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The Ecological Condition of Estuaries in the Gulf of Mexico

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U.S. Environmental Protection Agency
Office of Research and Development
National Health and Environmental Effects Research Laboratory
Gulf Ecology Division
Gulf Breeze, Florida 32561

Interagency Agreement #DW14938557
J. Kevin Summers, Project Officer

This study was conducted in cooperation with
Department of Interior, United States Geological Survey,
Biological Resources Division
Gulf Breeze Project Office

National Health and Environmental Effects Research Laboratory
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Washington, D.C. 20460

Disclaimer

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Acronyms

USEPA	U.S. Environmental Protection Agency
EMAP	Environmental Monitoring and Assessment Program
EMAP-E	Environmental Monitoring and Assessment Program - Estuaries
NEP	National Estuary Program
NERRS	National Estuarine Research Reserve System
NPDES	National Pollution Discharge Elimination System
NOAA	National Oceanic and Atmospheric Administration
ADEM	Alabama Department of Environmental Management
ALAMAP	Alabama Monitoring and Assessment Program
R-EMAP-TX	Regional Environmental Monitoring and Assessment Program - Texas
NSSP	National Shellfish Sanitation Program
MNET	Gulf of Mexico Aquatic Mortality Network
USGS	United States Geological Survey
CCMP	Comprehensive Conservation and Management Plan
OCS	Outer Continental Shelf
AVHRR	Advanced Very High Resolution Radiometer
DO	Dissolved Oxygen
HAB	Harmful Algal Bloom
NSP	Neurotoxic Shellfish Poisoning
ER-L	Effects Range - Low (Long et al. 1995)
ER-M	Effects Range - Median (Long et al. 1995)
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
DDT	Dichlorodiphenyltrichloroethane
TBT	Tributyltin
SAV	Submerged Aquatic Vegetation

Executive Summary

The Gulf of Mexico is a vast natural resource encompassing the coastal areas of western Florida, Alabama, Mississippi, Louisiana, and Texas, as well as a portion of Mexico. Many estuaries flow into the Gulf of Mexico and serve as nursery grounds for fish, habitat for a wide variety of wildlife, shipping routes, and a source of recreation. Estuarine-dependent species constitute more than 95 percent of the commercial fishery harvests from the Gulf of Mexico, and many important recreational fishery species depend on estuaries during some part of their life cycle. Gulf estuaries are diverse and productive ecosystems that provide a variety of valuable resources, including fish and shellfish, recreation, transportation, and water supply.

Assessing the overall condition of Gulf of Mexico estuaries required incorporating data from other federal, state, and local monitoring programs to augment the information on ecological indicators collected by the U.S. Environmental Protection Agency's (USEPA) Environmental Monitoring and Assessment Program (EMAP). The resulting document would provide a synthesis of the available knowledge about the condition of Gulf of Mexico estuaries. This document is intended for use by scientists and other citizens concerned with the ecological condition of estuaries, as well as by managers and lawmakers interested in the sustained use of estuaries for commercial and recreational purposes. It also addresses public concerns about the aesthetic quality of coastal areas vital to tourism and recreation. By producing this report on the ecological condition of estuaries in the Gulf of Mexico, we have taken one step in assessing the health of this environmental resource. We have produced an environmental "report card" to be used as a guide in the evaluation of management decisions and research directions.

This report is organized in three parts: (1) an introduction that gives background information on the Gulf of Mexico, estuarine ecology, and the factors that impact estuaries in the gulf, (2) the main section on priority ecological indicators used to measure the condition of estuaries in the gulf and (3) an ecological report card that summarizes the data on ecological indicators and provides a rating of the condition of estuaries in each gulf state and for gulf estuaries overall. Many of the ratings were based on the percent area of estuaries in each state exhibiting degraded or adverse levels of an indicator.

Eutrophication, a condition of high nutrients often resulting in low oxygen levels and other adverse effects, is an important water quality concern for estuaries along the gulf coast. The National Oceanic and Atmospheric Administration (NOAA) has compared the Gulf of Mexico to other coastal regions like the middle Atlantic and has ranked the Gulf of Mexico as having the highest number of point sources of nutrients and the highest percentage of land use devoted to agriculture. We evaluated monitoring data for nitrogen, chlorophyll, and dissolved oxygen as indicators of eutrophication. Although most of the estuaries exhibited high nitrogen or chlorophyll or low dissolved oxygen concentrations at least once during a survey, many times these conditions were observed in small rivers or bayous rather than in the entire estuary. Often, the percent area affected was low. The gulf estuaries had moderate conditions overall for nutrients and dissolved oxygen. Definite nutrient problems were observed in >25% of the estuarine area in Louisiana and Texas and definite dissolved oxygen problems were observed in Alabama.

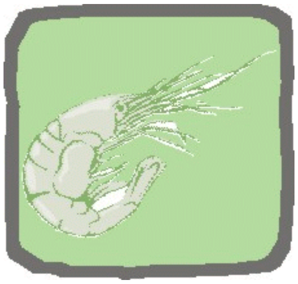
Contaminants in estuarine sediments provide evidence of the accumulation of chemicals from anthropogenic sources. We compared the concentrations of sediment contaminants to established guideline values to determine the proportion of estuarine area that could have potential adverse effects on living organisms. Although detectable levels of contaminants were measured in almost every estuary in the Gulf of Mexico, <25% of the estuarine area in all states had contaminant concentrations that exceeded these guidelines.

Wetlands are integral parts of estuarine systems. Declining acreage means habitat loss that may be the result of commercial and residential development, hydrologic alterations, or dredge and fill operations. The Gulf of Mexico region contains more than 50% of the coastal wetland acreage in the U.S. and yet it also has the highest rate of coastal wetland loss. Nine of the top ten estuarine drainage areas ranked by total wetland area are in the Gulf of Mexico region. The most current estimates of total wetland loss over the past 200 years range from 41% to 54% for the gulf states. Although coastal wetlands continue to be altered or destroyed, some estimates indicate that the rate of loss has slowed. All gulf states were rated as having severe problems with wetland loss.

The condition of benthic (bottom-dwelling) invertebrates, fish and shellfish, birds, and threatened and endangered species was used to evaluate the health of estuarine fauna. Degraded benthic communities inhabited <25% of the estuarine area in all gulf states except for Texas. Commercial fish and shellfish landings may be used as an indicator of population stability while fish biomarkers are used to measure the health of individuals in the population. Commercial landings of the top four fisheries (shrimp, menhaden, blue crab, and oyster) are stable in the gulf states while fish biomarkers indicate fair to poor fish health in Alabama and Texas and good fish health elsewhere. Coastal and marine bird populations appear to be in good condition throughout the gulf. Four threatened or endangered species inhabit coastal areas in the Gulf of Mexico: brown pelican, Gulf sturgeon, manatee, and Kemp's ridley sea turtle. In general, populations of these species are in good to fair condition in the gulf states.

Public health indicators include shellfish bed closures and chemicals found in edible fish tissue. Harvest of shellfish (primarily oyster in the Gulf of Mexico) is restricted or prohibited when concentrations of bacteria or other pathogens reach levels that could impair human health. The gulf states contain the most acreage of shellfish-growing waters in the U.S. but also have the most acreage restricted for harvest. All gulf states except Mississippi have >25% of their shellfish-growing waters restricted for harvest, mostly due to pollution from wastewater treatment plants or other upstream sources. Advisories may be issued that limit consumption when the concentrations of chemicals in fish tissue exceed levels known to be harmful to humans. Although seafood consumption advisories have been issued in all gulf states, the percent of the fish population with high concentrations of contaminants is relatively low in the gulf overall.

Table of Contents



Introduction

The U.S. Gulf of Mexico region encompasses two biogeographical provinces: 1) The Louisianian Province which covers estuarine systems from Rio Grande, Texas, to Anclote Key, Florida and 2) the West Indian province which includes the western Florida coast from Tampa Bay to the Florida Keys (Fig. 1; estuaries in Mexico were not included in this assessment). This expanse includes many large estuarine systems (surface area > 280 km^2) such as Corpus Christi Bay, Galveston Bay, Sabine Lake, Vermilion-Atchafalaya Bay, Terrebonne Bay, Barataria Bay, Breton Sound, Lake Pontchartrain, Mobile Bay, Pensacola Bay, Choctawhatchee Bay, Tampa Bay, and Florida Bay, in addition to several hundred small estuaries.

Estuaries are bodies of water that are balanced by freshwater and sediment influx from rivers and the tidal actions of the oceans, thus providing transition zones between the freshwater of a river and the saline environment of the sea. The result of this interaction is an environment where estuaries, along with their adjacent marshes and seagrasses, provide a highly productive ecosystem, that supports wildlife and fisheries and contributes substantially to the economy of coastal areas. As spawning, nursery, and feeding grounds, estuaries are invaluable to fish and shellfish. Estuarine-dependent species constitute more than 95 percent of the commercial fishery harvests from the Gulf of Mexico, and many important recreational fishery species depend on estuaries during some part of their life cycle. Gulf estuaries are diverse and productive ecosystems that provide a variety of valuable resources, including fish and shellfish, recreation, transportation, and petroleum and minerals.

What began as an overall summary of the activities of the USEPA's Environmental Monitoring and Assessment Program for Estuaries (EMAP-E) in the estuaries of the Louisianian and West Indian provinces (the Gulf of Mexico and south Florida) has evolved into the report you see here. One of EMAP-E's goals was to assess ecological conditions using environmental monitoring data from multiple spatial and temporal scales. From 1991 to 1995 EMAP collected data on ecological indicators from estuaries in the Gulf of Mexico. The ecological condition of these estuaries was reported in annual statistical summaries that enumerated areas found to have deleterious conditions (e.g., low dissolved oxygen, degraded benthic habitat, or contaminated sediments).

Evidence of the diminishing quality of our estuaries has been found in the large amounts of debris washing up on shores; beach closures due to trash, bacteria, or red tide; reduced water clarity and water quality; fish consumption advisories issued to warn consumers of contaminated fish; shellfish bed closures; and fishing bans. This evidence contributes to the public's perception that something must be done to restore our estuaries to a healthy state. In

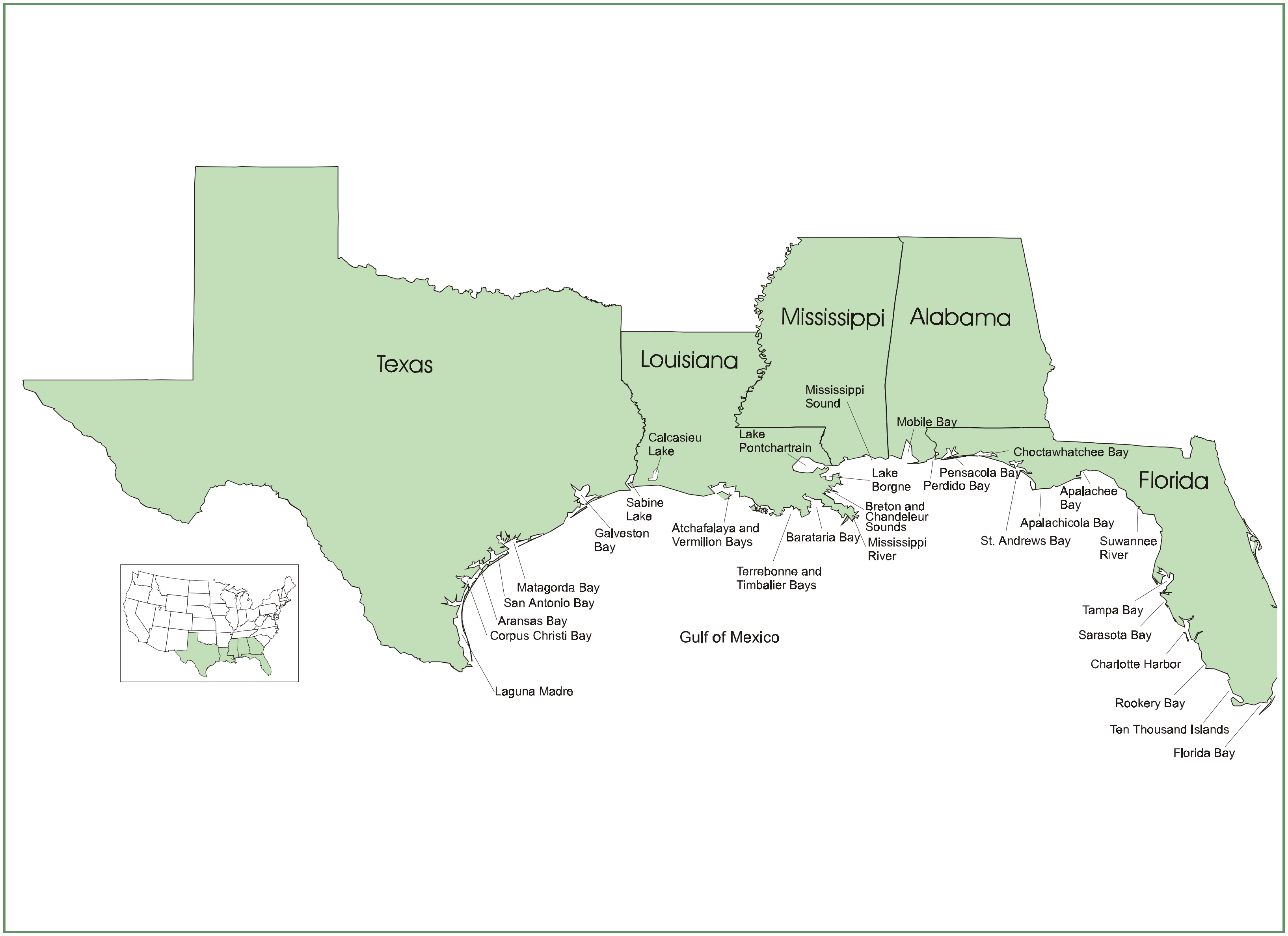


Fig. 1. Estuarine systems located in the Gulf of Mexico (United States; NOAA 1997).

order to effectively gauge whether future management actions are improving the situation, however, a baseline for gulf-wide estuarine conditions must first be established. The current report focuses on the ecological condition or health of estuaries in the Gulf of Mexico, using indicators that are well established in the scientific community and incorporating both the most current information and historical trend data where available. This report provides much-needed information to scientists and others concerned with the ecology of estuaries, and to managers and lawmakers concerned with the sustained use of estuaries for commercial and recreational purposes. It will also address public concerns about the aesthetic quality of coastal areas that are vital to tourism and recreation.

Estuaries and Their Value

Estuaries and wetland environments are intertwined. Coastal emergent wetlands border estuaries and the Gulf of Mexico and include tidal saltwater and freshwater marshes and mangroves. Encompassing over two million hectares (five million acres or more than half of the national total), the Gulf of Mexico coastal wetlands serve as essential habitat for a diverse range of species. These wetlands are used by shorebirds, migratory waterfowl, fish, invertebrates, reptiles, and mammals. A large percentage of the migrating waterfowl and migrant Neotropical birds of the U.S. utilize these coastal habitats. Mudflats, salt marshes, mangrove swamps, and barrier island habitats also provide year-round nesting and feeding grounds for abundant populations of gulls, terns, and other shorebirds. Gulf estuaries and marshes and associated watersheds provide habitat for many threatened and endangered species, including sea turtles (e.g., leatherback, hawksbill, Kemp's ridley, loggerhead, and green), piping plover, bald eagle, brown pelican, Gulf sturgeon, West Indian manatee, and American crocodile. Estuaries and wetlands support complex food webs that provide an abundant food source for juvenile and adult fishes (Fig. 2). In addition to providing habitat, wetlands also improve water quality by filtering pollutants and sediment and offer a buffer zone to protect upland areas from flooding and erosion.

Estuaries provide humans with a variety of uses. They both supply water and provide a point of discharge for municipalities and industries, and support agriculture, commercial and sport fisheries, and recreational uses such as swimming, diving, and boating. The complex network of channels and wetlands within the gulf shoreline provides habitat for estuarine-dependent commercial and recreational fisheries. In the Gulf of Mexico commercial and recreational fisheries and tourism are economically important. Tourism in the gulf coast states contributes an estimated $20 billion to the economy each year. The Gulf of Mexico ranks second only to Alaska in total commercial landings. The rich waters yielded approximately 684 million kg (1.51 billion pounds) of fish and shellfish in 1996. This represented at least a two-fold increase in the commercial landings of fish in the gulf since 1950, with the peak years from 1982 to 1987 yielding more than one billion kg of fish and shellfish annually (Fig. 3). Worth more than $689 million at dockside, the 1996 harvest represented 33% of the total annual domestic harvest (excluding Alaska) of commercial fish.

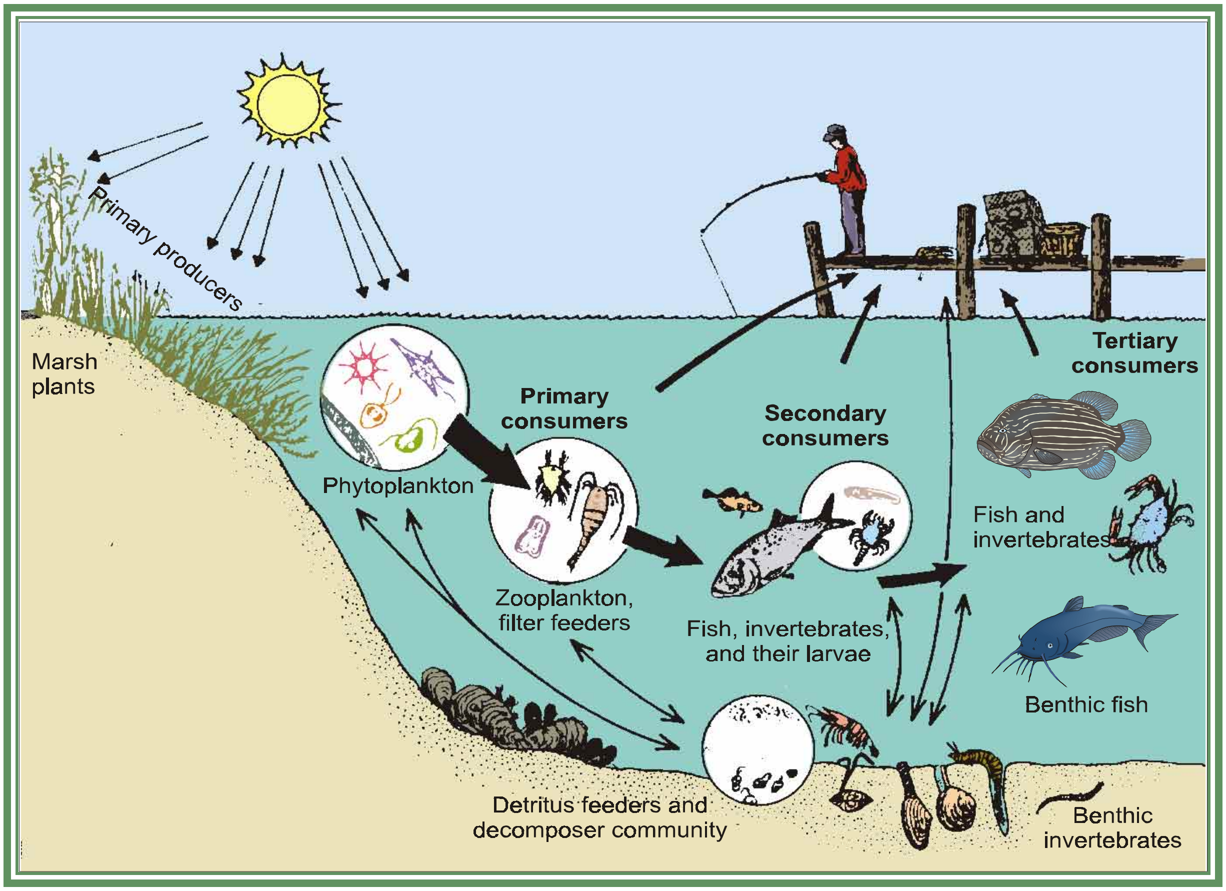


Fig. 2. Conceptual diagram of the food web in Gulf of Mexico estuaries (redrawn from Weber, et al., 1992).

The gulf boasts the largest and most valuable shrimp fishery in the U.S. (99 million kg or 69% of the national total in 1996) and also contributed 57% of total oyster production in the U.S. in 1996. Other important gulf fisheries include crabs and spiny lobsters, menhaden, herring, mackerel, tuna, grouper, snapper, drum, and flounder. The entire Gulf of Mexico fishery yields more finfish, shrimp, and shellfish annually than the south and mid-Atlantic, Chesapeake, and Great Lakes regions combined. The gulf's waters draw millions of sport fisherman and beach users each year. It is estimated that the gulf supports more than one-third of the national marine recreational fishing, hosting 4.8 million anglers in 1995, who caught an estimated 42 million fish.

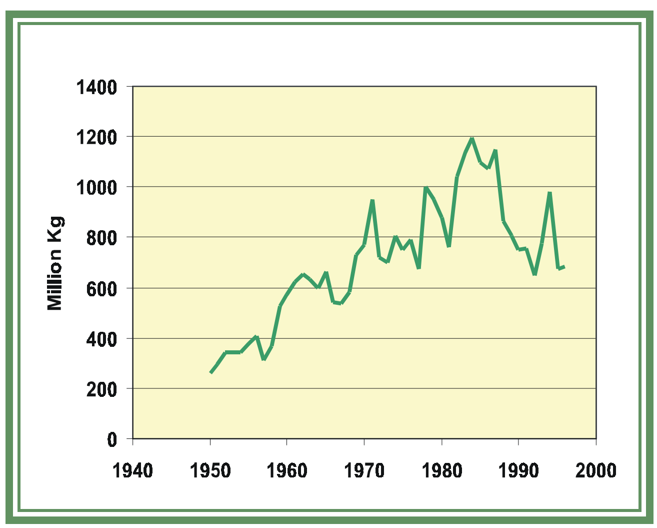


Fig. 3. Commercial landings in million kg of all species from Gulf of Mexico waters from 1950 to 1996 (National Marine Fisheries Service).

Gulf oil and gas production are equally valuable to the region's economy and are a critical part of the nation's total energy supply. In 1990, more than 1,600 Outer Continental Shelf (OCS) leases were in production (Melancon et al 1997). OCS royalties from the Gulf of Mexico annually contribute about $3 billion to the Federal Treasury. The Gulf of Mexico ranks second only to Alaska in terms of potential petroleum reserves, contributing 13% of the U.S. domestic oil and gas production in 1994 (Lore et al 1996). The Minerals Management Service projects a doubling in Gulf of Mexico oil production by the year 2000. Petroleum and chemical products also constitute the majority (69%) of shipping tonnage that passes through gulf ports and harbors.

Shipping and marine transport is an important industry in the gulf. Seven of the top ten busiest ports in the U.S. in terms of total tonnage are located in gulf estuaries (Port of South Louisiana, Houston, Baton Rouge, New Orleans, Port of Plaquemines, Corpus Christi, and Tampa). Shipping tonnage in the gulf has increased from 83 million tons in 1982 to 118 million tons in 1995 with 98% of the traffic traveling via the intracoastal waterway.

Population Distribution

Millions of people live along the Gulf of Mexico coastline, attracted by its shorelines and waterways, temperate climate, and abundant resources. The 1990 census indicated that coastal counties in the Gulf of Mexico accounted for only 11% of the nation's total coastal population and had the lowest population density (187 persons per square mile) of all coastal regions of the continental U.S. (i.e., northeast, southeast, Great Lakes, and Pacific, excluding Alaska and Hawaii). The coastal counties in the gulf are experiencing the second fastest rate of growth; between 1970 and 1980, the population grew by more than 30 percent, and between 1980 and 1990, the population grew by more than 16% (Fig. 4). Texas and Florida have the largest populations in coastal counties of the Gulf of Mexico and similar relative growth rates (Fig. 4). All but four coastal counties in Florida had more than a 100% increase in population from 1950 to 1990 (Fig. 5). According to projections by the U.S. Department of Commerce, the gulf's total coastal population will increase by 144 percent between 1960 and 2010, to almost 18 million people. This increase in population is a concern due to the added impacts and competing needs for the gulf's natural resources.

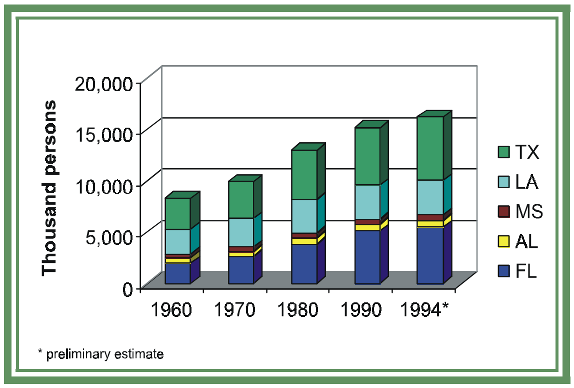


Fig. 4. Population estimates based on the 10-year Census for coastal counties in the Gulf of Mexico (U.S. Census Bureau).

A growing population will require land to expand into, converting other habitats such as forest or agriculture to urban areas. Increased housing and road construction puts pressure on the receiving waters that have to assimilate the additional storm water runoff from the

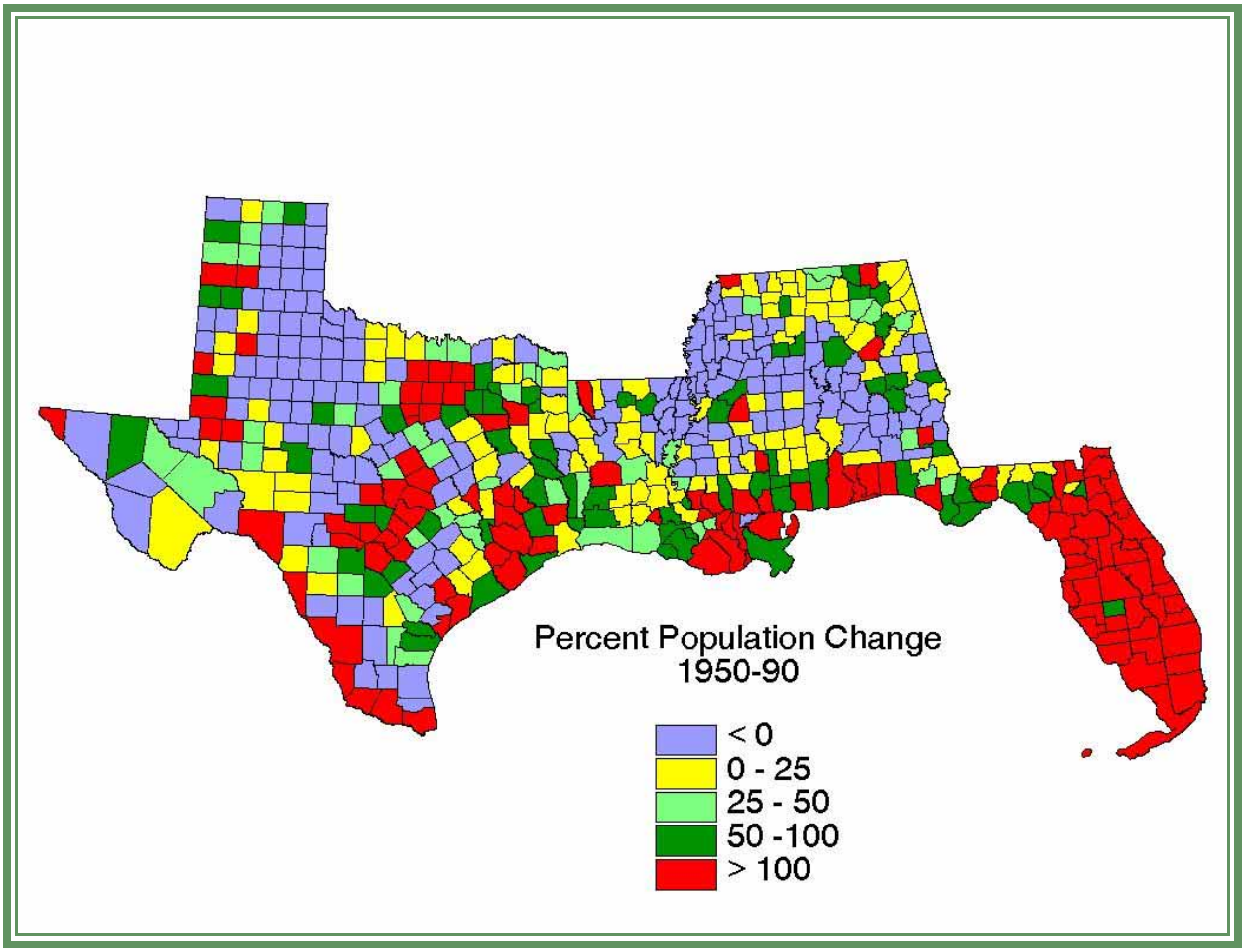


Fig. 5. Percent change in population from 1950 to 1990 in counties of Florida, Alabama, Mississippi, Louisiana, and Texas (U.S. Census Bureau).

expanding impervious surfaces associated with urbanization. A growing population also generates more wastewater and solid waste that require disposal and increase emission of pollutants to the air. Pollutants carried in water runoff and by atmospheric deposition affect the health of estuaries.

Consequences of Human Usage

The ability of estuaries to function as nursery grounds depends upon the quantity, timing, and location of freshwater inflows. Estuarine ecosystems are impacted by humans, primarily via upstream withdrawals of water for agricultural, industrial, and domestic purposes; contamination by industrial and sewage discharges and agricultural runoff carrying pesticides and herbicides; eutrophication caused by excessive nutrient inputs from a variety of nonpoint (agricultural drainage, faulty septic systems) and point sources (sewage treatment plants); and habitat alterations (e.g., construction and dredge and fill operations). Common effects of human use of estuaries include degraded natural habitats, declining plant and animal populations, diminishing fish and shellfish harvests, and impaired water quality. These

Effects of human use on estuaries:

- Texas, Louisiana, and Alabama ranked first, second, and fourth in the nation in 1995 in terms of discharging the greatest amounts of toxic chemicals.
- More than half of the oyster producing areas along the gulf coast are permanently or conditionally closed. These closure areas are growing as a result of increasing human and domestic animal populations along the gulf coast.
- Diversions and consumptive water use for human activities have resulted in significant changes in the quantity and timing of freshwater inflows to the Gulf of Mexico habitats.
- Louisiana is losing valuable coastal wetlands at the rate of approximately 65 km^2 (25 mi^2) per year.
- Up to 18,000 km^2 (7,000 mi^2) of oxygen deficient (hypoxic) bottom waters have been documented off the Louisiana and upper Texas coasts.

Source: Gulf of Mexico Program, 1994.

effects are clearly observable in some estuaries of the Gulf of Mexico. Growth of human populations in the estuarine watersheds, combined with industrial and agricultural discharges, places more demands on the natural resources. In some areas, estuaries are unable to safely assimilate the amounts of pollution being added to the system and become adversely affected. Most problems observed in estuaries are related to land use practices and to human population density.

Land Use Patterns

Understanding land use within watersheds is a prerequisite to understanding the ecological condition of Gulf of Mexico estuaries. Gulf estuaries encompass approximately 30,000 km^2 (42% of the total estuarine surface area of the U.S. excluding Alaska). Including the Mississippi River, the Gulf of Mexico drainage area encompasses more than 4 million km^2 or more than 55% of the total area of the conterminous U.S. (Fig. 6). The Gulf of Mexico receives an average of 27,473 cubic meters per second of freshwater inflow daily (more than 50% of the daily average for the continental U.S.). Although the land use within the entire watershed determines what materials are carried by runoff into estuaries, we estimated the percent area that was classified into land use categories of just the five gulf states and not the entire watershed. Forest and agriculture comprise approximately 58% of the land area in the five gulf states (Fig. 7). While forests provide filtration for sediment and nutrients from runoff, as well as structure to stabilize shoreline and reduce erosion, many of the forests are in areas distant from the shores of the estuarine waters. Many are being replaced by urban and agricultural expansion.

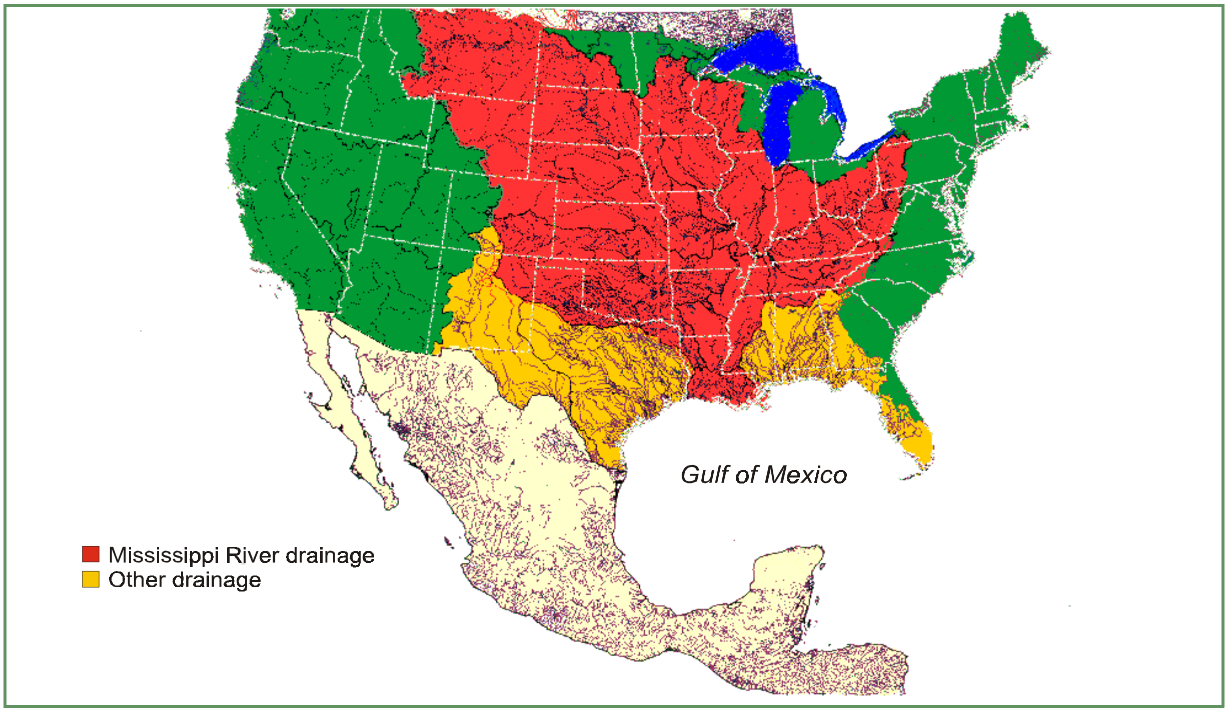


Fig. 6. Sources of freshwater inflow into the Gulf of Mexico from the Mississippi River and non-Mississippi watersheds. (USEPA, Region 6)

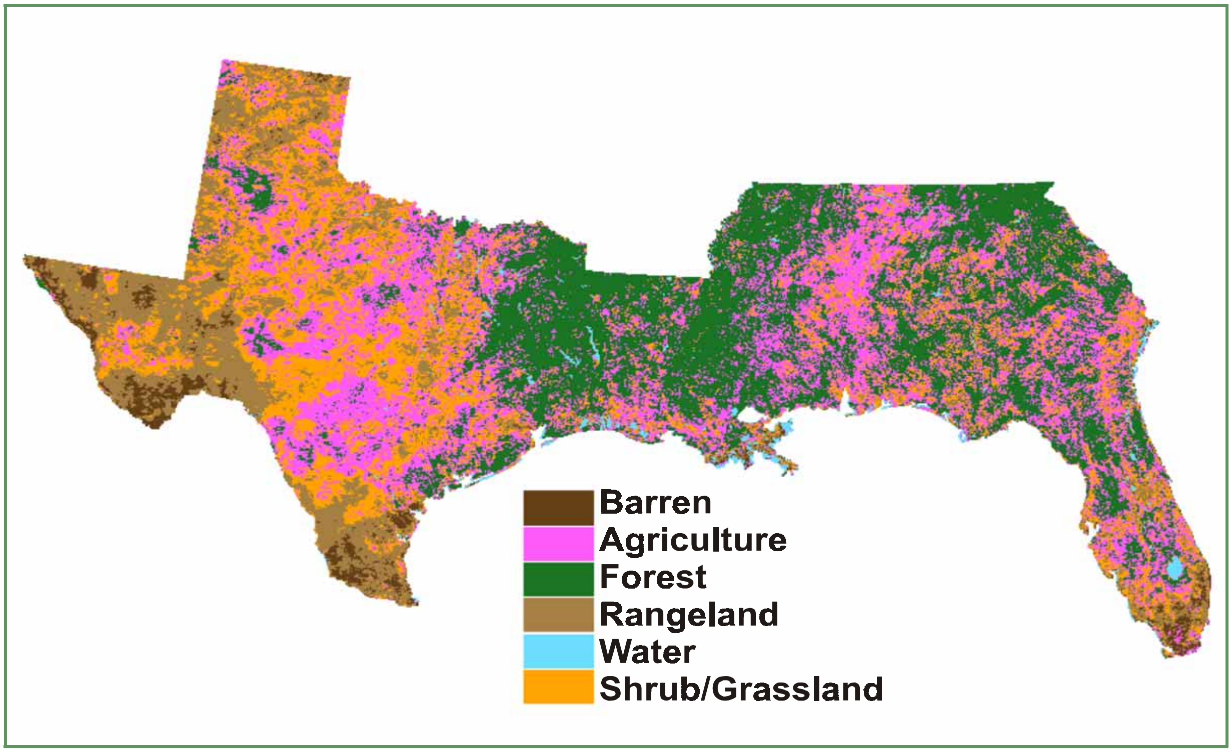


Fig. 7. Satellite Advanced Very-High Resolution Radiometer (AVHRR) image of vegetation types in the gulf coast states (USGS Earth Resources Observation Systems Data Center).

Agricultural land can be divided into pasture and cropland. Pasture land consists of grassy areas for raising and feeding livestock, while cropland consists of cultivated areas which provide various food products. Other land uses include wetland habitats (17%) and urban areas (5%) that are generally located close to the coastline.

Natural Habitat Characteristics

Salinity, temperature, water depth, and sediment type are the primary natural habitat characteristics that affect estuaries. Water depth affects the distribution of shellfish and submerged aquatic vegetation. Salinity is influenced by rainfall and tidal surges and affects the distribution of benthic animals, fish, and plants. Temperature is relatively stable in Gulf of Mexico estuaries, but changes in temperature can influence when animals feed, reproduce, move locally, or migrate. Sediment type is an important factor determining the composition of the benthic community and in the sediment's potential for absorption and adsorption of contaminants.

- Average water depth of estuaries in the Gulf of Mexico is 3 m, with maximum depths (greater than 10 m) occurring in dredged shipping channels and the Mississippi River.
- Gulf sediments change from terrigenous to carbonate as one goes from west to east. EMAP's survey of estuarine sediments found that they are primarily mud (more than 80% silt-clay) and mixed mud-sand (20-80% silt-clay) from Tampa Bay, Florida, to the Rio Grande, Texas (Fig. 8). In south Florida, however, sediments are primarily sand (less than 20% silt-clay).
- Water clarity is valued by society and contributes to the maintenance of productive biological communities. We define low water clarity as less than 10% transmission of ambient light at 1m depth or water in which divers would not be able to see their hands when held at arm's length. Moderate water clarity is defined as 10-25% transmission of ambient light at 1m depth or as water in which waders are unable to see their feet in waist-deep water. Few gulf estuaries have low water clarity (Fig. 8).
- Estuaries are characterized by gradients in salinity from near fresh water at the mouths of tributaries to near marine at the mouth of the estuary. Gulf of Mexico estuaries are predominantly polyhaline (more than 18 ppt) during the summer months (Fig. 8).
- Shallow estuaries are less able than are deeper ones to store heat, and water temperature fluctuates from 4 to 32°C annually.
- Stratification of the water column occurs when layers of water with different salinity or temperature do not mix. In the gulf this usually occurs during the summer but is highly variable and often diurnal in nature. Benthic organisms are exposed to rapidly fluctuating dissolved oxygen and salinity due to tides and inflow.

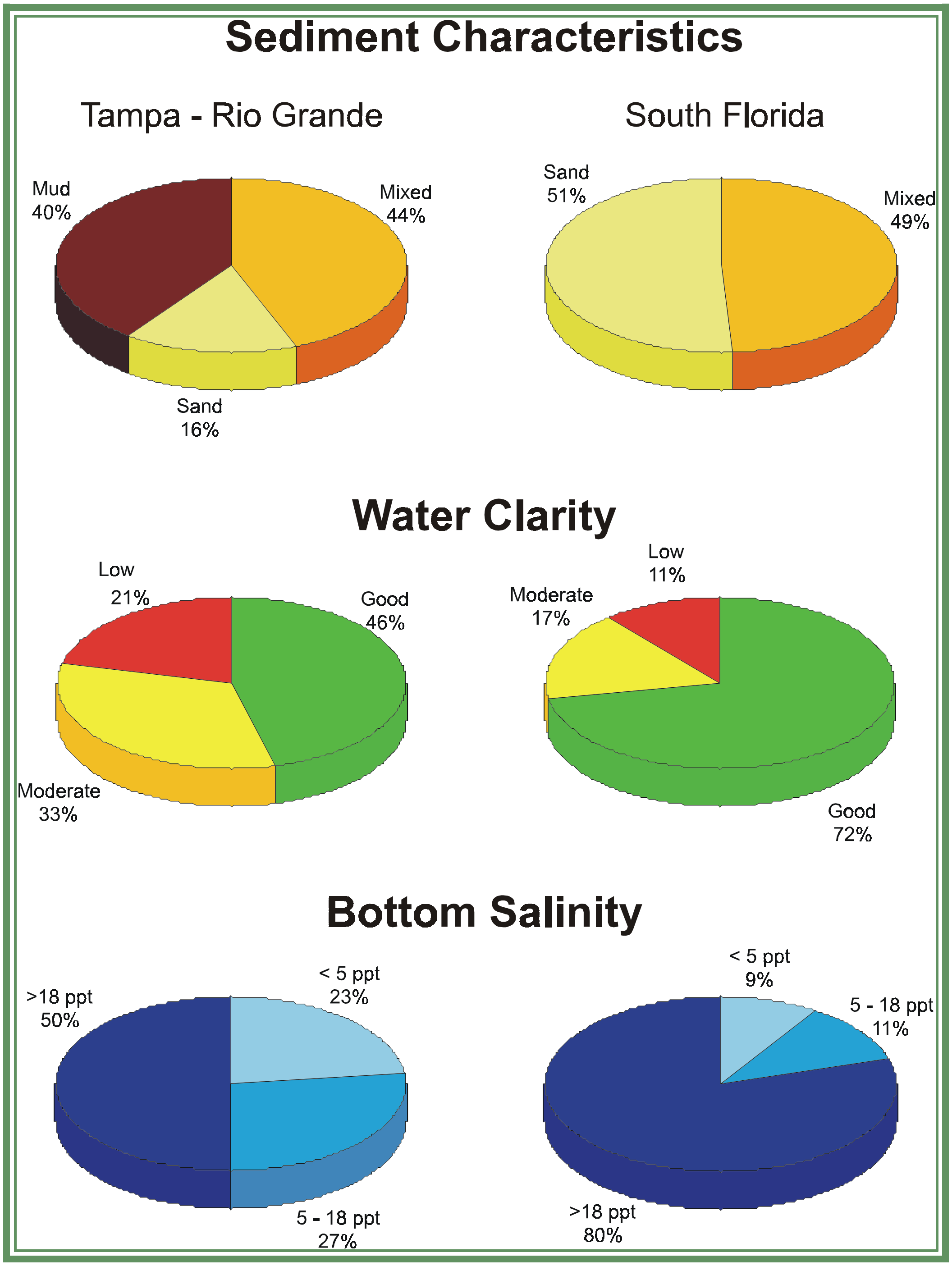


Fig. 8. Distribution of sediment characteristics, water clarity, and salinity condition in estuaries from the Gulf of Mexico. Percentages represent percent area of the Louisianian Province (Tampa-Rio Grande) and the West Indian Province (South Florida); USEPA EMAP-E Database for the Louisianian [1991-1994] and West Indian [1995] Province.

Federal Response to Concerns about Estuaries

In 1987, the National Estuary Program (NEP) was started by the USEPA "to protect and restore the health of estuaries while supporting economic and recreational activities." Since then, seven NEP's (Fig. 9) have been established in the Gulf of Mexico, representing partnerships between government agencies responsible for managing estuarine resources and people who depend on estuaries for their livelihood and quality of life. EMAP focused much of its early efforts on determining the status of estuarine habitats nationwide. More recently, attention has been focused on estuaries by the Estuary Habitat Restoration Partnership Act (S.1222, introduced in Congress in 1997), which is specifically designated to provide assistance to communities to restore estuarine habitat.

To achieve the goals of the NEP, the USEPA helps create local partnerships between government agencies responsible for managing estuarine resources and the people who depend on the estuaries for their livelihood and quality of life. A major benefit of the NEP is that it brings communities together to decide the future of their own estuaries. Citizens, business leaders, educators, and researchers work with representatives from government agencies to identify their estuary's problems and to recommend solutions. Each NEP formulates a Comprehensive Conservation and Management Plan (CCMP) that serves as a blueprint for revitalizing the estuary and protecting it from new dangers. The Gulf of Mexico NEP's are demonstrating practical and innovative ways to revitalize and protect their estuaries (see Appendix 1 for brief descriptions of individual NEPs).

Recognizing the natural value of estuaries, Congress created the National Estuarine Research Reserve System (NERRS) in 1972. NERRS is dedicated to fostering a system of estuary reserves that represents the wide range of coastal and estuarine habitats found in the U.S. and its territories. In pursuit of this goal, NERRS works with federal and state authorities to establish, manage, and maintain reserves, and to provide for their long-term stewardship. Research and education are also crucial to meeting this goal. Reserves in the system serve as laboratories and classrooms where the effects of both natural and human activity can be monitored and studied. To date, 22 estuaries nationwide have been designated as NERRS, 3 of which are located along the gulf coast (Fig. 2; see Appendix 1 for brief descriptions of individual NERRS).

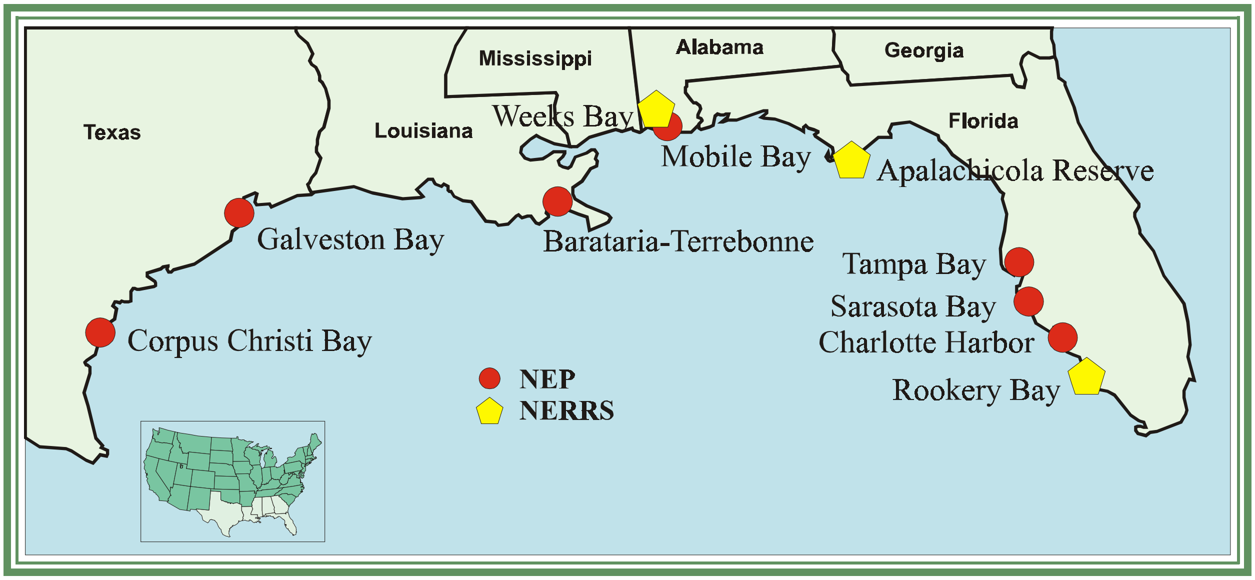


Fig. 9. Locations of National Estuary Programs and National Estuarine Research Reserve Systems in the Gulf of Mexico (USEPA).

Summary

This overview of the estuarine resource characteristics in the Gulf of Mexico sets the context within which to describe the state of the Gulf of Mexico estuaries. For example, a combination of environmental factors may underlie changes in fish abundance, size, and species composition in estuaries. Among these factors are turbidity (water clarity) from resuspension of sediments and phytoplankton growth, salinity, depth, temperature, nutrient enrichment, and pollution. Susceptibility of fish to poor water quality is, in part, determined by the estuarine characteristics. This report provides a review of the state of the estuarine environment in the Gulf of Mexico region. This is a summary of historical information and of our current state of knowledge about a set of indicators of estuarine condition for water and sediment quality, habitat change, condition of living resources, and aesthetic quality. Each indicator is briefly discussed relative to its importance for understanding estuarine condition; then the current condition of the indicator is summarized. Each indicator is then used to assess the status of estuarine condition relative to the indicator. This report is an assessment of the health of estuaries in the Gulf of Mexico based on historical and current conditions. It serves to emphasize how important estuaries are and why we should continue to preserve, protect, and correct problems within the gulf's estuaries.

Freshwater Inflow

Estuaries function as transition zones between the freshwater of a river and the saline environment of the sea and, by definition, receive freshwater inflows. The ability of an estuary to function properly and to sustain populations of animals and plants depends on the quantity, quality, timing, and location of freshwater inflows. The effects of the diversion of freshwater inflow is of great concern to resource managers. Whether freshwater inflow is diverted away from an estuary (e.g., for agriculture or water supply) or into an estuary (e.g., effluent, river discharge diversion), the effects upon an estuary include habitat loss, changes in salinity, and altered nutrient and sediment loads. These changes affect wetlands, phytoplankton, zooplankton, benthos, and fish directly and indirectly by altering suspended sediments, dissolved oxygen, water temperature, pH, and water clarity.

> Functions of freshwater inflow in estuaries:
> - Provide a food supply by stimulating both photosynthesis and microbial decomposition;
> - Deposit sediments that stabilize coastal wetlands against erosion, subsidence, and sea level rise;
> - Drive estuarine circulation and establish salinity gradients; and
> - Create a range of salinities under which plants and animals thrive.

Source: Gulf of Mexico Program, 1994.

The areas throughout the Gulf of Mexico that have been most adversely affected by alterations in freshwater inflow are Florida Bay, the Louisiana coastal marshes, and the Texas gulf coast. Florida Bay receives freshwater inflow from the Everglades, where the natural sheet flow through this wetland has been altered by canals and water management structures. Seagrass die-off, a declining shrimp fishery, algal blooms, and fish kills in Florida Bay have been attributed to the effects of altered freshwater inflow. The vast majority of the freshwater inflow to the Gulf of Mexico comes through the Mississippi River delta. Historically, the natural flow from the Mississippi River deposited sediments on the coastal marshes and deltas of Louisiana; this accretion of sediment countered the loss of land due to subsidence. The Mississippi River's flow is now controlled and managed by levees and dikes. Because of this change in the natural flow, sediments from the Mississippi River are now deposited in the Gulf of Mexico, and the rate of land loss exceeds the rate of accretion in Louisiana's coastal wetlands. In Texas, reduced freshwater inflow to estuaries is of concern to resource managers primarily because of the adverse effects of salinity changes on commercial fish and shellfish as well as other estuarine species. Altered freshwater inflow indirectly affects the metabolism, reproduction, and migration of fish and shellfish as well as other organisms that inhabit estuaries. Texas state agencies are currently assessing the freshwater inflow requirements of estuaries in order to sustain a healthy ecosystem and productivity of fish, shellfish, and other estuarine life.

Water Quality

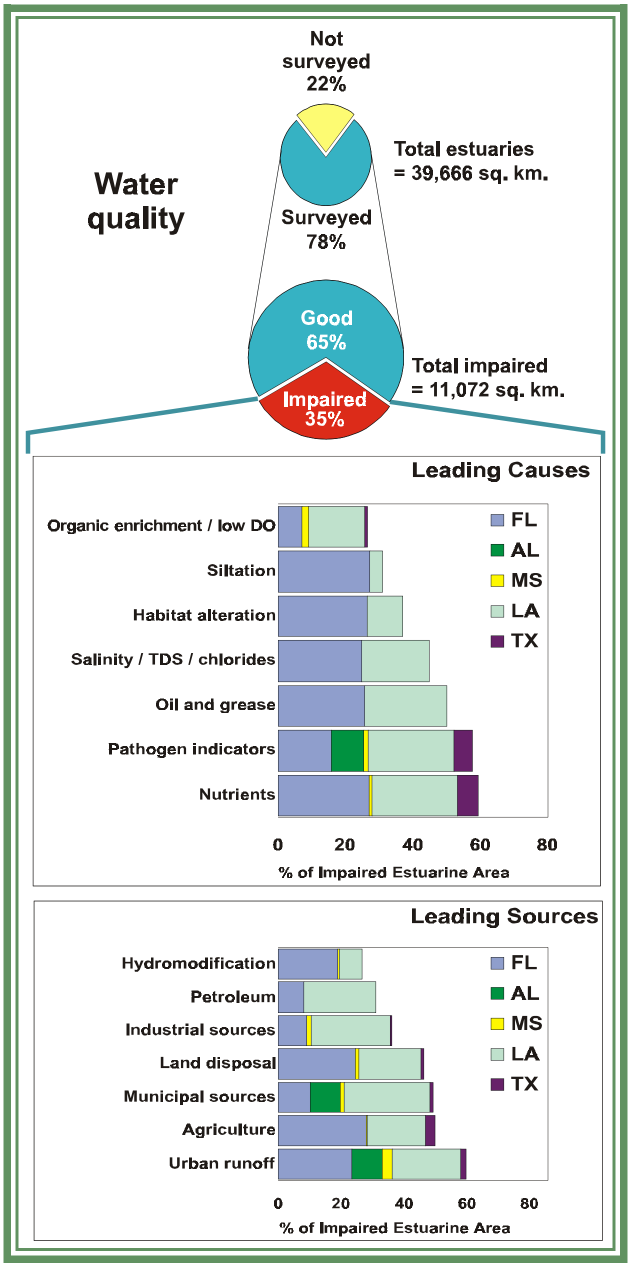


Fig. 10. Summary of classification of estuaries in terms of water quality from 1996 305(b) reports submitted by Florida, Alabama, Mississippi, Louisiana, and Texas.

In the 25 years since the passage of the Clean Water Act, billions of pounds of pollution have been prevented from entering waterways and the number of rivers lakes, streams, and estuaries that are safe for swimming and fishing has doubled (USEPA 1997). Pursuant to Section 305(b) of the Clean Water Act, the states must report on the status of water quality in their jurisdiction every 2 years. The results from the 1996 assessment of water quality in estuaries and coastal waters of the Gulf of Mexico are shown in Fig. 10. Estuaries are classified according to their designated beneficial uses, which represent the desirable activities that water quality should support. For estuaries these include primarily aquatic life support, fish consumption, or recreation. States may require an individual estuary to support multiple uses. The states are responsible for conducting monitoring and assessment programs to evaluate whether or not the water quality in estuaries is fully, partially, or not supporting of the designated uses. In addition, the states identify indicators that document the impact of water quality degradation. States also identify pollutants or processes that are responsible for degraded water quality. The percent of a state's estuaries that has impaired water quality when tracked over time is a good indicator of whether or not efforts to improve estuarine water quality are successful. Of the 78% of total estuarine area in the gulf that was surveyed in 1994-95, 65% fully supported designated uses. Of the estuarine area that was impaired (35%), most of the impairment came from pathogen indicators (e.g. fecal coliform) and eutrophication indicators (e.g. nutrients, organic enrichment, and low dissolved oxygen). The primary sources of impairment of estuaries included municipal and industrial point sources as well as nonpoint sources like urban runoff, agriculture, and land disposal from septic tanks.

Evaluating the water quality in estuaries involves many levels of monitoring and regulation including National Pollution Discharge Elimination System (NPDES) permits for discharges into estuaries; evaluation of wastewater treatment plant effluent; and monitoring for bacteria (fecal coliform), salinity, and dissolved oxygen. The water quality of estuaries affects all classes of biota that inhabit this ecosystem, including humans. The quality of estuarine waters determines whether or not (1) we can consume the fish and shellfish from estuaries, (2) we can swim safely without fear of infection, (3) we can inhabit waterfront property without the aesthetic nuisance of algal blooms, noxious odors, or masses of dead and decaying fish, and (4) all levels of biota in the estuarine food web can exist in a healthy, stable environment. Some of these water quality issues will be discussed in a later section on public health.

Eutrophication

Some nutrient inputs to coastal waters are necessary for a healthy, functional estuarine ecosystem. When sediments, sewage, or fertilizers are introduced into an estuary, however, the concentration of available nutrients can increase beyond natural background levels, resulting in a condition known as eutrophication (Fig. 11). Even relatively modest increases in the concentration of nitrogen or phosphorus may be sufficient to trigger an algal bloom. In addition to being unsightly and malodorous, masses of algae can deprive an estuary of much-needed oxygen, interfere with swimming and

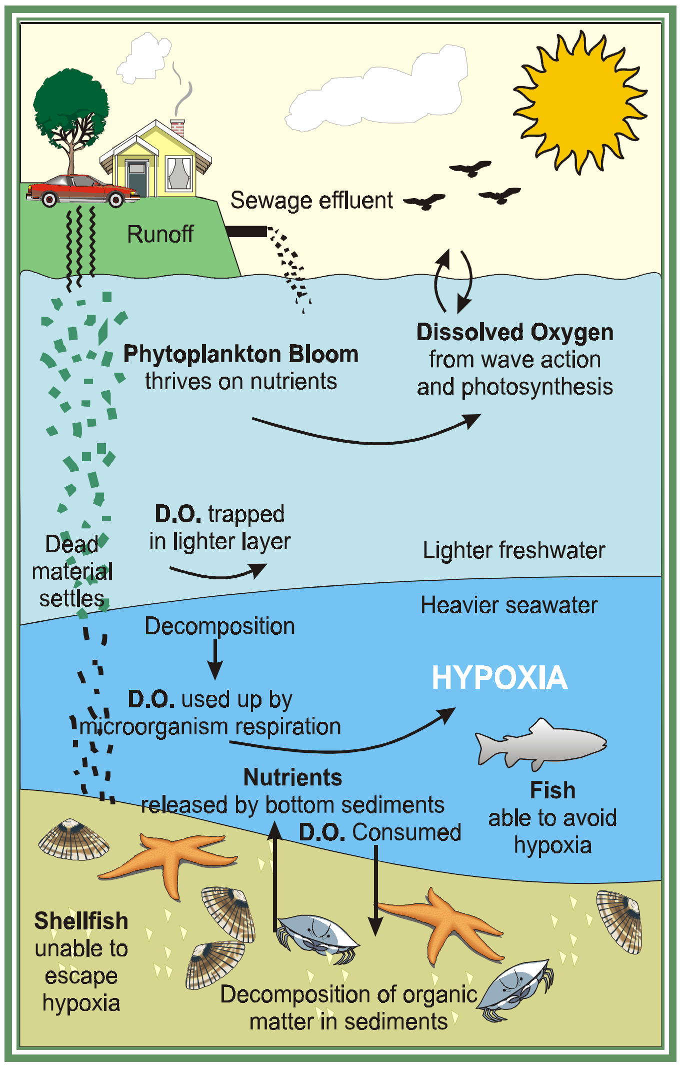


Fig. 11. Conceptual diagram of the conditions that may lead to eutrophication in estuaries (redrawn from USEPA, 1998; D.O. = Dissolved Oxygen).

boating, and outcompete native submerged aquatic vegetation. Although algae during periods of light produce oxygen as a result of photosynthesis, metabolic processes such as respiration during periods of darkness and decomposition can use up dissolved oxygen in the water column. Natural stratification exacerbates this condition and the bottom water quickly becomes devoid of oxygen (hypoxic or anoxic). Oxygen replenishment in the bottom water is diminished because the heavier, saltier water layer on the bottom is resistant to mixing with the lighter, fresher water on the surface. Oxygen depletion can also occur in unstratified waters, however. The lack of oxygen forces fish and mobile benthic invertebrates to migrate out of an area. In extreme cases anoxia can lead to fish kills. Organisms living in the sediments that cannot escape are variably affected as the oxygen levels decline. State and Federal agencies monitor indicators of eutrophication in estuaries including concentrations of nitrogen and phosphorus, chlorophyll *a*, reports of algal blooms, and dissolved oxygen.

Nutrients

Nitrogen and phosphorus are the primary anthropogenic nutrient inputs of concern in coastal waters, with nitrogen being more important in marine and estuarine systems and phosphorus being more important in freshwater systems. Monitoring concentrations of nitrogen in estuarine waters provides an indicator of the potential of a water body to become eutrophic. Although nutrients are difficult to control (primarily because they are recycled within an estuary and often come from nonpoint sources), frequent monitoring in estuaries can serve as an early warning in an effort to prevent eutrophication.

The major nonpoint sources of nitrogen are fertilizer, animal manure, and atmospheric deposition. Fertilizer nonpoint source runoff can account for up to 25% of the nutrient input to estuaries. The highest levels of nitrogen fertilizer use (Fig. 12) in the nation occur within the Mississippi River drainage basin.

Point sources consist mainly of wastewater treatment plants and other industries. According to the NOAA National Estuarine Inventory (1990), the Gulf of Mexico region ranks highest of all coastal regions in the U.S. in the number of wastewater treatment plants (1,300), number of industrial point sources (2,000), percent of land use devoted to agriculture (31%), and application of fertilizer to agricultural lands (62,000 tons of phosphorus and 758,000 tons of nitrogen).

The NOAA Estuarine Eutrophication Survey indicated that high concentrations of total dissolved nitrogen were observed in up to 19% of the estuarine area of the gulf (Fig. 13) and that for 8 estuaries these high concentrations were persistent year round. Rabalais (1992) reported that out of 58 estuarine areas in the Gulf of Mexico for which information was available, 28 had evidence of a definite or potential problem with nutrient increases. State water quality inventories [1996 305(b) reports], indicated that the majority of estuaries in each state were rated with acceptable nitrate concentrations. Of those estuaries in each state

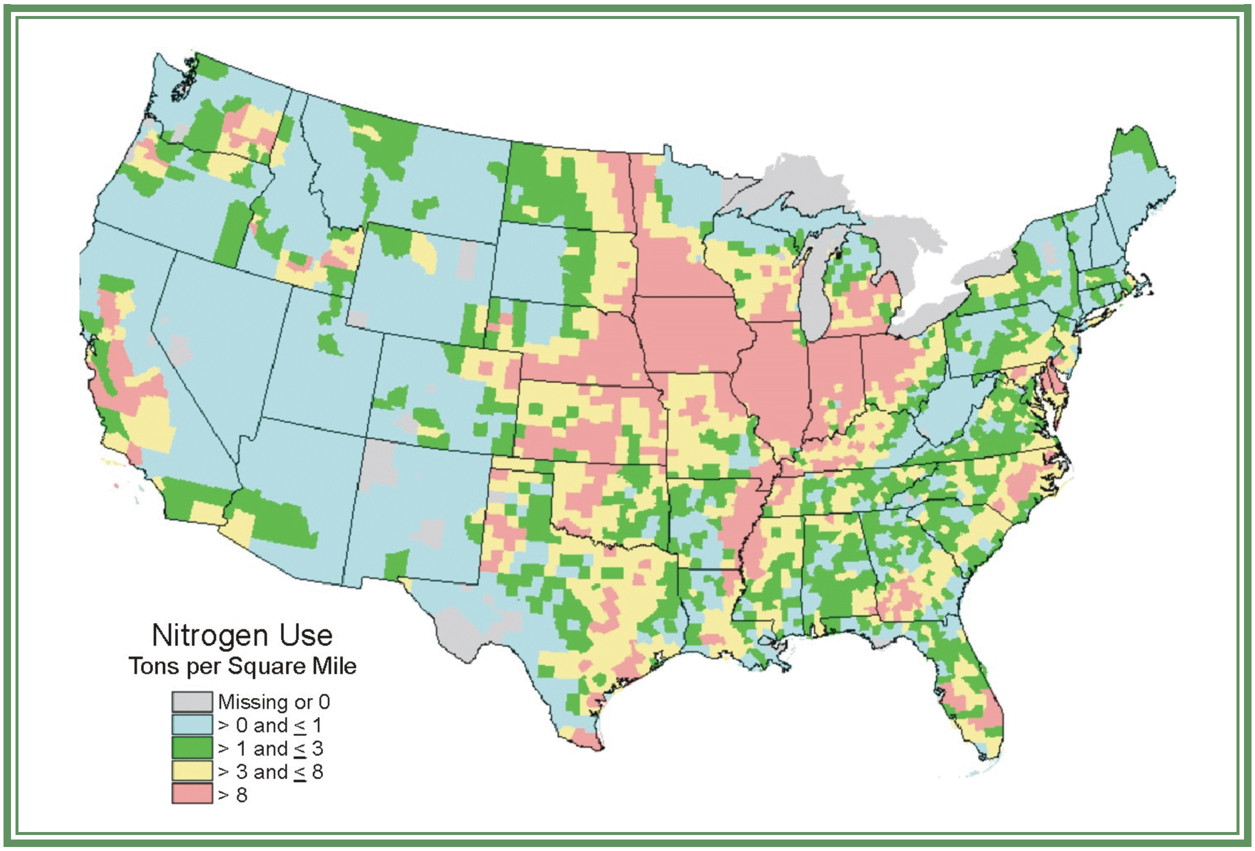


Fig. 12. Fertilizer use estimates for the United States, 1991. Data are from the USGS.

that were rated with impaired water quality, nutrients were listed as a major cause in Florida, Louisiana, and Mississippi (Fig. 10).

Chlorophyll a

Nutrient loading is just one indicator of the potential an estuary has to become eutrophic. Chlorophyll *a* can be an indicator of the first level response to nutrient enrichment. Measurements of chlorophyll *a* in the water column represent the standing stock or biomass of phytoplankton. Blooms of phytoplankton often indicate that an estuary is undergoing eutrophication. In some estuaries, like Tampa Bay, there is a good correlation between nitrogen loadings from various sources and concentrations of chlorophyll *a*. In other estuaries, however, the relationship does not hold and it is possible, in fact, for an estuary to receive heavy loads of nitrogen and yet not exhibit increases in phytoplankton biomass. Other factors such as light limitation, depth of the mixing zone, flushing rates, and contaminants may affect the growth of phytoplankton. The NOAA Estuarine Eutrophication Survey represents the only gulf-wide assessment of chlorophyll *a* concentrations in estuaries. This survey indicated that hypereutrophic (chl *a* > 60 μg/L) conditions were observed in seven estuaries and that high chlorophyll concentrations (20-60 μg/L) were observed in 18 estuaries (Fig. 13).

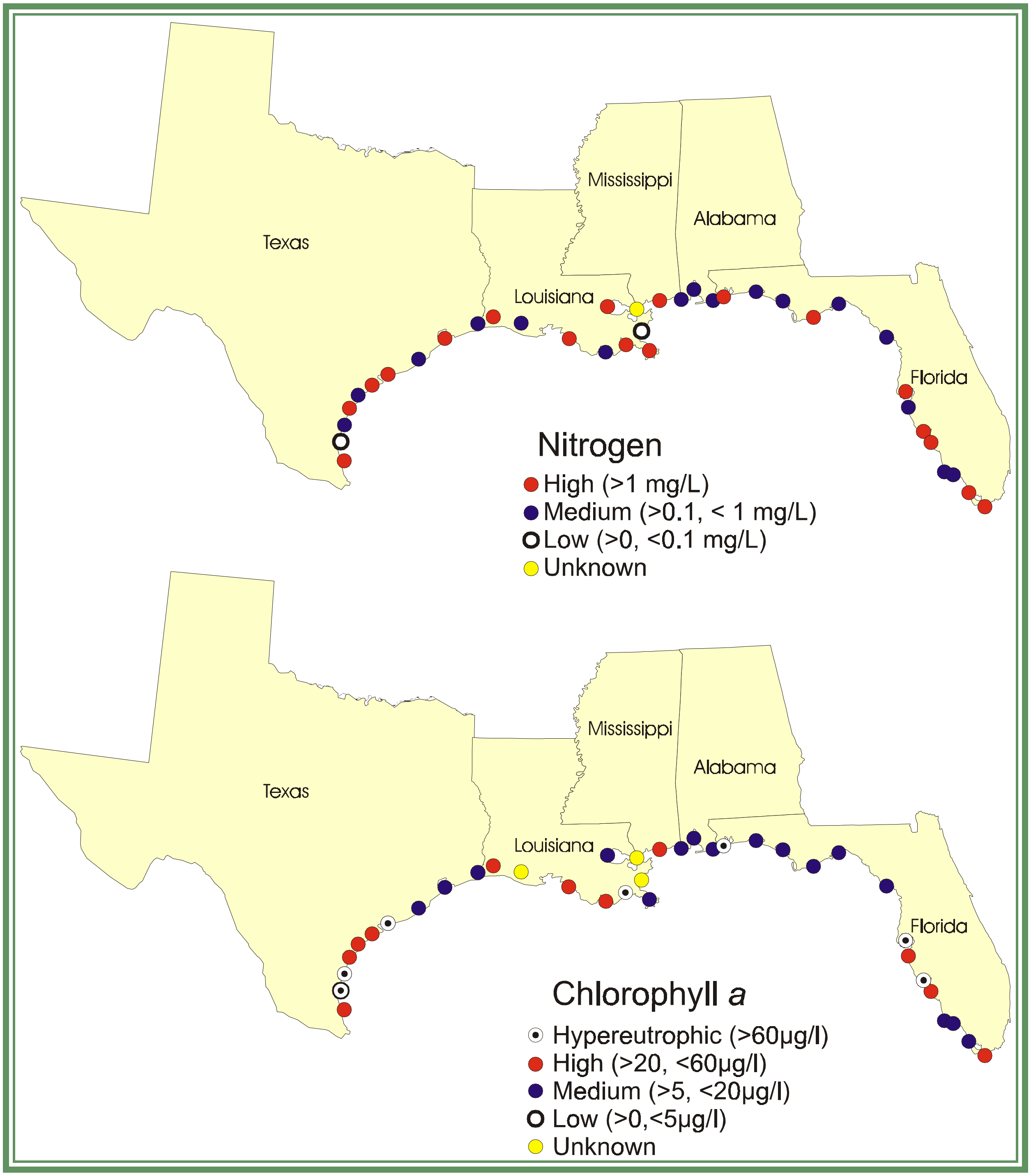


Fig. 13. Concentrations of nitrogen (mg/l) and chlorophyll *a* (µg/l) observed in estuaries of the Gulf of Mexico based on the Estuarine Eutrophication Survey (NOAA, 1997).

Dissolved Oxygen

Because dissolved oxygen (DO) is an indicator of the habitability of estuarine waters for marine life, DO is routinely measured by monitoring programs interested in characterizing the eutrophic state of estuaries. DO is recognized as an indicator of the extent of eutrophication because wide fluctuations in DO often result from increased primary productivity and may reflect prior nutrient loading. DO concentrations may also vary because of natural processes (stratification, depth, wind-induced mixing, tidal fluxes). DO is necessary for respiration in most aquatic animals but different biota have different requirements for adequate DO. Hypoxia may increase stress from other factors (e.g., contaminants) on marine organisms, whereas anoxic conditions produce toxic hydrogen sulfide which can be lethal to marine biota.

Although many states require DO concentrations of 4-5 mg/L for estuaries to meet their designated use criteria, hypoxia is often defined as DO < 2 mg/L, and anoxia as DO < 0.1 mg/L. Sufficient evidence exists that DO < 2 mg/L is extremely stressful to most aquatic organisms. EMAP reported the occurrence of hypoxia in 10% of bottom waters of the Louisianian Province during summer sampling from 1991 to 1994, but in only 3% of bottom waters in south Florida in 1995 (Fig. 14). The NOAA Estuarine Eutrophication Survey reported periodic hypoxia in 30 of 37 estuaries (25% of estuarine area) and anoxia in 16 estuaries (6% of estuarine area; Fig. 14). The apparent discrepancies between the EMAP and NOAA assessments of hypoxia were due to programmatic differences in design and interpretation. Low DO was usually observed from June through October and was primarily driven by stratification of the water column.

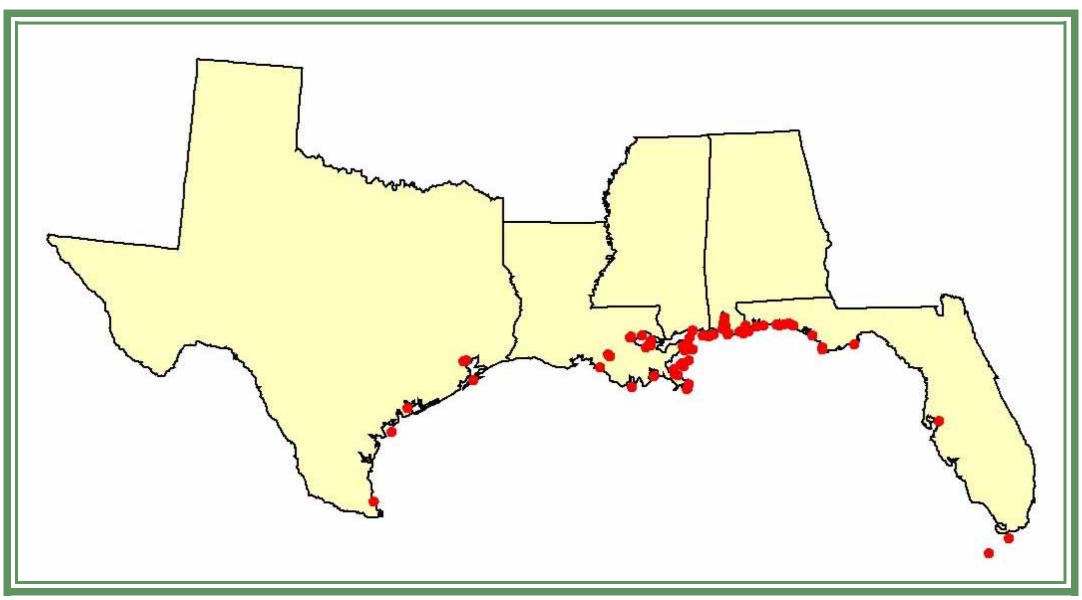


Fig. 14. Estuaries in the Gulf of Mexico with observed dissolved oxygen < 2 mg/L (marked with red dots) on at least one sampling visit during the summer (USEPA, EMAP Database for the Louisianian [1991-1994] and West Indian [1995] Provinces).

Mobile Bay, the largest estuary in Alabama, is a good example of a "Priority Hypoxia Area" identified by Rabalais (1992). It is relatively shallow (avg. depth 3 m) with a few deep holes and a dredged shipping channel. Mobile Bay has a historic problem with seasonal hypoxia that often culminates in "jubilees," where fish and invertebrates migrate to the shore attempting to escape low DO. Alabama's Department of Environmental Management (ADEM) implemented an intensive estuarine monitoring program (ALAMAP - Coastal) in 1993. Although the extent and duration of hypoxia in Mobile Bay varies annually, ALAMAP - Coastal measured low DO in more than 50% of the bottom water area in Mobile Bay during the summers of 1993 and 1994 (Fig. 15). Periodic hypoxia in Mobile Bay is part of the natural ecology and is most often related to salinity patterns and the degree of water column stratification.

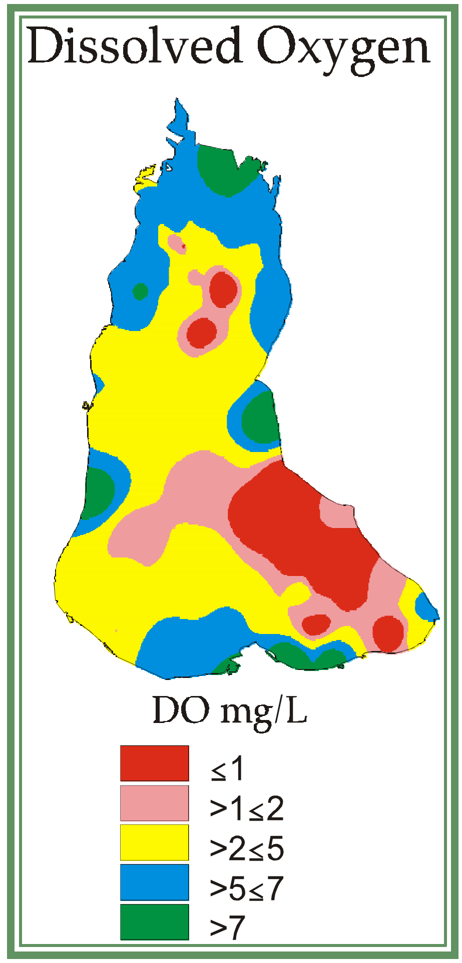
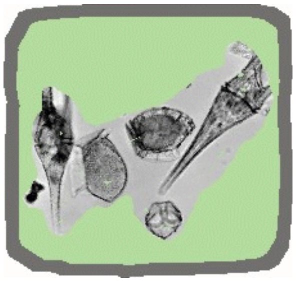


Fig. 15. Dissolved oxygen conditions observed in Mobile Bay, Alabama during the summer of 1994 (Alabama Department of Environmental Management 1997).



Harmful Algal Blooms

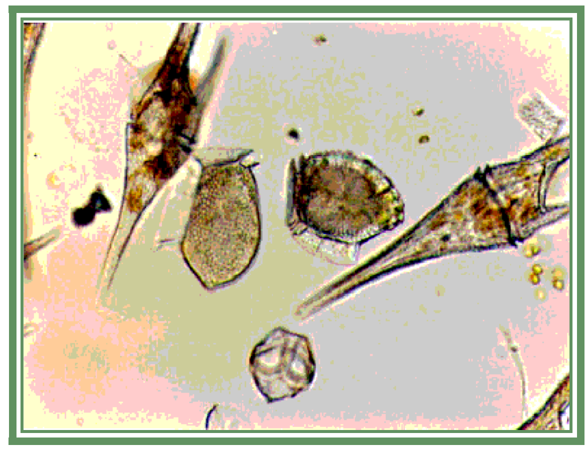


Fig. 16. Mixed bloom of dinoflagellates. Photo credit: Don Anderson, Woods Hole Oceanographic Institution.

Microscopic, single-celled plants (phytoplankton) serve as the primary producers of energy at the base of the estuarine food web (Fig. 16). Some species of phytoplankton grow very fast, or "bloom," and accumulate into dense, visible patches near the surface of the water. Although the causes of algal blooms are not entirely known, scientists suspect that blooms occur as a result of a combination of high temperatures, a lack of wind, and, frequently, nutrient enrichment. Some algal blooms are called brown tides, and, while not harmful to humans, they cause serious ecosystem impacts due to decreases in light penetration and dissolved oxygen. Brown tides can cause seagrass die-offs and fish kills. Some algae produce potent neurotoxins that can be transferred through the food web, where they cause damage, even death, to animals from zooplankton to humans.

Fig. 17. Electron photo micrograph of *Gymnodinium breve*. Photo credit: Department of Environmental Protection, Florida Marine Research Institute.

The most well-known harmful algal bloom (HAB) events in the Gulf of Mexico involve blooms of *Gymnodinium breve* (also known as red tides; Fig. 17), which occur regularly in the fall off the coasts of Florida and Texas. This organism discolors the water red (although other less harmful algae can also discolor the water red) and has been implicated in fish kills and the deaths of manatee and other marine mammals. *G. breve* produces brevetoxins that cause Neurotoxic Shellfish Poisoning (NSP). NSP induces gastrointestinal and neurological symptoms in humans that, although debilitating, are not fatal. In addition, toxic aerosols are formed by wave action and can produce asthma-like symptoms in humans. This often leads to beach closures.

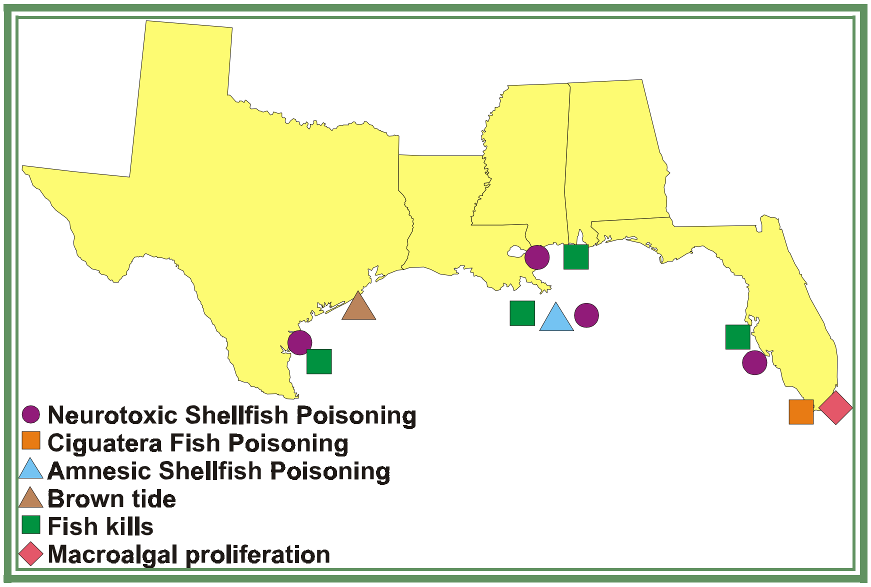


Fig. 18. Occurrence of HAB-related events in the Gulf of Mexico (National Office For Marine Biotoxins and Harmful Algal blooms, Woods Hole Oceanographic Institution).

Prior to 1972, NSP and fish kills due to harmful algal blooms only occurred along the gulf coasts of Florida and Texas in relatively localized areas. In the fall of 1996, a bloom of *G. breve* spread into Alabama, Louisiana, and Mississippi waters for the first time (Fig. 18). Brown tides have occurred in the Laguna Madre area of the Texas coast since 1990. The NOAA Estuarine Eutrophication survey indicated that biological resource impacts caused by nuisance algae occur in 22 estuaries and by toxic algae in 25 estuaries in the Gulf of Mexico. The causes of the increase in number and distribution of major harmful algal blooms are unknown, but three possible explanations are offered: (1) algal species are transferred by ballast water from ships, (2) ocean currents deposit seed populations, and (3) pollutants add nutrients to the water. Many scientists believe that the *G. breve* blooms in the Gulf of Mexico are a natural phenomenon because they originate 10-50 miles offshore in low-nutrient water (Fig. 19). This is supported by records dating back to the 1500s of blooms occurring offshore. Others speculate that, although the currents in the Gulf of Mexico may initiate a bloom with an upwelling of nutrients, the actual bloom does not occur until the currents or winds carry the organisms into the nutrient-rich, shallow, near-coastal waters.

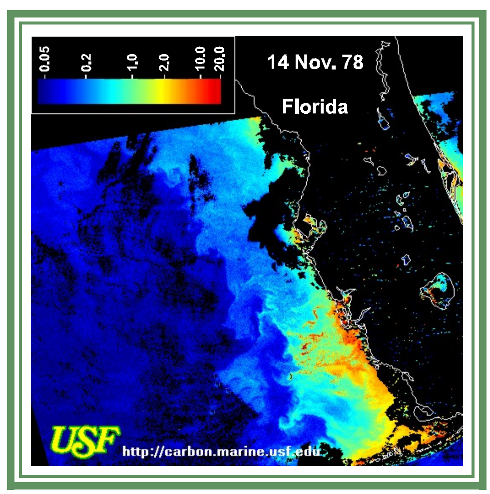


Fig. 19. Red Tide bloom off the west Florida shelf . Photo credit: Dr. Frank Muller-Karger, University of South Florida.

Sediment Contaminants

Toxic substances and pesticides enter Gulf of Mexico estuaries from industrial and municipal discharges, urban and agricultural runoff, accidental spills, and atmospheric deposition (Fig. 20). These activities often have adverse effects on estuarine habitat. For example, the U.S. Coast Guard received an annual average of 6217 notifications of oil or chemical spills in Gulf of Mexico ports from 1991 to 1997. Chemicals that enter estuaries are often bound to suspended particulate matter that eventually deposits on the sediment surface. Sediment deposition and accumulation rates in an estuary depend greatly on the rate of freshwater inflow and access to flushing from the Gulf of Mexico. Once deposited in the sediment, toxic chemicals may be available for uptake by benthic organisms. Bioavailability is greatly dependent on the characteristics of the sediment, including concentrations of total organic carbon and acid-volatile sulfide. Some chemicals are acutely toxic, resulting in death of the animal; others may have chronic toxicity effects, affecting growth or reproduction. Toxic chemicals can affect humans because they may become biomagnified as they are stored in animal tissue and transferred through the food chain. When sediment chemistry information is combined with sediment toxicity data and benthic health indicators, a better assessment of overall sediment quality can be accomplished.

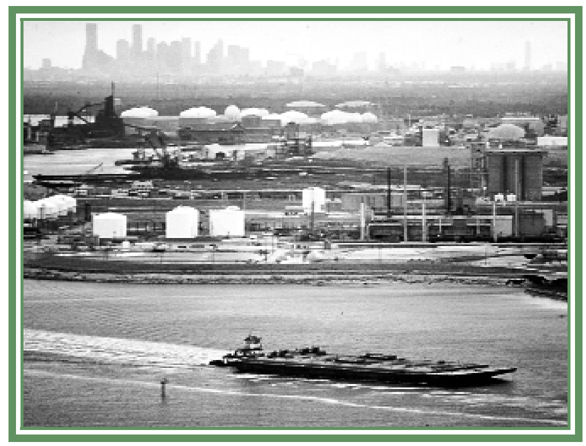


Fig. 20. Houston Ship Channel surrounded by petrochemical industries and shipping activities. Photo credit: Galveston Bay National Estuary Program.

Evaluation of the potential effects of contaminated sediments on estuarine organisms is difficult because few applicable state or federal regulatory criteria exist to determine "acceptable" sediment concentrations of all substances. Informal guidelines based on many field and laboratory studies have been suggested, however. Guidelines such as effects range-low (ER-L) and effects range-median (ER-M) values (Long et al. 1995) provide environmental managers with benchmarks to determine if contaminated sediments have the potential to adversely affect aquatic organisms. These (and other) guidelines benefit from the weight of evidence afforded by large data sets associating sediment contaminant concentrations with biological effects, but suffer from a failure to incorporate the effects of multiple chemicals in complex mixtures, as the chemicals exist in the environment. In sediments in the Gulf of Mexico estuaries, EMAP measured polycyclic aromatic hydrocarbons (PAHs; components of petroleum and produced by combustion processes), polychlorinated biphenyls (PCBs; used in insulators and capacitors), aliphatic hydrocarbons (e.g., alkanes which are abundant in crude oil), pesticides (e.g., dichlorodiphenyltrichloroethane [DDT], chlordane, dieldrin, endosulfan), organotins (e.g., tributyltin [TBT] found in anti-fouling paint) and trace metals (e.g., zinc, lead, mercury,

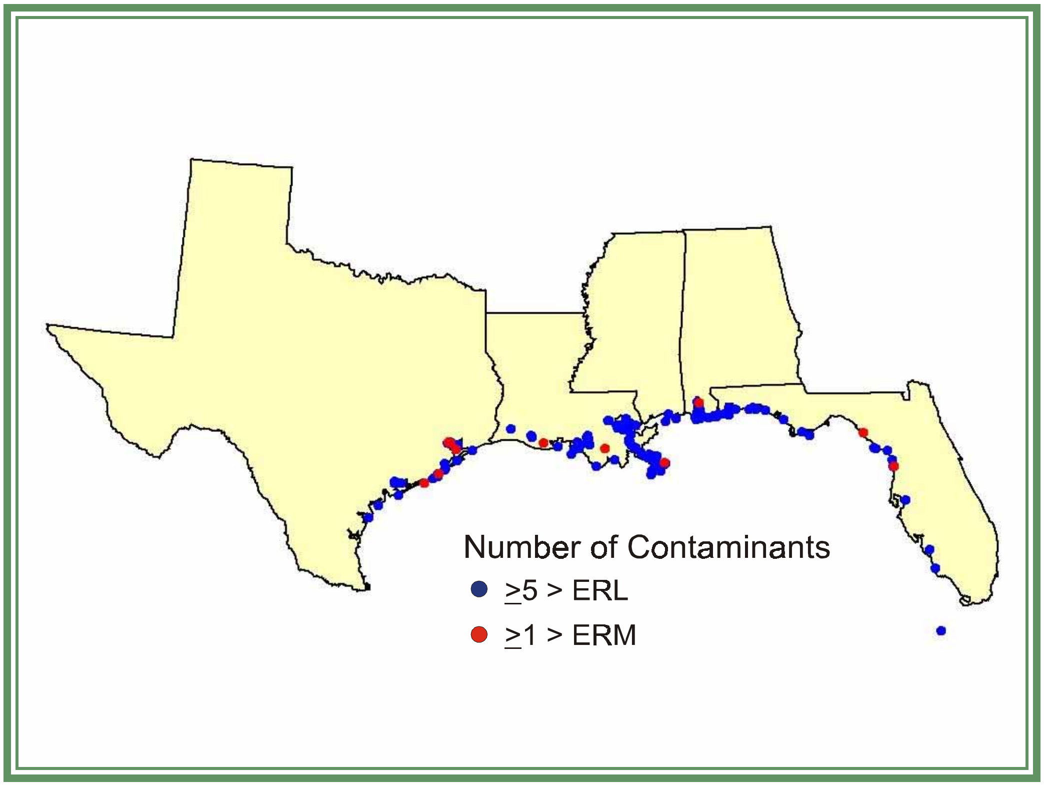


Fig. 21. Sites where contaminants (metals or organic) exceeded Long et al. (1995) ER-L or ER-M guidelines (USEPA, EMAP Database for the Louisianian [1991-1994] and West Indian [1995] Provinces).

cadmium, copper). EMAP reported that ER-L guidelines were exceeded for all of the major groups of sediment contaminants, albeit at very low rates (<1% of area) for PAHs and PCBs. There was a fairly even distribution of sites from the Florida panhandle to Corpus Christi Bay, Texas, where contaminants exceeded ER-L or ER-M guidelines (Fig. 21). Based on the percent area of each estuary that was contaminated, however, the majority of estuarine systems in all gulf states were identified by EMAP as having fair to good sediment quality. EMAP identified several estuaries as having predominately contaminated sediments. These correspond well with those watersheds identified by the USEPA National Sediment Inventory

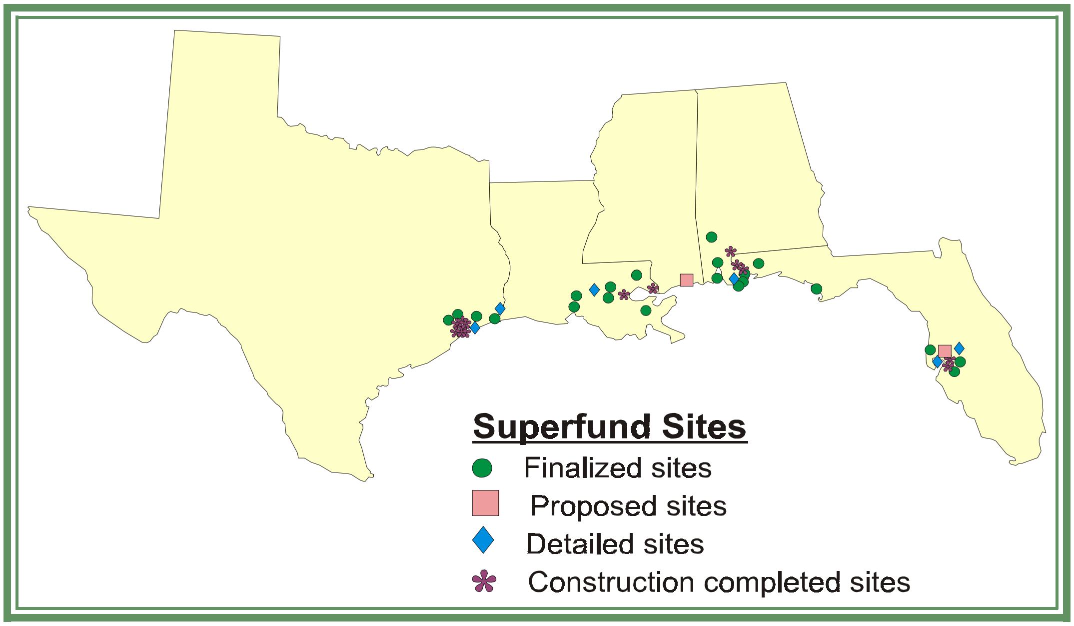


Fig. 22. Location of Superfund sites near coastal areas of the gulf states (USEPA).

as "areas of probable concern." Several USEPA Superfund sites are also located near heavily industrialized estuaries, particularly Galveston Bay, Tampa Bay, and the Florida panhandle (Fig. 22).

With one-half of the total chemical production and 30% of the total petroleum industry in the U.S. located in and around Galveston Bay, Texas, this estuary provides a good example of the impacts of urban and industrial sources on sediment quality. Galveston Bay has a history of environmental problems as a result of rapidly escalating demands placed upon the bay's resources. Sediment chemistry analyses by USEPA's Region VI (R-EMAP-TX) indicated that sites in East Bay Bayou, Trinity Bay, the marinas, and small lakes had as many as seven contaminants exceeding ER-L guidelines (Fig. 23). In East Bay Bayou, several PAHs, including fluorene and phenanthrene, exceeded ER-L guidelines. At the marinas and in Offats Bayou, copper and chlordanes exceeded ER-L values. Offats Bayou also had high levels of lead, zinc, and DDT.

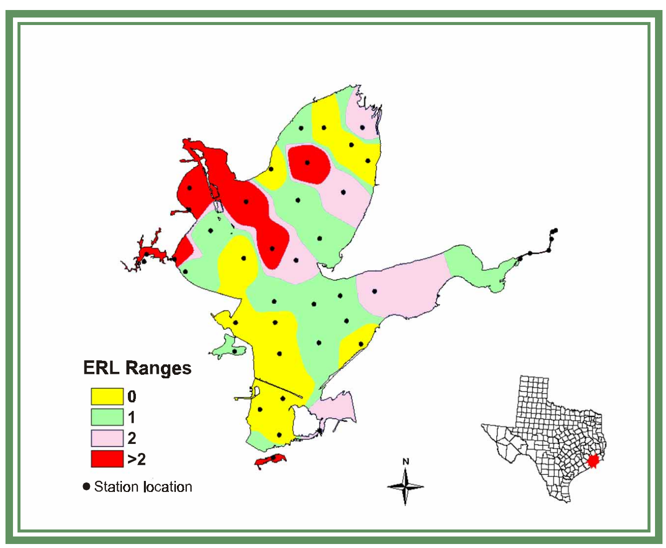
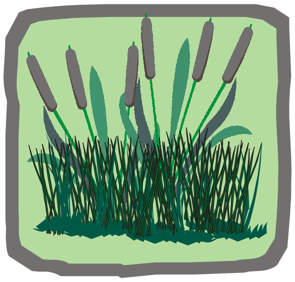


Fig. 23. Distribution of sites with sediment contaminants greater than ER-L guidelines in Galveston Bay, TX (R-EMAP, Texas, 1993).



Habitat Change

Wetlands

Wetlands are the interface between the aquatic and terrestrial components of estuarine systems. In the Gulf of Mexico, wetlands include both emergent (i.e., marshes and certain forested scrub-shrub habitats) and submerged vegetated habitats (seagrasses; Fig. 24). These habitats are critical to the life cycles of fish, shellfish, migratory birds, and other wildlife; they also filter and process residential, agricultural, and industrial wastes, thereby improving surface water quality, and they buffer coastal areas against storm and wave damage. An estimated 95% of commercial fish and 85% of sport fish spend a portion of their lives in coastal wetland and estuarine habitats. Adult stocks of commercially harvested shrimp in the Gulf of Mexico are directly related to wetland quality and quantity (Turner and Boesch, 1988). Wetlands in the Gulf of Mexico region are being rapidly damaged or destroyed by human activities (e.g., flood control, agriculture, waste disposal, real estate development, shipping, commercial fishing, and oil and gas exploration and production) and natural

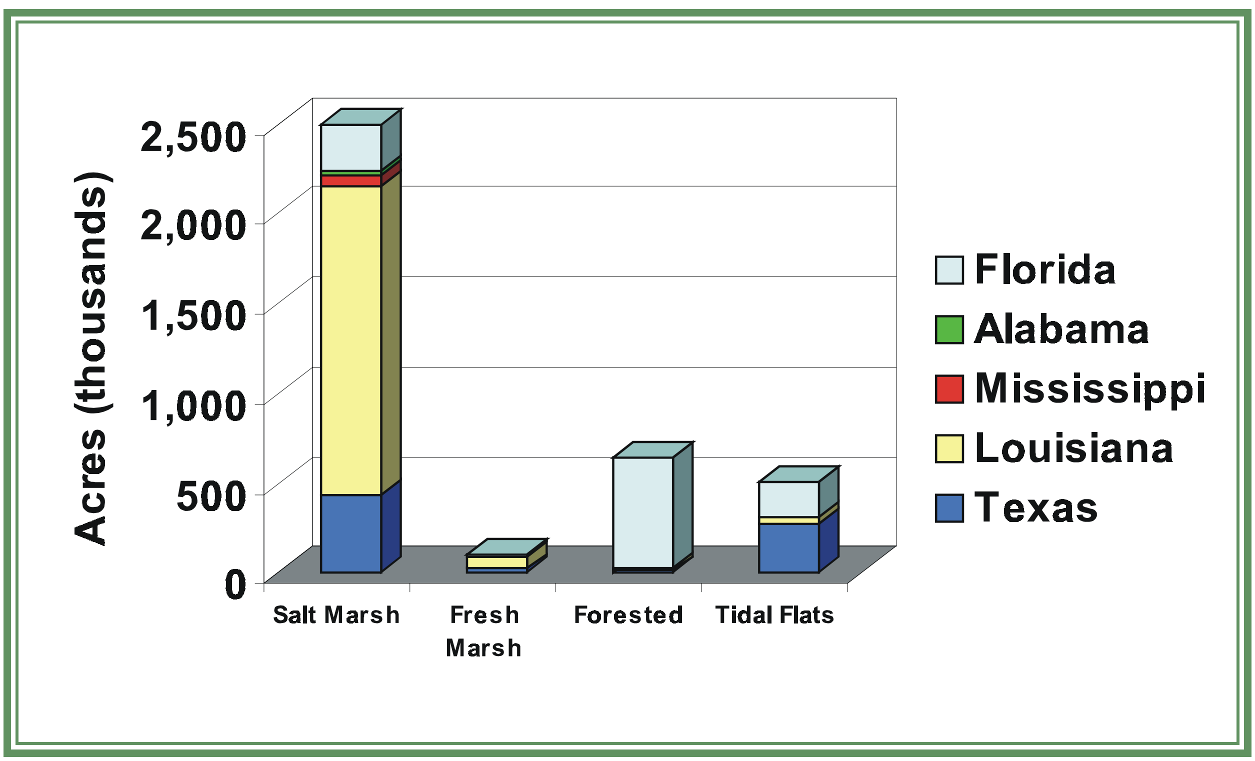


Fig. 24. Total acreage of dominant coastal wetland types by state based on U.S. Fish and Wildlife Service wetland inventory maps (NOAA, 1991).

processes (e.g., rising sea level, sediment compaction and submergence, droughts, animal "eat-outs," storms, and floods; Table 1).

Table 1. Primary causes of diminishing quality and acreage of coastal emergent wetlands in the Gulf of Mexico by state (Duke and Kruczynski, 1992).

State	Cause
Texas	Subsidence due to extraction of oil, gas, and fresh water
Louisiana	Navigation channels altering hydrodynamic flow Natural subsidence Reduced sediment deposition
Mississippi	Dredge and fill operations
Alabama	Dredge and fill operations
Florida	Conversion to commercial and private developments

Total existing coastal wetland acreage and historical wetland loss estimates are the most frequently cited indicators of wetland status. In a pilot study EMAP evaluated additional indicators of wetland health that included the condition of individual plant species and soil characteristics, in addition to acreage and loss estimates. These indicators were not measured gulf-wide, however, and were not used for assessment in this report. Discrete estimates for wetland acreage or loss for estuaries in the Gulf of Mexico were not available. Where information on coastal wetland loss was available (e.g., for Louisiana) it was used; otherwise, total wetland loss estimates were gathered for each gulf state. Total wetland loss (coastal and inland) for the five gulf states from 1780 to 1980 was estimated to be 40 million km^2 (approximately 50%; Fig. 25). Although agriculture is the leading cause of all wetland losses, including coastal and inland, residential and commercial development accounted for 42% of estuarine wetland loss nationwide from 1985 to 1995. Between 1985 and 1995 the southeastern U.S. lost the greatest area of wetlands (51% of national total), but the rate of wetlands loss both nationally and in the gulf has slowed considerably.

Coastal emergent wetland loss for Louisiana represents 67% of the nation's total loss (177,625 ha or 438,911 acres) from 1978 to 1990 (Fig. 26). Much of this loss is related to altered hydrology stemming from navigation, flood control, and mineral extraction and transport projects. Most actual wetland loss is the result of the indirect effects of these projects, specifically the disruption of water flow and natural movement of water and sediments rather than actual loss due to erosion.

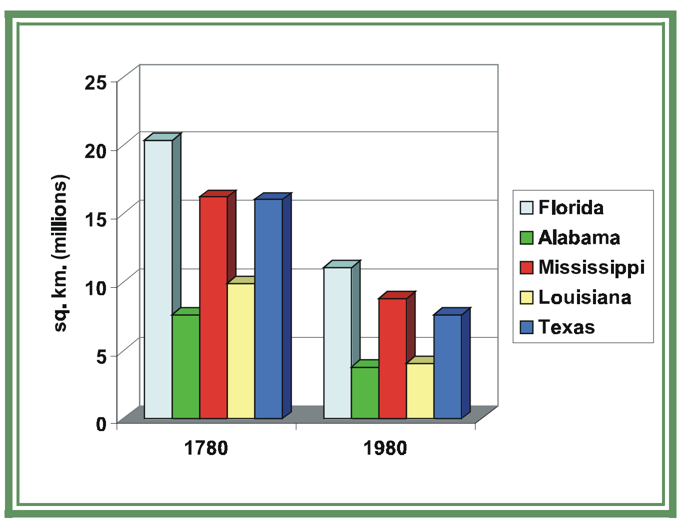


Fig. 25. Estimated total area of wetlands by state in 1780 and 1980 (Dahl, 1990; U.S. Fish and Wildlife Service).

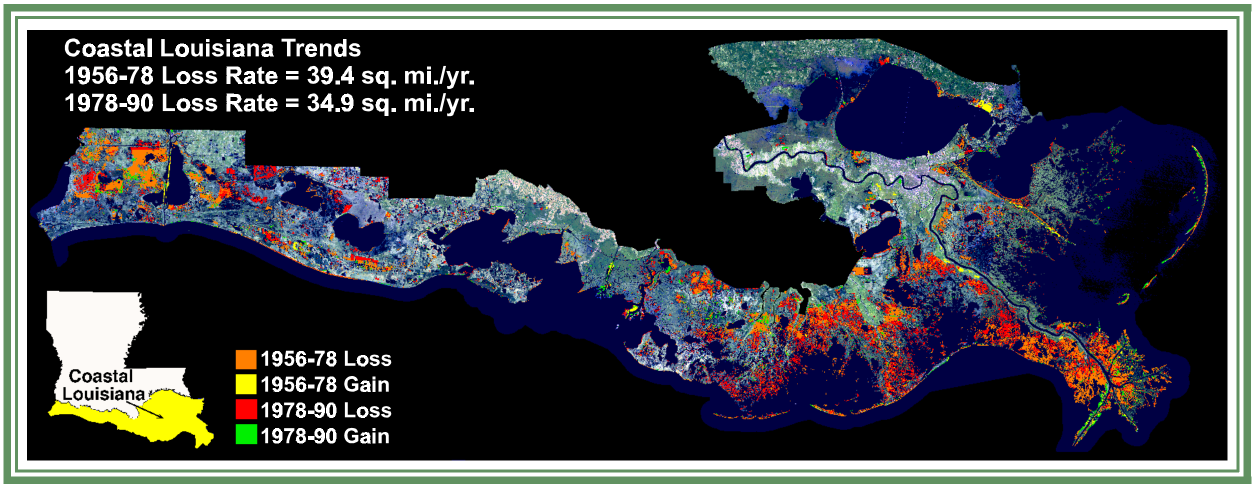


Fig. 26. Changes in wetland area for coastal Louisiana based on National Wetland Inventory data and Landstat TM Imagery compiled by USGS Baton Rouge Project Office.

Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) species, or seagrasses, are particularly sensitive to light and water quality. Seagrasses have an important ecological role in providing food for waterfowl, manatees, and green sea turtles, and in providing habitat for many fish and shellfish species. SAV also affects physical processes in estuaries, such as nutrient cycling, sediment stability, and water turbidity. Changes in seagrass distribution, therefore, can reflect the health of an estuary, and losses of seagrasses may be an indicator of water quality problems. Seagrass habitat loss ranges from 20% to 100% over the last 50 years for most estuaries in the northern Gulf of Mexico (Handley, 1995). This decline is related primarily to coastal population growth and accompanying municipal, industrial, and agricultural development, but some losses may also be attributed to natural causes (i.e., hurricanes, storms, and salinity changes). Currently, 95% of the seagrass acreage in the Gulf of Mexico is localized in estuarine areas of Florida and Texas. The NOAA Estuarine Eutrophication Survey reported that the spatial coverage of SAV was very low to low (>0 to 25% coverage) in 32 estuaries, particularly in the mixing zone. Spatial coverage was high in Apalachee Bay, Florida and Laguna Madre, Texas. NOAA estimated that the spatial coverage of SAV in the gulf was equivalent to 12-24% of the estuarine area. Where trends in SAV coverage were observed, both increasing and decreasing trends were attributed to habitat alteration or to changes in nonpoint and point sources of pollution and in hydrology.

Biological Integrity

Changes in biological communities may indicate a disruption of healthy environmental conditions. Quantifying the condition of biological communities enables us to identify the cumulative effects of pollution or habitat alteration. EMAP-E uses biological monitoring of benthos and fish to evaluate estuarine condition. The National Marine Fisheries Service (NMFS) monitors the productivity of fisheries to ensure the economic health of the fishing industry. The U.S. Fish and Wildlife Service (USFWS) is responsible for tracking the population status of waterfowl, which is an important indicator of wetland condition. Monitoring the recovery of threatened and endangered species provides important information about the success of management actions designed to protect the habitat of those species.

Benthos

The worms, clams, and crustaceans that inhabit the bottom substrates of estuaries are collectively called benthic macroinvertebrates or benthos. These organisms play a vital role in maintaining sediment and water quality, and are an important food source for bottom-feeding fish, shrimp, ducks, and marsh birds. Benthos are often used as indicators of perturbations in the estuarine environment because they are relatively nonmobile, and therefore cannot avoid environmental problems. The response of benthic communities to alterations in sediment and water quality is relatively well understood and is often expressed as changes in community structure, density, and diversity. Benthic population and community characteristics are sensitive indicators of contaminant and dissolved oxygen stress, salinity fluctuations, and disturbance and serve as reliable indicators of estuarine environmental quality. EMAP-E developed a benthic index of environmental condition for estuaries that incorporates changes in diversity and the populations of indicator species to distinguish degraded benthic habitats from undegraded benthic habitats (Engle *et al.* 1994; Engle and Summers 1999). Using the benthic index, 25% of the estuarine area in the Louisianian Province was determined to have

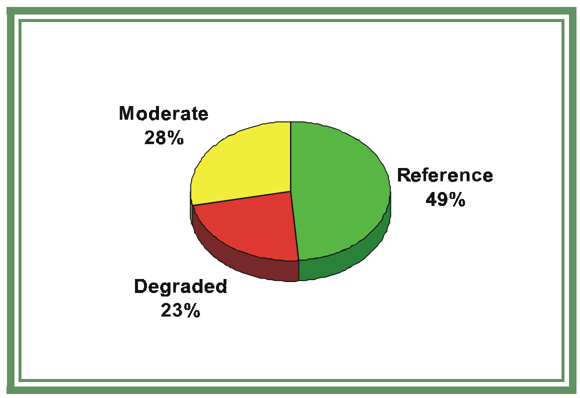


Fig. 27. Percent area of estuaries in the Louisianian Province classified by the benthic index as degraded (< 3), moderate (3-5), or reference (> 5) (USEPA, EMAP Database for the Louisianian Province, 1991 to 1994).

degraded benthic resources from 1991 to 1994 (Fig. 27) (Macauley *et al.* 1999). When examined on the level of an individual estuary (e.g., Pensacola Bay, FL), degraded benthic resources were most often associated with sediment contaminants or hypoxia (Engle and Summers 1998).

Pensacola Bay, an estuary in northwest Florida, has a sedimentation problem because of poor flushing and high suspended sediment input from its tributaries. Evidence of problems in the bay include low benthic diversity, decline of seagrasses and oyster populations, and contaminated sediments, especially in the bayous. Pensacola Bay has predominantly muddy sediments, dominated by polychaete and nemertean worms that are, in general, tolerant to habitat disturbances. The benthic index identified 12 degraded sites located primarily in the mainstem of Pensacola Bay and in the three bayous near Pensacola (Bayous Chico, Grande, and Texar) (Fig. 28). Areas of Pensacola Bay have severely contaminated sediments, with as many as 40 chemicals at concentrations greater than ER-L guidelines, especially in the bayous. The benthic community is severely impoverished in the areas of the bay with low sediment quality.

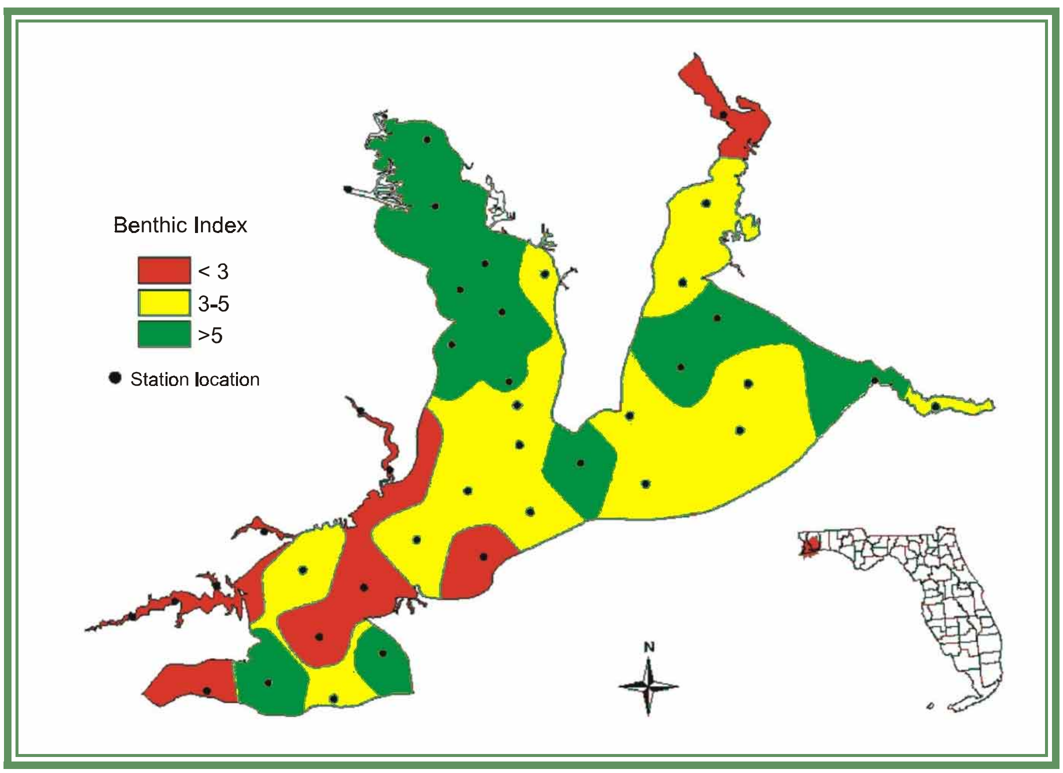


Fig. 28. Areas in Pensacola Bay, Florida that were classified by the benthic index as degraded ( ), moderate ( ), or reference ( ) (Engle and Summers, 1998).

Commercial and Recreational Fisheries

There is much public concern about the quality and abundance of fish, especially commercially and recreationally important species. Estuaries provide food, refuge from predation, and habitat for a wide variety of fishes and invertebrates. Many of these species are economically important and use various estuarine habitats to complete their life cycles. Estuaries are especially important as nursery areas for many species during their early and juvenile life stages. As a result, the economic viability of the commercial and recreational fisheries of the Gulf of Mexico is also estuarine dependent. Tracking the status of fishery resources is one step in the effort to build sustainable fisheries. The decline of fisheries may be due to overfishing or habitat degradation. As the carrying capacity of an estuary declines, the fish stocks which inhabit it can no longer support fishing levels that were previously sustainable. Therefore, the status of fishery resources can be used as an indicator to assess the suitability of estuarine habitat for sustaining those fisheries. The top four fisheries in the Gulf of Mexico (menhaden, shrimp, oyster, blue crab) use estuaries extensively (Fig. 29). The Gulf of Mexico yielded the nation's largest regional commercial fishery (excluding Alaska) by weight in 1996, representing 33% of the national total by weight and 32% by value. The total commercial harvest in the Gulf of Mexico was dominated by the landings from Louisiana (Fig. 30). The Gulf of Mexico shrimp fishery is the largest and most valuable in the United States, accounting for 69% of the total domestic harvest, with most of the shrimp landings in Louisiana and Texas (Fig. 31). Shrimp are especially dependent on estuaries, and the degradation of estuarine water quality and loss of gulf wetlands are considered significant threats to this fishery.

Recreational fishing is also important to the economy of gulf states. Over 40% of the nation's marine recreational fishing occurs in the Gulf of Mexico, with the highest number of anglers fishing in Florida and Texas (Fig. 32). Although many of the recreational fish species are exclusively offshore, some use estuaries for a major part of their life cycle. Speckled trout (or spotted seatrout; *Cynoscion nebulosus*), for example, spawns over seagrass beds but is known to migrate offshore and red drum (*Sciaenops ocellata*) spawns in estuaries where the

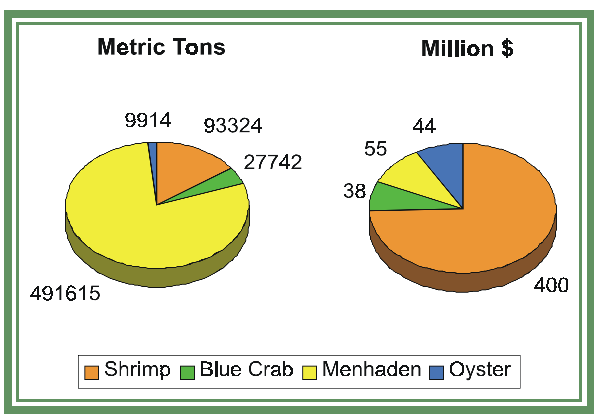


Fig. 29. Landings in 1996 by weight and value for the top four commercial species in the Gulf of Mexico (National Marine Fisheries Service).

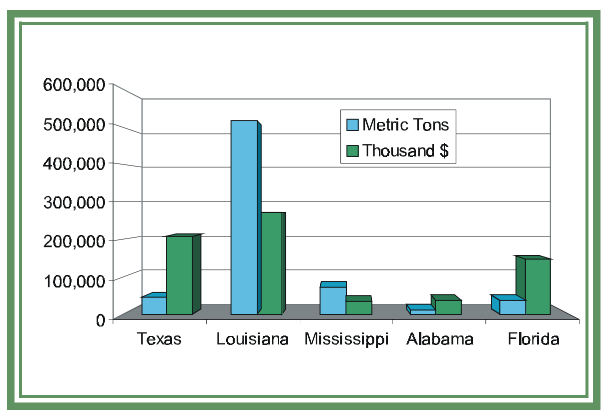


Fig. 30. Landings by weight and value of all commercial species by state in the Gulf of Mexico in 1996 (National Marine Fisheries Service).

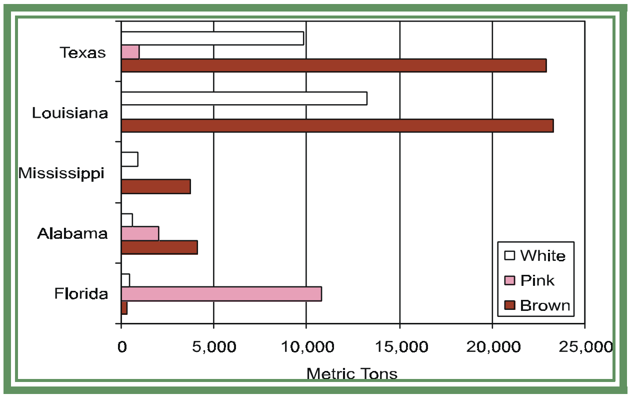


Fig. 31. Landings of shrimp by state and species in the Gulf of Mexico in 1996 (National Marine Fisheries Service).

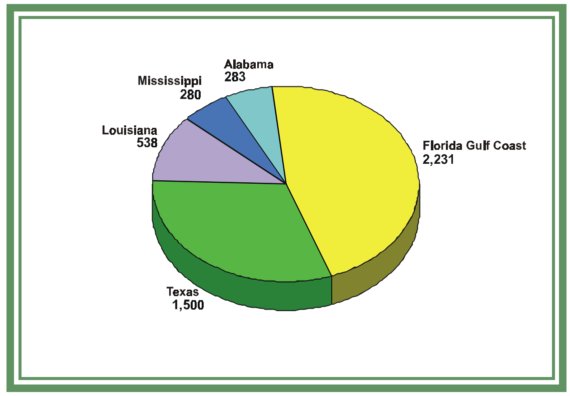


Fig. 32. Numbers in thousands of recreational anglers fishing in coastal waters in 1995 by state in the Gulf of Mexico (National Marine Fisheries Service; Texas Parks & Wildlife).

young develop for 2-3 years before moving offshore.

The Red Drum Fishery

The drums (Family *Sciaenidae*) are characteristic of inshore fishes found in the northern Gulf of Mexico and include important commercial and recreational species such as red drum (or redfish), black drum (*Pogonias cromis*), spotted seatrout, and Atlantic croaker. Most species spawn in shallow offshore waters or at the entrance to a bay; the larvae enter estuaries, where they spend one or more summers and take advantage of the greater availability of food and protection which estuarine habitats afford. Some species, such as red and black drum, are long-lived.

The red drum commercial fishery was closed to all harvest in U.S. Federal waters of the Gulf of Mexico on January 1, 1988 (Fig. 33). Stock assessments indicated that red drum were heavily fished prior to moving offshore to spawn and that those fish less than 12 years of age were poorly represented in the offshore spawning population. In addition to the federal closure, states enacted stringent measures to reduce red drum mortality in inshore areas. Red drum populations appear to be responding to the management measures, and, although all five states have recreational bag limits and slot limits that exclude large fish, Texas has issued "Red Fish Tags" that allow anglers to keep two large fish per year.

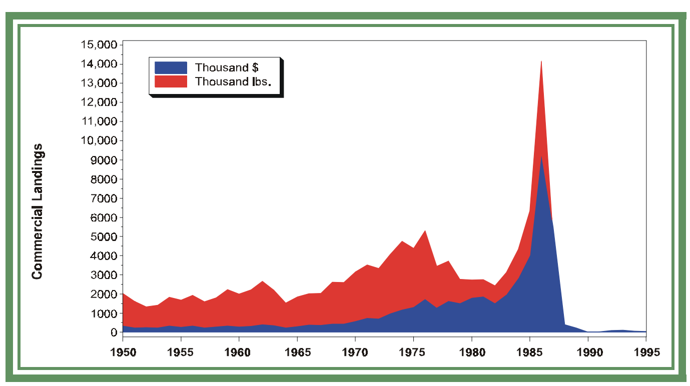


Fig. 33. Commercial landings of red drum by weight and value in the Gulf of Mexico from 1950 to 1995 (National Marine Fisheries Service).

Following the federal closure and state regulatory actions on red drum, black drum were accepted as a substitute within the commercial market (Fig. 34). This "new" fishery added to the already existing pressure on black drum and led the gulf states to establish interim regulatory measures. As a result, present harvest levels are well below those which are thought to negatively affect recruitment and spawning stocks.

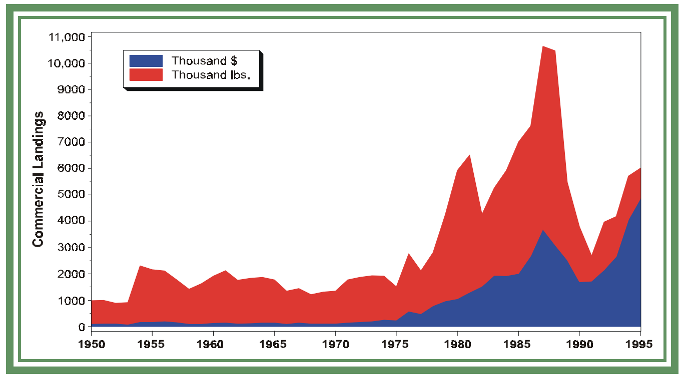


Fig. 34. Commercial landings of black drum by weight and value in the Gulf of Mexico from 1950 to 1995 (National Marine Fisheries Service).

Fish Biomarkers

An increased awareness of the adverse effects of environmental degradation on fish populations has led many federal and state monitoring programs to include fish health assessment (Blazer *et al.* 1994). Fish from contaminated waters often display pathological conditions such as fin rot, skin ulcerations, skeletal abnormalities and epidermal growths. In addition, these abnormalities may be indicators of health risk to birds, mammals, and even to humans. Therefore, as an indicator of environmental conditions, fish abnormalities should be of interest to resource and regulatory agencies as well as to the general public. Fish biomarkers such as gross pathology, splenic macrophage aggregates, and skeletal anomalies were investigated by EMAP in the Gulf of Mexico from 1991 to 1994.

The frequency and type of gross pathologies on fish taken from trawls in estuarine waters are indicators of the overall condition of fish populations. Field and laboratory studies have shown an association between gross pathological disorders in fish and exposure to pollution. Gross pathological disorders in fish include tumors and lesions on the skin, malformations of the eye, gill abnormalities, and parasites. From 1991 to 1994, in the Louisianian Province, EMAP examined 64,082 fish caught in trawls for external gross pathological disorders. Gross pathologies were observed on 408 fish, which gives a background pathology incidence rate of 0.6%. Of all pathologies observed, 61% were parasites and 45% occurred in menhaden (*Brevoortia patronus;* Fig. 35). The majority of observed pathologies (88.8%) occurred in

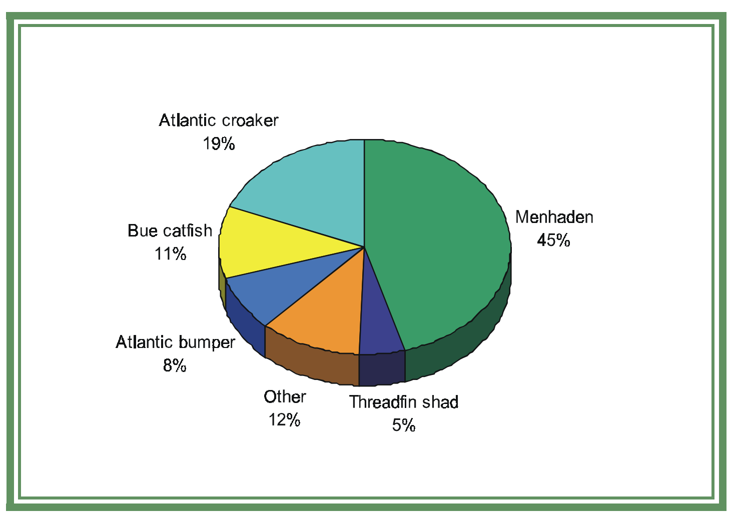


Fig. 35. Distribution by species of the 408 fish with observed gross pathological disorders (USEPA, EMAP Database for the Louisianian Province, 1991 to 1994).

Texas and Louisiana, with 47% of all pathologies found in fish from Galveston Bay, Texas. Gross pathological abnormalities were more prevalent at sites with high sediment contaminant concentrations (Fournie *et al.* 1996.)

Macrophage aggregates are a prominent feature of fish spleen, kidney, and liver. Recent studies suggest that the size and density of macrophage aggregates may be sensitive histological indicators of fish health and environmental quality (Blazer *et al.* 1994). Although macrophage aggregates have been criticized as nonspecific, there is some evidence that, when demersal fish are examined, increased size and density of macrophage aggregates are associated with environmental contamination. One hundred ninety-one fish samples from 149 sites were examined for macrophage aggregates by EMAP-E from 1992 to 1994. Fish from only five of these samples contained spleens with more than 40 macrophage aggregates per square millimeter (Fig. 36). This incidence of relatively high macrophage aggregate density represents a small percentage of the total number of fish examined indicating a localized effect of pollution on fish.

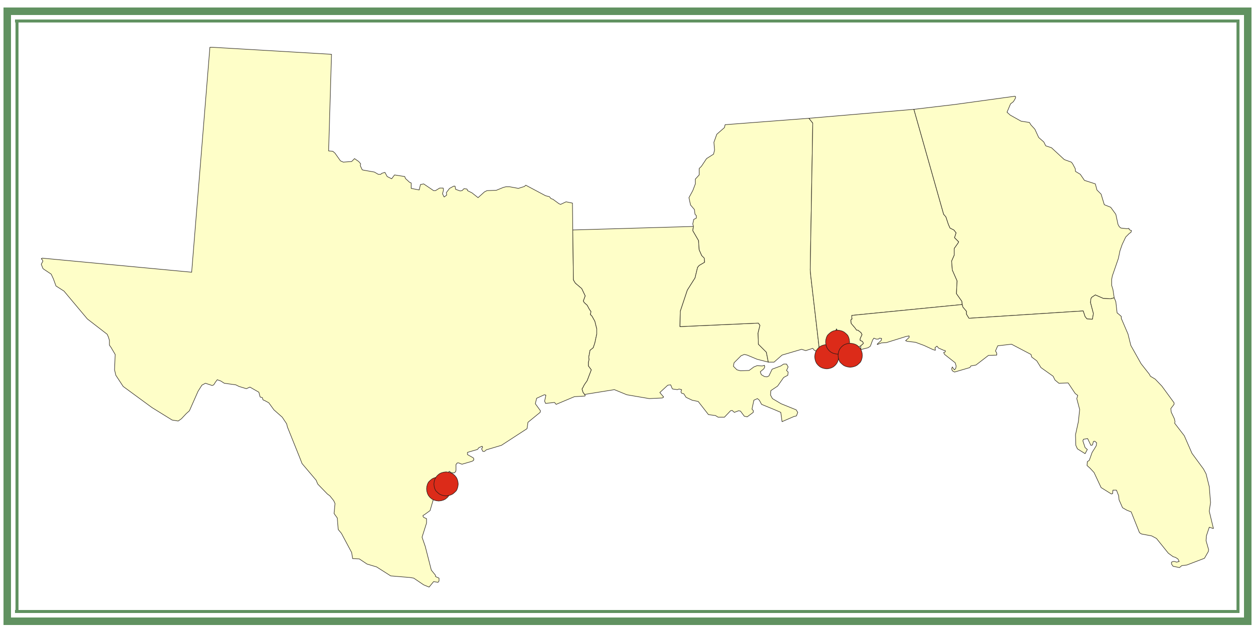


Fig. 36. Sites in the Gulf of Mexico where fish samples contained spleens with > 40 macrophage aggregates per mm^2 (USEPA, EMAP Database for the Louisianian Province, 1991 to 1994).

Coastal and Marine Birds

Gulf of Mexico estuaries provide necessary habitat for both migrant and resident coastal and marine birds. Waterfowl, primarily ducks and geese, migrate to Gulf of Mexico feeding grounds during winter to take advantage of the vast estuarine resources. Canvasback (*Aythya valisineria*), redhead (*Aythya americana*), and scaups (*Aythya spp*.) and other divers such as the ruddy duck (*Oxyura jamaicensis*), feed and congregate in open waters of estuaries, often clustered in dense rafts. An estimated 80% of the redhead population overwinters in the brackish to hypersaline waters of Laguna Madre, Texas. Other redhead wintering grounds in the Gulf of Mexico include Chandeleur Sound, Louisiana and Apalachee Bay, Florida. Redheads are especially dependent on healthy SAV beds in their wintering areas. If the decline in SAV continues (over 50% of shoalgrass beds in Laguna Madre have disappeared since the 1960's), the redheads may be forced to find new wintering grounds. Healthy and stable populations of waterfowl are indicators of healthy estuarine and wetland conditions in the Gulf of Mexico. Although redheads declined below their target population size of 760,000 during the 1980's, redheads currently exceed their target population size (Fig. 37).

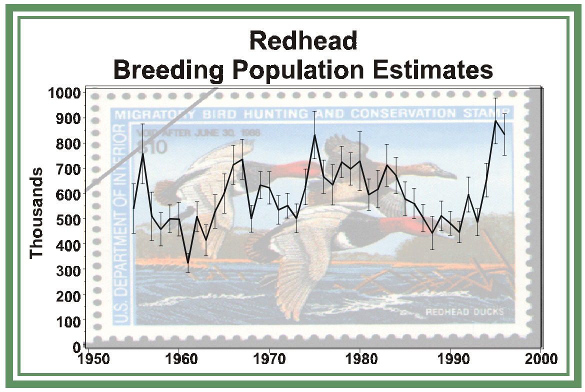


Fig. 37. Estimates of the number of redhead ducks in the North American breeding population from 1950 to 1996 (Smith, 1995; Federal Duck Stamp, 1987-1988).

Wading birds of the coastal Gulf of Mexico include the families, *Ardeidae* (herons, egrets and bitterns), *Ciconiidae* (storks), *Gruidae* (cranes), and *Threskiornithidae* (ibis and spoonbills). The most abundant species in estuaries are tricolored herons (*Egretta tricolor*) and snowy egrets (*Egretta thula*). More than 80% of the total number of breeding tricolored and little blue herons (*Egretta caerulea*) nest along the gulf coast. Although the number of colonies of wading birds on the gulf coast is often less than the number of colonies on the Atlantic Coast, the gulf colonies are larger in number of birds, accounting for a majority of the total breeding population of wading birds (Fig. 38). The wading birds listed in Figure 38 prefer salt marshes and other wetlands bordering coastal bays. The North American Breeding Bird Survey summarizes trends in wetland breeding birds (e.g., herons) from 1966-1996. Significant decreasing

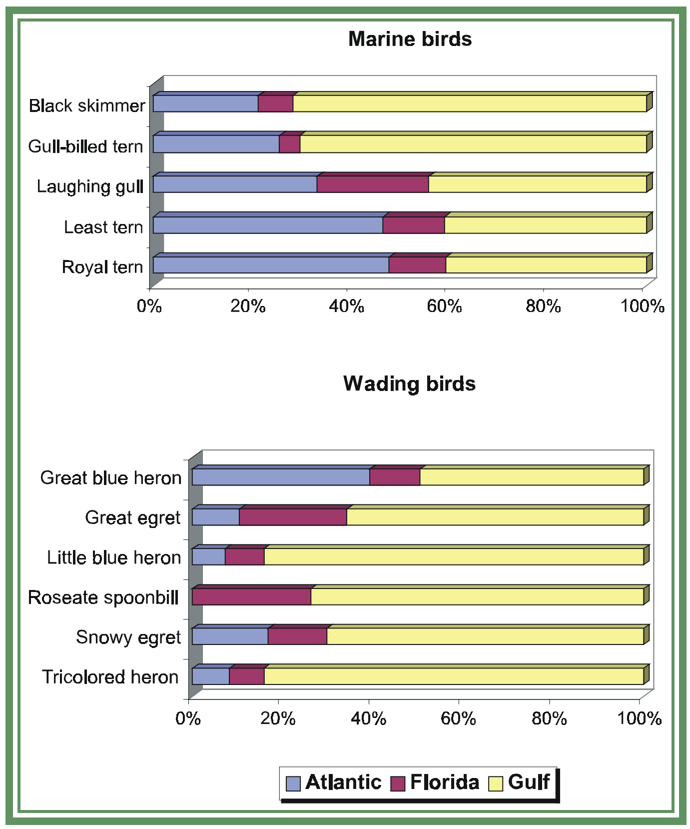


Fig. 38. Breeding populations of wading birds and seabirds common to the gulf coast showing the percent of population located among the gulf, Florida, and Atlantic coasts (U.S. Fish and Wildlife Service, 1988).

trends in little blue heron populations were indicated for Alabama and Florida, while significant increasing trends for other wading birds were indicated for all of the gulf states.

The most common marine birds along the gulf coast include laughing gulls (*Larus atricilla*), terns (*sub Family sterninae*), and migrating sandpipers (*Family Scolopacidae*) and plovers (*Family Charadriidae*). Laughing gulls are the only gull species that nest on the gulf coast, and are the most abundant marine birds to nest in this region. The largest populations of black skimmers (*Rynchops niger*) and gull-billed terns (*Sterna nilotica*) in the U.S. nest along the gulf coast (Fig. 38). These birds utilize almost exclusively coastal bays and nearshore waters for both nesting and feeding. The North American Breeding Bird Survey had little or no trend information for these marine birds in the gulf states, however, laughing gulls were listed as showing a significant increase in population from 1966-1996 in the southeast.

Threatened and Endangered Species

Degraded water quality, altered water flow, and loss of suitable habitat are the greatest threats to aquatic species at risk of extinction. Efforts to minimize water pollution or restore natural flow should contribute to the protection of threatened or endangered species. Because these species are already at risk, they act as sentinels, providing us with early warnings of even small perturbations in their environment. Charting their recovery also provides us with an indicator of the success of management programs designed to ensure that these species have a clean and safe habitat.

The **Gulf sturgeon** (*Acipenser oxyrhynchus desotoi;* Fig. 39) was listed as a threatened subspecies on September 30, 1991. The Gulf sturgeon is an anadromous fish, migrating from salt water into large coastal rivers. Historically, the Gulf sturgeon occurred in rivers from the Mississippi River to the Suwannee River and in bays and estuaries from Florida to Louisiana. Little is known about current population levels outside the Suwannee, Apalachicola and Pearl Rivers but they are thought to have declined from historic levels. Although much of the sturgeon's life is spent in fresh water, it utilizes bays and estuaries for feeding and migration. Major threats to this rare, primitive species include physical barriers (e.g., locks and dams) to spawning grounds, habitat loss, and poor water quality.

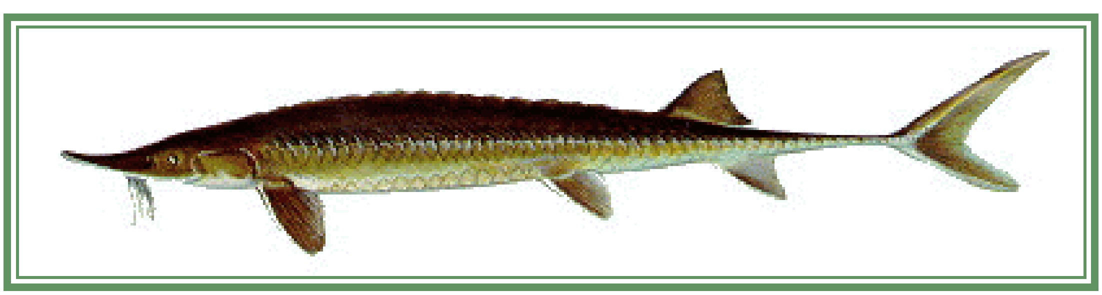


Fig. 39. Illustration of a Gulf sturgeon.

The Florida **manatee** (*Trichechus manatus*; Fig. 40) is currently listed as an endangered species, although ongoing efforts to protect manatee have been successful and the Florida population appears to be rebounding. Manatee inhabit freshwater, brackish, and marine waters throughout the gulf coast, although the largest population is in Florida. Along the gulf coast of Florida, the principal summer habitats of manatee are estuaries and riverine grassbeds where they feed on submerged, emergent, and floating vegetation. Because manatee depend on healthy estuarine habitat, shifts in population counts may indicate degradation of the coastal environment. The greatest human impacts on manatee survival include recreational boat traffic and intensive coastal development, but some manatee mortalities may also be attributed to natural causes (e.g., cold temperatures or red tide). In 1996, a record number of manatee (2,639) were counted in the January survey, but a record number of deaths also occurred (416), with 151 deaths attributed to toxic red tide and 60 to watercraft. The U.S. Fish and Wildlife Service's first 1997 survey reported an encouraging population count of 2,229 manatee with a record high 1329 on the Florida west coast despite the 1996 red tide deaths.

Fig. 40. Photograph of two manatee. Photo credit: Homosassa Springs State Wildlife Park.

The **brown pelican** (*Pelecanus occidentalis*; Fig. 41) is still listed as endangered in Louisiana, Texas, and Mississippi, while stable populations now thrive in Florida and Alabama. Brown pelicans nest in colonies along the gulf coast and feed primarily on fish from shallow waters of estuaries. Because they depend on high quality coastal habitat, declining trends in brown pelican nesting populations may indicate degradation of nesting substrate or fluctuations in food supply. Brown pelican populations declined sharply in the 1950's and 1960's, primarily due to the ingestion of fish contaminated with pesticides like DDT. In the 1970's, the banning of DDT and listing the pelican as an endangered species contributed to its successful rebound. The gulf coast population, while still considered endangered, was recently estimated at 6,000 breeding pairs.

Fig. 41. Photograph of adult brown pelican. Photo credit: Marcus G. Martin, University of Minnesota.

Several sea turtles are listed as endangered in the Gulf of Mexico, including the **Kemp's ridley** (*Lepidochelys kempii;* Fig. 42), green (*Chelonia mydas*), loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), and hawksbill (*Eretmochelys imbricata*). Adults of the Kemp's ridley sea turtle are restricted to the Gulf of Mexico, where their major non-nesting habitat includes nearshore and inshore waters (especially in Louisiana) and salt marshes where they feed on crabs and other invertebrates. The entire population of Kemp's ridley sea turtles has expanded its nesting range beyond the 5 miles of beach in Tamaulipas, Mexico. In 1947 the population was estimated at 42,000 females; currently, an estimated 1500 females return to nest and their numbers have been declining each year. Major threats to this turtle have included overharvesting, shrimp nets, oil spills, marine debris, and dredging. Currently the Mexican government has banned harvest of Kemp's ridleys and instituted strict management and protection efforts while the National Marine Fisheries Service has implemented regulations that require shrimp fisherman to use turtle excluder devices in their trawls.

Fig. 42. Photograph of a baby Kemp's ridley sea turtle. Photo credit: Bill Reaves, Texas Parks and Wildlife Department.

Public Health

Many pollutants found in Gulf of Mexico waters have the potential to produce acute and chronic human health effects. Humans may be exposed to waterborne toxins or pathogens via two principal pathways: consumption of fish and shellfish and direct contact with water. The degree of human health risk depends upon the specific characteristics of the pollutant, including its potential to reach and thereby cause adverse impacts in humans. As an example, an advisory was issued by the Louisiana Department of Health and Hospitals in June 1997 for Lake Pontchartrain. This advisory was for swimming, consuming, inhaling spray or otherwise contacting the water after a toxic cyanobacterial bloom spread over the lake following the opening of a spillway from the Mississippi River.

Shellfish - Growing Waters

Shellfish resources in Gulf of Mexico estuaries range from those located only in brackish water to those found mainly in salt marshes and inshore coastal areas, and include penaeid shrimp (*Penaeus spp*.), blue crab (*Callinectes sapidus*), and oysters (*Crassostrea virginica*). Oysters are important ecologically because they have a major role in altering water clarity through filter-feeding and because oyster reefs are vital habitats for other species. The Gulf of Mexico is the largest oyster-producing region in the Nation, with 57% of the national total in 1996.

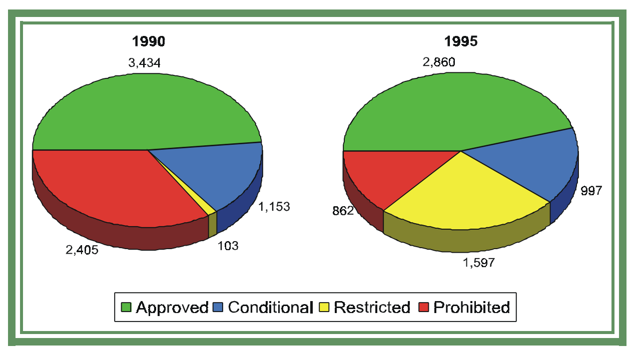


Fig. 43. Classified shellfish - growing waters in thousand acres in the Gulf of Mexico (NOAA, National Ocean Service).

Shellfish-growing waters in the Gulf of Mexico refer mainly to oyster-producing waters. These are affected by urbanization and may be closed to harvest because of pollution. The National Shellfish Sanitation Program (NSSP) classifies shellfish-growing waters to protect public health. Shellfish-growing waters are classified as approved, conditionally approved, restricted, or prohibited based on sanitary surveys that identify actual pollution sources and evaluate water quality data (Fig. 43). In cases where water quality problems are the cause of shellfish bed closures, this indicator could be used to determine the area and extent of pollution. The acreage of shellfish-growing waters that are harvest-restricted because of pollution can be used as an indicator of water quality to measure the progress of improved coastal zone management efforts. Although the gulf region contains the most classified shellfish-growing waters in the nation (6.3 million acres in estuaries in 1995), it also ranks first in total acres of prohibited shellfish-growing waters. From 1990 to 1995 the total acres of approved shellfish-growing waters decreased by 574,000 acres (Fig. 43). The top three pollution sources affecting harvest limitation in 1995 were upstream sources, individual wastewater treatment plants, and wildlife. Commercial landings of oysters decreased from 1985 to 1990 but have increased since 1990, especially in Louisiana and Texas (Fig. 44).

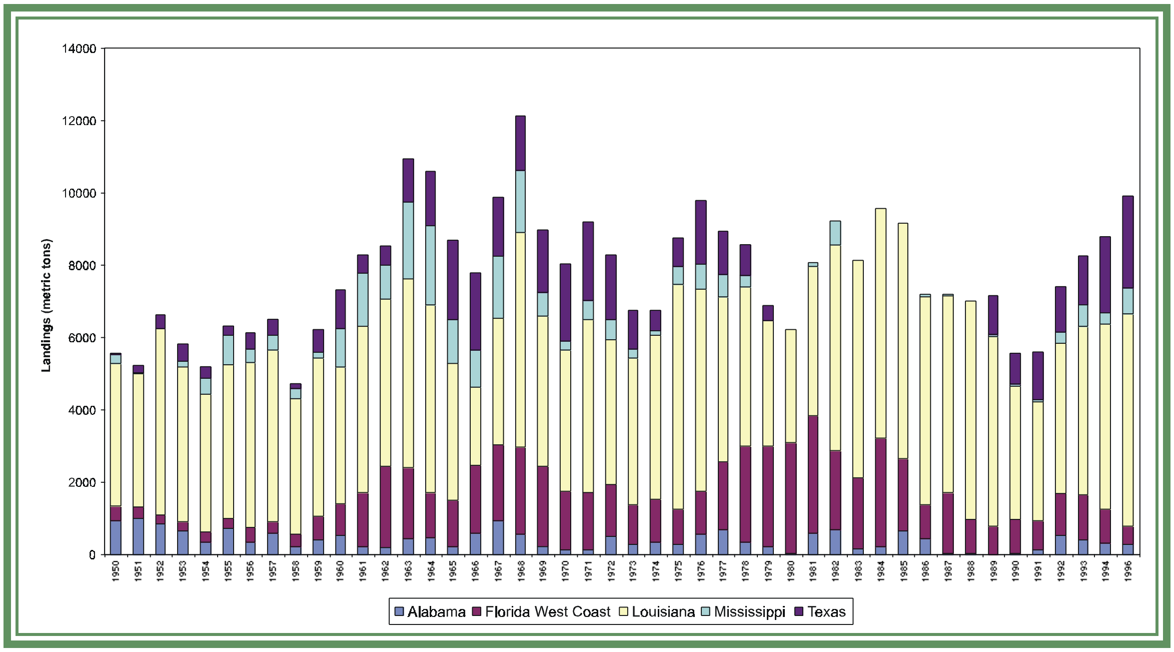


Fig. 44. Commercial landings of oyster in the Gulf of Mexico by state from 1950 to 1995 (National Marine Fisheries Service).

Contaminants in Fish and Shellfish

Seafood consumption advisories are designed to protect the public from the health risks of consuming contaminated fish and wildlife. These advisories serve as a warning that high concentrations of harmful chemicals (e.g., mercury and dioxins) have been found in local fish and wildlife. Consumption advisories are useful as a benchmark because the number of waterbodies added to the list each year is frequently a direct indicator of increasing environmental contamination. As of 1997, Florida, Alabama, Louisiana, and Texas had fish consumption advisories in effect for selected estuarine waters (Table 2).

Other federal monitoring programs that track the occurrence of chemicals in fish and shellfish tissue include EMAP and the NOAA National Status and Trends Program Mussel Watch Project. Analysis of chemical contaminants in the edible tissue of fish and shellfish provides information on the bioaccumulation of contaminants released to the environment. This information could provide an early warning for emerging problems that could affect the viability of estuaries. Guidance values (U.S. Food and Drug Administration or international) for metal concentrations were exceeded in catfish, croaker, and shrimp tissues analyzed by EMAP. In most cases, however, only a low percentage of the fish populations showed elevated concentrations of trace metals (Fig. 45), and none showed elevated levels of either pesticides or PCB’s. The high concentrations of arsenic in catfish (Fig. 45) may be an artifact of the chemical analysis that did not separate organic forms of arsenic from inorganic forms. The NOAA Mussel Watch Project identified increasing trends, however, in the concentrations of at least one target contaminant in oyster tissue from 21 of 55 monitored sites in the gulf. Only six sites with increasing trends also had high concentrations of one or more metals.

Table 2. 1997 Active Fish Consumption Advisories for Gulf of Mexico Estuarine Waters (USEPA 1997).

Advisory Location	Pollutant	Species	Population affected[1]
Florida marine waters	Mercury	shark	Restricted—general Restricted—special
Gulf of Mexico, FL	Mercury	King mackerel 33-39"	Restricted—general Restricted—special
		King mackerel > 39"	No consumption—general
Charlotte Harbor, FL	Mercury	Spanish mackerel, crevalle jack, spotted seatrout	Restricted—general Restricted—special
Tampa Bay, FL	Mercury	gafftopsail catfish, crevalle jack, ladyfish, Spanish mackerel	Restricted—general Restricted—special
Florida Keys, FL and Florida Bay, FL	Mercury	crevalle jack and spotted seatrout	Restricted—general Restricted—special
Alabama Coastal Waters	Mercury	King mackerel >39"	No consumption—general
		King mackerel <39"	Restricted—general No consumption—special
Bayou D'Inde, LA	PCB's Hexachlorobenzene Hexachlorobutadiene	fish and shellfish	Restricted—general
Calcasieu River	PCB's Hexachlorobenzene Hexachlorobutadiene	fish	Limited consumption
Gulf of Mexico - off of LA Coast	Mercury	King mackerel ≤ 39"	Restricted—general Restricted—special
		King mackerel > 39"	No consumption—general
Lavaca Bay, TX	Mercury	fish and crab	Fishing ban
Houston ship channel, TX Upper Galveston Bay, TX	Dioxins	catfish and blue crab	No consumption—special Restricted—general
Gulf of Mexico, TX	Mercury	King mackerel	Restricted—general Restricted—special

[1] Terms for Population Affected:
Restricted - consumption should be limited to one meal per week; this varies by state
No consumption - fish should not be consumed at all by the population affected
General - population, in general
Special - population, special high-risk groups (e.g., children and women of child-bearing age)

Fish Kills

The assessment of mortalities of fish, or fish kills, can be used by environmental managers to determine areas of concern. Large numbers of dead or dying fish in estuaries are an aesthetic nuisance as well as a health threat. Fish kills may be indicators of natural phenomena like sudden changes in temperature ("freeze kills"), oxygen depletion resulting from sustained periods of hot weather coupled with low-flow conditions, or red tide. Human activities such as accidental toxic chemical spills, toxins released in wastewater, or nutrient enrichment may also contribute to fish kills. Most states are mandated to respond to fish kill events, to determine the most probable cause, and to compile summaries of fish kills. NOAA compiled a nationwide database of fish kills in coastal waters from 1980-89. Results indicated that there was no trend in fish kill events during this time (Fig. 46), but that the majority of fish kill events occurred during the summer months and were caused by hypoxia (Fig. 47). A national "hot spot" for fish kills was in Texas, where Galveston County had the highest number of fish killed and Galveston Bay had the most reported events. Currently, an association of Federal and State agency personnel are creating a network for Gulf of Mexico coastal waters to report fish kill events (Gulf of Mexico Aquatic Mortality Network or GMNET). GMNET's mission is (1) to enhance cooperation among the Gulf states so that fish kill data are collected and reported in a timely and consistent manner, and (2) to determine if fish kill events can be used as an indicator of environmental perturbation in estuaries.

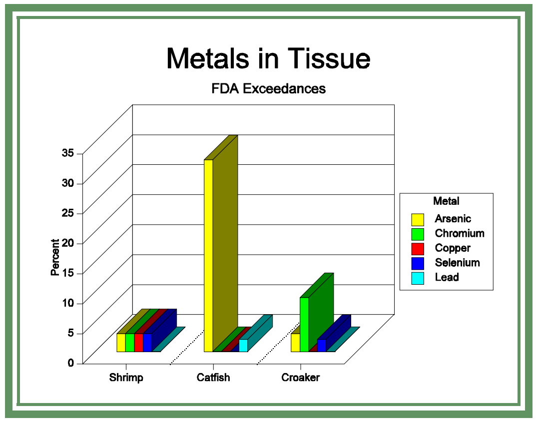


Fig. 45. Percent of sampled population for target species with tissue concentrations of metals that exceeded FDA guidelines (USEPA, EMAP Database for the Louisianian Province, 1991 to 1994).

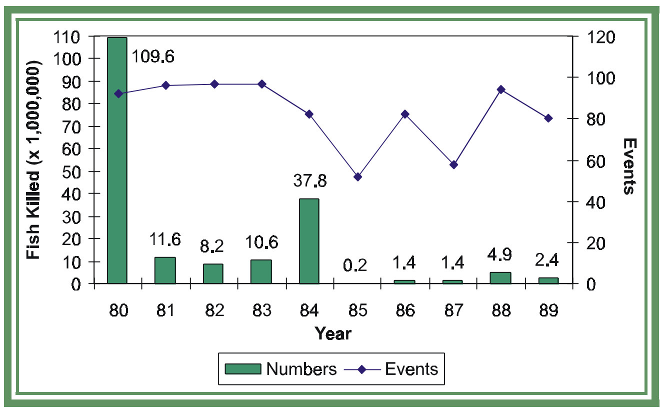


Fig. 46. Number of fish kill events and number of fish killed in Gulf of Mexico coastal waters from 1980 to 1989 (NOAA/ORCA 1991).

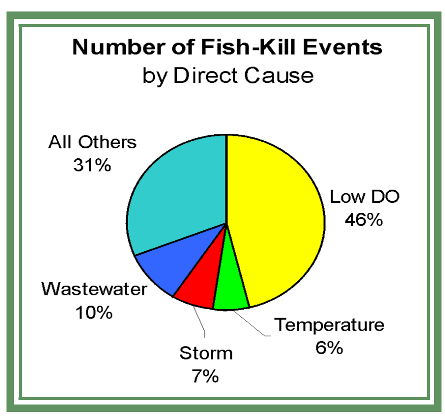
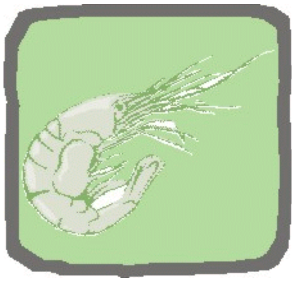


Fig. 47. Percent of all fish kill events in Gulf of Mexico coastal waters from 1980 to 1989 that were caused by low dissolved oxygen, temperature, storms, or waste water (NOAA/ORCA 1991).



Ecological Report Card

In a letter addressed to participants attending a National Environmental Monitoring and Research Workshop at the Smithsonian Institution on September 25, 1996, Vice-President Gore challenged federal agencies to “work with the scientific community and other interested parties to produce a ‘report card’ on the health of our Nation's ecosystems by 2001. This report card should establish an environmental baseline to evaluate the status of our ecosystems.” Partly in response to this challenge, EMAP’s research strategy includes regional-scale geographic assessments that will result in “State of the Region” reports. Geographic assessments will use ecological indicators to describe the status and trends in the condition of environmental resources within a region and to evaluate the probable causes of the observed effects.

This report takes one step in assessing the health of Gulf of Mexico estuaries. This assessment may serve as a baseline for conditions in gulf estuaries. Progress to date can be estimated and the effects of future management decisions can be gauged by comparing future conditions to the data presented in this report.

The rating of each indicator is summarized separately using a green to red (rank scores of 1 to 5) color scheme where green means good or no problem, and red means poor or severe problem. Where possible, rankings were based on the percent area of estuaries that were affected by levels of one or more indicators that described “problem” conditions (see final report card at the end of this chapter for a key to the color scheme).

Nutrients	**FL**	**AL**	**MS**	**LA**	**TX**	**Gulf**

Eutrophication is potentially one of the most critical problems facing gulf coastal ecosystems. Excess nitrogen enters gulf estuaries via fertilizer runoff from agricultural and residential land, animal manure, and atmospheric deposition. The gulf region has the highest number of wastewater treatment plants and the most land devoted to agriculture with the most applied fertilizer. Many gulf estuaries show evidence of pre-eutrophic or eutrophic conditions. The goal of State and Federal agencies responsible for managing coastal ecosystems is to identify potential problems and take preventive actions before they become a reality. Four indicators of nutrient enrichment were used to assess the overall nutrient status of estuaries: the NOAA Estuarine Eutrophication Survey, state 305(b) assessments of nitrogen and chlorophyll levels, and Rabalais’ (1992) evaluation of nutrient increases. Nutrient problems ranged from minimal in Alabama to definite problems in Louisiana and Texas with overall moderate problems throughout the gulf.

Dissolved Oxygen	FL	AL	MS	LA	TX	Gulf

Dissolved oxygen (DO) in the Gulf of Mexico has received much press recently due to the large area of hypoxia located on the continental shelf off the Louisiana coast. Estuarine hypoxia, on the other hand, is less understood except at a local level (e.g., the "jubilee" phenomenon in Mobile Bay). Low DO in estuaries may be attributed to natural cycles of stratification, metabolism, seasonal storm events, and depth/tide regimes. Low DO is often exacerbated by the anthropogenic effects of nutrient enrichment habitat modification, and channelization. Using EMAP and NOAA data and Rabalais' (1992) assessment of oxygen depletion, gulf estuaries ranked as fair overall, with most of the estuaries with persistent low DO occurring east of the Mississippi River.

Sediment Contaminants	FL	AL	MS	LA	TX	Gulf

Long et al.'s (1995) ER-L and ER-M values provide guidance for environmental managers to identify sediments with a possible or probable likelihood of causing adverse effects to the biota. Using these and other guidelines in an assessment of contaminants in gulf estuaries, Engel and Evans (1997) concluded that "the coastal Gulf of Mexico is not broadly at risk from persistent chemical contaminants." We compared the EMAP data to these guidelines and also concluded that estuarine sediments in the Gulf of Mexico, are in fair condition overall with respect to contaminants. The few "hot spots" that have been identified by large-scale monitoring programs seem to be localized to shipping channels and point sources.

Wetlands	FL	AL	MS	LA	TX	Gulf

We were unable to obtain standardized data on coastal wetland loss rates throughout the Gulf of Mexico region. The National Oceanic and Atmospheric Administration reported in 1991 that although the gulf had the most acreage of coastal wetlands in the United States, the region also had the highest rate of wetland loss. Total loss of wetlands (coastal and inland) in the gulf states ranged from 41% in Louisiana to 54% in both Florida and Mississippi from 1780 to 1980. Seagrass habitat loss ranged from 20% to 100% for most gulf estuaries over the past 50 years. The acreage of coastal wetlands has continued to diminish since the 1950's in all states, although the rate of wetland loss has slowed (e.g., from 42 mi^2/yr during the 1970's to 25 mi^2/yr in the 1990s in Louisiana). Most coastal wetlands are lost to residential and commercial development although, in Louisiana, coastal wetlands are often destroyed by hydrologic alterations. The high rate of coastal wetland loss in the Gulf of Mexico is mostly the result of man's influence.

Benthos	FL	AL	MS	LA	TX	Gulf

EMAP-E collected benthic samples from northern gulf estuaries from 1991 to 1994. A benthic index of estuarine condition was developed by EMAP-E that can be used to indicate whether the benthic communities are similar to known degraded communities, known reference communities, or are somewhere between these two extremes. Twenty-three percent of the estuarine area in the northern Gulf of Mexico (excluding Tampa Bay to Florida Bay) had degraded benthic communities. When the condition of the benthos is examined on a local level, degraded benthic communities are often associated with sediment contaminants or hypoxia.

Fish/Shellfish Landings	FL	AL	MS	LA	TX	Gulf

The top four fisheries in the Gulf of Mexico (menhaden, shrimp, oyster, blue crab) use estuaries extensively. Trends in commercial landings vary among the gulf states but are, in general, stable. The shrimp fishery in the gulf, for example, accounts for 69% of the domestic harvest of shrimp. Shrimp landings are stable in Florida, Alabama, and Mississippi, but they have been decreasing in Louisiana and Texas. Degraded water quality and loss of wetlands have been cited as possible causes of the declines in shrimp fisheries in these states. A fishery management success story can be seen in the history of the red drum. Following a severe population crash due to overfishing in the late 1980's, the red drum fishery was closed to all commercial harvest. A decade later, however, the red drum population in the gulf is recovering, and limited fishing is now allowed in all gulf states.

Fish Biomarkers	FL	AL	MS	LA	TX	Gulf

Fish health assessments were made by EMAP-E in the northern gulf estuaries (excluding Tampa to Florida Bay) by examining fish for gross pathological disorders and splenic macrophage aggregates. Incidences of fish pathologies and macrophage aggregates occurred at a higher rate in Alabama and Texas than in the other gulf states but were, in general, confined to certain estuaries. Most of the pathologies observed were parasites, and most occurred in menhaden. High rates of gross pathological abnormalities and high densities of macrophage aggregates may be associated with environmental contamination.

Coastal and Marine Birds	FL	AL	MS	LA	TX	Gulf

Gulf of Mexico estuaries and wetlands provide essential habitat for migratory and resident birds. Waterfowl use these ecosystems as winter feeding grounds. Resident wading birds and marine birds rely on estuaries and wetlands for nesting and feeding. In general, gulf estuaries and wetlands support large, healthy, stable populations of waterfowl and other coastal birds.

Threatened Species	FL	AL	MS	LA	TX	Gulf

Many threatened and endangered species inhabit the gulf states but only four use estuaries almost exclusively: brown pelican, Gulf sturgeon, manatee and Kemp's ridley sea turtle. These species' populations are stressed primarily because of degraded water quality and habitat alterations. The brown pelican is stable in Florida and Alabama and, while population numbers are low elsewhere, there is some evidence that they are increasing. There is little information about the population stability of the Gulf sturgeon outside of Florida, and the manatee is found routinely only in Florida. Manatee numbers are still low but appear to be recovering slowly. The Kemp's ridley sea turtle population has been steadily declining since the 1940's and is currently estimated to have only a thousand nesting females.

Shellfish Bed Closures	FL	AL	MS	LA	TX	Gulf

Although the gulf region contains the most classified shellfish-growing waters in the U.S. (6.3 million acres in 1995), this region also has the most acreage of waters that are restricted or prohibited for shellfish harvest. The percent of waters among the gulf states that were harvest-restricted from 1985 to 1995 ranged from 24% to 43% with increases in restricted waters over that time from 4% to 65%. Gulf waters lost 574,000 acres of approved shellfish-growing waters between 1990 and 1995, mostly due to pollution from upstream sources and wastewater treatment plants.

Tissue Contaminants	FL	AL	MS	LA	TX	Gulf

Environmental contaminants found in the edible tissue of fish and shellfish could potentially pose a threat to human health. Seafood consumption advisories were issued in Florida, Alabama, Louisiana, and Texas in 1997. EMAP-E analyzed 718 composite fish/shellfish samples for chemical contaminants. Comparing the results to FDA and international consumption guidelines yielded a low percentage of fish/shellfish with elevated concentrations of contaminants.

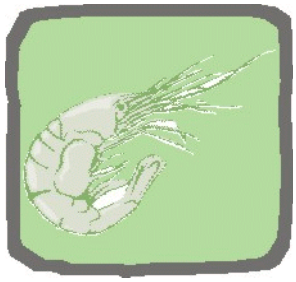
Priority Ecological Indicators	FL	AL	MS	LA	TX	Gulf
Nutrients *						
Dissolved oxygen *						
Sediment contaminants *						
Wetland *						
Benthos *						
Fish/shellfish landings						
Fish biomarkers						
Coastal and marine birds						
Threatened species						
Shellfish closures *						
Fish tissue contaminants						

* **Key to color scheme where % area indicates the best estimate of % area affected by adverse condition levels of the indicator.**

Color	% area	Subjective rank
	0-5%	good; no problem
	> 5-10%	good-fair; minimal problem
	>10-25%	fair; moderate problem
	>25-35%	fair-poor; definite problem
	>35%	poor; severe problem

The final product of this report is a report card that represents the best estimates of the extent of ecological conditions based on the most recent available data. For the gulf estuaries overall, most indicators ranked in fair condition. Minimal or no problems were observed for fish and bird populations gulf-wide. Wetland loss and shellfish bed closures were rated as definite or severe problems for almost all gulf states and these indicators presented the most severe ecological concerns for gulf estuaries. Estuaries on the Florida gulf coast had moderate problems identified by most of the indicators and, of all states, Florida rated most similarly to the gulf overall. Alabama rated good to fair for most of the indicators, with problems indicated by dissolved oxygen and fish biomarkers. Mississippi rated good to fair for all indicators except wetland loss. Louisiana and Texas had definite problems with nutrients. Fish tissue contaminants were a definite problem in Louisiana while degraded benthic communities and fish health were indicated as problems in Texas.

The mix of colors in the report card suggest that estuaries in the Gulf of Mexico have some significant environmental problems but that the extent of these problems varies among the gulf states. There has been some improvement in the condition of estuaries since the Clean Water Act was passed as indicated by the good condition of some estuarine fauna and the relatively moderate problems with water quality and contaminants. The orange and red areas, however, indicate that effective management and protection of estuaries must continue in the Gulf of Mexico. Special attention should be directed toward stemming the loss of coastal wetlands gulf-wide and improving the quality of wastewater and other effluents in order to increase the acreage of shellfish beds that are approved for harvest.



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Appendix I:

National Estuary Programs (NEP) and National Estuarine Research Reserve Systems (NERRS) in the Gulf of Mexico

The Sarasota Bay NEP

The Sarasota Bay NEP began in 1989 in response to public concern about pollution and habitat loss from rapid growth, development, and overuse. Fifty years ago, Sarasota Bay was described as a pristine estuary with lush seagrass meadows, abundant fish and shellfish, and clean, clear water. Since then, Sarasota Bay has lost 40% of its wetlands and suffers from high nutrient loading from nonpoint sources and toxic contamination of sediments. Through the Sarasota Bay NEP, a baywide monitoring program was instituted to evaluate the status of and trends in priority problems such as nitrogen loadings and loss of wetland and seagrass habitat. In order to improve management of the Bay's resources, the program has also recommended (1) an alternative development strategy which increases open space and reduces stormwater runoff and (2) treated wastewater reclamation to be used as an alternative water source. Sarasota Bay NEP homepage at **http://pelican.gmpo.gov/gulfofmex/estuarypartner/Sarasota/SarasotaBay.html**

The Tampa Bay NEP

Recognizing the need for a comprehensive bay restoration and protection plan, the Tampa Bay NEP was established in 1991 to address the harmful effects of growth and development on the water quality and wetland/seagrass habitats of Tampa Bay. The NEP has sponsored research into the bay's problems, tested early management actions, and initiated several public outreach programs to get citizens involved in protecting the bay. The NEP lists its priority concerns as water and sediment quality, bay habitats, dredging and dredged material management, fish and wildlife health, and spill prevention and response. Tampa Bay has seen marked improvements in water quality and general health over the past several years, and the goal of the NEP is to ". . . maintain this steady progress, even in the face of continued growth." Tampa Bay NEP homepage at **http://access.tampabayrpc.org/nep**

The Barataria-Terrebonne NEP

Many of the priority issues affecting the health and stability of the Barataria-Terrebonne basin relate back to hydrologic modifications, including levees, dredge canals, and other artificial structures that change the natural flow of water. In this basin, hydrologic modifications have led to a reduction in the amount of sediment from the Mississippi River that settles on the wetlands. The wetlands in this basin are subject to subsidence if the rate of sediment building falls below the rate of sinking. Habitat loss affects the condition of living resources and reduces the recreational and commercial value of wetlands and estuaries. Although habitat loss is the most pressing ecological issue facing the Barataria-Terrebonne basin, the NEP is also concerned with eutrophication, pathogen contamination, and toxic contamination. The NEP is currently developing a computer landscape model that will be used to evaluate the impacts of actions that could be taken to conserve habitat in this estuarine watershed. Barataria-Terrebonne NEP homepage at **http:/www.btnep.org/**

The Galveston Bay NEP

The Galveston Bay NEP was established in 1988 with a mission to characterize, identify, and assess problems and issues affecting water quality in Galveston Bay. The major problems affecting the bay are (1) changes in the amount and timing of freshwater inflow that have altered salinity patterns in the bay, (2) loss of wetland and seagrass habitats, and (3) point and nonpoint sources of wastewater that contribute toxic substances and bacterial contamination to water and sediments and lead to poor water quality. The greatest challenge facing the Galveston Bay NEP is finding a balance between competing human uses and the environment. The NEP has designed a monitoring program, has implemented management tools to enhance interagency coordination, and has produced a "State of the Bay" report that characterizes the Galveston Bay ecosystem. Galveston Bay NEP homepage at **http://gbep.tamug.tamu.edu/**

The Corpus Christi Bay NEP

The Corpus Christi Bay NEP, established in 1992, is a community based effort to identify the problems facing the bays and estuaries of the Texas Coastal Bend. The mission of the NEP is (1) to enhance cooperation among business, government, and the general public to identify priority problems needing attention, (2) to encourage the use of appropriate and feasible management actions that will ensure sustainable utilization of resources in the future, (3) to coordinate research, planning, management, and public outreach efforts, and (4) to ensure that "everyone has a voice in managing the Coastal Bend's bays and estuaries." The NEP is currently investigating several priority issues: altered freshwater inflow, declines in living resources, loss of wetlands and other habitats, degradation of water quality, altered estuarine circulation, selected public health issues, and debris. These investigations will identify the status and trends of water quality and living resources. Corpus Christi Bay NEP homepage at **http://www.sci.tamucc.edu/ccbnep/**

The Charlotte Harbor NEP

Charlotte Harbor was named to the National Estuary Program in 1995. The NEP was established to address priority problems in Charlotte Harbor, including hydrologic alterations, water quality degradation, and fish and wildlife habitat loss. As urban development increases in the watershed, local governments are faced with balancing conflicting needs for a reliable water supply, treating residential wastewater, and preserving habitat. The goals of the Charlotte Harbor NEP are to (1) improve environmental integrity; (2) preserve, restore, and enhance seagrass and wetlands; (3) reduce point and nonpoint pollution; (4) provide proper freshwater inflow; and (5) develop and implement a strategy for public participation and education as well as a formal management plan to achieve these goals. Charlotte Harbor NEP homepage at **http://www.epa.gov/region4/waterpgs/water/coastal/chnep.htm**

The Mobile Bay NEP

Mobile Bay was designated as a NEP in 1995. Mobile Bay NEP is currently working towards prioritizing the environmental problems of Mobile Bay by holding monthly workshops that involve the public and the Technical and Citizens Advisory Committees. These workshops allow everyone to voice their concerns about the bay and to come to consensus on priority issues. Concurrently, a scientific literature review will compile and analyze the existing data for Mobile Bay water quality, living resources, and human uses. Mobile Bay NEP homepage at **http://www.epa.gov/OWOW/estuaries/mobile.htm**

Weeks Bay NERRS

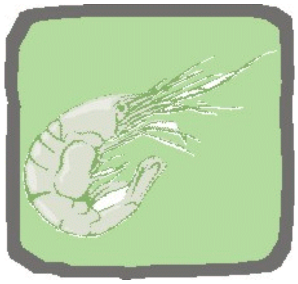
Weeks Bay is a small, shallow, estuarine embayment off Mobile Bay, fringed with marsh and forested wetland. Designated an Outstanding National Water Resource in 1992, the Weeks Bay watershed is ideally sized for estuarine research projects. Research from before 1990 focused primarily on obtaining baseline data, including projects on SAV type and abundance, nursery habitats and indicator species since little was known about the relatively pristine and unimpacted rural bay. Post-1990 research has included estuarine modeling, studies of salinity regime, non-point source pollution and land-use studies, nutrient production and input, community and habitat studies, migratory bird banding, and pesticide impacts. Current research efforts at the Weeks Bay NERR and within its watershed include hydrodynamic modeling, floral and faunal inventories and ongoing assessment and abatement of nonpoint pollution.

Apalachicola Bay NERRS

The Apalachicola Bay is the largest of the currently existing NERR sites, with 193,758 acres of land and water within its boundaries, and potential for considerable expansion. The overall high water quality of the Apalachicola estuary, combined with other factors, provides ideal living conditions for estuarine biota, resulting in a highly productive estuarine system. The myriad of habitats found within the reserve support a wide range of plant and animal species, many of which are threatened or endangered. Research activities of the reserve include long-term monitoring of physical, chemical, and biological parameters important to estuarine productivity; a marsh restoration/breakwater demonstration program; on-site assistance for regional research projects; and protection and monitoring programs for threatened sea turtles and migratory bird nests. An onsite, computerized library consisting of over 3,700 publications is available for use by visiting researchers. From 1990 to 1995, over 40 research and monitoring projects were undertaken by staff and outside investigators.

Rookery Bay NERRS

The Rookery Bay NERR is located at the northern end of the Ten Thousand Islands on the gulf coast of Florida, one of the largest mangrove-forested regions in the U.S. Rookery Bay represents one of the few remaining undisturbed mangrove estuaries in North America. Pristine mangrove forests surround shallow bay waters and the upland buffer consists of pine flatwoods and dry-zone scrub. Visiting scientists utilize on-site laboratory facilities for systems and baseline studies of the plant and animal communities of the reserve. Research conducted at the site has included the study of nutrient cycling in mangrove systems, estuarine food webs, estuarine faunal abundance, and bird population dynamics. Long-term ecological monitoring efforts of the Rookery Bay NERR include water quality monitoring (physical, chemical, and biological), meteorological and tidal conditions, and benthic invertebrates. Data generated from the research programs are used to assess the health of the Rookery Bay ecosystem, guide future research efforts, and develop new management policies and educational programs for the reserve.



Appendix II:

Characteristics of Estuaries in the Gulf of Mexico

Definitions

Low Water Clarity = < 10% Transmission of ambient light to 1 m depth
High TDN = Total dissolved nitrogen >= 1 mg/L
High Chlorophyll = Chlorophyll *a* > 20 ug/L
Hypoxia = at least 1 event of DO >0, <= 2 mg/L
Anoxia = at least 1 event of DO =0 mg/L
Low DO = Minimum bottom dissolved oxygen conc. over 12 hours is < 2 mg/L
High Sediment Contaminants = more than 5 analytes had concentrations > ER-L (Long et al. 1995)
Coastal Wetlands includes Salt/Fresh Marsh, Forested Scrub/Shrub, Tidal Flats
SAV = Submerged Aquatic Vegetation
Degraded Benthos = Benthic index < criteria for a province
% Fish with Pathology = Number of fish with observed pathology / number of fish sampled
Harvest Limited Shellfish Beds include beds conditionally approved, restricted, & prohibited for harvest

Estuary	Surface Area (sq. km)[7]	Total Drainage Area (100 sq km)[7]	Avg. Depth (m)[2]	Avg. Daily Freshwater Inflow (100 cfs)[7]	Avg. Salinity (ppt)[2]	Avg. % Silt-Clay[2]	% Area with Low Water Clarity[2]	% Area with High TDN[1]	% Area with High Chlorophyll[1]
Florida Bay	1393	28	2		31	37	0	10	10
Ten Thousand Islands	697	62	3		17	42	50	27	0
Charlotte Harbor	805	130	2	48	13	9	67	42	22
Sarasota Bay	114	8	2	4	30	2	0	0	25
Tampa Bay	896	67	3	24	27	11	0	<1	43
St. Josephs Bay	170	2	10		66	40	0		
Waccasassa Bay	40	44	1		26	22	0		
Suwannee Sound	109	264	2	112	16	58	96	0	0
Apalachee Bay	412	119	3	53	30	17	16	0	0
Apalachicola Bay	554	531	3	291	22	32	12	7	0
St. Andrew Bay	243	28	4	45	31	7	0	0	0
Choctawhatchee Bay	334	140	5	85	25	61	<1	0	0
Pensacola Bay	370	181	4	116	23	43	<1	<1	<1
Perdido Bay	130	31	3	22	15	78	8	0	0
Mobile Bay	1059	1155	3	793	19	72	<1	0	0
Mississippi Sound	4792	697	4	436	24	60	5	<1	<1
Lake Borgne	730	383	3	251	7	75	9	n/a	n/a
Lake Pontchartrain	1839	142	3	107	2	74	13	<1	0
Breton/Chandeleur Sounds	5403	65	3	103	27	46	9	0	n/a
Mississippi River	1554	29311	6	4644	6	77	36	100	0
Barataria Bay	1673	57	2	55	13	67	23	100	100
Terrebonne/Timbalier Bays	1761	41	2	46	18	62	3	0	100
Atchafalaya/Vermilion Bays	1821	2606	2	2238	1	83	59	100	70
Calcasieu Lake	256	111	1	63	12	63	99	25	100
Sabine Lake	243	541	2	172	11	48	6	0	0
Galveston Bay	1399	635	2	152	11	61	39	<1	0
Brazos River	5	5	3	74	28	96	0	0	0
Matagorda Bay	1093	1093	2	53	19	68	32	20	2
San Antonio Bay	531	531	2	41	13	71	72	44	20
Aransas Bay	539	539	3	10	15	87	0	0	1
Corpus Christi Bay	497	497	3	12	22	73	34	<1	4
Laguna Madre	1507	1507	2	9	36	32	0	1	75

Sources of Data:

[1] NOAA (1997) Estuarine Eutrophication Survey
[2] EMAP-E Louisianian Province (1991-1994) and West Indian Province (1995) database
[3] NOAA (1991) Coastal Wetlands of the United States
[4] Deegan et al. (1986) in Estuarine Variability
[5] NOAA (1995) National Shellfish Register

Estuary	% Area with Hypoxia[1]	% Area with Anoxia[1]	% Area with Low DO[2]	% Area with High Sediment Contaminants[2]	Coastal Wetlands (1000 acres)[3]	SAV (1000 acres)[4]	% Area with Degraded Benthos[2]	% Fish with Pathology[2]	% Acres of Harvest Limited Shellfish Beds[5]
Florida Bay	100	15	3	3		260	12		
Ten Thousand Islands	58	46	0	50	2165	5	50		7
Charlotte Harbor	48	42	0	11	624	53	89		50
Sarasota Bay	25	25	0	0	[9] 3	[9] 9	50		100
Tampa Bay	14	10	8	8	252	30	58		69
Waccasassa Bay			0	4		91	0	0	
Suwannee Sound	0	0	0	32	229	8	4	0	52
Apalachee Bay	3	<1	0	0	695	32	0	0	100
Apalachicola Bay	14	0	36	26	592	9	5	0	71
St. Josephs Bay			100	0			100	0	
St. Andrew Bay	13	13	0	0	251	13	0	0	100
Choctawhatchee Bay	54	23	55	42	280	3	58	3.25	100
Pensacola Bay	16	0	25	62	245	8	25	0	100
Perdido Bay	48	1	100	92	170	0	100	0	100 [6]
Mobile Bay	46	8	32	61	655	5	19	0.03	100
Mississippi Sound	19	<1	19	6	1069	30	18	<0.01	63
Lake Borgne	0	0	0	0			0	0.01	17 [6]
Lake Pontchartrain	25	9	9	22		[8] 0	13	0.01	100 [6]
Breton/Chandeleur Sounds	13	5	20	5		[8] 14	5	0.01	18
Mississippi River	0	0		58		[8] 0	76	0.01	92
Barataria Bay	22	14	11	0			0	0.05	41
Terrebonne/Timbalier Bays	0	0	7	7			16	0.02	13
Atchafalaya/Vermilion Bays	5	3	<1	23	462		54	0.04	100
Calcasieu Lake	50	10	0	1	122	0	0	0	100
Sabine Lake	10	0	0	0	239	0	44	0.58	100
Galveston Bay	21	<1	<1	17	394	18	45	0.06	61
Brazos River	47	0	0	100	20		100	0.03	100
Matagorda Bay	25	0	1	2	86	7	22	0.09	23
San Antonio Bay	20	0	0	13	67	16	80	0.01	35
Aransas Bay	0	0	49	0	97	21	98	0	24
Corpus Christi Bay	23	0	0	15	30	13	21	0	26
Laguna Madre	17	7	0	0	451	191	24	0	79

<u>Sources of Data</u>:

[6] NOAA (1990) National Shellfish Register

[7] NOAA (1990) Estuaries of the United States

[8] National Biological Service (1995) Our Living Resources

[9] Personal Communication K. Gustafrom, Sarasota NEP

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Back to Start Page