THE MISSISSIPPI DELTA: SYSTEM FUNCTIONING, ENVIRONMENTAL IMPACTS AND SUSTAINABLE MANAGEMENT

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INTRODUCTION

Ecosystem functioning and sustainability of the Mississippi Delta is controlled by interactions of the Mississippi River and marine processes. The Mississippi River has a total watershed of about 3 million km^2, encompasses about 40% of the lower 48 United States, and accounts for about 90% of the freshwater inflow to the Gulf of Mexico. Major tributaries to the lower Mississippi River include the Ohio, Upper Mississippi, Missouri and Arkansas rivers. Approximately 60% of the estuaries and marshes in the Gulf of Mexico are located in coastal Louisiana (Lindstedt *et al.* 1991).

The Mississippi Delta is ecologically and economically important. Ecologically, the coastal wetlands and shallow waters of the eelta provide habitat for fish and wildlife, produce food, regulate chemical transformations, maintain water quality, store and release water, and buffer storm energy (Day *et al*. 1989, 2000). These processes support economically important activities. The Mississippi Delta supports a diversity of economic activities vital to the state and national economies. Commercial harvest of fish and shellfish contributes over US$1 billion annually (LCWCRTF 1993). Other wetland-related activities, such as ecotourism, hunting, production of wild furs and alligator harvest, generate well over USD $1 billion after associated good and services are incorporated (Day *et al*. 1997).

Since the early 20th century, the delta has been impacted by a variety of human activities such as levee construction, massive hydrological alternation, and impoundments, resulting in saltwater intrusion, wave erosion, exposed shorelines and wetland loss (up to 100 km^2/yr). These stresses are partially a result of the current managerial pattern in which the priority has been navigation and flood control. This is carried out by a complicated array of regulations administered by numerous Federal, State, and local governments and agencies. The socioeconomic stakes in this issue include the nation's highest annual fisheries yield (Turner 1977) and massive economic investments and social amenities, including the heritage of one of the U.S.'s largest unassimilated distinct cultural groups, the Cajuns of southern Louisiana.

This chapter reviews: (1) Geological, ecological, and economic aspects of the Mississippi Delta; (2) environmental problems in the delta and their causes; and (3) governing administrative structure including stakeholder views, and proposes suggestions for better management of the delta.

BACKGROUND: GEOLOGY, PULSES, ECOLOGY, AND ECONOMY

GEOLOGY

The Mississippi Delta (Fig. 29.1) formed over the past 6,000-7,000 years as a series of overlapping delta lobes (Roberts 1997). There was an increase in wetland area in active deltaic lobes and wetland loss in abandoned lobes, but there was an overall net increase in the area of wetlands over the past several thousand years. The delta has been often described in terms of a

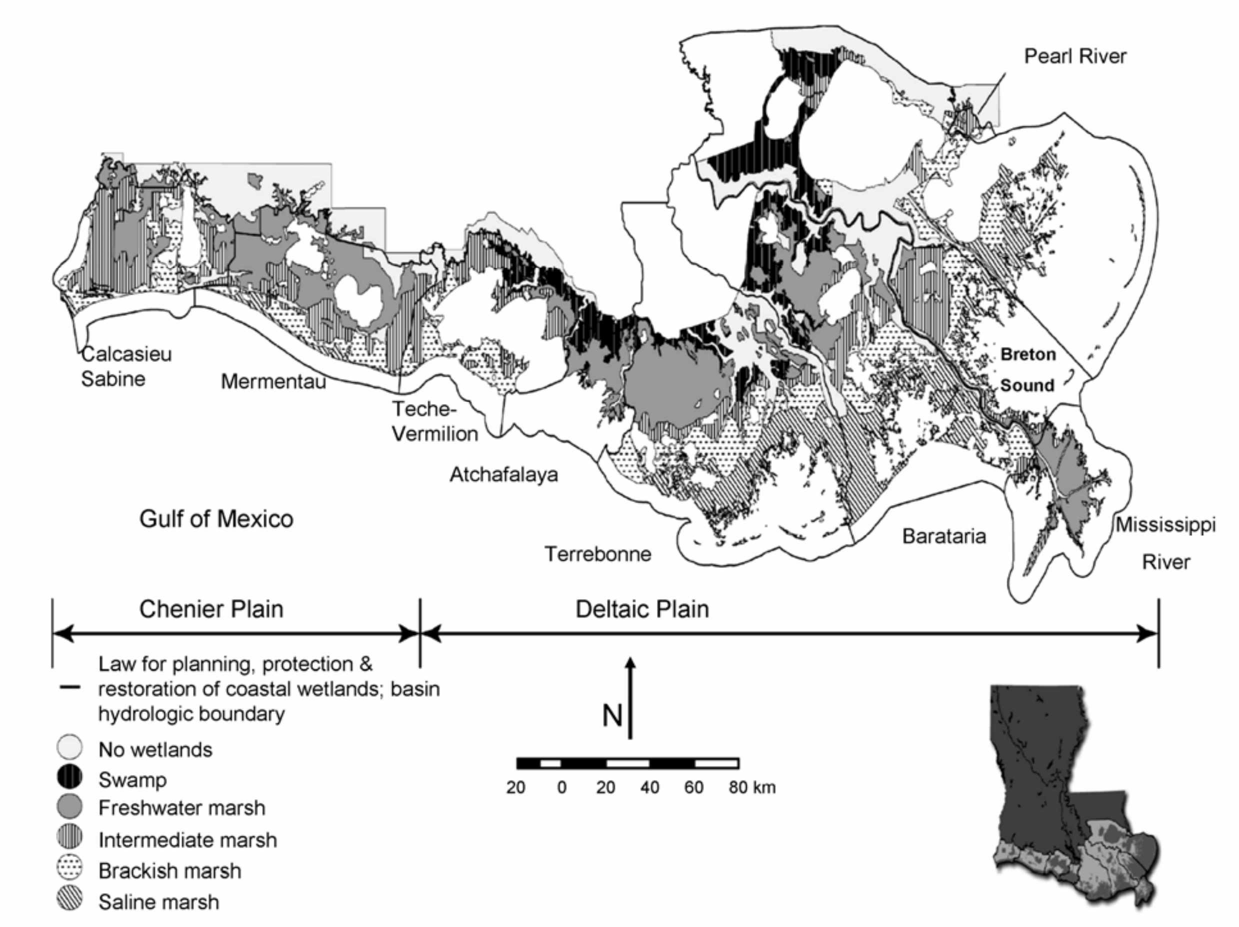

Fig. 29.1. Louisiana coastal zone (Modified from Linscombe *et al*. 2001).

series of hydrologic basins that are separated largely by current or abandoned distributary channels. Coastal wetlands of the Mississippi Delta consist of two physiographic units, the Deltaic Plain to the east and the Chenier Plain to the west (Roberts 1997). Active deltaic lobe formation took place in the Deltaic Plain, which is divided into six hydrologic units. These are, from east to west, the Pontchartrain, Breton, Birdfoot (Balize, at the mouth of the Mississippi River), Barataria, Terrebonne, and Atchafalaya and Teche-Vermilion basins. The Birdfoot delta, although not technically a basin, has been considered a separate hydrologic unit for most analyses of Louisiana coastal wetlands. The Chenier Plain was created by a series of beach ridges and mud flats formed by periods of westward down drift of sediments. It is comprised of two hydrologic units, the Mermentau and Calcasieu-Sabine basins (Fig. 29.1).

The coast is also characterized by a series of vegetation zones (saline, brackish, intermediate and fresh marshes, and freshwater forested wetlands) from the coast to inland, and the vegetation zones are determined primarily by salinity. Changes in these zones over the past half century have been described in a series of four vegetation maps (O'Neil 1949; Chabreck *et al*. 1968; Chabreck and Linscombe 1978, 1988). By the 20th century, the total area of the Delta including wetlands, shallow inshore water bodies and low elevation upland areas located mainly on distributary ridges was about 25,000 km^2.

PULSES

The input of water, sediments and nutrients from the Mississippi River enhances vertical accretion directly through the deposition of mineral sediments and indirectly through the stimulation of plant growth and organic soil formation. The input of materials to the Mississippi Delta is not constant over time, but occurs in a series of hierarchical pulses which produce benefits that vary spatially and temporally (Day *et al*. 1995, 1997, 2000). These pulsing events range from daily tides to switching of river channels which occur from hundreds to greater than 1,000 years and include storms such as those associated with frontal passages, annual river floods, strong storms such as hurricanes, and great river floods. Sustainable management of the Mississippi Delta requires that functions of these pulses be included in management (Day *et al*. 1997).

ECOLOGY AND ECONOMY

Deltas are very important ecologically and economically and the Mississippi Delta is no exception. In the natural state, deltas are broad areas of near-sea level wetlands interlaced with channels through which fresh water and sea water mix. Each year, the river flood supplies a pulse of fresh water, inorganic nutrients and organic materials. These stimulate primary and secondary productions. The rate of marsh production in the Mississippi Delta is the highest in North America (Mendelssohn and Morris 2000). Increased primary production leads to higher rates of food production for consumers and to increased organic soil formation. Sediments and nutrients fertilize wetland plants. Freshwater input also maintains a salinity gradient from fresh to saline, which creates estuarine conditions and supports a high diversity of wetland and aquatic habitats. The increased area and productivity of wetlands resulting from riverine input lead to higher secondary production of fisheries and wildlife. Marine and estuarine fisheries are the highest of any state in the United States. Wetlands also tend to take up and process nutrients. This leads to higher wetland productivity and lessens water quality problems. The relationship between riverine input and the productivity of estuaries has been demonstrated by a number of authors (Moore *et al*. 1970; Nixon 1981; Boynton 1982; Cadee 1986).

The regional economy has greatly depended on the Mississippi Delta. For example, commercial fishing harvests in 1995 for the State of Louisiana accounted for approximately 81% of the total catch in the Gulf of Mexico and 40% of the market value. The majority of this harvest (76%) was caught within three miles of the coast (NMFS 1995). The presence of the Mississippi Delta makes the Gulf of Mexico one of the most commercially important fishing areas in the United States. For example, total commercial landings of the Gulf of Mexico (782,190 metric tons) surpassed the entire Atlantic coast (677,820 metric tons) for 2002 (NMFS, http://www.st.nmfs.gov). Coastal fisheries from Louisiana, most of which derive from the delta, are about 600,000 metric tons per year with a dockside value of about USD $300 million (NMFS, http://www.st.nmfs.gov). Recreational fishermen contribute USD $944 million to the Louisiana economy annually (Raynie and Beasley 2000). 61,000 jobs in Louisiana are related to ecotourism and other non-comsumptive uses of the Louisiana coastal deltaic zone (LCWCRTF 1993).

Gas production in the Louisiana coastal zone represents 21% of the U.S. supply and is valued at USD $7.4 billion per year. Petroleum products produced by refineries located in the Louisiana coastal zone are valued at USD $30 billion annually. Though there is no dollar figure available, the storm and flood protection provided by coastal wetlands allows two million people to live in coastal Louisiana. Pipelines, oil and gas production facilities, roads, supply bases, and other infrastructure rely on coastal wetlands to buffer storm surges. Waterborne commerce transiting Louisiana's coastal wetlands is approximately 460 million tons per year, the highest of any state in the United States Port facilities. The area between Baton Rouge and the mouth of the River handles 230 million tons annually with a value of USD $30 billion (LCWCRTF 1993).

In addition, there are non-market values of delta wetlands and estuaries which have been calculated (Costanza *et al*. 1997). These are "free" services provided by estuaries which are not normally considered valuable because there is no market price for them. Table 29.1 contains an accounting of some of these free services along with some market services such as food production and recreation.

ENVIRONMENTAL PROBLEMS AND THEIR CAUSES IN THE MISSISSIPPI DELTA

WETLAND LOSS

The condition of net growth of the delta which had been the case for over 5,000 years, has been dramatically reversed. From the 1930s to the present, there has been a dramatic loss of wetlands in the Mississippi Delta with loss rates as high as 100 km^2 per year (Gagliano *et al*. 1981), and a total area of about 3,900 km^2 of coastal wetlands has been lost (Boesch *et al*. 1994). Wetland loss rates were highest in the 1960s and 1970s and have declined since, although rates remain high (Baumann and Turner 1990; Britsch and Dunbar 1993; Barras *et al*. 1994). An understanding of the causes of this land loss is important not only for a scientific understanding of the mechanisms involved but also so that effective management plans can be developed to recover these losses (see Boesch *et al*. 1994 for a review of these issues).

Flood-control levees along the Mississippi River resulted in the elimination of riverine input to most of the delta. Prior to European settlement along the Mississippi River, various fluvial processes, such as overbank flooding, crevassing, channel bifurcation, and delta switching, offset natural subsidence in the Deltaic Plain and maintained a net gain of wetlands. In addition to the flood-control levees, most active distributaries were closed, and the river mouth was made more efficient. This resulted in the loss of most sediments to deep waters of the Gulf of Mexico. There has also been a reduction of the suspended sediment load in the Mississippi River caused by dam construction in the Upper Mississippi River (Kesel 1988, 1989).

Altered wetland hydrology mostly caused by canals is another factor contributing to wetland loss. Canals, originally dredged for drainage and navigation, are now overwhelmingly linked to the petroleum industry. Oil-rig access canals, pipeline canals, and deep-draft navigation channels for oil-industry support vessels have left a dense network of canals in the coastal wetlands. Although canals are estimated to comprise about 2.5% of the total coastal surface area, their destructive impact has been much greater (Craig *et al*. 1979; Turner *et al*. 1982). Spoil banks composed of the material dredged from the canals tend to smother adjacent marshes, thereby converting wetlands to functional uplands and interrupting natural hydrologic processes.

Table 29.1. Values of ecosystem services for wetlands and estuaries in the Mississippi Delta. Wetlands area for the Mississippi Delta = 14,833 km^2; area of estuaries in the Delta = 18,616 km^2 (Twilley and Barras 2003).

Services	Wetlands		Estuaries	
	Global mean values (US$ ha/yr)[a]	Annual values for the Delta (millions of US$)	Global mean values (US$ ha/yr)[a]	Annual values for the Delta (millions of US$)
Gas regulation	133	197		
Disturbance regulation	4,539	6,733	567	1,056
Water regulation	15	22		
Water supply	3,800	5,637		
Nutrient cycling			21,100	39,280
Waste treatment	4,177	6,196		
Biological control			78	145
Habitat/refugia	304	451	131	244
Food production	256	380	521	970
Raw materials	106	157	25	47
Recreation	574	851	381	709
Cultural	881	1,307	29	54
Total	14,785	21,931	22,832	42,505

[a] Values per ha come from Table 2 of Costanza et al. (1997).

Spoil banks interrupt sheet flow, impound water, and cause deterioration of marshes. Long, deep navigation canals connect saline and freshwater areas, tend to lessen freshwater retention time, and allow greater inland penetration of saltwater. The wakes generated by boats erode the banks, and many canals have widened tremendously since they were first dredged (Craig *et al*. 1979).

Reduced sediment input to the delta is another cause of the wetland loss in Louisiana. There are two sources of allochthonous sediments that accrete on the surface of wetlands in the Mississippi Delta. One source is the direct input of riverine sediments during the annual spring flood. This source has been eliminated for most of the coastal zone by the dikes and jetties along the Mississippi River. The other source is sediments resuspended from water bodies and deposited in wetlands during storms. This great reduction of sediment input has led to vertical accretion deficits of 4.1 to 8.1 mm per year, depending on marsh type (Templet and Meyer-Arendt 1988). Vertical accretion can be converted to an areal deficit by using the percentage of inorganic material in the marsh and the bulk density. The mineral (inorganic) deficits are in the range of 400 to 2,500 g/m^2/yr depending on marsh type (Templet and Meyer-Arendt 1988) (Table 29.2).

Another factor contributing to wetland loss is impoundment. Almost a third of the delta has been isolated or semi-isolated through the purposeful or accidental construction of various types of impoundments (Day *et al.* 1990). Impoundments are areas that are completely or partially surrounded by levees. In managed impoundments, water levels are controlled to some extent by water control structures. In the most extreme case, pumps completely remove water and the area is converted to dry land. For example, most of metropolitan New Orleans was once a wetland and this area is the largest impounded area in the delta. But many impounded areas are still in a semi-natural state and control structures control the level and flow of water. These areas were originally designed to prevent saltwater intrusion and lower water levels to promote plant growth, but it has been shown that this type of management can lead to lower plant growth and result in lower sediment input and accretion and can restrict the movement of migratory marine and estuarine species (Reed 1992; Boumans and Day 1994; Cahoon 1994).

In summary, most researchers have concluded that land loss is a complex interaction of these causing factors acting at different spatial and temporal scales (e.g., Turner and Cahoon 1987a, b, c; Day and Templet 1989; Boesch *et al*. 1994; Day *et al*. 1995, 1997). Day *et al*. (2000) concluded that isolation of the Delta from the river by levees was an important factor.

HIGH RATE OF RELATIVE SEA LEVEL RISE

Relative sea-level rise (RSLR) is a combination of eustatic sea level rise and subsidence. The current rate of eustatic sea-level rise is between 1-2 mm per year (Gornitz *et al*. 1982) but RSLR in the Mississippi Delta is in excess of 10 mm per year. Thus, eustatic sea-level increase accounts for only 10-15% of total RSLR. If wetlands in deltas do not accrete vertically at a rate equal to the rate of RSLR, they will become stressed because of waterlogging and salt stress and will ultimately disappear.

Historically, marshes were built upward by a combination of *in-situ* organic soil formation and trapping introduced mineral sediments. However, organic production is often not sufficient for vertical marsh accretion to keep pace with the rate of subsidence. Generally, only streamside marshes, subject to tidal waters overflow, receive enough mineral sediment to maintain themselves. While prevailing subsidence rates are estimated as 12 to 13 mm per year in the Mississippi Delta, inland marsh accretion rates have been measured at only 6.7 to 7.8 mm per year (DeLaune *et al*. 1978, 1983; Hatton *et al*. 1983). In other words, marshes inland from the edge of water bodies generally cannot keep pace with the combined processes of subsidence and sea level rise, and, as a consequence, are rapidly submerging and breaking up (Day *et al*. 2000).

DETERIORATING WATER QUALITY

Water quality deterioration is a problem in the delta on two levels. Many waterbodies and waterways in the Delta are nutrient enriched; the sources of nutrients are point (e.g., inadequately treated sewage from wastewater treatment plant) and non-point (agricultural and urban runoff). In addition to inadequate source control and treatment, the elimination and channelization of wetlands have exacerbated the problem. Most upland runoff used to flow through wetlands, causing a reduction of nutrients, before reaching waterbodies. Now the runoff more often flows

Table 29.2. Wetland accretion deficit. Modified from Table 3 of Templet and Meyer-Arendt (1988).

Marsh type	Vertical accretion deficit (mm/yr)	Areal accretion deficit, inorganic ($g/m^2/yr$)
Fresh	4.1	409
Intermediate	7.1	1361
Brackish	8.1	2,476
Saline	6	960

directly to waterbodies. The use of wetlands as filters to improve water quality is an economical and environmentally friendly approach (e.g., Breaux and Day 1994; Zhang *et al*. 2000).

HYPOXIA

Another water quality problem that has received widespread attention is the seasonally severe and persistent hypoxic conditions (low dissolved oxygen conditions in bottom waters, generally <2 mg/L) that have been measured on the continental shelf of the northern Gulf of Mexico for the past decade. The aerial extent of the hypoxia zone has ranged from 13,000 to 18,000 km^2 between 1993 and 1999 (Rabalais *et al*. 1996, 1998, 1999). The hypoxia is, in part, related to the discharge of the Mississippi River which has elevated levels of nutrients, especially nitrate. Linkages between the freshwater inflow from the Mississippi River (and subsequent nutrient flux) and the net surface productivity and bottom water oxygen deficiency have been generally established (Rabalais *et al*. 1991, 1996, 1999; Justic *et al*. 1995; Brezonik *et al*. 1999; Diaz and Solow 1999). There are suggestions that the hypoxia may have potentially severe effects on the biota of the north central Gulf (Turner and Allen 1982; Rabalais *et al*. 1991; Bierman *et al*. 1994; Justic *et al*. 1996, 1997; Diaz and Solow 1999), but thus far fisheries have not been impacted (Diaz and Solow 1999). Mitsch *et al*. (2001) recently outlined a suite of management practices for the Mississippi basin which, taken together, could significantly reduce nitrogen flux to the Gulf of Mexico. These included changes in agricultural practices, use of wetlands in the drainage basin to reduce nitrogen input in the Mississippi River, and river diversions in the delta.

PRESENT GOVERNANCE OF THE DELTA

BACKGROUND

Activities in the Mississippi Delta are governed by a combination of federal, state and local agencies, with primary regulation of river hydrology by federal authorities for navigation and flood control. The U.S. Army Corps of Engineers (the Corps) is the Federal agency charged with the primary responsibility of managing the Mississippi River in the national interests. The Corps also has permit authority over all activities which have an impact on coastal waters and wetlands, as does the State of Louisiana. As early as the 1870s the Corps began leveeing and jettying the river to increase flow velocity and to prevent flooding. After the great flood of 1927, the pace of levee building along the river increased enormously and the river is now leveed along nearly its entire length. Environmental issues first appeared in the early 1970s when it became apparent that wetland loss was occurring (Gagliano and Van Beek 1975, 1976) and that the loss was probably linked to the way in which the river was managed. This was first observed much earlier (Viosca 1927).

EXISTING FEDERAL NAVIGATION AND FLOOD-CONTROL POLICY AFFECTING THE MISSISSIPPI DELTA

Federal policy concerning navigation and flood control on the Mississippi River has its origins in the development history of the river. Humans have been seeking ways to control the river since Bienville ordered his engineer to construct levees in the early 1700s for the protection of New Orleans, even as it was being founded. Levee building continues up to the present. The early levees were locally funded, uneven, and frequently gave way during spring floods. Beginning in 1917, the expenditure of federal funds directly for flood control purposes was authorized on a two-thirds federal/one-third local cooperative basis. In 1927 one of the greatest floods to hit Louisiana breached the levees and inundated 60,000 km^2 (23,000 $mile^2$). Damage was extensive, and 414 lives were lost. The next year the U.S. Congress recognized the national interest in preventing flooding on the Mississippi by authorizing the Flood Control, Mississippi River and Tributaries Project (Act of May 15, 1928, 70th Congress) to provide a comprehensive plan of flood control. Implementation was 100% federally funded. The plan included provisions for flood overflows to be diverted into the Atchafalaya River and lakes, and other basins in Louisiana.

The choice of linear levees to confine the river for flood protection was probably influenced by the Corps' earlier concern for navigation. Throughout the history of this country, the battle to keep the river mouth open for navigation has been waged, at first with giant plows and dredges (Houck 1983). A novel solution was proposed by James B. Eads, who had previously built the first bridge across the Mississippi River at St. Louis. Eads' solution involved building levees and jetties to constrain the river, decreasing the size of the floodplain, and thus increasing the rate of flow of the river so that it would scour its own bed and maintain a channel for navigation. His plan completed in 1878, and worked, at least from a maintenance dredging perspective. Linear levees along the whole length of the lower river seemed to solve both the flooding and the navigation problems. Confining the river became the accepted way to manage it, and that approach has since been codified into law and subsequent policies, even though other alternatives proposed might have prevented environmental losses (Viosca 1927).

A relatively new addition to the federal governance schema is the Coastal Wetlands Planning, Protection and Restoration Act (PL 101-646, Title III; "Breaux Act") of 1990 which created a task force including five federal agencies and the State of Louisiana, chaired by the Corps, to develop a "comprehensive approach to restore and prevent the loss of coastal wetlands in Louisiana." Through this mechanism, some intersectoral or horizontal integration for planning and managing the delta is possible. The task force reviews and funds projects using 85% federal funds with a 15% state match and is the only multiagency, intersectorial institutional arrangement working in the Mississippi Delta and comes closest to being comprehensive. However, the task force has not necessarily viewed the Delta as a system and its approach is not comprehensive for all uses. The implementation of multiple projects and expenditures of hundreds of millions of dollars over ten years have not had a noticeable effect on the high wetland loss rates in Louisiana, except where river diversions have been built or wetlands have been built with dredged material. All of the previous discussion is concerned with hydrology, i.e. with water quantity. Water quality is regulated primarily by states under a delegation from the U.S. Environmental Protection Agency (EPA).

The State of Louisiana has developed and implemented a coastal management program (approved by the federal government in 1980) and permits activities which impact coastal resources jointly with the Corps. The program is housed in the Louisiana Department of Natural Resources which is also responsible for promoting oil and gas development in Louisiana. The program issues permits for activities in the coastal zone which affect water and wetlands, which includes the Mississippi Delta. These activities include oil and gas activities, recreation, dredging, discharging of spoil materials, filling, clearing, channeling, canalling, etc. Local governments can develop their own coastal management programs and, once their program is approved by the State, begin permitting "local activities" which are smaller in nature and have smaller impacts than ones that the State regulates.

In addition to the Louisiana Department of Environmental Quality which has authority over water quality, the Louisiana Department of Agriculture and Forestry has authority over agricultural and aquacultural uses of the delta, and the Louisiana Department of Wildlife and Fisheries regulates wildlife and fisheries resources and regulates protected areas. The Louisiana Department of Natural Resources, the home agency of coastal management, has developed a comprehensive plan for reducing wetland losses (Coast 2050), and is currently trying to implement it through the Breaux Act task force with the usual problems of interagency and transgovernmental conflicts. The most recent plan for delta restoration is the Louisiana Coastal Area (LCA) plan, which is a US$10-15 billion comprehensive effort to restore the delta over 30 years.

A recent issue, hypoxia on the delta's continental shelf, caused by excessive nutrients mainly from upstream agriculture illustrates the lack of planning, management and governance of the Mississippi River drainage basin. The nutrients enter the river as runoff, primarily from agricultural fields in the U.S. Midwest, and from other non-point sources. Upon reaching the delta and the adjacent continental shelf the nutrients lead to eutrophication and a loss of oxygen (hypoxia) from the bottom waters, which can lead to fish kills and reduce productivity. Although the U.S. Environmental Protection Agency, in conjunction with State agencies, has primary responsibility for regulating such sources, it is difficult to address the nutrient issue because it crosses state boundaries. Multiple Federal task forces have studied the issue (Bresonik *et al*. 1999; Diaz and Solow 1999; Goolsby *et al*. 1999; Rabalais *et al*. 1999) and there is a growing consensus that a combination of changes in agronomic practices, and wetland restoration and creation throughout the basin will lead to a solution to this problem (e.g., Mitsch *et al*. 2001).

INSTITUTIONAL RESPONSES IN LOUISIANA

Coastal and wetland management in Louisiana is very complex. Federal, state, and local public agencies and private groups (landowners, sportspeople, commercial fishers, trappers, nonrenewable resource exploiters, and conservationists) are involved in the management process. In addition, over the past half century or more, management has been performed for a variety of reasons (e.g., wetland enhancement and restoration, aquaculture, waterfowl enhancement, land access control, fur mammal management, and mineral and timber production). Only during the last 10-20 years, has management been strongly focused on the problem of land loss and RSLR, and some of the techniques used or proposed to address the land loss problem were originally developed for some other wetland management purpose. In addition to activities directed specifically at coastal and wetland management, other activities, such as flood protection and minerals extraction, also have profound impacts on wetland loss. Because it is likely that some of these activities, such as flood control, will be used in response to rising water levels, it is important to consider their impacts on wetland loss in Louisiana.

Considering the present rate of subsidence and the prospects for future increases in eustatic sea-level rise, it appears that some past management actions have been contrary to what is necessary to address the wetland loss problem in the long term. A number of management approaches, however, have become common because they produced short-term benefits or were not immediately or obviously harmful in the short term (10 to 20 years). The effects of slow submergence on wetlands are gradual and cumulative and the lag time in the response by the natural system to RSLR is on the order of decades. Thus, the effects of deleterious management practices on wetland loss become apparent only slowly. As addressed in the following paragraph, governance has evolved towards a broad, coordinated plan.

In the past, there were little consistent, coordinated sets of priorities or goals for the river, and coordinating mechanisms between single-purpose agencies were weak or nonexistent. Over the past several years, however, as the magnitude of the problem became clear, a strong consensus has evolved that a broad, coordinated effort is needed to address the restoration of the Mississippi Delta. First, the Coast 2050 Plan which included a number of management actions such as river diversions, barrier island restoration, and hydrologic restoration, was developed. Currently, a broad-based plan is being developed called the Louisiana Coastal Area (LCA) plan. This plan envisions a US$10-15 billion, 30 year effort to reverse wetland loss in the delta. Like Coast 2050, the LCA includes diversions, barrier island restoration, and hydrologic restoration. The LCA plan also recognizes the need to address problems throughout the Mississippi drainage basin. Adaptive management will play a central role in the LCA with a strong emphasis on monitoring, modeling, and process-oriented, hypothesis-driven applied research. The LCA plan is presently being prepared to submit to the U.S. Congress.

STAKEHOLDERS IN WETLAND LOSS

There are many diverse stakeholders involved in the restoration of the Mississippi Delta and this makes delta restoration more difficult. Because wetlands are part of the base of the food chain, or provide habitat, for nearly all commercial fisheries species taken from the Gulf of Mexico, fishers and those dependent on fish products (e.g., restaurants and the tourist trade centered around New Orleans) are prime stakeholders. Trappers are also stakeholders because their target species tend to be wetland species. Property owners will be affected if their land is submerged because some uses will be lost and the submerged lands, or “waterbottoms”, may become the property of the state. Recreational hunting and fishing are also highly wetland-dependent, which adds these groups to the stakeholder list. Those with investments in the subsiding delta are stakeholders because they will be required to spend money to protect their investments or they will lose them. These investors include the petroleum and petrochemical industries and the navigation and shipping industries. The public is also a stakeholder because wetlands provide many benefits not captured by markets (e.g., flood protection for New Orleans and other communities in south Louisiana, water-quality improvements, water storage, gas exchange, carbon sequestration, etc. Governments (federal, state, and local) are stakeholders because it will be required to spend more for flood control, sinking roads, water quality treatment, and protection of infrastructure as wetlands are lost. It is thus very clear that involvement of these stakeholders in the management process of delta restoration will be extremely important.

Another complicating problem of wetland management in the Mississippi Delta is land ownership. Land ownership patterns are characterized by a mosaic of private and public properties that rarely coincide with natural drainage basins. Thus, management plans are often formulated for management units based on ownership, even though most resource managers would agree that management-based natural landscape units such as a drainage basin would be more appropriate. Issues related to land ownership have been a complicating factor in wetland management worldwide (Day *et al*. 1989).

Most of the Mississippi Delta wetlands are privately owned, and the objectives of landowners may not necessarily coincide with those of public agencies or of a broad, scientifically based restoration. Although wetlands have high ecological value, only part of this value may be transformed into economic value for the landowner. Thus, a landowner may opt only for resource management that has an immediate economic return (such as waterfowl or furbearers) rather than for management with objectives valuable for society in general (such as water cleansing, export of organic matter, or habitat for fishery species). A particular problem faced by private landowners in Louisiana is revenue related to oil and gas production. If wetlands deteriorate into open water, the area may become public and the land owner loses revenues from any mineral production. Although this kind of deterioration rarely happened, it is still a strong factor in landowner decision-making. Thus, a landowner may feel forced to choose between a course of action that ensures recognition of mineral rights as opposed to one that is best for wetland conservation. For example, one way a landowner can define property boundaries is with a system of low dikes, but these dikes may block the input of sediments that nourish wetlands. Conversely, an approach without dikes that maximizes sediment input and maintains a larger area of wetlands could also lead to wave erosion of wetlands along the wetland-water interface and to a net loss of property to the landowner.

Because of this complicated matrix of stakeholders with differing perspectives on coastal resources, it is imperative that all of these stakeholders be involved in the Delta restoration. This is a daunting problem, but unless it is addressed soon, restoration will be much more difficult.

THE EVOLUTION OF GOVERNANCE IN THE MISSISSIPPI DELTA

Governance of the Mississippi Delta has evolved over time to address the needs of management. For many years, federal policy and the resultant institutional arrangements maintained the nearly total dedication of the river's resources to navigation and flood control and this is one of the most important factors that has led to the deterioration of the Mississippi Delta. Management has been for confinement of the river and, historically, little attention has been paid to environmental problem solving. Only relatively recently have technical studies demonstrated that past management is related to the delta deterioration.

Even after recognition of the causes of delta deterioration, the institutional arrangements and guidance for managing the Mississippi Delta were initially inadequate for the task. Most agencies have a primary focus. For example, the Corps has traditionally focused on navigation and flood control. The National Marine Fisheries Service has dealt with issues related to marine fisheries whereas the U.S. Fish and Wildlife Service has focused more broadly on wildlife and habitat issues. Water quality is a main issue for the U.S. EPA. These agencies have had to broaden their purviews to develop a more comprehensive approach to delta restoration. River diversions, which are emerging as perhaps the primary tool in restoration, serve as an example. Diversions are a response to the recognition that flood control and navigation activities are important factors leading to coastal wetland loss. Diversions also introduce large quantities of nutrients into coastal waters and may lead to salinity regimes that are suboptimal for fisheries production.

Another limit of the current management mechanism has been the lack of appreciation for unexpected consequences of management actions over the long term. If impacts are minimal and changes occur slowly at first, approaches to addressing the initial problems and symptoms may make the problem worse in the long term. As an example, semi-impoundment and reclamation may be suggested as a way to deal with sea-level rise, but reduction of sediment input may further lower the rate of vertical accretion of wetlands and gravity drainage will become less and less effective.

In conclusion, at issue are sometimes contradictory policies which seek to maintain the Mississippi River in its present channel for the benefit of navigation, and at the same time to preserve wetlands as a habitat for fisheries and other wildlife. It is difficult to do both unless there is a broad, comprehensive, integrated management approach. Both uses of the river are in the national interest; therefore, the solution to the problem lies in changing Federal policy through Congressional action and realistically re-evaluating the available alternatives which could maintain navigation and flood control without sacrificing the wetlands of southern Louisiana.

DIRECTIONS FOR BETTER MANAGEMENT

A comprehensive effort under the LCA plan has been designed to address the above problems and to formulate an ambitious plan for restoration of the delta. In this section, we discuss in general some of the issues that must be addressed in such a plan.

REDEFINITION OF GOALS

The historical focus on navigation and flood control must be modified to include delta restoration on an equal basis. There has been much talk of this but restoration projects need to be effectively put in place. Flood protection should not eliminate widespread sediment and freshwater inputs to coastal wetlands. Continuous levees, constructed along the Mississippi River, reduce or eliminate most sediment and freshwater input to coastal wetlands. These inputs are needed to counter submergence and salinity increase. Alternative approaches to protecting developed areas in the coastal zone while ensuring sediment and water input, such as encircling dikes and floodways, need to be considered in comprehensive planning. Finally, it must be realized that flood control using gravity drainage will become increasingly unworkable unless the surface of land is built up. If areas where water levels are initially controlled by gravity drainage are to be maintained, then much more expensive pumped drainage will become necessary.

DIVERSIONS OF RIVER WATER INTO DETERIORATING MARSHES

When freshwater diversions were first planned in Louisiana over two decades ago, the primary goal was to reduce salinity to enhance oyster production in surrounding regions (Chatry *et al*. 1983; Chatry and Chew 1985). More recently, diversions have increasingly been used as a way of delivering sediments and nutrients to wetlands in an attempt to counter RSLR (Day and Templet 1989; Day *et al*. 1997, 2000). Recently completed and ongoing research indicates that diversions lead to enhanced accretion, higher marsh productivity, and higher fisheries (Day *et al*. 1997; Lane *et al*. 1999). There is concern that nutrients in diverted water will lead to eutrophication, but Lane *et al*. (1999, 2001a, b) have shown that there is rapid reduction of nitrogen and other nutrients as diverted water flows over wetlands and shallow water bodies.

Diversions, coupled with complementary management actions such as restoring natural hydrology, and nourishing barrier islands, will retard and possibly reverse the land loss problem of the Mississippi deltaic plain. Implementation of many of these alternatives requires major Congressional policy changes regarding the management of the Mississippi River. The LCA plan seeks to do this.

NATURAL ENERGY UTILIZATION

Utilization of natural energies, such as vegetation productivity, winds, river currents, and tides, should be maximized in a delta restoration plan. For example, insofar as possible, currents should be used to distribute sediments. Vegetation should be enhanced to increase organic soil formation and thus help increase vertical accretion. This is the principle of ecological engineering where small amounts of fossil fuel energies are used to channel much larger flows of natural energies (Odum 1971; Mitch and Jorgenson 2003). An example for using natural energies is an energy analysis of the Mississippi River basin, which showed that while energy savings accrued to navigation and development caused by dikes on the river, overall losses of system energy were greater (Odum *et al.* 1987). The implication is that the state and nation would benefit more if the river's water and sediments were used constructively to nourish the wetlands while maintaining navigation and protecting development. Mitsch *et al*. (2001) showed that restoration of wetlands throughout the Mississippi River basin could also help solve the problem of low oxygen in the Gulf of Mexico.

Problems of water-quality deterioration can also be addressed by using natural energies. There is high nutrient loading to inshore coastal waters from non-point source agricultural and urban runoff and inadequately treated point sources such as sewage and industrial wastes (e.g., seafood processing wastewater). In the past, point sources have often been dealt with using conventional wastewater treatment, which is capital and energy-intensive. However, the wastewaters can be treated using natural wetlands. Wetlands assimilate nutrients and organic matter in wastewater resulting in improved water quality, increased productivity, and enhanced vertical accretion (Breaux and Day 1994; Hesse *et al*. 1998; Zhang *et al*. 2000; Rybczyk *et al*. 2002). Several studies of wetland assimilation in Louisiana have shown this to be a cost-effective and energy efficient process (Cardoch *et al*. 2000; Ko *et al*. 2004).

In addition, water quality problems, caused by altered hydrology, can be solved by making most upland runoff flow through wetlands by restoring hydrology, prior to reaching waterbodies. Wetlands are natural sinks for nutrients (Hatton *et al*.1982; Sharp *et al*. 1982; Reddy *et al*. 1993) and thus represent a viable mechanism for decreasing the nutrient load of river water prior to reaching offshore. Thus, restoring hydrology and enhancing wetland contact will lead to improved water quality.

INTEGRATED PLANNING

Better management for the Mississippi Delta requires an integrated planning at the local, basin, and national levels. This is the aim of the LCA plan. To support integrated planning, a comprehensive institutional arrangement should be designed for: (1) Increased information exchange among diverse stakeholders (e.g., private landowners, fishers, etc.) and multiple government agencies in order to enhance understanding of complex ecosystem functioning and the consequences of management options, (2) support of holistic studies on wetland loss, water quality deterioration, and the relation between natural ecosystem and human economic activities, and (3) consideration of long-term impacts such as global change in managing the Mississippi Delta. Some suggested elements of such a plan are given in Table 29.3. The solution to the problems caused by short-term, piecemeal practices is an integrated approach, which takes a long-term, comprehensive view of wetlands loss, including RSLR. In addition to comprehensive planning, there is a need for strong leadership which can get difficult political and regulatory decisions made.

As an example for integrated planning, we use the case of sea-level rise. Significant sea-level rise is likely to occur over the next half century and it is imperative to formulate long-term planning at a variety of different scales in an integrated way. When planning for institutional response to counter the impacts of sea-level rise on coastal ecosystems, a number of factors need to be considered, especially related to timing and appropriateness of different actions (Day and Templet 1989; Day *et al*. 1997). There is likely to be a considerable time lag (decades or more) before the effects of sea-level rise become clear and the rate of change will likely accelerate.

Thus action should be taken early, even though neither the need nor the culmination of the sequences of events that lead to land loss may be readily apparent. Federal planning efforts should take the impacts of sea-level rise into account in all pertinent plans or projects. State-level guidelines can be issued to local governments for the regulation of land use through zoning, setbacks, subdivision standards, sewer and other utility placement, and drainage and flood control. State-level coastal zone management agencies can also take the lead in these planning efforts because the earliest impacts will be felt in the coastal areas, and because state coastal zone agency mandates are generally more comprehensive than traditional single-sector agency directives. In addition, existing coastal management agencies can include information and mitigation suggestions in existing permit processes to offset some of the effects of sea-level rise (Bigford 1987). These different levels of planning should be at least loosely integrated with each other. On privately owned lands, as much a possible, landowners should not be put into situations in which decisions deleterious to natural resources are in their best economic interests. Landowners may be given some form of compensation (such as a tax break) for management that is not in their immediate economic self-interests. These points indicate the importance of coordinated planning. It would be much better to manage the coastal zone based on natural landscape units. In a number of ways, problems associated with land ownership may complicate efforts to address the effects of sea-level rise. Politically and legally, it is much easier to implement management plans based on landscape units defined by ownership. However, ecosystem management, especially in the case of wetlands, is most effectively done on natural landscape units such as the drainage basin. Different landowners will likely have different

Table 29.3. Approaches to management of the Mississippi Delta.

Goal	To manage the lower Mississippi Delta and the Mississippi River basin in a manner designed to reverse loss of coastal wetlands and solve water quality problems while retaining navigation and flood control.
Policy	Use water, sediments, and nutrients of the Mississippi River to replenish and nourish the wetlands while maintaining water quality by nutrient retention.
Strategy	Distribute Mississippi River water to the Deltaic Plain using diversions. Managers should consider salinity, sediment need, and nutrient uptake.
Tactics	1. Increase river flow in the Atchafalaya River and improve Atchafalaya hydrology to enhance flow through wetlands.
	2. Use spring flood pulse of the Mississippi River to deliver sediments to the marsh surface. Use natural pulsing events to enhance marsh sedimentation.
	3. Use former distributaries of the Mississippi River to move water and sediments into the Deltaic Plain wetlands.
	4. Consider moving navigation out of the lower (Birdfoot) delta via a lock system and letting the lower Delta evolve into a more natural hydrology with more overbank flooding.
	5. Use low-level sills in the lower Mississippi River levees to move spring flood waters into adjacent wetlands.
	6. Use the Atchafalaya River's bedload to increase the delta building in Atchafalaya Bay.
	7. Create many small diversions from the main channels to efficiently move water into the sinking wetlands.
	8. Use canal acreage reduction, barrier island restoration, and regulatory approaches to complement and increase the effectiveness of diversions.
	9. Use man-made waterways, such as the Gulf Intercoastal Waterway, as lateral channels to move water across basins and inter-basins.

objectives in the management of their lands. Private landowners may naturally prefer to manage for resources that provide a direct economic return (such as furbearers or waterfowl) rather than for the more general public good. Thus, the land ownership issue should be included as a primary part of the integrated planning.

Development in low-lying areas presents special problems. It will become more difficult to maintain such areas with increasing sea levels. The construction of dikes and drainage of peat soils will aggravate subsidence in the long term. For agricultural areas, a rotating agricultural system in which riverine sediments are introduced into specific fields may maintain accretion and help fertilize crops. High-biomass crops may also be important in maintaining vertical accretion if organic matter is allowed to accumulate. Erosion control techniques, such as cover crops, fallow areas, and no-till agriculture, can help to reduce erosion and to increase accretion. As indicated earlier, gravity drainage is effective for a relatively short period of time where water levels are increasing. Pumped drainage is normally not feasible for agricultural areas. It has been sustained only for highly intensive agriculture in developed countries such as the Netherlands.

Additionally, coordinated monitoring and planning for the Mississippi Delta should include consideration of information from other coastal areas of the world, especially deltas. The Mississippi Delta is the only large delta in the continental U.S. and, therefore, information should be sought from deltas in other countries where similar conditions and problems exist (e.g., Day *et al*. 1997). Some possible areas include deltas of other major rivers and other coastal areas: Grijalva-Usumacinta, Ebro, Po, Nile, Camarguc, Danube, Rhine, Ganges and Chesapeake Bay. Modeling can be a powerful tool to help evaluate the impacts of different management practices on the Mississippi Delta.

CONCLUSION

The problem of deterioration of the Mississippi Delta resulted from a disruption of the natural functioning of the system. Two important impacts were separation of the Deltaic Plain from the river and pervasive hydrologic alteration of the delta. In order to solve these problems, a comprehensive policy that includes both the delta and the drainage basin is needed. Reconnection of the river to the delta must be a central component of delta restoration. The LCA project to restore the Mississippi Delta has many of these elements, but there is a need for stronger stakeholder participation and a connection of the program to the whole basin.

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