. For example, restored barrier islands and back barrier saline marshes in the Terrebonne Basin, Louisiana, fared substantially better than a similar, largely unrestored barrier island chain in Barataria Basin, Louisiana (LDWF 2007b). Some of this difference, however, may be due to the storm track of Hurricane Katrina.

Distribution of Habitat versus Extent, Duration, and Severity of Injury
Barrier islands occur on the coasts of all Gulf states. Barrier island land loss was estimated for several islands in Chapter 3 of this report and varied from low levels (e.g.

approximately 2 percent for Cat Island, Mississippi) to very high levels (e.g., approaching 50 percent for the Chandeleur Island chain, Louisiana; Breton Island National Wildlife Refuge; and Deer Island, Mississippi and 100 percent for the island at Pelican Shoal Critical Wildlife Area, Florida). The land losses on the barrier islands will likely continue unless human intervention to reestablish sediment sources encourages land building and maintenance processes. Given that many of the estuarine habitats are protected by the barrier islands, the level of injury is considered severe.

As noted earlier, beaches in the study area often protect wetland or coastal forest systems from the open sea, in addition to providing habitat services themselves. The beaches in Texas were especially noted as experiencing erosion from Hurricane Rita. Several coastal National Wildlife Refuges with large wetland areas behind barrier beaches are in danger of more frequent saltwater inundation if beach areas and elevations are not restored. The injury to barrier beaches is considered very serious, while the loss of wetland areas behind those beaches, should it occur, would be ecologically catastrophic to the Refuges. It is not clear if the restoration of these wetlands would be practical, once inundation occurs because of salinity impacts to the soils.

Long-Term Perspective

Stone et al. (1997) present a historical perspective of hurricane-caused changes to the Louisiana coast; they estimate that hurricanes were responsible for 90 percent of the retreat in barrier island shorelines between 1901 and 1996. Between 2000 and 2006, East Timbalier Island—a barrier island in Terrebonne Parish along a sediment-starved portion of the Louisiana coast—lost 173 acres, or about 39 percent of its area, primarily due to hurricanes (i.e., Lili in 2002, Ivan in 2004, and Katrina and Rita in 2005) (Thomas 2007, unpubl. data). With long-term sea level rise, the outlook for barrier islands and shorelines is poor without human intervention. Human intervention includes island reconstruction—an effective but expensive and ultimately short-term fix—and the reestablishment of enhanced, long-shore sediment transport fed by coastal river systems.

Offshore Marine Habitats

The continental shelf is largely composed of muddy or sandy terrigenous sediments from the Rio Grande River Delta to DeSota Canyon off Pensacola, Florida. East of DeSota Canyon, the shelf is composed of carbonate rocks and sediments. Surface sediments may affect shrimp and fish distributions directly in terms of feeding and burrowing activities, or indirectly through food availability, water column turbidity, and related factors (Darnell et al. 1983).

Soft Bottom (Mud, Sand, Clay)

Importance

Adult shrimp are found offshore. White shrimp *(Litopenaeus setiferus)* are found to depths of 130 feet, pink shrimp *(Farfantepenaeus duorarum)* to about 210 feet, and brown shrimp *(F. aztecus)* to about 360 feet. Sediment type is a major factor in determining the associated fish community (Hildebrand 1954, 1955; Chittenden and McEachran 1976; Darnell et al. 1983). Shrimp distribution closely matches sediment distribution. White shrimp and brown shrimp occupy terrigenous muds, while pink shrimp occur on calcareous sediments (Pattillo et al. 1997). Shrimp have been shown to actively select substrate type (Williams 1958). Similar sediment-associated distributions also have been observed for many demersal fishes (Caldwell 1955; Hildebrand 1955; Dawson 1964; Topp and Hoff 1972).

Chittenden and McEachran (1976) found Atlantic croaker (*Micropogonias undulatus*) to be the dominant species of the white shrimp grounds. The most dominant family was the drums, along with representatives from the snake mackerels, threadfins, sea catfishes, herrings, jacks, butterfishes, bluefishes, and lefteye flounders. The dominant family of the brown shrimp grounds is the porgies, and the longspine porgy (*Stenotomus caprinus*) is the dominant species. Important supporting fauna include a variety of species from the drums, sea robins, sea basses, lefteye flounders, lizardfishes, snappers, jacks, butterfishes, toadfishes, batfishes, scorpionfishes, goatfishes, and puffers (Hildebrand 1954; Chittenden and McEachran 1976). The dominant fish species of the pink shrimp grounds include Atlantic bumper (*Chloroscombrus chrysurus*), silver jenny (*Eucinostomus gula*), sand perch (*Diplectrum formosum*), leopard sea robin (*Prionotus scitulus*), fringed flounder (*Etropus crossotus*), pigfish (*Orthopristis chrysoptera*), and dusky flounder (*Syacium papillosum*) (Hildebrand 1955).

Sand/shell and soft bottoms are inhabited by various infauna (e.g., worms and crustaceans) and epifauna (e.g., sea pens), which act as ecosystem engineers and modify these habitats by the presence of their physical structure or burrowing in the substrate. In addition, some fishes (e.g., tilefish, *Lopholatilus chamaeleonticeps*, and red grouper, *Epinephelus morio*) construct burrows or excavate depressions in sediments, increasing the habitat's original complexity (Coleman and Williams 2002; Scanlon et al. 2005). Burrowing activities also affect biogeochemical cycling and the decomposition of organic matter in the substrate (Coleman and Williams 2002). Therefore, ecosystem engineers can be considered an integral part of the habitats in which they occur. Activities that directly or indirectly kill or remove ecosystem engineer species may substantially alter the nature of these habitats.

A number of protected species also occur in both the shallow and deeper water habitats in the Gulf of Mexico. For example, cetaceans are primarily found in offshore habitats; however, nearshore habitats are used by nine of 23 species, including bottlenose dolphin (*Tursiops truncatus*) and Atlantic spotted dolphin (*Stenella frontalis*). The bottlenose and Atlantic spotted dolphins are the most commonly found species in nearshore waters, along with sea turtles.

Impact of Hurricanes

Damage to the offshore oil and gas infrastructure and the physical conditions noted in reports from the Minerals Management Service (MMS) may be used to indicate the degree of disturbance caused by Hurricanes Katrina and Rita on offshore fishery habitat. Fifteen mobile drilling rigs were torn from their moorings and drifted mostly northwesterly toward the coast, periodically making contact with, scraping, and gouging the seabed and damaging pipelines until coming to rest in shallow water (MMS 2007a). Hurricanes Katrina and Rita also caused the destruction of 115 oil platforms, extensive damage to another 54, and damage to over 600 pipeline segments, all of which became debris spread out thinly over a huge area (estimated to be at least 28,000 mi^2) affecting (i.e., crushing, breaking, and burying) offshore benthic habitat.

Because the offshore oil and gas facilities were shut down for Hurricanes Katrina and Rita, oil losses were mostly limited to the oil stored on damaged structures or contained in the damaged pipeline segments. There were 127 spills amounting to 16,032 barrels (673,344 gallons) of petroleum products. Ninety percent of these spills were minor (less than 238 barrels) according to the U.S. Coast Guard, and 10 percent were medium spills (238 to 2,380 barrels). None of the offshore spills reached shore, or oiled birds or mammals (MMS 2007b). In a related incident, on November 11, 2005, a barge *(DBL-152)* struck a partially submerged oil rig torn loose from its moorings by Hurricane Rita and released 1.8 million gallons of heavy fuel oil (i.e., oil that is heavier than water) into the Gulf of Mexico. The impacts of the spill on habitat and biota are being determined.

Waves from Hurricanes Katrina (52 to 55 feet high) and Rita (46 to 49 feet high) not only disturbed the water column, but also increasingly stirred the seabed in waters shallower than 325 to 520 feet along a 300-mile-wide swath as they approached the coast from the outer continental shelf. As a consequence, about 85 percent of Mississippi's nearshore low-profile artificial reefs and 90 percent of Mississippi's offshore reefs were scoured and/or buried and no longer functioned as reef habitat.

Hurricane-induced waves temporarily alleviated low oxygen conditions in the Mississippi River plume by disrupting the summer thermocline and allowing mixing and re-aeration of hypoxic bottom waters. However, once the storms passed, the decay of bottom sediments and organic material resuspended by the storm rapidly resulted in the re-establishment of low oxygen conditions (Rabalais 2006).

The large waves from Hurricane Katrina caused a submarine slope failure (i.e., mudslide) that broke apart a 20-inch gas pipeline about 8 to 10 mi. off the end of the Mississippi River Delta in about 200 ft of water (MMS 2007a; J. Matthews 2007, pers. com.). With previous hurricanes mud slides have occurred on the continental slope over an area of one to a dozen or so miles square (based on figure 3-17) off the Mississippi River Delta. These mud slides move sediments down the slope carrying and disrupting everything in their path, including benthic habitat and biota.

Distribution of Habitat versus Extent, Duration, and Severity of Injury
Hurricanes Katrina and Rita cut a swath through the waters of the Gulf of Mexico 300 miles wide that resulted in significant injury to the offshore oil and gas industry and impacted offshore fishery habitat. The injury to the oil and gas industry spread debris thinly over a huge area. Where the primary effect of the debris was to crush, break, or bury portions of the habitat, the impacts are likely to be detrimental. However, the debris provides hard surfaces and structure on a largely sandy to muddy bottom that may enhance offshore habitat locally. Where debris does not impair other uses (e.g., fishing, navigation, cable laying) and when it is substantial enough to not pose a hazard of being tossed about by future storms, some habitat benefit might accrue.

The spills of petroleum products are likely to have little long-term impact, because of the low volumes spilled compared to the large volume of the receiving waters and the natural dispersion and decomposition rates of the petroleum products over time. The spills may have caused adverse impacts to offshore habitat, but to date none have been reported.

The effect of storm-generated waves on bottom features are likely to be longer lasting. The structure of Mississippi's nearshore and offshore artificial reefs was destroyed. The reefs may require rehabilitation before they are fully productive.

Long-Term Perspective
The offshore debris field left behind by Hurricanes Katrina and Rita is likely to remain for some time and may even develop its own influence on portions of the offshore habitat. The long-term impact of the debris field is unknown. The impacts to the nearshore and offshore reefs of Mississippi are likely to be permanent or nearly so without human intervention to rehabilitate them.

Shrimp Habitat

Distribution and Life Cycle of Shrimp
Brown shrimp and white shrimp are concentrated in waters and estuaries of the northern Gulf of Mexico (mainly off Texas and Louisiana), and pink shrimp are most abundant near southern Florida. Within estuaries, high densities of all three species are associated with vegetation (either emergent marsh or seagrass meadows). Offshore, adult white shrimp occur to depths of about 130 ft, pink shrimp to about 210 ft and brown shrimp to about 360 ft. Adults of the three species generally live and spawn in waters on the continental shelf; the planktonic larvae are carried by currents to estuarine nursery habitats where postlarvae grow to become subadults over a period of several months. Subadults then migrate offshore.

Impact of Hurricanes and Significance of Habitat Impacts to Shrimp
Hurricanes Katrina and Rita greatly accelerated (i.e., 8 to 11 times) ongoing rates of loss of emergent marsh along perhaps 50 percent of the coastline in the region of the Gulf of

Mexico, where emergent wetlands are most abundant (i.e., northern Gulf from Galveston Bay, Texas to Cedar Key, Florida). Strong correlations have been demonstrated between penaeid shrimp yield and wetland area in the Gulf of Mexico. Most juvenile shrimp production occurs along the marsh edge, and this is probably why marsh edge length is the best predictor for inshore shrimp catch. As a marsh begins to break into pieces, the amount of marsh edge increases. At some point, continued wetland erosion will reduce marsh edge as the remaining fragments of marshland convert to open water. At that time or shortly thereafter, a decline in wetland-dependent fisheries (e.g., shrimp, oysters, and blue crab) is predicted. The hurricane-induced loss of wetlands may diminish shrimp production in the future, but the timing and magnitude of the reduction is uncertain.

Seagrasses occur in all states on the Gulf of Mexico, although they are nearly extirpated from Louisiana. Seagrass meadows generally were not significantly impacted by the hurricanes except for those in close proximity to the eyes of the storms. Those near to the eyes of hurricanes Katrina and Wilma were destroyed or severely impacted. Hurricane Rita did not impact seagrass meadows, because the storm's track and area of landfall "avoided" areas of significant seagrass. Seagrass loss from the 2005 hurricanes is unlikely to reduce shrimp production.

Adult shrimp utilize offshore water column and benthic habitats. With the exception of marine debris, hurricane effects on these habitats are believed to have been ephemeral or inconsequential. The effect on shrimp of additional marine debris on benthic habitats is uncertain.

Coral Reefs

Importance
Coral reefs are widely recognized as significant habitat providing structural heterogeneity and serve as refuge for a multitude of sessile and mobile organisms (Jaap 2000). Reef structures are impressive natural breakwaters; they dissipate prodigious wave forces that strike their frontal masses. Nearshore reefs protect low-lying coastal areas that would otherwise experience severe flooding during tropical cyclones or major frontal storms. Coral reefs exhibit high biological diversity and concentrated biomass within the benthic communities. Coral reefs increase habitat complexity and provide structure, protection, and trophic support to juveniles and adults of many marine fish species.

The symbiotic algae (zooxanthellae) contained in some coral and sponge species supplies its coral host with nutrients. The algae can only flourish in areas where sufficient light is transmitted through the water. The community (i.e., corals and other invertebrates) living on nearshore hard bottom areas can withstand periodic short-term turbidity and sedimentation, but extended episodes of turbidity from dredging, runoff, prolonged meterological events, or other causes may result in damage or death of the community. Loss of productivity from coral habitat would certainly impact both estuarine and nearshore zones of the Gulf and Atlantic south Florida and diminish productivity of selected offshore fisheries.

In the Florida Keys, the corals live at depths of 3 to 148 feet. Species associated with coral reefs number in the hundreds to thousands. Off the Gulf coast of Florida, 175 species of fish have been observed or collected on the Florida Middle Ground at depths of 80 to 115 feet (Hopkins et al. 1977). Commercially important species include striped mullet (*Mugil cephalus*), spotted sea trout (*Cynoscion nebulosus*), Spanish mackerel (*Scomberomorus maculatus*), king mackerel (*S. cavalla*), Florida pompano (*Trachinotus carolinus*), and a variety of snappers, and groupers, several of which are primarily nearshore/estuarine inhabitants.

Impact of Hurricanes

Hurricanes Dennis and Katrina caused physical breaking and scouring of coral at the M/V *Connected* restoration site in the Florida Keys National Marine Sanctuary (Schittone et al. 2006). Branch tips of *Acropora palmata* were broken and tissue was lost because of sand scouring. A restoration module was overturned and two reef crowns were buried under unconsolidated reef rubble. Sediment and *Acropora palmata* debris were eroded from the base of three other reef crowns. At a reference site, living coral declined by 88 percent due to burial by translocated sediment and rubble.

At Molasses Reef, off Key Largo, Florida, Hurricane Rita dislodged the reef framework (Gleason et al. 2006). The dislodged coral colonies were smothered and buried by sand.

In Broward County, Florida (Atlantic Ocean north of Miami), Hurricane Wilma caused coral to be buried and damaged by debris (i.e., by items such as tires and lobster traps). However, the *New York Times* reported Hurricane Wilma gave relief to Florida coral by removing filamentous algae that had covered portions of the reef in Broward County and by dragging "cooler, life saving water into the region" (Lyman 2006; C. Kelble 2007, pers. comm.). On Delray Ledge in Palm Beach County, Florida (Atlantic Ocean north of Broward County), Hurricane Wilma damaged octocorals. Coral branches were reduced in height from 4–5 feet to 1–2 feet.

Distribution of Habitat versus Extent, Duration, and Severity of Injury

Subtidal hard bottom communities—usually submerged rocky outcroppings or coral reefs—occur in coastal nearshore and estuarine regions of the Gulf of Mexico, primarily in Florida (the exception is off the south Texas coast). They range from Hernando Beach on the west-central Florida coast to the Florida Keys. Coral reefs dominate hard bottom areas in the Keys, whereas limestone outcroppings are prevalent in the west-central region. Along the east coast of Florida, shallow water reef coral are found at least as far north as Delray Ledge in Palm Beach County on hard substrate outcroppings.

Hurricanes Katrina, Rita, and Wilma extensively damaged and broke shallow water coral from the Florida Keys to Delray Ledge in Palm Beach County (Gleason et al. 2006; Schittone et al. 2006), a very significant proportion of the shallow water reef coral in the mainland United States. All of the branching corals were heavily damaged by waves and, in some cases, the reef framework also was broken. There is no documentation of damaged coral along the west coast of Florida north of the Florida Keys National Marine

Sanctuary. Most evaluations have documented that it takes at least a decade for recovery following moderate disturbance events (Pearson 1981; Sheppard 1982; Connell 1997).

The passage of these hurricanes caused changes in coastal hydrography (C. Kelble 2007, pers. comm.; Proni 2007). Salinity was precipitously lowered and sessile organisms stressed due to enhanced freshwater runoff. Temperature decreased because of upwelling of cold, nutrient-rich water, which probably provided some brief relief to thermally stressed coral. Recent research (Michaels 2007; Benitez-Nelson et al. 2007; McGillicuddy et al. 2007; Sriver and Huber 2007) has demonstrated that hurricanes cause upwelling along their tracks. Chlorophyll and suspended matter increased, causing a reduction in ambient light over the reefs. All of these changes were short-lived; the longest—the salinity decrease—lasted only several months. However, these impacts were on top of those already caused by the hurricanes' mechanical stress of dislodging, breaking, and scouring due to wave action.

Additionally, the southwest shelf of Florida experienced a reversal in current, from toward to coast to away from it. This may have threatened the survival of local larval pink shrimp (Farfantepenaeus duorarum) populations; however, the current reversal occurred over a brief period during a broad spawning interval (May–September). The resulting impact is believed to have been small, but the actual impact to pink shrimp is unknown.

Long-Term Perspective

Widespread ecosystem changes have been documented in the Florida Keys and eastern Florida reef systems since the late 1970s, including precipitous declines in living coral cover, declines in fish stock biomass of key fisheries species, and losses of key herbivores like the long-spined urchin (*Diadema antillarum*). These changes result from a combination of multiple synergistic human impacts (ranging from overfishing, poor water quality and pollution from fertilizers, sediments and nutrients, to vessel groundings) as well as natural factors such as cold winter fronts, disease, bleaching, and hurricanes (Jaap et al. 1988). Hurricanes have had particularly devastating effects on Florida's reef systems through sedimentation, scouring, breaking and overturning corals, with damage ranging from complete destruction of dense, massive, and branching framework corals, to patchy and minimal effects observed on adjacent reefs. The acroporids (elkhorn coral and staghorn coral) are among the corals most susceptible to storm damage, primarily because of their preference for high wave exposure, shallow environments, and branching morphology. Historically (pre-1977), acroporid-dominated coral reefs showed rapid recovery related to high survival of detached coral branches and rapid reattachment and growth (Shinn 1976). Since the mid 1980s, however, hurricanes and tropical storms have had greater impacts, as injured or broken corals have exhibited lower rates of recovery. This likely results from synergistic impacts such as bleaching, disease epizootics, predator outbreaks, and other stressors (Bruckner 2003). Throughout much of the Florida reef track, living coral cover plummeted from 30 to 50 percent in the 1970s to 15 to 20 percent by the mid 1990s, with additional loses of 50 to 60 percent over the past 10 years (Dustan and Halas 1987; Andrews et al. 2005).

Shelf Edge Reefs

Importance
The shelf and shelf edge of the Gulf of Mexico are characterized by a variety of topographic features. The value of these topographic features as habitat is important in several respects. Some support hard bottom communities of high biomass and high diversity and abundance of plant and animal species. These features are unique in that they are small, isolated, highly diverse areas within areas of much lower diversity. They support large numbers of commercially and recreationally important fish species by providing either refuge or food (Dennis and Bright 1988; Brooks 1991). Some managed fishery groups found in deeper marine habitats are calico scallops (*Argopecten gibbus*), Atlantic golden crab (*Chaceron fenneri*), adult migratory pelagic fish (e.g., round herring, *Etrumeus teres*), deep water reef species (snappers, groupers, and tilefish), adult red drum (*Sciaenops ocellatus*), dolphin fish (*Coryphaena hippurus*), and wahoo (*Acanthocybium solanderi*).

In deeper waters, large, elongate mounds called "deepwater banks," which may be hundreds of meters long, often support a rich fauna compared with adjacent areas. The East and West Flower Garden Banks located on the outer edge of the continental shelf, respectively 120 miles and 107 miles southeast of Galveston, Texas, are one such set of banks, They have been designated as a National Marine Sanctuary and, as a consequence, have been studied extensively. The banks are topographic prominences of bedrock uplifted by the underlying salt diapirs. The bedrock is capped with a relatively thin layer of calcareous reef building organisms. The Flower Garden Banks are the two largest of more than 130 calcareous banks charted in the northwest Gulf of Mexico that exhibit topographic elevation (up to within about 55 ft. of the water surface) above an otherwise smooth continental shelf at depths of over 300 ft (Bright et al. 1985). The Flower Garden Banks are considered near the northern physiological limits for tropical hermatypic corals in the Gulf of Mexico and are the northernmost thriving tropical coral reefs on the North American continental shelf (Rezak et al. 1985).

Impact of Hurricanes
Hurricane Rita passed within 30 miles of the East Flower Garden Bank, with wave heights estimated at over 30 feet. Large pieces of reef rock were dislodged from the reef framework, overturned, and deposited on surrounding sand flats. Other corals and barrel sponges were fragmented, scoured, and detached. Branching coral *(Madracis mirabilis)* was flattened, with branch fragments and coral debris accumulating in large piles at the edge of the reef. As much as 3 feet of sand was scoured from the sand flats and redeposited elsewhere on the reef, including onto corals where it interfered with their growth and survival.

Based on previous hurricanes (Dimarco 2004), it is thought that a zone of nutrient-rich, cooler upwelled water may occur along the tracks of hurricanes. Such upwelling may occur along a path 30 to 200 mi. wide and extend downward as much as 750 ft. Recent research (Michaels 2007; Benitez-Nelson et al. 2007; McGillicuddy et al. 2007; Sriver and Huber 2007) has identified upwelling along the paths of cyclones. No measurements of upwelling were made during Hurricanes Katrina, Rita, or Wilma, but the occurrence of upwelling would explain several post Hurricane Rita observations -- the lower temperatures and turbid water (perhaps algal bloom) observed over Flower Garden Banks National Marine Sanctuary. In March 2006, an outbreak of coral disease was observed. Although the outbreak cannot be conclusively linked to the lower temperatures and turbid water associated with Hurricane Rita, the event is unprecedented.

The shallow (60 ft) Sonnier Banks about 90 to 100 mi. to the northeast of Flower Garden Banks experienced major damage with the passage of Hurricane Rita. At the deeper Geyer (110 ft) and Bright Banks (115 ft), approximately 30 and 16 mi east of Flower Gardens, respectively, no damage was observed (G. Boland 2007, pers.com.).

Distribution of Habitat versus Extent, Duration, and Severity of Injury

Although these banks extend in patches along the outer shelf, only the Flower Garden Banks National Marine Sanctuary, Bright, Geyer, and Sonnier Banks were monitored with pre- and post-hurricane surveys. Hurricane Rita did extensive documented damage to the shelf edge reefs at the Flower Garden Banks. To the east damage is documented only for Sonnier Banks (G. Boland 2007, pers. comm.). Coral is very slow growing, and injuries of the type sustained are likely to last for years. Although we cannot say anything about long-term trends, we know these reefs have endured hurricanes in the past based on storm tracks.

Long-Term Perspective

The long-term prognosis for shelf edge reefs is good. While the 2005 hurricane season had significant effects on the Flower Garden and Sonnier Banks and not on Geyer and Bright Banks, these habitats have persisted in the face of many previous storms. Flower Garden and Sonnier Banks offer an excellent opportunity to monitor recovery from storm-related injuries. Such investigations also should inform future decisions on the necessity for or benefit and feasibility of restoring future injuries to these communities from similar storms.

5.

Identification of Actions to Mitigate or Prevent Future Injury to Fishery Habitat

The response to habitat effects caused by Hurricanes Katrina, Rita, and Wilma is defined by actions of the Federal Government and the States of Florida, Alabama, Mississippi, Louisiana, and Texas. Some of the actions were in place before the hurricanes struck while the remainder were implemented in response to one or more of the hurricanes. The first three actions are regional, applying to the Gulf of Mexico as a whole. These are followed by plans pertaining to each of the states.

Regional Actions/Action Plans and Programs

Gulf States Marine Fisheries Commission/National Marine Fisheries Service Fisheries Disaster Recovery Program

The National Marine Fisheries Service (NMFS), Southeast Region (SER), State/Federal Liaison Branch facilitates the conservation, development, and management of marine and estuarine resources in the U.S. Territorial Sea and the Exclusive Economic Zone through competitive and noncompetitive grants and cooperative financial assistance programs. A "Fishery Disaster Relief" program was authorized under Section 312(a) of the Magnuson-Stevens Fishery Conservation and Management Act (16 USC 1861a) and Section 308(d) of the Interjurisdictional Fisheries Act to provide grants to mitigate for commercial fishery failures brought about by fishery resource disasters including natural and anthropogenic events. Through its Fishery Disaster Recovery Program, NMFS SER State/Federal Liaison Branch has awarded approximately $127 million in disaster funds (allocated in P.L. 109-234), to the Gulf States Marine Fisheries Commission (GSMFC). Each Gulf state (Texas, Louisiana, Mississippi, Alabama, and Florida) is to use the funds for recovery of oyster and shrimp industries and habitats in the Gulf of Mexico damaged during the 2005 hurricane season. The habitat and fishery restoration program began on September 1, 2006, and is to continue until August 31, 2011.

The area to be benefited by fishery disaster assistance funds primarily consists of existing and relict oyster reefs in estuaries and shallow coastal areas from Galveston Bay, Texas, to Waccasassa Bay, Florida. Recovery efforts also include marsh and artificial reef areas damaged during the 2005 hurricane season, as well as fishing/shrimping grounds and navigation channels blocked with debris. A geographic list of areas identified for restoration and debris removal are listed by state in Table 5-1.

Table 5-1. Areas identified for restoration and debris removal actions in the Gulf of Mexico.

State	Area
Texas	Existing reef habitat and navigational channels in the Sabine Lake and Galveston Bay ecosystems
Louisiana	Private oyster leases, public oyster seed grounds, fishing/shrimping areas, and navigation channels statewide.
Mississippi	Oyster reefs, marsh areas, and fishing/shrimping grounds, as well as navigation channels in Hancock, Harrison, and Jackson Counties.
Alabama	Mobile Bay and Alabama coastal waters.
Florida	Escambia Bay (Escambia and Santa Rosa Counties), East Bay and Blackwater Bay (Santa Rosa County), Choctawhatchee Bay (Okaloosa and Walton Counties), West Bay, North Bay and East Bay (Bay County), Apalachicola Bay (Franklin County), Ochlochonee Bay and Oyster Bay (Wakulla County), Suwannee Sound and Waccasassa Bay regions (Dixie and Levy Counties).

Each of the affected Gulf states has submitted a proposal to:
1) reseed, rehabilitate, and restore existing and relict oyster reefs;
2) rehabilitate and restore shrimping grounds; and,
3) conduct research and monitoring to determine the status of the shrimp and oyster fisheries (see Table 5-2).

Table 5-2. Programmed spending distribution (effective October 2006).

Recovery Category	Funds (Thousand Dollars)					Total by Year	Total by Activity
	AL	FL	MS	LA	TX		
Oyster Reef Reseeding, Rehabilitation & Restoration							
Year 1	33.3	373.7	5,643.3	9632.8	883.5	16,566.6	
Year 2	2,000.0	944.9	3,676.7	8,850.3	311.6	15,783.4	
Year 3	2,000.0	795.9	2,610.0	3,592.0	312.0	9,309.9	
Year 4	2,000.0	846.9	1,888.3	487.5	307.8	5,530.6	
Year 5	1,100.0	846.9	1,181.7	337.5		3,466.1	
Total	**7,133.3**	**3,808.3**	**15,000.0**	**22,900.0**	**1,814.9**		**50,656.6**
Oyster Bed & Shrimp Ground Rehabilitation							
Year 1	1,550.0		1,450.0	5,467.7	157.5	8,625.2	
Year 2	3,950.0		12.5	5,100.0	294.6	9,357.1	
Year 3	2,750.0		12.5	4,816.0	283.6	7,862.1	
Year 4	2,150.0		12.5	4,816.0	232.9	7,211.4	
Year 5	100.0		12.5	4,817.0	8.6	4,938.1	
Total	**10,500.0**		**1,500.0**	**25,016.7**	**977.3**		**37,993.9**
Cooperative Research/Monitoring							
Year 1	2,800.0	219.3	6,704.0	1,000.0	127.6	10,850.9	
Year 2	2,300.0	166.6	5,601.8	1,000.0	127.6	9,196.1	
Year 3	2,300.0	39.2	3,525.8	1,000.0	127.6	6,992.6	
Year 4	2,300.0		2,355.0	1,000.0		5,655.0	
Year 5	2,300.0		2,355.0	1,000.0		5,655.0	
Total	**12,000.0**	**425.0**	**20,541.7**	**5,000.0**	**382.8**		**38,349.5**
Total by State	**29,633.3**	**4,233.3**	**37,041.7**	**52,916.7**	**3,175.0**		**127,000.0**

Detailed GSMFC and affected states' activities, only as they relate to the restoration of fishery habitats, are discussed briefly (a companion report will address restoration of fishing grounds and infrastructure).

Oyster Recovery

All individual Gulf states will use a portion of the hurricane supplemental funding to conduct benthic surveys using side-scan sonar, global positioning system, and traditional poling techniques to determine the location, areal extent, and damage to existing and relic oyster reefs. Benthic surveys will also be used to determine the location of debris occurring on reefs, in shrimp fishing grounds, and in navigation channels used by the fishing industry. In some cases, other hydrographic data will be collected to determine the optimal locations for reseeding, rehabilitation, and restoration of oyster reefs. Upon completion, monitoring will determine the success of rehabilitation and restoration efforts.

The majority of the funding apportioned to each Gulf state will be used to restore oyster reef habitat by acquiring and depositing cultch material (oyster shells, clam shells, limestone, and crushed concrete) on existing and relic reefs. In some cases, cultch may be dredged from existing, degraded or buried reefs. Dredging may also be used to remove sediment and debris from reefs to provide optimal substrate for cultch deposition. Proposed restoration activities may also include placing live oysters and oyster spat to further rehabilitate and hasten restoration activities. (Please see the individual state sections later in this chapter for more details.)

Marshes and Artificial Reefs

In addition to restoration and rehabilitation of oyster reefs, the states are proposing to restore other habitats that support shrimp and fish species in the Gulf, through marsh restoration and the establishment of artificial reefs. Marsh restoration would occur in the areas that experienced the greatest marsh loss due to the 2005 hurricanes. Material used for recreating marsh elevations would be dredged from areas where sediment was deposited by the hurricanes, often blocking natural hydrology in the ecosystem. Wave attenuation devices, such as floating or submerged breakwaters, may be placed adjacent to restored marsh to protect these areas from erosion.

To aid in the recovery of Gulf finfish populations, the states have indicated that they may restore existing artificial reefs, and new artificial reefs may be created in shallow water or permitted offshore reef areas.

Summary

Work is under way on oyster reef rehabilitation projects. Debris removal projects are ongoing. Project planning is under way for marsh and artificial reef restoration projects.

Coastal Impact Assistance Program—Energy Policy Act

The Coastal Impact Assistance Program (CIAP) was renewed by Congress as part of the Energy Policy Act of 2005. CIAP will distribute to producing states and coastal political subdivisions $250 million for each of the fiscal years 2007 through 2010. This money will be shared among Alabama, Alaska, California, Louisiana, Mississippi, and Texas. It is expected that much of the funding provided through CIAP will be used to restore coastal wetlands, thus offsetting some impacts to fishery habitat caused by Hurricanes Katrina and Rita.

States are required to submit a CIAP Plan to the U.S. Minerals Management Service (MMS), and MMS must approve it before disbursing CIAP funds. Plans will include projects and activities for the conservation, protection, or restoration of coastal areas, including wetlands; mitigation of damage to fish, wildlife, or natural resources; implementation of a federally approved marine, coastal, or comprehensive conservation management plan; and other actions. CIAP states have begun soliciting input and project proposals from the coastal counties/parishes, state and federal agencies, non-governmental organizations, landowners, and the public. In the February 16, 2007, Continuing Resolution, Congress approved a 3 percent appropriation of the CIAP funds to be used by MMS to administer the CIAP program. A Plan for at least the first year's funds is to be submitted to MMS for approval by July 1, 2008.

Summary
Planning processes by the states for CIAP-funded projects are under way or nearing completion.

Public Law 110-107, U.S. Troop Readiness, Veterans' Care, Katrina Recovery, and Iraq Accountability Appropriations Act, 2007, 2006 (5th Supplemental)

Habitat-related activities under the 5th Supplemental will be implemented with emergency supplemental appropriations provided by Congress for additional hurricane disaster relief and recovery related to hurricanes Katrina, Rita, and Wilma in the area covered by the disaster declaration made by the President under the Robert T. Stafford Disaster Relief and Emergency Assistance Act, P.L. 93-288, 88 Stat 143, as amended (42 U.S.C. sec. 121 et seq.).

Within the scope of this report, the 5th Supplemental provides additional hurricane response funding for activities undertaken by NOAA and the USACE. NOAA is provided $110 million. Of that amount $1 million is for real-time observations and forecasts for coastal navigation and to repair and replace tide gauges throughout the Gulf of Mexico region and $109 million is for expenses related to the fishery and habitat impact remediation from hurricanes Katrina and Rita. Of the $109 million, $24 million is allocated to conduct scanning and mapping as well as to provide debris removal in Louisiana’s traditional fishing grounds; and $85 million is for assistance programs authorized under section 115 of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006.

In addition to funds provided to NOAA, the 5th Supplemental provides funding to the USACE to further its response to Hurricane Katrina. This supplement includes $107.7 million to construct interim flood and storm damage reduction measures in Hancock, Harrison, and Jackson counties, Mississippi recommended in the Chief of Engineers report dated December 31, 2006, entitled’’ Mississippi Coastal Improvements Program, Interim Report’’, at full federal expense. In addition, $1.3 billion is allocated to complete the pre-Katrina authorized level of protection in Louisiana for the West Bank and Vicinity project as well as make progress toward providing authorized protection for the remaining portions of the Lake Pontchartrain and Vicinity Hurricane Protection project. Finally, the Conference Report on this bill provided some additional guidance and support for activities authorized under P.L. 109-234 and recommends the acceleration of the MRGO study, as practicable.

Essential Fish Habitat (EFH) Conservation Program

The Gulf of Mexico Fishery Management Council has identified essential fish habitat (EFH) per the Magnuson-Stevens Act and the NOAA National Marine Fisheries Service (NMFS) subsequently approved the identification (NMFS 2006). The NOAA National Marine Fisheries Service is required to provide EFH conservation recommendations whenever a federally sponsored or permitted activity may adversely affect EFH. Since implementing regulations for EFH conservation were promulgated in January 1997, NOAA Fisheries Service has acted on thousands of projects to help avoid, minimize or mitigate the losses on EFH that would otherwise have resulted from federal actions. Over the years, the EFH conservation program has contributed to the protection and conservation of thousands of acres of habitat in the Gulf of Mexico that supports commercially and recreationally important fish stocks. This on-going activity by NOAA Fisheries Service will continue to provide a layer of oversight and protection for these important fishery habitats.

Plans by State: Louisiana

Coastal Impact Assistance Program (CIAP)

Louisiana is projected to receive up to $523 million in CIAP funds over 4 years. CIAP funding is expected to be available in 2008. Louisiana Department of Natural Resources (LDNR) plans to begin implementing projects contained in the Plan before then, using money from the State's Coastal Protection and Restoration Trust Fund. LDNR has solicited input and projects and received 326 proposals for the eligible area.

The anticipated components of the Plan involving Louisiana's share of CIAP funds include:

1) Enhanced Management of Mississippi River Water and Sediment;
2) Protection and Restoration of Critical Land Bridges
3) Barrier Shoreline Restoration and Protection;
4) Interior Shoreline Protection (Lakes and Critical Reaches of Navigation Channels);
5) Beneficial Use of Dredged Material/Marsh Creation;
6) A Coastal Forest Conservation Initiative; and
7) Infrastructure Projects to Mitigate Onshore OCS Impacts.

The Louisiana Congressional delegation and the Governor have requested that CIAP funds be allowed to be used as non-federal matching funds for future U.S. Army Corps of Engineers (USACE) coastal restoration projects and programs in Louisiana. To date, USACE and the Department of the Interior have indicated such use of CIAP funds requires specific statutory authority.

Summary
CIAP planning for the first set of projects is nearly complete. Some projects may have begun implementation using other funds. Louisiana recommends that CIAP funding be considered as non-federal matching funds to allow their use in a greater number of projects. A draft executive summary is available at: http://dnr.louisiana.gov/crm/ciap/executivesummary.2007.02.06.pdf.

Coastal Wetlands Planning Protection and Restoration Act (CWPPRA)

http://www.lacoast.gov/cwppra/index.htm

Background
The Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) was authorized in 1990 as the first federally mandated program to address restoration of the Nation's coastal wetlands. To date, the program has provided about $643 million in federal funds dedicated exclusively to the long-term restoration of coastal wetlands in Louisiana. These federal funds are currently matched by a 15 percent state contribution. In Louisiana, the program is administered by a task force of five federal agencies (U.S. Fish and Wildlife Service, Natural Resources Conservation Service, NMFS, EPA, and USACE) and the State of Louisiana. The breadth of agency capabilities provides an optimal approach to addressing the complexities inherent in addressing Louisiana's land loss.

The authorizing statute requires that approximately 90 percent of program funds are expended directly on project development and construction, and emphasizes project implementation within 5 years. Since inception, the program has funded 78 projects for construction at a total cost of nearly $624 million. In the past 15 years, the program has constructed 70 projects, with NOAA serving as the lead agency on 25 of these. Eight additional projects are currently funded for full implementation and should be in construction during 2007 (Figure 5-1). These projects are expected to re-establish or protect a total of approximately 70,616 net acres and enhance 320,354 acres of additional wetlands.

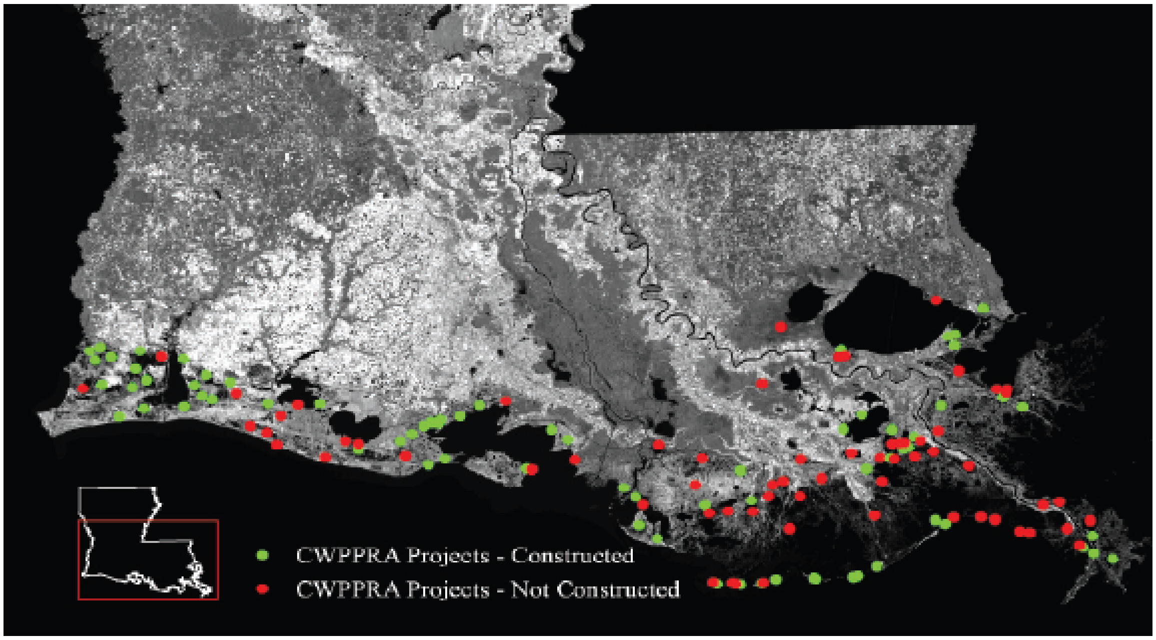


Figure 5-1 – Location and status of CWPPRA projects as of January 2006. (from Louisiana Coastal Wetlands Conservation and Restoration Task Force. 2006.)

The program has identified an additional 47 priority projects that would re-establish or protect approximately 32,665 net acres and enhance 194,859 acres of additional wetlands if implemented. Currently, engineering and design activities are ongoing and the majority of these additional priority projects should be "construction-ready" within a few years. However, program capacity and restoration needs exceed existing funding authorizations. It is estimated that with adequate funding, the CWPPRA program could immediately implement 11 unfunded priority projects in critically eroding areas (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2006). The 11 projects are located across south Louisiana, including areas impacted by Hurricanes Katrina and Rita, and include barrier shoreline protection, Gulf shoreline stabilization and protection, and restoration of interior coastal wetlands. If implemented, these projects would result in direct and indirect benefits to over 21,000 acres of coastal habitats, resulting in a net gain of 3,589 wetland acres in 20 years.

At the time of Hurricanes Katrina and Rita, six CWPPRA projects were being constructed. To date, two of those six projects have been completed and are functioning as designed. Construction activities are continuing for the other four projects, with three scheduled for completion in 2007 and one delayed due to contracting issues. In the 18 months since onset of the 2005 hurricane season, construction was initiated on four additional projects, with three completed and one scheduled for completion in 2007.

Continued post-storm project implementation under the CWPPRA program has occurred in six coastal parishes, including some of the most hurricane-impacted areas of south

Louisiana. Implementation of projects since the 2005 hurricanes will result in benefits to over 35,000 acres of fresh, brackish, and saline wetlands; barrier island habitats; and estuarine open water areas. These projects will produce direct benefits to about 3,600 acres of coastal habitats throughout the 20-year project terms and, importantly, will restore damaged fishery habitat and increase habitat resiliency during future storm events.

As priority project identification and coastal restoration needs continue to outpace incoming CWPPRA funds, the number of unfunded priority projects will grow throughout the life of the program. Funding increases would make efficient use of the existing interagency program already in place under CWPPRA and would further the recovery of habitats damaged and destroyed by Hurricanes Katrina and Rita.

Case Study: **Landscape-Level Planning**

Some parts of coastal Louisiana need larger restoration efforts than a single CWPPRA project can provide. CWPPRA projects can provide restoration following hurricane damage and future hurricane protection in certain areas by building several interrelated projects that collectively address a problem at hand. Combining projects can address basin-wide goals of restoring critical landforms, barrier shorelines, and historical hydrologic patterns. The CWPPRA program has recognized the importance of ensuring that individual restoration projects synergistically address landscape level needs. The CWPPRA program has funded extensive work in several regions throughout the state, including the Barataria Barrier Shoreline located south of New Orleans. (Figure 5-2.)

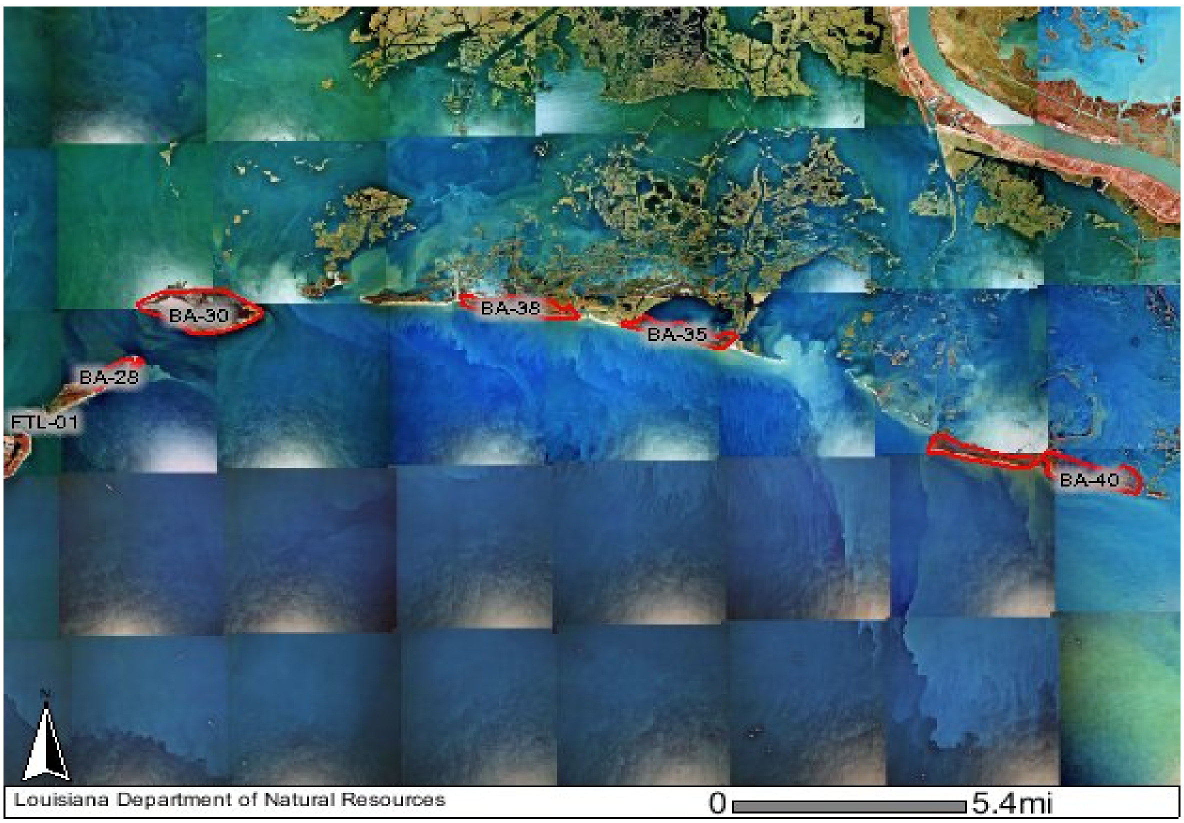


Figure 5-2. Location of NOAA's Barataria Shoreline Restoration Projects

The Barataria Barrier Shoreline is one of the most rapidly eroding shorelines in the U.S. This area spans approximately 30 miles and provides unique habitat for coastal fisheries and wildlife as well as serving as the first line of defense for coastal communities against hurricane storm surge, tidal inundation, frontal passages, and wave action. Approximately 102,000 acres of marsh have disappeared from this area since 1932. The rate of shoreline retreat along the Barataria shoreline ranges from 2 to over 100 ft per year, averaging about 18 ft per year over the last 100 years. The remaining wetlands behind the barrier shoreline are projected to be lost within the next 20 years (Coastal Research Laboratory 2000).

NMFS is the lead agency on six projects located along this critical shoreline (Table 5-3). Cumulatively, these projects would address shoreline erosion and habitat loss on over 13 miles of the 30-mile system. One of the remaining segments is currently under consideration for restoration by the Corps of Engineers, an example of restoration needs being addressed across federal programs. One of NOAA's six projects has been completed, providing immediate habitat benefits to over 400 acres along 2.5 miles of shoreline. NOAA has received CWPPRA construction funding for two additional projects; those projects are anticipated to be implemented by mid 2008, and will restore, protect and enhance over 500 acres of barrier island habitat and saline marsh. (Figure 5-3.)

Figure 5-3. Barrier Island Project Nearing Completion in Fall 2006

Table 5-3. NOAA Fisheries Barataria Barrier Shoreline Projects

Project	Shoreline length	Project Area [1]	Constructed Acres [2]	Net Acres [3]	Total Cost (millions) [4]	Status
Pelican Island	2.8	508	398	254	$37.70	Construction scheduled for 2007
Chaland Headland	2.4	609	426	279	$29.40	Completed
Bay Joe Wise	2.6	596	524	262	$29.80	Construction scheduled Fall 2007
West Grand Terre	N/A	297	N/A	27	$0.48	Completed
East Grand Terre	2.8	683	620	335	$30.8 [5]	Construction scheduled for 2008
Scofield Island	2.4	746	429	234	44.5 [5]	In design
TOTAL	**13**	**3,439**	**2,397**	**1,391**	**$172.70**	

[1] Total area affected directly and indirectly by project implementation

[2] Acres directly benefited immediately post-construction

[3] Sum of restored and protected acres present at the end of 20 years. Includes net gains in acres through restoration and acreage protected from loss through the full project life

[4] Includes engineering, construction, 20 years of monitoring and maintenance, and administration, unless otherwise noted per note [/5].

[5] Currently funded for Engineering and Design only; no construction funding

NMFS has three projects prepared for implementation but lacks construction funding. Implementation of the unfunded Rockefeller Refuge Shoreline Protection, Castille Pass Sediment Delivery, and East Grand Terre Barrier Island projects would provide over 1,800 acres of additional coastal habitats during their 20-year project life at a total cost of $98 million.

Summary
CWPPRA funding has built 70 projects since the program's inception. Projects constructed since the 2005 hurricanes will benefit over 35,000 acres of wetlands, estuaries, and barrier island habitats. Eight projects are funded for 2007. There are 47 additional projects identified as high priority, with 11 of those considered construction-ready. However, funding authorization is lacking for them.

Louisiana Coastal Area Ecosystem Restoration Study

http://www.lca.gov/

The goal of the Louisiana Coastal Area (LCA) Ecosystem Restoration Study, as stated in the Main Report (USACE 2004) was to "reverse the current trend of degradation of the coastal ecosystem." The LCA plan, if fully funded and implemented, would help offset fishery habitat impacts caused by Hurricanes Katrina and Rita by helping to restore Louisiana coastal wetlands that provide nursery and foraging habitat for the majority of the recreational and commercial fisheries that are estuarine-dependent. NMFS is a contributing agency in this program.

Components of the LCA plan include: 1) authorization of five critical restoration projects, which could be initiated within 5 to 10 years; 2) a science and technology program; 3) programmatic authorization for the beneficial use of dredged material; 4) investigations into the modifications of the use of existing structures; 5) preparation of feasibility analyses of additional projects that could become congressionally authorized; and 6) investigations into six promising large-scale and long-term restoration concepts.

The five critical projects that could be implemented in the near term are : 1) restoring habitat in the vicinity of the Mississippi River-Gulf Outlet (MRGO); 2) a small diversion of the Mississippi River into bottomland hardwood habitat in the vicinity of Hope Canal; 3) restoration of barrier shorelines in the Barataria Basin; 4) a small diversion of the Mississippi River into Bayou Lafourche; and 5) a medium diversion of the Mississippi River at Myrtle Grove. Project locations are shown on Figure 5-4 as numbers 1 through 5. It is estimated that these five components of the LCA plan would offset approximately 62.5 percent of the 462,000 acres projected to be lost within the Louisiana coastal area under the no-action alternative. In the portion of Louisiana nearest to New Orleans, it was estimated that these five projects would more than offset the anticipated future habitat loss. The combined cost of the projects is estimated to be approximately $864 million.

The LCA plan recommended 10 additional critical restoration projects for further studies, in anticipation that such features could be eventually recommended for Congressional authorization. Those 10 restoration projects are shown on Figure 5-4 as numbers 6 through 15. Because studies of these projects have not been initiated, it is not known how much each would benefit Louisiana wetlands. The plan estimates that the total costs of the evaluation of these 10 projects would be approximately $47.4 million.

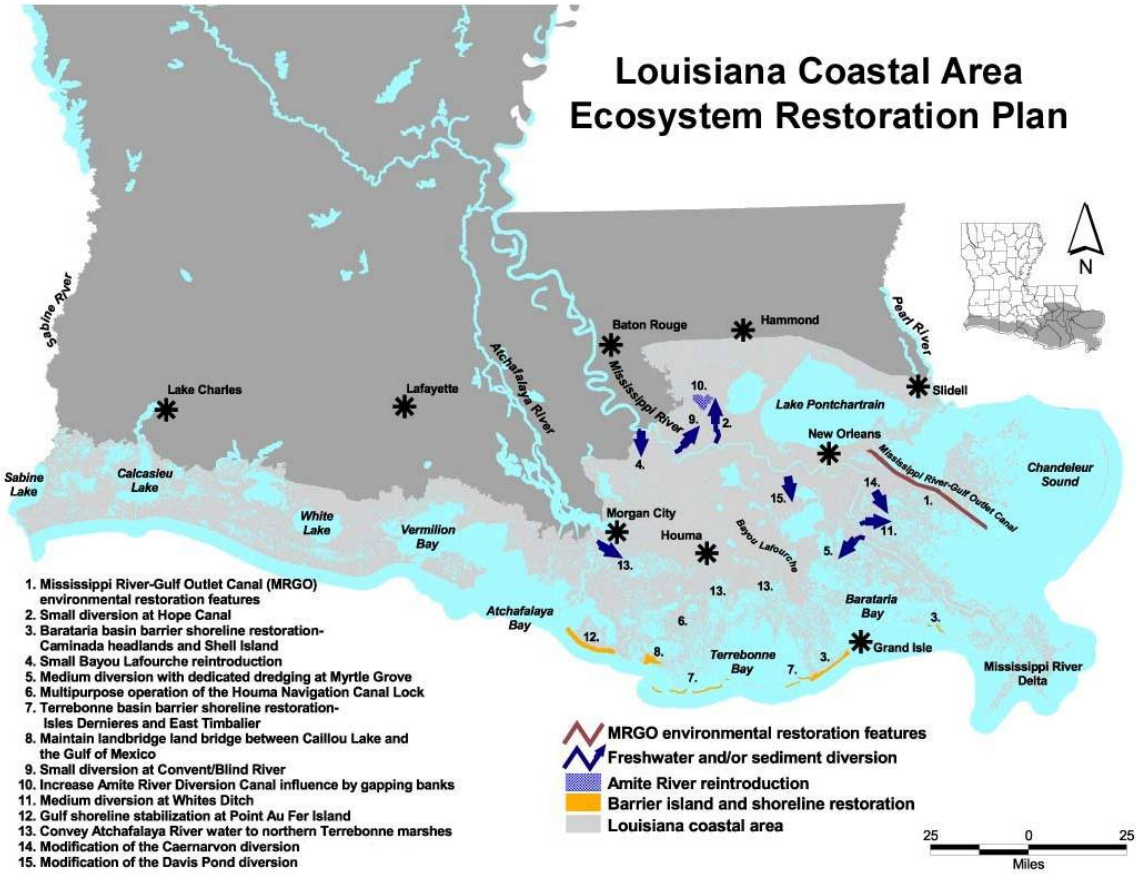


Figure 5-4. – LCA Ecosystem Restoration Plan Critical Restoration Projects

Several candidate large-scale and long-term concepts for potential incorporation into the plan were identified during plan formulation. These restoration concepts have significant potential to achieve habitat restoration in coastal Louisiana. As such, the plan recommends that the potential benefits and costs for these features be evaluated by feasibility-level studies. The total estimated costs for the large-scale studies are $60 million. The large-scale and long-term study components are:

1. Mississippi River hydrodynamic study.
2. Mississippi River delta management study.
3. Third delta study.
4. Chenier Plain freshwater and sediment management and allocation reassessment study.
5. Acadiana Bays estuarine restoration feasibility study.
6. Upper Atchafalaya Basin study.

NOAA, through NMFS acting as a cooperating agency, assisted in the evaluation of alternatives considered in the development of the LCA plan and with the drafting of the programmatic environmental impact statement. Since completion of the plan, NOAA has assisted the USACE in the further development of the various components of the plan.

Since passage of Hurricanes Katrina and Rita, project management plans and federal cost-share agreements have been developed for the beneficial use of dredged material program, the LCA component pertaining to developing a science and technology program, and the Barataria Basin barrier shoreline restoration project. During FY 2007, the USACE expects to develop project management plans and cost-share agreements for the Myrtle Grove freshwater diversion, the Mississippi River delta management study, and the Chenier Plain freshwater and sediment management study. To date, more work has been accomplished on the beneficial use of dredged material. The USACE has informed NMFS that they expect to develop nine beneficial use projects in the first 3 years of the program. However, it is unclear what projects could be implemented, as construction funds have not been authorized. In addition, the Barataria Basin barrier shoreline study has concentrated on two segments of shoreline to be restored: Shell Island in Plaquemines Parish and Chenier Caminada in Jefferson Parish. As with the beneficial use component of LCA, the USACE has planning dollars but no construction funds, making implementation uncertain.

Summary

Planning development efforts continue related to the study. Fifteen critical restoration projects were identified, and five of them could be implemented in the near term. NMFS and the USACE are working cooperatively to develop components of the plan. Cost-share agreements and project management plans related to beneficial use of dredged spoils are developed. The USACE expects to develop nine projects in the near term if construction funding for the projects is allocated.

Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006 (4th Supplemental)

Habitat-related activities under the 4th Supplemental will be implemented with funds appropriated by Congress for Flood Control and Coastal Emergencies related to Hurricane Katrina in the area covered by the disaster declaration made by the President under the Robert T. Stafford Disaster Relief and Emergency Assistance Act, P.L. 93-288, 88 Stat 143, as amended (42 U.S.C. sec. 121 et seq.).

The Supplemental directs the Secretary of the Army, through the Chief of Engineers, to reduce the risks of storm surge and storm damage to the greater New Orleans metropolitan area by restoring the surrounding wetlands, modifying the Caernarvon Freshwater Diversion structure or its operations, and developing a comprehensive plan, at full federal expense, to deauthorize deep draft navigation on the Mississippi River Gulf Outlet (MRGO).

The USACE is authorized to expend up to $20.2 million to reduce the risk of storm damage to the greater New Orleans area. Approximately $10 million is being used for work on the Caernarvon Freshwater Diversion for options such as increased flow, marsh creation via maintenance dredging of the conveyance channel, and degrading a spoil bank impeding flow distribution (Fig. 5-5). Approximately $10 million will be used to create or protect the tidally influenced intermediate and brackish marsh part of the Barataria Basin landbridge southwest of the greater New Orleans area (Fig. 5-6). Value engineering analysis of seven alternatives has been completed for marsh creation and shoreline projects. Identification of a preferred alternative remains to be completed.

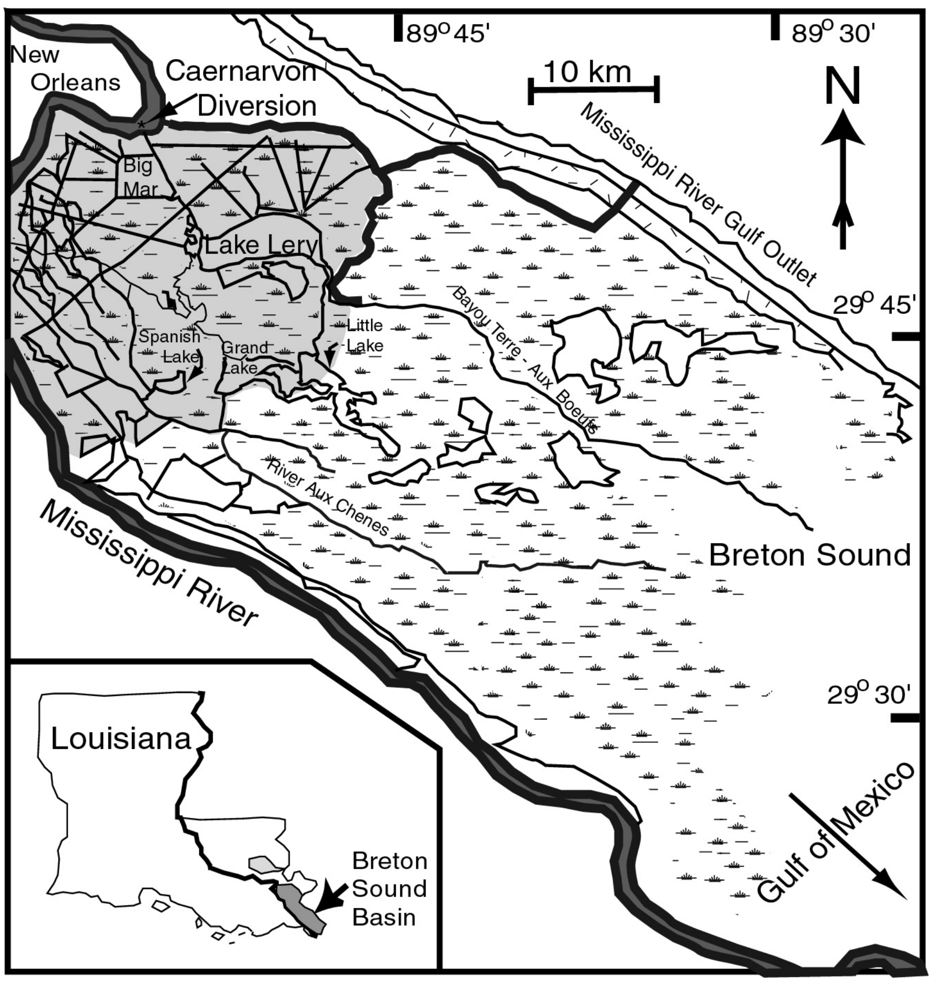


Figure 5-5. Breton Sound Basin with main region of estuary influenced by diversion highlighted in gray.

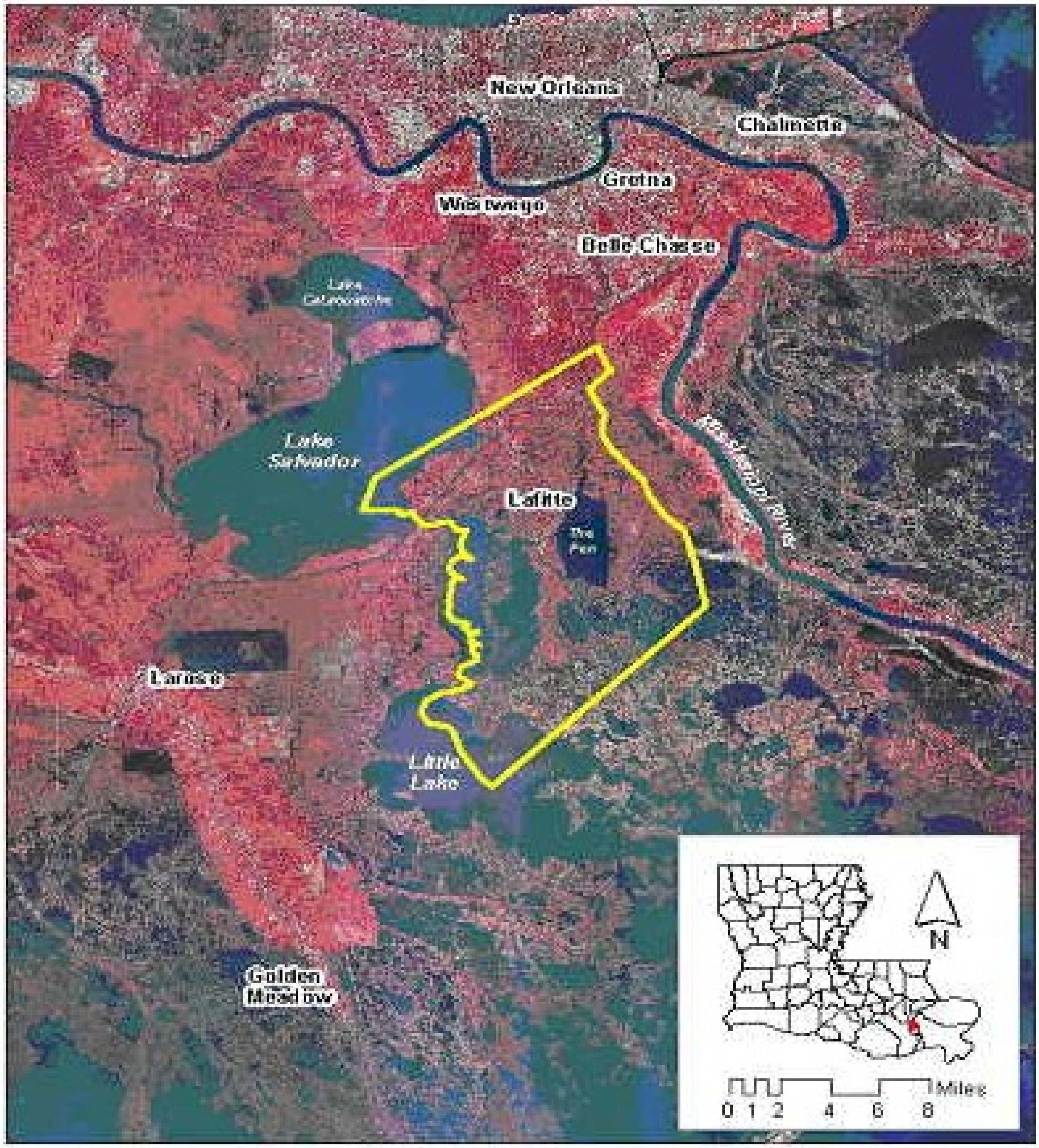


Figure 5-6. Barataria Basin Landbridge study area. Marsh creation and shoreline protection restoration projects being considered with construction funds approved under the 4th Supplemental Appropriations.

An interim report to Congress for deauthorizing deep draft navigation of the MRGO (Fig. 5-7) was submitted in December 2006. Measures being considered include a structure to reduce the channel to 12 feet, or plugging the channel with a dam. These measures could be viewed as ones that protect channel-side wetlands from wake-induced shoreline erosion with a reduction in vessel traffic. A MRGO channel restriction or plugging in concert with structures in the Gulf Intracoastal Waterway (GIWW) and potentially in the Inner Harbor Navigation Canal, also approved under supplemental appropriations, may improve water quality in Lake Pontchartrain for estuarine fisheries species by preventing

Figure 5-7. Mississippi River Gulf-Outlet De-Authorization Plan Area.

saltwater intrusion that seasonally contributes to low dissolved oxygen levels. A legislative environmental impact statement likely will be prepared for this plan and included in the required Final Technical Report to Congress in December 2007.

National Oceanic and Atmospheric Administration (NOAA)
The 4th Supplemental (P.L. 109-234) directs NOAA to provide assistance for activities involving the recovery of oyster, shrimp, and other fishery habitat. Louisiana is receiving $52.9 million from this fund. Using these funds, Louisiana will conduct side-scan sonar surveys of public oyster seed grounds and seed reservations to map and mark the size and location of oyster reefs, identify bottom types, and develop estimates of reef acreage. The oyster industry relies on the public grounds as a source of seed oysters for transplant to private leases and for a significant percentage of the annual harvest. Therefore, there is immediate need for funding for rehabilitation and restoration of reefs on the public oyster grounds (Roussel 2006). Limestone, crushed concrete, or recycled oyster shell and other suitable cultch material would be deposited to replace reefs buried by sediments and debris. Approximately 80,000 cubic yards of cultch material would be deposited over 500 acres of water bottoms within certain portions of the state's public oyster seed grounds and reservations. Following completion, biological and environmental monitoring of oyster recruitment, development, growth, and harvesting activities on public seed grounds would be conducted.

This funding will also be used for the construction of projects to optimize marine organism access to marsh impoundments and the monitoring of cultch to construct wave attenuation/shoreline stabilization structures in areas affected by hurricanes.

U.S. Fish and Wildlife Service

Chapter 5, 120 STAT. 460 authorizes additional funding to the U.S. Fish and Wildlife Service (FWS) for construction for necessary expenses related to the 2005 hurricanes. An existing foreshore rock dike will be extended approximately 5,400 feet along the Lake Pontchartrain shoreline near Bayou Chevee on the Bayou Sauvage National Wildlife Refuge. The project would protect tidal brackish marsh from wind-wave shoreline erosion. The anticipated cost of this rock dike construction is not presently known. In Terrebonne Parish, the FWS, through a grant to the Louisiana Department of Natural Resources, will conduct shoreline and interior marsh plantings to restore and enhance tidal marsh. Plantings will focus in the Lost Lake area and will include intermediate and brackish marsh vegetation. Up to $161,000 has been authorized for administrative oversight and implementation of the planting project.

Natural Resources Conservation Service (NRCS)

Chapter 5, 120 STAT. 444 and Public Law 109-148 (119 STAT. 2748) authorized funds through NRCS to remove and dispose of debris and animal carcasses that could adversely affect health and safety on non-federal lands caused by Hurricanes Katrina and Rita. Ongoing and planned contracts include debris and animal carcass removal and slope repair of tributaries and estuary headwaters across the state. To date, over 200,000 animal and bird carcasses have been removed and disposed (Sticker and Lafleur 2007). Removal of this debris has restored water conveyance to pre-storm conditions. This assists in restoring seasonal salinity gradients with freshwater input into the estuaries and improves water quality conditions that support estuarine fisheries. In some instances (e.g., the north shore of Lakes Pontchartrain and Maurepas), this could directly restore habitat seasonally used by low salinity tolerant estuarine fisheries species (e.g., gulf menhaden) and anadromous fisheries species (e.g., gulf sturgeon). Ongoing coordination with NRCS is necessary on a case-by-case basis to ensure flow restoration is conducted in a manner so as to avoid and minimize impacts to remaining channel-side wetlands that directly or indirectly support estuarine fisheries.

Summary

The USACE is analyzing alternatives for restoration of wetlands and other activities in the Caernarvon and Barataria basins to reduce the risk of storm damage to the greater New Orleans area. Twenty million dollars has been allocated for these two areas. The deauthorization of the MRGO also is being studied. Louisiana, using funding through the NMFS Disaster Recovery Program, will map and restore public oyster seed grounds using various, suitable cultch materials. Shoreline stabilization structures also will be constructed. The FWS is expanding an existing rock dike on Lake Pontchartrain and conducting some wetland replanting projects. The NRCS is continuing funding of debris removal programs that will aid in restoring water conveyance and water quality improvements.

Public Law 110-107, U.S. Troop Readiness, Veterans' Care, Katrina Recovery, and Iraq Accountability Appropriations Act, 2007, 2006 (5th Supplemental)

Habitat-related activities under the 5th Supplemental will be implemented with emergency supplemental appropriations provided by Congress for additional hurricane disaster relief and recovery related to hurricanes Katrina, Rita, and Wilma in the area covered by the disaster declaration made by the President under the Robert T. Stafford Disaster Relief and Emergency Assistance Act, P.L. 93-288, 88 Stat 143, as amended (42 U.S.C. sec. 121 et seq.).

Within the scope of this report, the 5th Supplemental provides additional hurricane response funding for activities undertaken by NOAA and the USACE. NOAA is provided $110 million. Of that amount $1 million is for real-time observations and forecasts for coastal navigation and to repair and replace tide gauges throughout the Gulf of Mexico region and $109 million is for expenses related to the fishery and habitat impact remediation from hurricanes Katrina and Rita. Of the $109 million, $24 million is allocated to conduct scanning and mapping as well as to provide debris removal in Louisiana's traditional fishing grounds; and $85 million is for assistance programs authorized under section 115 of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006.

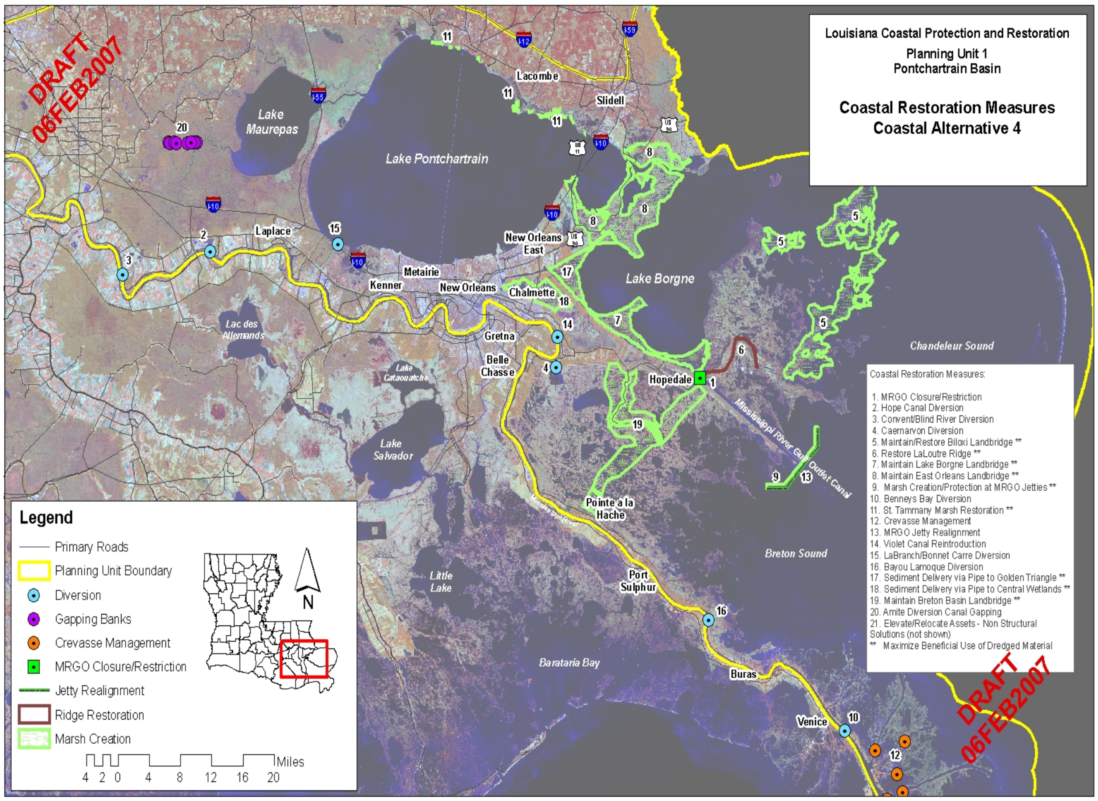
In addition to funds provided to NOAA, the 5th Supplemental provides funding to the USACE to further its response to Hurricane Katrina. This supplement includes $1.3 billion is allocated to complete the pre-Katrina authorized level of protection in Louisiana for the West Bank and Vicinity project as well as make progress toward providing authorized protection for the remaining portions of the Lake Pontchartrain and Vicinity Hurricane Protection project. Also, the Conference Report on this bill provided some additional guidance and support for activities authorized under P.L. 109-234 and recommends the acceleration of the MRGO study, as practicable.

Louisiana Coastal Protection and Restoration Project

Authorization and direction for the Louisiana Coastal Protection and Restoration (LaCPR) project is granted under the Energy and Water Development Appropriations Act of 2006 passed in November 2005 and the Department of Defense, Emergency Supplemental Appropriations to Address Hurricanes in the Gulf of Mexico, and Pandemic Influenza Act, 2006 passed on December 30, 2005, and June 15, 2006, as part of both the 3rd and 4th emergency supplements of Defense Appropriations Act (USACE

2006a). Under both acts, Congress and the President directed the USACE to conduct a comprehensive hurricane protection (risk reduction) analysis and design at full federal expense and to develop and present a full range of flood control, coastal restoration, and hurricane (risk reduction) measures exclusive of normal policy considerations for South Louisiana. The final technical report is due by December 2007.

Figure 5-8. Preliminary draft restoration measures for the Pontchartrain and Breton Basins under Alternative 4 of LaCPR (subject to revision).



Four storm protection and restoration measure alternatives are presently being evaluated with additional alternatives or combinations to be considered with ongoing risk informed plan formulation. Ecosystem-level habitat restoration projects being considered include marsh creation via dedicated dredging, freshwater and sediment diversions, barrier island/shoreline restoration, shoreline protection, and ridge restoration (Fig. 5-8). Maximum gross estimates of habitat restoration over the 100 year project life are available for only two alternatives at this time (Table 5-4). The cost of these restoration measures are preliminarily estimated in the tens of billions of dollars and may be insufficient to offset both the direct impact of levee construction and the background wetland loss rates. The more robust restoration measures rely more heavily on freshwater and sediment diversions and would result in widespread changes in coastal/gulf/freshwater interactions from freshening of basins. Widespread freshening of estuarine basins would displace, reduce, or in some circumstances eliminate certain marine fisheries or habitat supportive of certain fishery life stages. As an example, the low end range of diversion projects presently being considered would introduce an average annual flow of 70,800 cubic feet/second into the Lake Pontchartrain and Breton Sound Basins; this freshwater inflow would adversely affect the most productive public oyster fishery in the nation (LDWF 2006a; NMFS 2007). Funding has not been authorized for constructing restoration projects under LaCPR. At a minimum, any preferred actions should include sufficient type and quantity of habitat restoration to offset direct impacts from planned levee construction and mitigate 2005 hurricane damage to fishery habitat.

Table 5-4. Estimated maximum gross habitat created or protected under Alternatives 1 and 2 of LaCPR without including background loss rates. Habitat creation or restoration under these alternatives from freshwater introduction or diversions is not available at this time.

Measure	Fresh Marsh (acres)	Int Marsh (acres)	Brackish Marsh (acres)	Saline Marsh (acres)	Swamp (acres)	Wetland Shrub/Scrub (acres)	Bottomland Forest (acres)	Barrier Island (acres)
Alternative 1 total	17,601	70,244	58,578	88,007	476	788	3,495	15,844
Alternative 2 total	25,957	26,895	69,530	114,283	1,751	4,033	5,430	25,424

Summary
Planning and analysis of the options is ongoing. The final report is due in December 2007.

NOAA Community-based Restoration Program

http://www.nmfs.noaa.gov/habitat/restoration/projects_programs/crp/index.html

The NOAA Community-based Restoration Program (CRP) began in 1996 to inspire and sustain local efforts to conduct meaningful, on-the-ground restoration of marine, estuarine, and riparian (i.e., stream edge or bank) habitat with an opportunity for hands-on community participation. The program is a systematic effort to catalyze partnerships at the national and local level to contribute funding, technical assistance, land, volunteer support, or other in-kind services to help citizens carry out sound habitat restoration projects that promote stewardship and a conservation ethic for living marine resources. The program links seed money and technical expertise to citizen-driven restoration projects, and emphasizes collaborative strategies built around improving NOAA trust resources and the quality of life in the communities they sustain. Community-based Restoration Program projects often address immediate areas of concern within a 12- to 18-month time period. The program fills a critical small-scale-project niche.

Since 1996, participants of the program have constructed over 1,000 projects in 27 states, Canada, and the Caribbean, which have typically leveraged 3 to 5 non-federal dollars for every NOAA dollar invested. In Louisiana 35 projects have been funded to date directly benefiting over 4,500 acres. The Louisiana projects have leveraged an average of $3.20 for every federal dollar spent, and have accumulated over 30,000 volunteer hours.

The program has been successful in Louisiana for partnering with industry and landowners to build projects that not only restore marine fisheries habitat but also help protect critical infrastructure. Examples include maritime ridges and buffering marshes at port facilities, hurricane levee protection, reef shorelines near developing communities, and hydrologic restoration to restore tidal flow and reduce community flooding. As a whole, the program's projects in Louisiana performed well and in most cases survived the storms. Of the 35 projects funded in Louisiana, 12 were initiated after the storms, in part as a means of revitalizing damaged communities. Of the 23 projects constructed before the storms, only six were significantly damaged. Appendix 5 provides a post-storm evaluation of each project.

Summary

Thirty-five projects were funded in Louisiana, with 12 of those after the 2005 hurricanes, directly benefiting over 4,500 acres. Funding of qualifying projects will continue based upon appropriations for the program.

Louisiana Regional Restoration Planning Program

The Louisiana Regional Restoration Planning Program is designed to expedite the restoration of Louisiana's habitats injured by frequent oil spills, including those caused by hurricanes. Because of the number of petroleum activities in Louisiana, the state has a higher likelihood of a spill than most other states. Between 1991 and 2001, Louisiana had 19 percent of the total oil spills in the United States and 21 percent of the volume of discharges of petroleum products. The cumulative impact of oil spills on fish, wildlife, and the environment can harm industries and the communities that depend on natural resources for commerce and recreation. Natural resource trustees, including NOAA, the U.S. Department of the Interior, and the State of Louisiana, developed this statewide program to assist with their responsibilities under Oil Pollution Act and various other statutes.

Under the Louisiana Regional Restoration Planning Program the state is divided into nine regions and for each region a Regional Restoration Plan will describe the:

- Resources and services likely to be injured by an oil spill,
- Suitable restoration types for various injuries, and
- Available projects that can be implemented at the local level to compensate for these injuries.

Having these regional restoration plans in place will help the natural resource trustees respond to and manage the oil spills in Louisiana and reduce the cost and time required for restoration planning and implementation. The framework and the major provisions of the Regional Restoration Planning Program are outlined in a Final Programmatic Environmental Impact Statement (PDF) available at http://www.darrp.noaa.gov/southeast/rrpp-la/index.html. The first regional plan (PDF), for the delta area in southeast Louisiana, also is available on the NOAA Damage Assessment, Remediation and Restoration Program (DARRP) website.

Coastal Protection and Restoration Authority

Senate Bill 71 of the State of Louisiana First Extraordinary Session in November 2005 was approved by the Louisiana Legislature and signed by the Governor of Louisiana as Act 8. This legislation created the Coastal Protection and Restoration Authority (CPRA) and charged CPRA with coordinating the efforts of local, state, and federal agencies to achieve long-term, comprehensive coastal protection and restoration, as well as to ensure ongoing integration of flood protection and wetland restoration. Act 8 defines coastal protection as the combination of hurricane protection and coastal restoration activities needed to provide for a safe and sustainable Louisiana.

The act also charged CPRA with developing a master plan (submitted to the State Legislature on April 30, 2007, and unanimously approved May 30, 2007) that presents a conceptual vision of a sustainable coast based on the best available science and engineering (Louisiana CPRA 2007). It is envisioned that all other restoration programs would be consistent with the restoration measures contained in the master plan. Attaining this consistency will be a great challenge, because various mandates and scales of restoration differ greatly among programs. The CPRA will resolve policy issues (such as protective zoning regulations and landowner cooperation), secure dedicated funding streams, and ensure consistent planning at local, state, and federal government levels.

Summary

The Master Plan was approved by the Louisiana State Legislature on May 30, 2007. NMFS and other agencies will work with the State as the process moves forward.

Plans by State: Mississippi

Governor's Commission on Recovery, Rebuilding, and Renewal

Mississippi Governor Haley Barbour's Commission on Recovery, Rebuilding, and Renewal evaluated the extensive damage from Hurricane Katrina in coastal Mississippi and prepared a report (Barksdale 2005) detailing a range of options and recommending measures to facilitate the recovery of communities and resources, including habitats supporting marine fishery resources. Barksdale (2005) describes 15 specific restoration projects at a projected cost of $117 million. The report also identifies 11 additional restoration/flood reduction projects in coastal Mississippi, estimated by the Mississippi Department of Marine Resources (MDMR) to cost an additional $41 million. Funding for these projects and others still must be secured.

Restoration and protection activities already underway include a debris removal program (which the Commission recommends be led by the U.S. Coast Guard) and oyster reef rehabilitation, which includes mapping and monitoring components. Marine debris removal, from mean high tide to 4 miles into the Mississippi Sound, has been conducted. More than 237 sites were reviewed, prioritized, and documented from November 2005 to January 2006.

In addition, MDMR Public Affairs took on the mission of implementing a plan with the counties to conduct volunteer efforts to collect marine debris along those beachfront areas from mean high tide to 100 yards out that county leaders identified as high-priority areas. About 900 volunteers removed more than 1,500 cubic yards of storm debris embedded in the shoreline and shallows of the Mississippi sound during the Post- Katrina volunteer beach cleanups.

Restoration of oyster reefs to their former productivity levels has also begun. The Commission recommends beginning the process in the near term for shrimp nursery areas and other habitats. MDMR is leading this restoration along with local partners such as the Mississippi–Alabama Sea Grant Consortium, The Nature Conservancy, Coastal Conservation Association, the charter boat industry, and other local seafood and sportfishing organizations. Federal partners include USACE, NMFS, NOAA Restoration Center, Department of Transportation, EPA, and FWS.

Other recommendations brought forth by the Commission include:

- Protect, restore, and create essential ecosystems. Hurricane Katrina's devastation reduced both the total acreage and function of Mississippi's estuarine and vegetative wetland habitat. The decreased area and fragmentation has led to a decline in the essential ecological functions provided by these habitats. The Commission supports the use of the Estuary Restoration Act of 2000, which calls for a national strategy with a goal of restoring 1 million acres of estuarine habitat by 2010. Restoring artificial reefs is another recommendation of the report.
- Focus the rebuilding effort on restoration and enhancement of riverine floodplains and nearshore resources. Specific activities include de-snagging and reconfiguring the streambed of some tributaries to the major river systems to reduce flood potential; to reclaim barrier islands, including Deer Island; and to restore coastal marsh habitats and beaches.
- Survey the current size of estuarine habitat by using historical side-scan sonar and conventional surveys to document the pre–Hurricane Katrina status of the state's oyster reef resources and coastal preserves. Aerial surveys of the coast's marshlands could provide similar measures for the wetlands. The effort will identify specific areas where restoration should be focused.
- Restore Deer Island to its 1900 footprint by reclaiming the recently created 55 acres of marsh on the northeast end damaged by Hurricane Katrina, filling the "gap" created by previous hurricanes, and continuing restoration of additional marsh and beach acreages to essentially double the footprint of Deer Island as it exists today.
- Coordinate the development of an adaptable estuarine habitat restoration plan that will describe and prioritize restoration sites through the Mississippi–Alabama Sea Grant Consortium.
- Use the bridge rubble from the Biloxi–Ocean Springs and Bay St. Louis bridges to create reefs, erosion control, and wave attenuation structures.

The Commission recommends that the Mississippi legislature coordinate three long-term restoration efforts:

- Restoring the Pearl River and tributaries from Jackson to Mississippi Sound, the Pascagoula drainage basin to Mississippi Sound, and other Mississippi Rivers and coastal watersheds to the Sound.
- Using the Mississippi Coastal Area Restoration Initiative for restoration of mainland coastal marshes and beaches, including an estimated 1,890 acres of coastal marshes and forests that were severely damaged or destroyed.
- Using the Mississippi and Louisiana Coastal Studies to guide the implementation of water and silt diversions, reduce saltwater intrusion, restore fisheries infrastructure, and related projects.

Summary
The Governor's Commission notes activities already under way and mentioned earlier, such as debris removal and oyster reef rehabilitation. The report recommends restoration of coastal wetlands, riverine floodplains, nearshore areas, and Deer Island (a barrier island). It supports a survey of habitat types, development of an estuarine habitat restoration plan, examination of potential long-term restoration efforts, and the use of rubble for creating reefs and wave attenuation structures. It also recommends rebuilding the Seatrout Hatchery and developing aquaculture. Funding is needed.

Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006 (4th Supplemental)

Oyster Reef Restoration, Enhancement, and Monitoring
Using $37.0 million appropriated through P.L. 109-234 and distributed by NOAA, Mississippi is surveying public reef areas and likely cultivation sites using real-time differential global positioning systems and side-scan sonar. Resultant maps consist of geo-referenced pictures of reef areas and bathymetry depicting oyster bed relief, hollow spots, and holes or mounds in the reef areas. Total acreage is calculated and mapped and compared to pre-hurricane data to determine oyster reef habitat loss following Hurricane Katrina.

Based on the loss of oyster reef habitat, MDMR is restoring damaged habitat by towing bagless dredges over the reefs to re-expose shell material covered by sedimentation or debris and to break up hooked mussels that have encrusted the oysters, and harvest and relocate oysters from areas where they are in greater abundance to areas that had high mortality due to Hurricane Katrina.

To monitor restoration success, selected oyster reefs will be sampled. The presence and abundance of oyster predators or competitors will be documented, including the oyster drill, flat worm, and the hooked mussel. The time, success, and density of spat set will be conducted with the aid of spatfall collectors in selected approved or conditionally approved waters.

To initiate a detailed oyster reef damage evaluation, in late 2005 and continuing into 2006 harvesters were employed to map the damage to Mississippi's oyster reefs using sounding poles and GPS. In total, 70 fishermen were employed, supported by funding provided by NOAA. Following the hurricane damage survey work, MDMR took the following actions to restore damaged oyster reef habitat (B. Randall 2007, pers. comm.):

- *May 2006, Spring Shell Plant* – 5,022 cubic yards of oyster shells were planted on Square Handkerchief Reef, rehabilitating 75 acres.
- *August 2006, Fall Shell Plant* – 9,000 cubic yards of limestone were planted, rehabilitating 100 acres at Telegraph Oyster Reef. Additionally, 1,000 sacks of live oysters were used to seed the areas with the MDMR vessel *Conservationist*.
- *September 2006* – submitted "Mississippi's Hurricane Katrina Disaster Recovery, Restoration, Enhancement and Monitoring Program to Restore Gulf Fisheries" to NOAA.
- *November 2006–January 2007, Oyster Relay Program* – MDMR and 82 fishermen relayed 75,059 sacks of oysters from Biloxi Bay and Graveline Bayou to the western Mississippi Sound, seeding six damaged oyster reefs.
- *March–May 2007* – MDMR will place 21,428 cubic yards of oyster shells and 37,500 cubic yards of limestone in the spring of 2007 to restore 600 acres of oyster reef habitat. In addition, the agency will continue to monitor and assess the progress of all reef rehabilitation work in Mississippi.

Marsh Habitat Restoration and Enhancement and Historical Fresh Water Inflow into the Mississippi Sound

Also using funds allocated through P.L. 109-234, MDMR is to identify specific areas that suffered major marsh loss due to Hurricane Katrina, use dredge spoil or other appropriate material to restore marsh elevations and storm-related losses, and hire contractors to remove excessive sediment from selected areas. Dredged material is to be transferred to locations to rebuild damaged marsh habitat and restore storm-related losses.

Artificial Reef Habitat and Monitoring of Nearshore and Offshore Ecosystems

Also using funds allocated through P.L. 109-234, MDMR proposes to survey and select reef habitat to identify areas for restoration and/or creation of shallow water and permitted offshore reef areas. Restoration areas identified will be monitored and mapped and areas for the storage of reef-building material will be specified. As of March 2007, 240 pyramid reefs have already been installed under Mississippi's Artificial Reef Restoration Program, and more than 9,600 derelict crab traps have been removed from the fishing grounds since Hurricane Katrina.

Summary

Using funding through the NMFS Disaster Recovery Program, Mississippi has begun to survey, map, and restore public oyster grounds using various, suitable cultch materials. Oyster harvesters have been employed in this work. Marsh areas will be identified for restoration and artificial reef habitats surveyed for damage and rehabilitation. Nearshore and offshore ecosystem monitoring will take place.

Public Law 110-107, U.S. Troop Readiness, Veterans' Care, Katrina Recovery, and Iraq Accountability Appropriations Act, 2007, 2006 (5th Supplemental)

Habitat-related activities under the 5th Supplemental will be implemented with emergency supplemental appropriations provided by Congress for additional hurricane disaster relief and recovery related to hurricanes Katrina, Rita, and Wilma in the area covered by the disaster declaration made by the President under the Robert T. Stafford Disaster Relief and Emergency Assistance Act, P.L. 93-288, 88 Stat 143, as amended (42 U.S.C. sec. 121 et seq.).

Within the scope of this report, the 5th Supplemental provides additional hurricane response funding for activities undertaken by NOAA and the USACE. NOAA is provided $110 million. Of that amount $1 million is for real-time observations and forecasts for coastal navigation and to repair and replace tide gauges throughout the Gulf of Mexico region and $109 million is for expenses related to the fishery and habitat impact remediation from hurricanes Katrina and Rita. Of the $109 million, $85 million is for assistance programs authorized under section 115 of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006.

In addition to funds provided to NOAA, the 5th Supplemental provides funding to the USACE to further its response to Hurricane Katrina. This supplement includes $107.7 million to construct interim flood and storm damage reduction measures in Hancock, Harrison, and Jackson counties, Mississippi recommended in the Chief of Engineers report dated December 31, 2006, entitled'' Mississippi Coastal Improvements Program, Interim Report'', at full federal expense.

Mississippi Coastal Improvements Program (MSCIP)

The Department of Defense Appropriations Act, 2006 (P.L. 109-148; enacted December 30, 2005), designated $37.3 million to expedite studies of flood and storm damage reduction related to the consequences of hurricanes in the Gulf of Mexico and Atlantic Ocean. The Act directed the Secretary of the Army, through the USACE, to use $10 million of the funds provided to conduct an analysis and design for comprehensive improvements, or modifications to existing improvements, in the coastal area of Mississippi in the interest of hurricane and storm damage reduction, prevention of saltwater intrusion, preservation of fish and wildlife, prevention of erosion, and other related water resources purposes. The USACE was directed to provide interim recommendations for near-term improvements by June 30, 2006, with final comprehensive recommendations provided by December 30, 2007. This effort has been designated the Mississippi Coastal Improvements Program (MSCIP).

Near-Term Plan
The near-term projects are those that contribute to the recovery of coastal Mississippi and can be implemented in the near term without significant engineering, economic, and environmental impacts and controversy. The required interim recommendations for near-term improvements have been submitted through USACE Headquarters to the Assistant Secretary of the Army for submission to Congress. Of the 15 recommended MSCIP near-term projects included in the interim report, eight are related (wholly or in part) to restoring coastal habitat of the Mississippi Gulf Coast (Table 5-6).

Table 5-6. Near Term Projects Related to Coastal Habitat Restoration.

Project Title	Description
Bayou Caddy	Material dredged from Bayou Caddy will be beneficially used to create 18 acres of marsh adjacent to the shoreline within Mississippi Sound.
Hancock County Beaches	Sand mined from upland borrow sites will be used to renourish 8 miles of beach; a dune will be added to the existing beach, stabilized with fencing, and planted with dune vegetation.
Hancock County Streams	Debris and sediment will be removed from 6.6 miles of tidal canals and streams.
Jackson Marsh	Debris and sediment blocking tidal conduits to 977 acres of tidal marsh will be removed.
Harrison County Beaches	Sand mined from offshore borrow sites will be used to renourish 26 miles of beach; a dune will be added to the existing beach, stabilized with fencing, and planted with dune vegetation.
Courthouse Road	Approximately 0.33 acre of tidal marsh will be created to replace marshes existing at the site prior to the hurricane.
Gautier Coastal Streams	Debris and sediment will be removed from 5 tidal canals and streams.
Pascagoula Beach Boulevard	The beach and dune system will be restored along 7,700 feet of shoreline along Mississippi Sound.

Detailed information about the near-term projects is available online at http://mscip.usace.army.mil/downloads.asp (USACE 2006b).

Comprehensive Plan
The long-term comprehensive plan will include an extensive array of measures to promote the recovery of coastal Mississippi from the hurricanes of 2005 and to provide for a reduction of future damages to the maximum extent practicable. Multiple natural and engineered alternatives are being evaluated for various levels of protection for the Mississippi mainland coast. Development of this overall damage reduction system involves identifying potential "lines of defense," moving from offshore to nearshore, the shoreline, and along existing elevated features inland, to effectively reduce damage from large hurricane and storm events. Alternatives being considered include restoration of storm-damaged habitats such as coastal marshes, beaches, maritime forests, oyster reefs, and submerged aquatic vegetation in Mississippi Sound; restoration of historical water flows to coastal watersheds, including freshwater diversion from Louisiana; and

watershed-based drainage modifications for flood damage reduction. Over 190 projects have been compiled by the USACE through public meetings, workshops, and coordination with federal, state, and local governments; non-governmental organizations; and private citizens. These project concepts are being considered for inclusion in the comprehensive plan. Of the 115 projects still under consideration, 45 have a component that addresses coastal habitat restoration, enhancement, and/or protection. More detailed information about the projects under consideration for the comprehensive plan is available online at: http://mscip.usace.army.mil/potential-projects.asp, or in Appendix 6.

Summary

This USACE-led program is still in the planning stages but has identified eight near-term projects that would benefit coastal habitats. Another 45 (of a potential 115) projects under consideration on a longer time scale would benefit coastal habitats. NMFS is coordinating with the USACE as planning progresses. The Coastal Impact and Assistance Program, administered by the Minerals Management Service under the Energy Policy Act of 2005, is providing $30.39 million per year for FY 2007 and FY 2008 for the conservation, protection, or restoration of coastal areas, including wetlands, and mitigation of damage to fish, wildlife, or natural resources.

Mississippi CIAP Projects

FY 07 and 08 CIAP funding for Mississippi is $39.9 million. Funding may be used for projects and activities for the conservation, protection, or restoration of coastal areas, including wetlands; mitigation of damage to fish, wildlife, or natural resources; implementation of a federally-approved marine, coastal, or comprehensive conservation management plan; and mitigation of the impact of Outer Continental Shelf activities through funding of onshore infrastructure projects and public service needs. Mississippi through MDMR proposes to emphasize funding for: 1) barrier island restoration/shoreline stabilization; 2) storm drain consolidation and sewer system upgrades to improve water quality; 3) acquisition of ecologically significant and important natural areas; 4) wetland and aquatic habitat improvement in the coastal zone; and 5) education on the importance of coastal natural resources.

Plans by State: Alabama

Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006 (4th Supplemental)

Map Alabama's Marine and Estuarine Habitats
Using $29.6 million appropriated through P.L. 109-234 and distributed by NOAA, the State of Alabama will identify and quantify oyster, shrimp, and other marine fishery habitats throughout Alabama's coastal waters in a GIS-compatible format. This work will encompass an area of approximately 500 square miles, and includes all of Alabama's inside jurisdictional waters.

Oyster Grounds Restoration
Program resources also will be used to replenish cultch material on oyster grounds. High-quality cultch materials (oyster shell or a functional and chemical equivalent) will be placed on existing hard bottom areas known to have previously supported oyster populations. It is anticipated that up to 500 acres of oyster reef habitat may be restored using up to 162,500 cubic yards of cultch material. Two plantings are to be undertaken annually to achieve optimal oyster spat set and reef rehabilitation.

Oyster, Shrimp, and Fish Nursery Habitat Restoration
Selected oyster, shrimp, and finfish nursery habitat lost to erosion during recent hurricanes will be restored to protect those habitats from future storm events. Work will be contracted through Alabama Department of Conservation and Natural Resources/Lands Division to reestablish selected habitat and construct wave attenuation devices. One of the areas most adversely affected includes Portersville Bay in Alabama's portion of Mississippi Sound, where approximately 5.4 miles of shoreline will be replanted with aquatic vegetation and protected by installing wave attenuation devices.

Summary
Alabama plans to quantify and map fishery habitats, restore oyster habitats that were impacted, and control shoreline erosion through the use of techniques such as wave attenuation devices in order to mitigate or protect habitat. The Coastal Impact and Assistance Program, administered by the Minerals Management Service under the Energy Policy Act of 2005, is providing $25.55 million per year for FY 2007 and FY 2008 for the conservation, protection, or restoration of coastal areas, including wetlands, and mitigation of damage to fish, wildlife, or natural resources.

Public Law 110-107, U.S. Troop Readiness, Veterans' Care, Katrina Recovery, and Iraq Accountability Appropriations Act, 2007, 2006 (5th Supplemental)

Habitat-related activities under the 5th Supplemental will be implemented with emergency supplemental appropriations provided by Congress for additional hurricane disaster relief and recovery related to hurricanes Katrina, Rita, and Wilma in the area covered by the disaster declaration made by the President under the Robert T. Stafford Disaster Relief and Emergency Assistance Act, P.L. 93-288, 88 Stat 143, as amended (42 U.S.C. sec. 121 et seq.).

Within the scope of this report, the 5th Supplemental provides additional hurricane response funding for activities undertaken by NOAA and the USACE. NOAA is provided $110 million. Of that amount $1 million is for real-time observations and forecasts for coastal navigation and to repair and replace tide gauges throughout the Gulf of Mexico region and $109 million is for expenses related to the fishery and habitat impact remediation from hurricanes Katrina and Rita. Of the $109 million, $85 million is for assistance programs authorized under section 115 of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006.

Alabama CIAP Projects

FY 07 and 08 CIAP funding for Alabama is $25.5 million. Funding may be used for projects and activities for the conservation, protection, or restoration of coastal areas, including wetlands; mitigation of damage to fish, wildlife, or natural resources; implementation of a federally-approved marine, coastal, or comprehensive conservation management plan; and mitigation of the impact of Outer Continental Shelf activities through funding of onshore infrastructure projects and public service needs.

Plans by State: Texas

Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery, 2006 (4th Supplemental)

Habitat Mapping
Using $3.2 million appropriated through P.L. 109-234 and distributed by NOAA, the State of Texas will purchase a vessel, side-scan sonar equipment, and necessary software

to determine conditions of oyster reef habitats in the Sabine Lake and Galveston Bay systems. Data will be collected on the conditions of the oyster reefs resulting from 2005 hurricane impacts, and provide baseline benthic data for these areas. Habitat restoration efforts will be undertaken on oyster reefs in these areas by purchasing and placing suitable cultch material on existing reef sites that have been identified through damage assessment. The proposed work will be conducted during winter seasons from 2008 through 2010. Survey results can also be used to provide a measurement to determine future impacts of natural disasters, anthropogenic impacts, and disease of oyster reefs. Data collection will be conducted from 2008 through 2010. The state also will contract with Texas A&M University, Galveston, to conduct a side-scan sonar survey of oyster habitat prior to May 2007.

Texas CIAP Projects

Using funding procured from the Coastal Impact and Assistance Program (detailed in the Louisiana section of this report), Texas plans to restore the upper coast beaches in Jefferson County, conduct stabilization of the Baily Road–West Sabine shoreline in Orange County, and conduct topographic LIDAR surveys of selected coastal beaches.

Actions Called For by the USFWS Refuges in Texas

Texas Point National Wildlife Refuge (NWR)

- Shoreline Protection and Marsh Restoration Through Use of Dredge Material – Such a project would both restore marshes lost and provide protection to over 4,000 acres of adjacent wetlands.
- Marsh Restoration with Terracing – It is proposed to restore vegetated marsh by establishing earthen terraces in larger open water habitats. Terrace construction would provide protection to over 800 acres of adjacent marshes. Funding is necessary to implement this project.
- Debris Removal – Federal funding authorities do not exist for removal of this debris because it is not a threat to navigation nor does it pose an immediate contaminants threat. Funding is necessary to implement this project.

McFaddin NWR

- Shoreline Protection, Gulf of Mexico Dune Restoration – Over 15 miles of the refuge’s Gulf of Mexico shoreline was eroded and retreated during Hurricane Rita. In response, there is a need to restore up to 2 miles of the most severely impacted dunes on the refuge. Restoration of dunes is a critical need to protect inland marsh habitats and to reduce rates of coastal land loss which would further accelerate following this storm. Funding is necessary to implement this project.
- Shoreline Protection, Gulf Intracoastal Waterway (GIWW) – Construction of 1.5 miles of offshore breakwaters and 4 miles of onshore armoring is necessary in

areas breached and eroded by storm surges and wave action along the GIWW. The loss of levees along the GIWW poses an immediate and long-term threat from saltwater intrusion to over 5,000 acres of freshwater coastal marshes. Existing breakwaters performed extremely well during this storm event. Funding is necessary to implement this project.

Anahuac NWR

- Shoreline Protection – Erosional land loss during Hurricane Rita along East Galveston Bay resulted in a direct loss of marsh and salty prairie habitats, and loss of levees along the GIWW poses an immediate and long-term threat from saltwater intrusion to over 3,500 acres of adjacent coastal marshes. Restoration and protection is proposed through the construction of 1.5 miles of offshore breakwaters and 2 miles of onshore armoring in areas breached and eroded by storm surges and wave action along Galveston Bay and the GIWW. Additional funding is necessary for this project to be conducted.

NOAA Community-based Restoration Program (CRP)

The only CRP site of note affected by Hurricane Rita was a dune restoration project at McFaddin National Wildlife Refuge in Texas. A project had been implemented at the site prior to Hurricane Rita, without any CRP involvement, and that project was damaged by the storm. CRP funding allowed this dune site to be rebuilt and funded an additional 2 miles of sand fence installation and planting of dune vegetation (Atlantic panicum). The CRP cost of $10,000 and was matched with $10,000 in local funds. Project completion resulted in re-establishment of 1 acre of sand dunes, protection of 15 acres of sand dunes, and added protection of 2930 acres of salt marsh.

Summary

The National Wildlife Refuges along the Gulf coast of Texas recommended a list of specific shoreline protection projects that would safeguard the marsh habitat behind them, but which are not funded. The NOAA Community-based Restoration Program did partially fund a shoreline protection project (Sand Dune Restoration) at the McFaddin National Wildlife Refuge.

Plans by State: Florida

Restore Oyster Reef Habitat

Using $4.2 million appropriated through P.L. 109-234 and distributed by NOAA, the Florida Department of Agriculture and Consumer Services, Division of Aquaculture, in collaboration with the Florida Fish and Wildlife Conservation Commission, proposes the restoration of damaged oyster reef habitat (M. Berrigan 2007, pers. comm.). The restoration program is designed to identify and assess damaged public oyster reefs, develop criteria for restoring oyster reef habitat, restore oyster reef habitat by depositing cultch, investigate alternative methods for increasing recruitment (reseeding) on restored reefs, restore oyster stocks by relaying and transplanting live oysters, enhance oyster production and facilitate ecological recovery of the estuaries adversely affected by hurricanes in 2005, and monitor the success of the restoration project.

They also plan to construct an oyster larvae dispersal model for the Pensacola Bay system, and conduct simulations of larval dispersal under various hydrodynamic and biological conditions. This work will help to update the Oyster Fisheries Management Plan for the Gulf of Mexico region.

In addition, the Division of Aquaculture proposes to re-establish a shell buying program to obtain processed oyster shell from local oyster processing plants. Processed oyster shell will be used to build substrate to restore reefs. Depending upon availability, it is anticipated that about 10,000 cubic yards of processed shell can be collected for the restoration project. To supplement the oyster shell planting, about 30,000 cubic yards of fossil shell and limestone cultch material may be required. These materials will be used to construct oyster reefs in areas where processed oyster shell is not readily available. The state estimates that about 200 acres of public oyster reefs will be restored during the 5-year project.

Finally, as a part of the restoration effort, live oysters will be collected from reefs located in waters where 1) conditions are not favorable for survival or growth, and/or 2) harvesting is restricted because of potential public health risks. The harvested, live oysters will be replanted on reefs located in areas where environmental conditions are more favorable for growth and survival and where public health concerns are minimal. The oyster transplanting and relaying component of the restoration project will plant 200,000 bushels of live oysters.

Numerous other, smaller scale restoration efforts are under way in Florida. For example, in the Florida Panhandle Area Preserves, Shelly Alexander (2007, pers. comm.) reported beach re-nourishment, oyster reef, and submerged aquatic vegetation restoration activities. In the Tampa Bay area, Tampa Bay Watch, Inc., has been installing oyster shell reefs to protect mangroves and salt marsh habitat from wave energy and storm surges (K. Sanderson 2007, pers. comm.).

Marine Debris

Partnering with FEMA for marine debris removal proved efficient (G. Garret 2007, pers. comm.). FEMA assisted with trap (crab and lobster) and vessel removal as a response to the 2005 hurricanes. Future improvements would include developing an action/response plan and setting up funds to minimize delay. The establishment of an action/response plan with in-place contracts would help minimize impacts from derelict vessel and lost traps. Reaction time was approximately 8 months from Hurricane Wilma impacts until the debris removal.

Expanded funding to the existing proactive derelict vessel program may prevent impacts to essential fish habitat before a storm occurs in these areas. Approximately 20 to 40 vessels are classified as derelict vessels within the Florida Keys National Marine Sanctuary each year. If these vessels were removed in a timely manner they would not threaten or affect EFH during periods of high wind and wave energies (D. Dipre 2007, pers. comm.).

G. Lytton (2007, pers. comm.) also suggested that funds could be made available for coastal land acquisition. As was demonstrated in Louisiana during Hurricane Katrina, natural vegetative shorelines suffered reduced storm impacts when compared to hard shorelines and those altered by anthropogenic activities.

Summary

Florida has conducted a marine debris removal program and is beginning an oyster habitat quantification and restoration program. Several smaller scale restoration projects are also known to have taken place after the 2005 hurricanes.

6. Recommendations

The data collected and analyzed for this report clearly reflect the ferocity of Hurricanes Katrina, Rita, and Wilma, the devastating and far reaching effects on habitats of the winds, flooding waters, and waves generated by the storms, and the collateral damage inflicted by debris scattered by the storms. The data also show that existing programs of large-scale conservation and restoration provide some hazard protection benefits but more such work is needed. It is clear that:

> *Restoration and protection of coastal wetlands and barrier islands will assure critical habitats for estuarine-dependent seafood species, and will act as a first line defense for the protection of coastal communities from a range of hazards* (NMFS 2006a).

Recommendations are grouped into two categories. Many significant government actions have been on-going since well before Hurricanes Katrina, Rita, and Wilma; other actions have been initiated in the wake of the storms. Several are singled out because of their value for short-term habitat protection and restoration and/or long-term re-establishment of natural ecosystem functions that support the valuable fisheries of the region. In addition, a series of actions is highlighted if the Nation is to: (1) more effectively manage fisheries habitat and associated fish stocks, (2) reduce impacts from future devastating tropical storms in the region, and (3) better respond to and learn from future events.

NOAA supports the listed programs in their stated goals and objectives. These address fishery-related habitats along portions of the northern Gulf of Mexico:

- The Louisiana Coastal Area Ecosystem Restoration (LCA) study, its components and recommendations that would rebuild or enhance living marine resource habitats.
- The Louisiana Coastal Protection and Restoration Project process.
- The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) projects and the adoption of the CWPPRA governance approach for other restoration programs in Louisiana and other states. The latter would enable federal partners to work with the USACE and the states cooperatively to protect and restore vital wetland habitats.

> *Stemming and then reversing the loss of coastal wetlands and barrier islands of the region will require a substantial increase in the number*

of projects currently funded or proposed. Because NOAA administered CWPPRA projects survived Katrina and Rita so well, these investments in wetland rebuilding, if replicated on a larger scale, could contribute to a more resilient coastal wetland network in the Gulf. These projects are a model for wetlands rebuilding should funds become available to scale-up protection programs consistent with the magnitude of the problem (NMFS 2006a).

- The Coastal Protection and Restoration Authority process to achieve long-term and comprehensive coastal protection and sustainability for the coastal ecosystem, including fishery habitat in the State of Louisiana.
- The Mississippi Coastal Improvement Program process and continued coordination with the USACE on the projects as they advance through plan formulation, implementation, and post-construction monitoring.
- The Mississippi Governor's Commission Report as it advances beyond the conceptual stage and moves into the planning process.
- The Louisiana Regional Restoration Planning Program to expedite remediation and restoration of marine habitats injured by frequent oil spills, including those caused by hurricanes.

The above programs provide a solid foundation upon which to build a comprehensive, system-wide strategy for coastal habitat protection and restoration. As was reported in the Plan for Recovering Gulf of Mexico Fisheries Using an Ecosystem Approach (NMFS 2006a):

> *Rebuilding the coastal wetlands is a key component of improving community protection and restoring ecological function. While damage can never be prevented fully, restoration of these natural areas can mitigate a considerable amount of coastal inundation from storm surge, and protect vulnerable man made structures at the water's edge. Levees should be viewed as the* ***last*** *line of defense for coastal communities, not the first and only. Barrier islands, coastal wetlands and levees working together can provide a tiered approach to defending coastal towns and cities in the Gulf region* (NMFS 2006a).

The analyses underlying this report underscored several issues that deserve action:

- Rebuilding and maintaining the extensive system of wetlands historically nourished by the Mississippi delta are essential for the health of estuarine-dependent fish populations, enhancement of Gulf water quality in areas influenced by the Mississippi River plume, and heightened storm protection for natural and human systems in the coastal zone. A key element is re-establishing freshwater and sediment supplies to deltaic wetlands of the area. Approaches should be implemented that allow predictable and regular deliveries of water and sediment to deteriorating coastal marshes while protecting human settlements, economic interests, and vital infrastructure.
- Barrier islands offer demonstrated protection against the effects of major storms on coastal wetland systems; however, geological processes that naturally create

these features presently are hampered by insufficient sediment supply. Human restorations of barrier islands, such as those undertaken under the aegis of the Coastal Wetland Planning, Protection and Restoration Act, are effective as partial solutions but come at high cost. Re-establishing permanent freshwater and sediment delivery to re-nourish barrier islands is likely to be a more efficient and cost effective option over the long run. In the interim, a combination of restoration and sediment and water flow enhancements will be needed.

- Programs which identify and reverse key wetland losses inflicted by the 2005 hurricanes and which protect and restore wetland habitat deserve robust support (e.g., at the McFaddin complex in Texas, restoring dune and beach areas would support wildlife and marine fishery production and protect interior wetlands from future hurricanes).
- Greater efforts must be made to conserve Essential Fish Habitat as a means to preserve the long-term vitality of coastal wetlands and related habitats that sustain healthy fish stocks, diminish storm impacts, and protect coastal communities and critical national infrastructure. Such actions to conserve existing habitat, taken in advance of storm events as opposed to after-the-fact restoration, would diminish the need to invest future resources for restoration and enhancement of habitat and for repair or replacement of infrastructure. Proactive efforts must engage stakeholders to identify and implement needed protection and conservation measures.
- Baseline assessments are required against which to compare the effects of future hurricanes and major storms along the Gulf and Atlantic coasts. No such comprehensive data set and analyses were available in the aftermath of the 2005 hurricane season, making assessments of the extent, severity, permanence, and implications of damage difficult or impossible to undertake.
- Federal agencies in partnership with the states must develop and implement plans to respond to future storms to collect a pre-determined suite of data using commonly-accepted protocols. Such plans should identify sites to which data will flow for analyses. Such sites must have the capability to produce region-wide analyses on time frames of weeks to months instead of years.
- A complementary mechanism is needed to assure the information from the above analyses is disseminated to on-the-ground managers in readily usable formats on a scale of weeks to months. Such analyses might target areas most in need of restoration and advise local and state governments on reconstruction that maximizes future protection, while avoiding past mistakes or harming remaining habitats. Such analyses might also be useful in identifying needs and opportunities for focusing conservation and protection efforts, so as to maximize the amount of habitat set aside from other uses that impair that habitat's capacity to provide storm protection services as well as beneficial ecosystem functions.
- The linkage between habitat (quality and quantity) and fisheries production must be mathematically defined to produce more precise estimates of the effects of habitat loss on fisheries and apply an ecosystem approach to the management of fisheries. This will require significant enhancements of research, assessment and monitoring. While this will be a costly undertaking, failure to make this investment will foreclose options for future generations. For the first time in

history, society has the computational tools, the ecological understanding, and the observational capabilities to significantly enhance the precision of fishery and habitat management approaches.

7.
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Appendix 1: Contact Information for This Report

Federal Agencies contacted for information

U.S. Department of Commerce
- National Oceanic and Atmospheric Administration
  - National Environmental Satellite Data and Information Service
    - National Coastal Data Development Center
  - National Marine Fisheries Service
    - Office of Habitat Conservation
      - Restoration Center
    - Office of Science and Technology
    - Southeast Region
    - Southeast Fisheries Science Center
    - Northwest Fisheries Science Center
  - National Ocean Service
    - Coast Survey
    - Coastal Services Center
    - Geodetic Survey
    - National Center for Coastal and Ocean Science
    - National Estuarine Research Reserves
    - National Marine Sanctuary Program
    - Office of Response and Restoration
  - Office of Oceanic and Atmospheric Research
    - Environmental Research Laboratories
      - Atlantic Oceanographic and Meteorological Laboratories
    - National Sea Grant Program
  - National Weather Service
    - National Hurricane Center

U.S. Department of Defense
- Army Corps of Engineers
  - Galveston District
  - Mobile District
  - New Orleans District

U.S. Environmental Protection Agency
- **Gulf Breeze**

U.S. Department of the Interior
- Fish and Wildlife Service
  - National Wildlife Refuges

Geological Survey
National Wetlands Research Center
Florida Integrated Science Center
Minerals Management Service
Environmental Division
Gulf of Mexico Regional Office
National Park Service

Gulf of Mexico Fishery Management Council
Gulf States Marine Fisheries Commission
Southeast Natural Resource Leaders Group

State agencies contacted for information

Mobile Bay National Estuary Program
Alabama Department of Conservation and Natural Resources
Alabama Department of Environmental Management
Florida Aquatic Preserve Offices
Florida Department of Agriculture and Consumer Services
Florida Department of Environmental Protection
Florida Fish and Wildlife Conservation Commission
Florida Fish and Wildlife Research Institute
Florida Water Management Districts
Florida Marine Research Institute
Florida Park Service
Louisiana Department of Natural Resources, Coastal Restoration Division
Louisiana Department of Wildlife and Fisheries, Marine Fisheries Division
Louisiana Governor's Coastal Protection and Restoration Authority
Mississippi Governor's Office
Mississippi Department of Marine Resources
Texas Bureau of Economic Geology
Texas General Land Office
Texas Parks and Wildlife Department
Coastal Fisheries Division
Wildlife Management Area Offices

Local governments and institutions contacted for information

Alabama
Dauphin Island Sea Laboratory

Florida
Monroe County Marine Resources Department
Mote Marine Laboratory
Palm Beach County

Louisiana
Louisiana Universities Marine Consortium (LUMCON)

Mississippi
University of Southern Mississippi, Department of Marine Sciences
The Northern Gulf Institute

Texas
Texas A&M University at Galveston
Texas Sea Grant Program

Appendix 2: Instructions to Open and Search CD Source Documents

A companion CD is provided with this report that provides access to digital versions of non-copyrighted references. Additionally the CD contains ancillary material used in the production of this report that the reader may find beneficial. To use the CD, simply insert it into a Windows or MacIntosh personal computer's CD drive. This companion CD is designed to automatically start the system's default web browser and open a web page that provides a brief description and web-based access to the references, appendices and ancillary material written on the CD. Depending upon user's particular computer operating system version or security settings on an individual computer or local network, such automatic start capability could be blocked. If the computer's default browser window does not start within 30 seconds, it is likely these security settings are in place. In such instances, a manual approach can be used:

For Windows:
(1) Start your default Web Brower
(2) Select from the browser menu 'File', then 'Open' [or 'File', 'File Open' in FireFox]
(3) Navigate and open the file listing for the CD labeled "NMFS" under "My Computer"
(4) Select the file "index.htm"
(5) Click OK

For MacIntosh
(1) Find the CD Disk symbol mounted on the Desktop labeled "NMFS"
(2) Double click to open the disk
(3) Double click on "index.htm"

From the initial companion CD web page, the reader can also select online access to the material. This online access is provided through the NOAA EcoWatch portal which offers an additional search capability into the material contained in the CD. The report resources can be searched through a Semantic Catalog and/or browsed and downloaded directly through this portal. To search for specific resources supporting this report, users can search on keywords such as the author, title, source, agency, date, storm name ('Katrina') and/or State, etc. Instructions can also be found on the portal itself: http://ecowatch.ncddc.noaa.gov

Appendix 3. List of Source Documents Found on the CD

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Gulf of Mexico Marine Debris Program, 2007, Survey Maps, NOAA Office of Response and Restoration.

Appendix 4. List of Websites Related to This Report

- Post-Katrina land cover and change maps are available for the Gulf of Mexico.
  * Post-Hurricane Katrina land cover data can be downloaded from www.csc.noaa.gov/crs/lca/katrina <http://www.csc.noaa.gov/crs/lca/katrina>.
  * Additional land cover maps for this region can be downloaded from www.csc.noaa.gov/crs/lca/gulfcoast.html <http://www.csc.noaa.gov/crs/lca/gulfcoast.html>.
- Evaluating the Potential Environmental Impacts of Hurricane Katrina on Living Marine Resources http://www.st.nmfs.noaa.gov/hurricane_katrina/documents/NOAA_Katrina_Operations_v5.pdf
- Glen Thomas, gthomas@agctr.lsu.edu, How have shrimp and finfish been impacted by Hurricane Katrina? Permanent damage to "nursery" habitats was caused by Katrina. Again, surveys have been preliminary, but are consistently alarming. Satellite photography of the marshes south of New Orleans indicates that the marshes below Caernarvon were severely cut up. Fishermen will find that area largely unrecognizable. Destruction of marsh edge habitats results in impacts to fisheries production that isn't immediately noticed but gradually reduce the populations of fish and shrimp. Satellite photos are showing that over 13,000 square acres of coastal wetlands and a number of offshore barrier islands in the Gulf of Mexico are gone. http://www.laseagrant.org/hurricane/archive/fisheries.htm#Q3
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Appendix 5. Post-Storm Evaluation for Each NOAA Community-based Restoration Project (see Chapter 5)

Project Name	Project Type	Federal Funding	Status after H. Katrina and Rita
Jefferson Parish Christmas Tree Marsh Restoration (2000)	Sediment trapping	$5,000	This program is maintained by the Parish on an annual basis. Cradles are repaired as necessary and trees replenished after holiday season.
Lake Pontchartrain Artificial Reef Creation (2000)	Shell reef	$15,000	Monitoring data required by the State indicate that the reef was undisturbed by the storms and remains intact.
Louisiana Coastal Roots Wetland Planting Program (2000)	Middle school wetland nursery program	$40,100	Some nurseries sustained damage; however, the plantings installed under the program appear to be fairing well.
Bayou Lafourche Bank Stabilization (2001)	Shoreline vegetative plantings	$77,800	The plantings have flourished and have begun to colonize along other sections of the bayou. The cutgrass is helping to abate wake erosion along the bayou.
Bird Island Artificial Reef Creation (2001)	Shell reef	$35,000	The reef is a popular recreational fishing location and appears undamaged from the storms.
Lake Pontchartrain Artificial Reef Creation-Phase 2 (2001)	Shell reef	$7,500	Monitoring data required by the State indicate that the reef was undisturbed by the storms and remains intact.
Port Fourchon Maritime Ridge- Phase 1 (2001)	Ridge and marsh restoration	$75,000	Phase 1 had minimal damage. The marsh fringe survived, however the ridge vegetation will require replacement. The 8 foot ridge helped to abate storm surge approaching Port Fourchon from the north.
Breton Island NWR Beach Stabilization (2002)	Sand fencing and vegetative plantings	$20,600	Breton Island was almost completely decimated by H. Katrina.
Pearl River Fisheries Habitat Restoration (2002)	Dam removal study	$23,400	N/A
Port Fourchon Maritime Ridge- Phase 2 (2002)	Ridge and marsh restoration	$117,000	Phase 2 lost elevation during the storm. The material from the ridge became new marsh in the adjacent area. The ridge vegetation will require replacement. The 8 foot ridge helped to abate storm surge approaching Port Fourchon from the north.
New Orleans City Park Fishing Improvements (2003)	Hydrologic restoration, vegetative plantings, restocking	$11,500	City Park was heavily damaged by H. Katrina. Numerous volunteer clean up efforts have taken place to help restore the lagoons. Two subsequent NOAA grants were awarded to City Park to revegetate the lagoons and replace the aerators.

Rainey Sanctuary Terracing Project (2003)	Marsh creation, shoreline protection	$60,000	The terraces performed very well and appeared to suffer no storm damage. The project helped to reduce wave erosion along adjacent shorelines and to trap sediment during the storms' passing.
Lafourche Parish Wisner Restoration Project (2003)	Marsh creation, beach fencing, hydrologic restoration	$150,000	The beach fencing and plantings were destroyed in the storm; however, the hydrologic restoration helped reduce flooding along Hwy 1, the hurricane evacuation route. The created marsh remains intact and healthy.
Pointe Platte Wetland Restoration (2003)	Shoreline protection	$10,000	The plantings and much of the Lake Pontchartrain shoreline were damaged during the storms.
Derelict Trab Programs in the Southeast Region- Louisiana (2003)	Marine debris removal	$61,000	The project helped remove derelict fishing gear that could have posed a safety hazard during the storms; however, the storms resulted in a significant volume of new marine debris.
Lake Pontchartrain Wetland Restoration (2004)	Vegetative plantings, shoreline protection	$47,000	The plantings and much of the Lake Pontchartrain shoreline were damaged during the storms. The project is ongoing to replace the lost vegetation and colonize additional sections of shoreline.
Grand Bayou Oyster Bedding (2004)	Reef restoration, shoreline protection	$22,000	This project has yet to be constructed.
Point aux Chenes Terracing Project (2004)	Marsh creation, shoreline protection	$70,000	The terraces performed very well and appeared to suffer no storm damage. The project helped to reduce wave erosion along adjacent shorelines and to trap sediment during the storms' passing.
Lafourche Parish Wisner Restoration Project- Phase 2 (2004)	Marsh creation, vegetative plantings	$17,600	The beach fencing and plantings were destroyed in the storm; however, the hydrologic restoration helped reduce flooding along Hwy 1, the hurricane evacuation route. The created marsh remains intact and healthy.
Peveto Beach Sand Fencing and Vegetative Planting Project (2004)	Beach protection, vegetative plantings	$42,500	Although some fencing and plantings remain, the majority of the project was destroyed by H. Rita. The plantings and sand fencing likely helped stabilize soils from being further displaced.
Lafayette Middle School Marsh Project (2004)	School nursery program	$70,000	The on-site wetland is intact. The nursery did not suffer damage. Project is on-going.
Penny Rhodes Island Restoration (2004)	Marsh creation, shoreline protection	$127,000	The terraces performed very well and appeared to suffer no storm damage. The project helped to reduce wave erosion along adjacent shorelines and to trap sediment during the storms' passing.
Lake Pontchartrain Wetland Restoration- Phase 2 (2005)	Vegetative plantings, shoreline protection	$43,000	The plantings and much of the Lake Pontchartrain shoreline were damaged during the storms. The project is ongoing to replace the lost vegetation and colonize additional sections of shoreline.
Lake Pontchartrain Artificial Reef Program (2005)	Reef restoration	$22,000	Post-storm construction, not yet complete.
Lake Boudreaux Marsh Creation (2005)	Marsh Creation, levee protection	$73,700	Post-storm construction. Intended to provide a marsh buffer for added protection to a hurricane protection levee. Not yet complete

Enhancement of Oyster Reef Development at Grand Isle (2005)	Reef restoration, shoreline protection	$41,200	Post-storm construction, not yet complete.
Plumb Point Marsh Restoration (2005)	Vegetative plantings, shoreline protection	$62,300	Post-storm construction. Intended to restore marsh damage and shoreline erosion within area impacted by H. Rita.
Lafitte Wetlands Restoration Using Treated Municipal Effluent (2006)	Hydrologic restoration, freshwater and nutrient introduction	$57,700	Post-storm construction. Intended to encourage beneficial use of municipal effluent as water treatment facilities are repairing storm damage. Not yet complete
Avoca Island Marsh Restoration (2006)	Hydrologic restoration, shoreline protection	$75,000	Post-storm construction.
Vermilion Bay Oyster Reef Restoration (2006)	Reef restoration, shoreline protection	$67,000	Post-storm construction. Intended to encourage reef development in Vermilion Bay and help repair adjacent shorelines eroded during the storms.
North Vermilion Bay Shoreline Restoration (2006)	Vegetative plantings, shoreline protection	$30,000	Post-storm construction. Monitoring data of similar projects in this area indicate a high colonization rate of vegetation and corresponding reduction of shoreline erosion rates.
Nicholls State University Native Plant Nursery (2006)	Nursery program, shoreline protection	$90,000	Post-storm construction.
Jean Lafitte National Park Bayou Debris Removal (2006)	Marine debris removal	$42,100	Post-storm construction. Intended to clean out 5 miles of natural bayou systems completely silted in during the storms. Will restore ecological and human access to waterways within park, not yet complete.
Avoca Island Marsh Terracing (2006)	Marsh creation	$60,000	Post-storm construction, not yet complete.
Bayou Terrebonne Terracing Project (2006)	Marsh creation, shoreline/levee protection	$75,000	Post-storm construction. Intended to restore marsh damaged by storms and to provide a marsh buffer for added protection to bayou levee. Not yet complete.

Appendix 6. Projects Under Consideration for the Mississippi Comprehensive Plan with a Coastal Habitat Restoration, Enhancement, and/or Protection Component (see Chapter 5)

Project Title	Description of Habitat Component
Front Beach Blvd Ecosystem Restoration and Erosion Control	Restoration of beach shoreline
Round Island Ecosystem Restoration/Round Island Lighthouse Relocation	Restoration of tidal channels to marsh
West River Delta restoration	Beneficial use of dredged material
West Ship Island	Beach nourishment on the north shore of Ship Island east and in front of Fort Massachusetts, a national historic site
Addition of Wetlands Along Main Drainage Systems	Wetland creation
Belle Fontaine Marsh	Sediment removal from damaged marsh, restoration of topography, vegetative plantings, potential construction of an offshore submerged breakwater
Bennett Bayou Tidal Marsh Restoration	Wetland restoration in a highly visible project area for public education and promotion of the Governor's Restoration Initiative
Biloxi Back Bay Watershed Management and Ecosystem Restoration	Beach restoration, sediment removal from marshes and tidal channels, vegetative plantings, freshwater management strategies for enhanced saltwater control in estuarine environments
Biloxi Marshes Comprehensive Ecosystem Restoration	Marsh restoration
Clermont Lake Ecosystem Restoration	Beach restoration, sediment removal from marshes and tidal channels, vegetative plantings, freshwater management strategies for enhanced saltwater control in estuarine environments
Coastal Mississippi Artificial Reef Project for Remediation of 2005 Hurricane Damage	Artificial reef construction, repair of damaged existing reefs, placement of fill for protection of reefs
Davis Bayou Ecosystem Restoration	Sediment removal from damaged marsh, restoration of topography, vegetative plantings
D'Iberville Wetlands Ecosystem Restoration	Beach restoration, sediment removal from damaged marsh, restoration of topography, vegetative plantings
Escatawpa River Diversion	Diversion of water from Escatawpa River into Bayou Cumbest to restore freshwater flow to the bayou and improve water quality
East Beach Road Ecosystem Restoration	Beach restoration, sediment removal from damaged marsh, restoration of topography, vegetative plantings, potential construction of an offshore submerged breakwater
Highway 90 Ecosystem Restoration	Ecosystem restoration along Highway 90 in Jackson County

Project Title	Description of Habitat Component
Grand Batture Island Ecosystem Restoration	Restoration of damaged island habitat and vegetative plantings
Greenwood Island Ecosystem Restoration	Restoration of damaged island habitat and vegetative plantings
Hancock County Beach Ecosystem Restoration	Relocation of highway and construction of erosion protection
Jackson County Seawall Improvement	Improve the Jackson County seawall through beach construction, marsh construction, or a combination of these and other elements
Jackson County Marsh Outlet Ecosystem Restoration	Removal of debris and fill, removal of bulkhead, salt marsh restoration
Jordan River Shores Ecosystem Restoration	Restoration of hydrology, mitigation for prior impacts, and prohibition of future development
Lakeshore Beach Ecosystem Restoration	Beach restoration, sediment removal from damaged marsh, restoration of topography, vegetative plantings
Beneficial Use of Dredged Materials	Maximize beneficial use of dredged materials
Mississippi Coastal Barrier Island Restoration	Temporary containment for sand fill, sand placement, erosion control measures saltwater intrusion prevention
Pascagoula Beach Blvd Restoration	Construction of boardwalk, beach, and marsh along Pascagoula front beach
Pascagoula Beaches Erosion Control	Construction of offshore breakwaters, dunes, reefs, and/or marshes to dissipate wave energy
Pascagoula Breakwater	Beach restoration and potential offshore submerged breakwater
Pearlington Ecosystem Restoration	Homeowner buy-out homeowners and restoration of hydrology
Oyster Reef Restoration	Restore 100 acres of oyster reef
Marsh Island	Restoration and expansion of Marsh Island
Restoration of Traditional Shrimping and Fishing Areas	Removal of storm debris from aquatic environments
Seagrass Restoration	Restoration of seagrass beds in Mississippi Sound
Shoreline Park Buy-out	Prohibition of development in marsh areas
St Louis Bay Comprehensive Ecosystem Restoration	Beach restoration, sediment and debris removal from marshes and tidal channels, vegetative plantings, freshwater management strategies for enhanced saltwater control in estuarine environments
Tchoutacabuffa River Flood Damage and Watershed Improvement	Examination of long-term watershed measures to ensure marsh restoration and preservation, as well as fish and wildlife preservation
Turkey Creek: Mt Pleasant UME Audubon Site 41	Tidal creek restoration of flood plain
West Pascagoula Delta Flood Damage Reduction and Ecosystem Restoration/Study	Beach restoration, sediment and debris removal from marshes and tidal channels, vegetative plantings, freshwater management strategies for enhanced saltwater control in estuarine environments
Wetland Area Buy-outs	Prohibition of development in wetland areas
Magnolia Branch Ecosystem Restoration	Use conservation easements to restore magnolia branch
Mississippi River Gulf Outlet Closure	Restoration of more natural freshwater flows by closing the Mississippi River Gulf Outlet
Inclusion of Cat Island in the Gulf Islands National Seashore	Increased habitat protection on Cat Island through its inclusion in the Gulf Islands National Seashore
Deer Island Ecosystem Restoration	Restoration of damaged habitat through placement of fill and vegetative plantings