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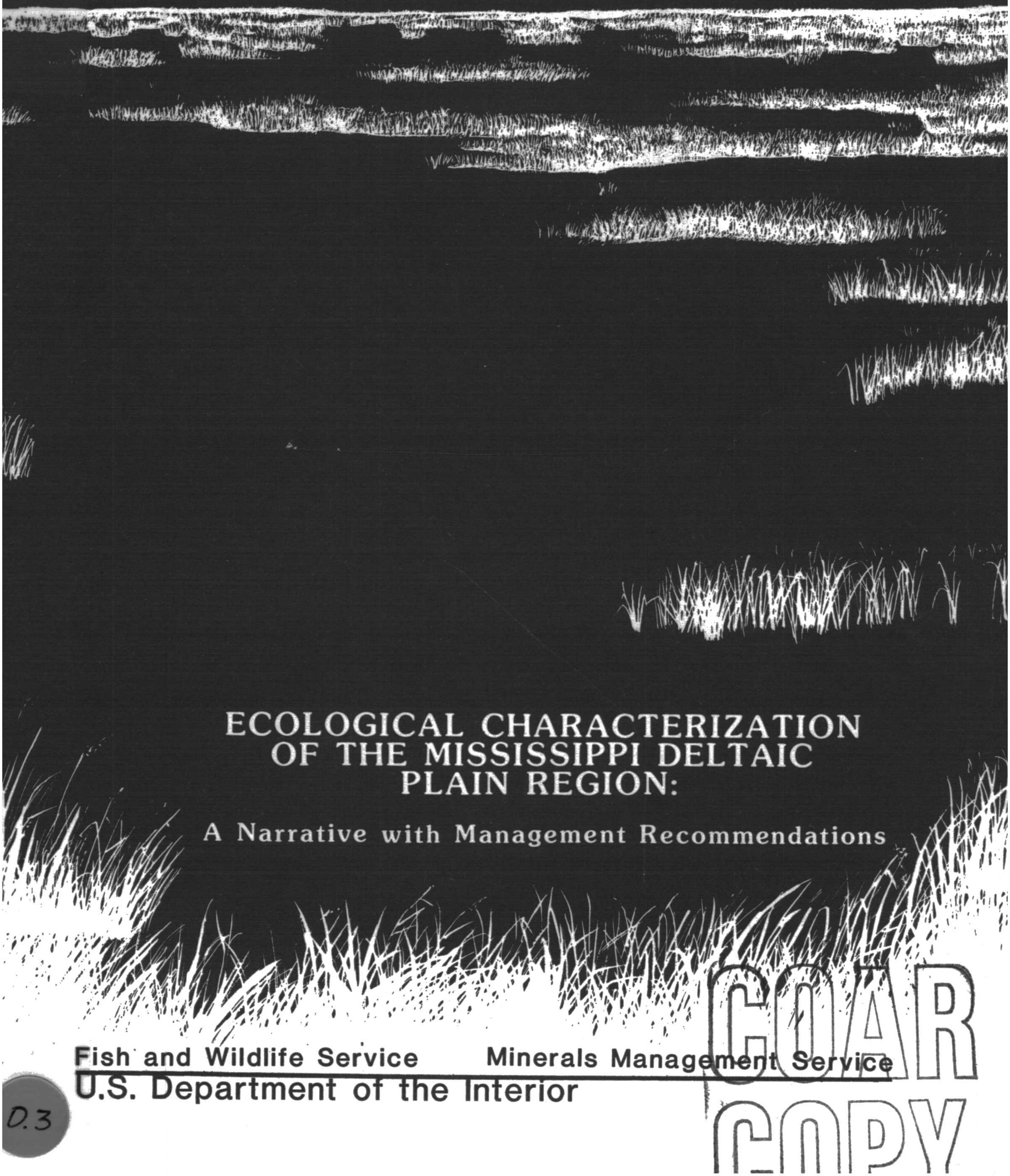

ECOLOGICAL CHARACTERIZATION OF THE MISSISSIPPI DELTAIC PLAIN REGION:

A Narrative with Management Recommendations

Fish and Wildlife Service Minerals Management Service
U.S. Department of the Interior

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ECOLOGICAL CHARACTERIZATION OF THE MISSISSIPPI DELTAIC PLAIN REGION: A NARRATIVE WITH MANAGEMENT RECOMMENDATIONS

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PREFACE

The purpose of this narrative report was to summarize existing information about the biology, hydrology, geology, and socioeconomics of the Mississippi Deltaic Plain Region in a framework that would both characterize the region and provide a basis for future research.

This report was designed to complement the companion technical report that provides detailed quantitative descriptions of the major ecological habitats of the Mississippi Deltaic Plain Region. Together the two volumes provide both general descriptions and detailed data on the region.

Any questions or comments about or requests for this publication should be directed to:

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ACKNOWLEDGMENTS

This report is a narrative synthesis of data collected and analyses performed as part of the companion technical report (Costanza, R., C. Neill, S. G. Leibowitz, J. R. Fruci, L. M. Bahr, Jr., and J. W. Day, Jr. 1983. *Ecological models of the Mississippi Deltaic Plain Region: data collection and presentation*. U.S. Fish and Wildlife Service, Division of Biological Services, Washington, D.C. FWS/OBS-82/68). In addition to those who contributed to the technical report, we thank the following people who provided information on critical components of this narrative: R. Baumann, W. Conner, L. Deegan, S. A. Hsu, B. Johnson, and F. Sklar. J. Bagur, P. Bianchi, E. Coleman, and J. Donley of Louisiana State University and G. Farris of the Fish and Wildlife Service assisted with editing. Proofreading was done by R. Martin and C. Willett. D. Baker and K. Westphal were responsible for drafting, as well as C. Duran and P. T. Gremillion. Typing was done by B. Grayson, J. P. Lantier, and C. McLean. S. Lauritzen of FWS handled overall layout and preparation of the manuscript for printing.

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INTRODUCTION

OVERVIEW

The Mississippi Deltaic Plain Region (MDPR) of southeastern Louisiana and Mississippi includes the 3,400,000 ha (8,398,000 acres) result of 7,000 years of sediment accretion on the northern Gulf of Mexico Continental Shelf between about Longitude 88 and 92 degrees W.

This report is a descriptive narrative aimed at characterizing the region's ecology and its environmental problems. A companion technical report (Costanza et al. 1983) was also prepared that includes more detailed quantitative descriptions of the major ecological habitats of the region. The data collected in the technical report are intended to serve as a data base for addressing specific environmental management questions. This narrative report summarizes: (1) the major classes of environmental problems, their complex origins and interdependencies; (2) the natural systems of the region, their histories, structure, and function; (3) the recommendations that have been proposed to deal with the environmental problems of the region; and (4) how the data base assembled in the technical report might help in dealing with these problems more rationally.

Much of the descriptive summary on the MDPR presented in this narrative report will be familiar to some readers, but it was included so that readers with diverse backgrounds could obtain the framework necessary to understand the region and its problems.

BACKGROUND AND ORGANIZATION

The National Coastal Ecosystems Team of the U.S. Fish and Wildlife Service (Department of the Interior) has completed the ecological characterization and syntheses of several coastal regions (e.g., Gosselink et al. 1979; Procter et al. 1980). This report is a part of a similar effort for the Mississippi Deltaic Plain Region (MDPR). Characterization studies review all relevant existing information about particular coastal regions and synthesize this information to provide a basis for informed management. The technical report (Costanza et al. 1983) is organized around a series of quantitative, hierarchically nested descriptive models at three levels of resolution: (1) the overall region, (2) the seven hydrologic units of which the region is composed, and (3) 20 habitats that have been identified as important in the various hydrologic units (Figure 1). The models illustrate (and quantify to the extent possible) the major physical and biological processes and interactions that occur at each level of resolution.

To facilitate cross-referencing between the technical and narrative reports, both documents are similarly organized, incorporating three levels of geographic resolution: region, hydrologic unit, and habitat. The habitat level is the most detailed, and each habitat is described as a system of interconnected physical components and organisms. The hydrologic unit level is intermediate, with each unit presented as a system of habitats interconnected by flows of water, dissolved and suspended inorganic and organic matter, and organisms. Each hydrologic unit is driven by physical and socioeconomic inputs. The broadest level of resolution is the entire MDPR. At this level, interactions among hydrologic units are examined, with socioeconomic and geological forces of paramount interest.

As a complement to the models, this report describes the MDPR, its habitats, and its hydrologic units. The narrative also provides additional information that is not included in the technical report. The descriptions are intended to interpret and summarize the data in the technical report. The narrative report also contains generalized management recommendations based on information developed in both documents. Analysis of the data base and applications to specific management questions have yet to be completed, however. Each report is intended to be useful inde-

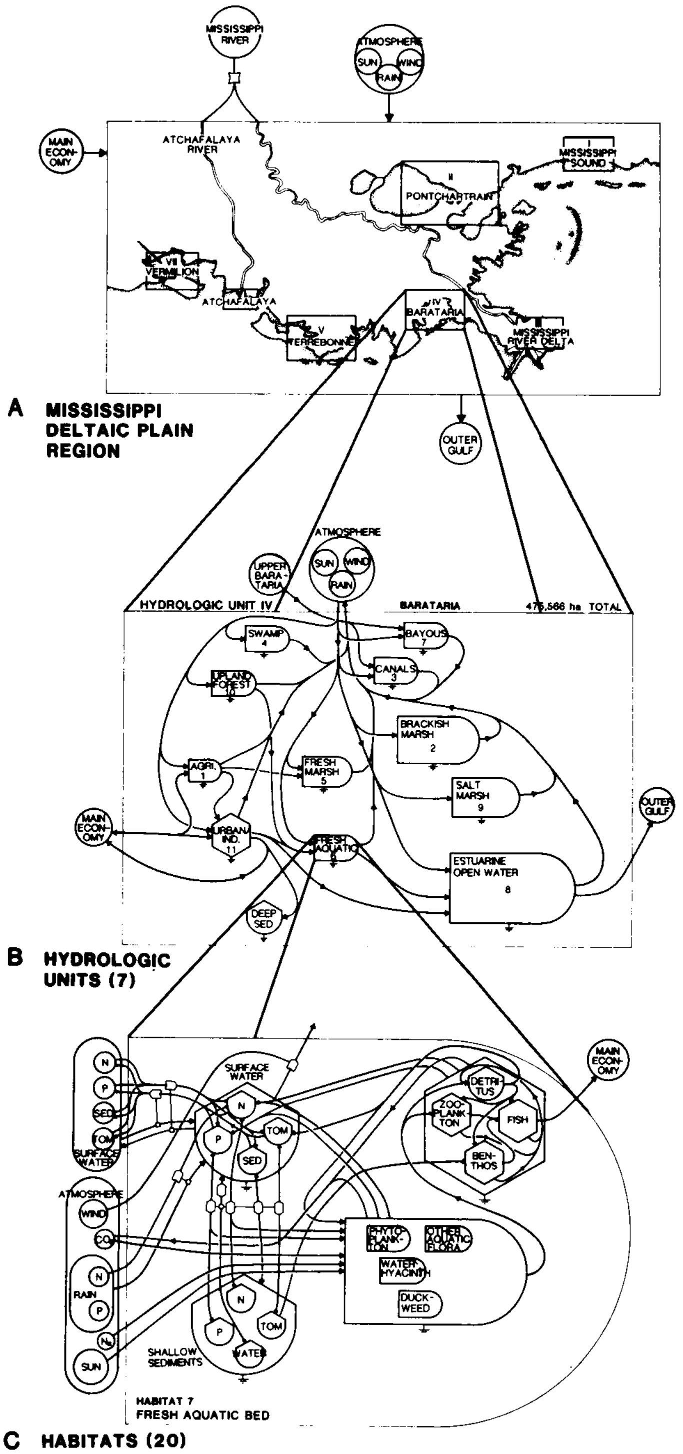


Figure 1. Hierarchical structure of the study components indicating (A) region; (B) hydrologic units; (C) habitats.

pendently of the other, but the two documents are designed to be complementary.

USES OF THIS STUDY AND OBJECTIVES

The primary users of this document include all those interested in the study area, particularly coastal zone managers and other decisionmakers in Louisiana and Mississippi charged with regulating coastal zone activities. Such persons routinely face the difficult task of recommending specific courses of action that will maximize long-term benefits but minimize the adverse environmental effects that inevitably accompany most socioeconomic activities in the coastal zone. Environmental impacts vary widely in kind, time, and consequences. Many cultural impacts on the coastal zone may go unrecognized because of our incomplete understanding of the functioning of ecosystems. Some activities, like canal dredging in wetlands, have produced cumulative adverse effects that have increased over time. The systems approach used in this report may improve our understanding of this situation.

Many habitats in the MDPR overlie rich deposits of nonrenewable resources, especially petroleum and natural gas. The immediate economic value of developing these resources has overshadowed long-term ecological values, which have been for the most part unquantified. Effective management has been hindered because environmental impacts are not usually stated in units commensurable with economic benefits. Management priorities, an assessment of the tradeoffs between the competing uses of resources, and the evaluation of socioeconomic and "natural" processes in common units are all implicit objectives of the specific data collection methodology presented in the technical report and summarized here.

MAJOR ISSUES

During the last two centuries, coastal regions in the United States have undergone dramatic changes that include: (1) land clearing and development; (2) impoundment and draining of wetlands; (3) construction of flood control structures; (4) dredging activities; (5) freshwater diversions; (6) pollution of many kinds, from point and non-point sources; (7) introduction of exotic pests; and (8) harvest pressure on coastal fish and wildlife. We have at present only a rudimentary understanding of the significance of most of these changes.

Some representative issues relevant to the MDPR are listed below, divided into groups according to the spatial scale of their impact.

Regional Level

1. Wetland loss. The conversion of wetland habitats to open water is accelerating in much of the MDPR. The present rate is estimated at 100 km^2/ yr or 40 mi^2/yr (Gagliano et al. 1981). This loss is the result of interrelated processes both natural and cultural, including worldwide sea level rise, erosion from dredging projects, Mississippi River entrainment, subsidence, saltwater intrusion, and the sediment starvation of marshlands.

2. River switching. The Atchafalaya River is currently poised to divert much of the flow of the Mississippi, with potentially major consequences for the economic structure of the region.

3. Industrial pollution. Water and air quality and chemical waste disposal are major issues in the MDPR, which includes petrochemical and port facilities that are among the most active in the world.

Hydrologic Unit Level

1. Role of wetlands in fishery production. Fishery production in the MDPR is believed to be dependent on organic matter produced in wetland habitats. Differences in wetland habitat composition among hydrologic units may be

reflected in fishery harvest differences among hydrologic units. Harvest data, however, are lacking or of poor quality. The development of quantitative data on carbon flow through hydrologic units should be a major objective of current research.

2. Hydrologic modifications. Cultural changes (e.g., canal construction, spoil bank and levee construction, and impoundments) disrupt the hydrology that integrates coastal ecosystems. The cumulative effects of hydrologic alterations are most apparent at the hydrologic unit level.

3. Water quality. Eutrophication and the introduction of toxic substances affect water quality throughout some hydrologic units. The optimal management of water quality requires knowledge about the fates and effects of nutrients and toxic substances.

4. Saltwater intrusion. Hydrologic modifications and natural processes have allowed the landward progression of isohalines in many of the drainage basins, resulting in loss of habitat and municipal water supply problems.

Habitat Level

1. Human-introduced stresses. Many cultural processes disturb specific habitats. A marsh area may be sublethally stressed by partial impoundment; a body of open water may be made eutrophic; or the soil in an agricultural habitat may be depleted of organic matter.

2. Estimation of resource productivity and value. The economy of the MDPR benefits from and depends upon the products and services of various habitats. Better estimates of the rates and value of ecological production from each habitat are needed.

AN ALTERNATIVE APPROACH TO ENVIRONMENTAL MANAGEMENT

The problem of environmental management was eloquently summarized by Garret Hardin (1968) in his essay, "The Tragedy of the Commons." Many important environmental components are "common property resources," for which an individual's cost and benefit calculations often differ from the costs and benefits to society as a whole. Hardin presented a parable in which shepherds using a commonly owned pasture could be expected to increase the size of their flocks based on their independent cost-benefit calculations until the land would no longer support grazing and the common property resource was destroyed. The moral is that avoiding environmental degradation requires a system of social control. Government performs this function either through regulations (e.g., limiting the number of fish harvested under penalty of fines and imprisonment); or through taxes and subsidies (e.g., taxing each additional fish caught according to its marginal social cost, or rewarding each fisherman for limiting his harvest).

Environmental management in the United States, as in most countries, has employed the regulatory approach almost exclusively. Some advocate a tax and subsidy approach, however, since it would mesh more easily with the existing market system. It would allow individuals to continue to make their own decisions, while making them economically aware of the full social costs of their alternative courses of action (Page 1977). To be effective, either the regulatory or the tax and subsidy approach to environmental management requires accurate information on the magnitudes of the social costs involved and how they differ from private costs.

Environmentalists have been wary of assigning economic value to environmental resources (such as an acre of salt marsh) mainly because they perceive that the standard economic methods for deriving these values consistently underestimate their worth (Gosselink et al. 1974). Some have, instead, taken the extreme position that environmental resources are "priceless" or of infinite value. Many of our existing environmental regulations reflect this attitude, which may have fostered the current scrutiny of such regulations as the Clean Air and Clean Water Acts. Business interests have taken the opposite position, that environmental resources are non-essential luxuries that can be sacrificed (at no cost) when necessary to stimulate economic growth. What is needed is the general recognition that neither extreme is accurate.

Economists term the process of calculating the hidden social costs of an activity "shadow pricing." Shadow prices are those that would prevail if private and social costs coincided exactly. Since current Western economic theory takes preferences as given, economists are most comfortable calculating shadow prices by asking people (directly or indirectly) to reveal their preferences for environmental goods and services (Batie and Shabman 1979). This approach does not work, however, if people are not aware of the consequences to their own welfare of the alternative allocations of environmental resources. Just as a child is unaware of the social implications of its behavior and must be instructed, most people are unaware of the larger social-ecological implications of resource-use decisions. Their uninformed preferences therefore cannot be taken too seriously as measures of the true shadow price.

One approach to this problem is to educate people about the workings of the environment on their behalf, so that their preferences will better reflect the real situation. An alternative approach involves the creation of explicit mathematical models of the physical interdependence between ecological and economic systems (Odum 1978; Costanza 1980; Costanza and Neill 1981a, 1981b). These models can incorporate the best available information on the implications of resource use decisions. The model results can be communicated to the public in the form of taxes and subsidies based on the calculated shadow prices, or they may be used to set standards for regulations.

As shown in the accompanying technical report, a major portion of this characterization study was devoted to developing data in the form of quantified flow diagrams and input-output tables for the three levels of organization of the MDPR. This laborious task was necessary to provide information on the workings of the MDPR environment, and the means to calculate the functional value of each habitat, hydrologic unit, and the entire MDPR. The collection and documentation of a suitable data base have been completed (Costanza et al. 1983). It should be noted, however, that, at present, analysis of the data and calculation of environmental impacts and values are incomplete.

DESCRIPTION OF THE MDPR

The study area is the seaward portion of the deltaic system that was produced from the coastal deposition of sediments by the Mississippi River during the last 7,000 years since worldwide sea level rose to about its present level. The boundary of the MDPR, as defined for this study, is shown in Figure 2 as comprising seven hydrologic units: I. Mississippi Sound, II. Pontchartrain, III. Mississippi River Delta, IV. Barataria, V. Terrebonne, VI. Atchafalaya, and VII. Vermilion.

The study area extends from the western side of Vermilion Bay in Louisiana to the Mississippi-Alabama state line. The inland boundary is the official Coastal Zone Boundary in Louisiana as defined in the State and Local Coastal Resources Management Act of 1978 and by the 15-ft contour line in Mississippi. The offshore boundary is the three-mile limit.

The MDPR includes the largest active delta system, the most productive inshore and nearshore fishery areas, one of the largest concentrations of oil and natural gas, and one of the most active port systems in North America (the New Orleans-Baton Rouge corridor of the Mississippi River). It also includes the largest contiguous area of coastal wetlands in the country. Forty percent of the coastal wetlands in the United States are in the Mississippi Deltaic Plain and the Chenier Plain to the west, with the largest portion in the former (Gosselink et al. 1979). The wetland habitats in this broad region are changing to open water at a rapid rate, and most of this change has occurred within the MDPR. The region's geologically dynamic nature, acknowledged biological productivity, intense economic activity, and vulnerability to human impacts create a challenge to resource managers.

The Holocene, or Recent Deltaic Plain of the Mississippi River, as defined by geomorphologists, includes the area shown in Figure 3: the lower deltaic plain fringing the coast; the active deltaic plain, limited to the leveed flood plains of the Mississippi and Atchafalaya Rivers; the abandoned deltaic plain, which includes a large portion of the alluvial valley of the Mississippi; and the subaqueous delta, some of which was formerly above water and some of which is presently forming. The complete Recent delta extends inland to the Pleistocene Terrace, an ancient shoreline. The MDPR study area is thus limited to about two-thirds of the total deltaic plain in Louisiana, while the Mississippi portion of the MDPR is actually outside the deltaic plain.

THE PHYSICAL SETTING

The present extent of the MDPR is the result of the physical and biological processes that have acted upon it throughout its history, processes that include interacting geological, hydrological, and climatological forces.

Geology

Geologically, the MDPR is a large, crescent-shaped, thick lobe of silts and sands derived from the drainage basin of the Mississippi River system, which includes about 40% of the area of the lower 48 States. The single most important geologic influence throughout the MDPR is the Mississippi River, which has supplied the sediment to sustain the region in an approximate balance between erosion and accretion. The entire region is composed of fine-grained sedimentary deposits, and these deposits are progressively thicker in a seaward direction.

The Recent geologic development of the MDPR occurred during the period of rising sea level following the Pleistocene epoch. There is disagreement about the time at which the sea level began rising, and when its rate of increase declined, but one estimate is illustrated in Figure 4.

Sea level worldwide rose rapidly, beginning about 18,000 years ago, after

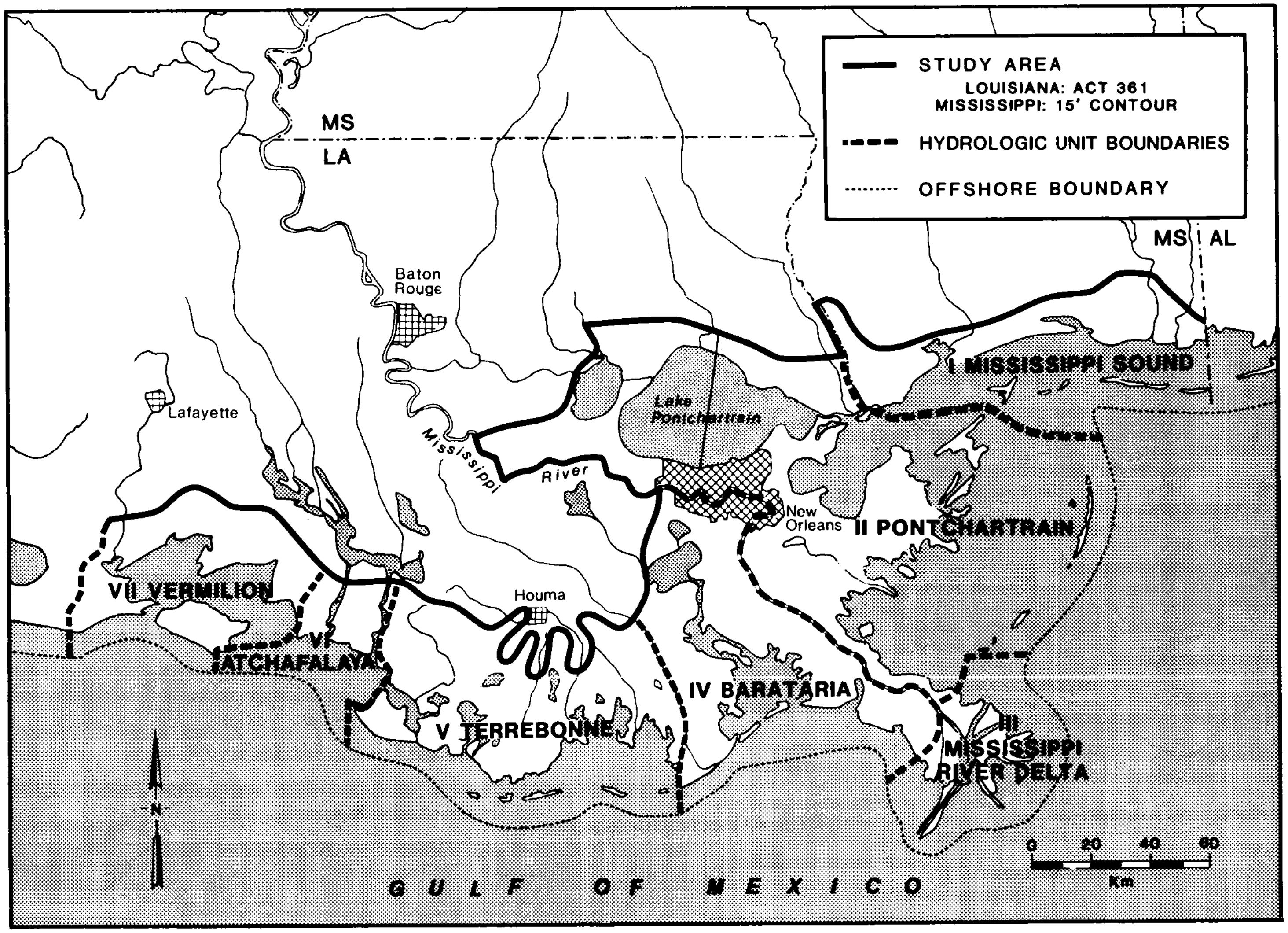


Figure 2. Components of the MDPR with hydrologic units labelled (I-VII).

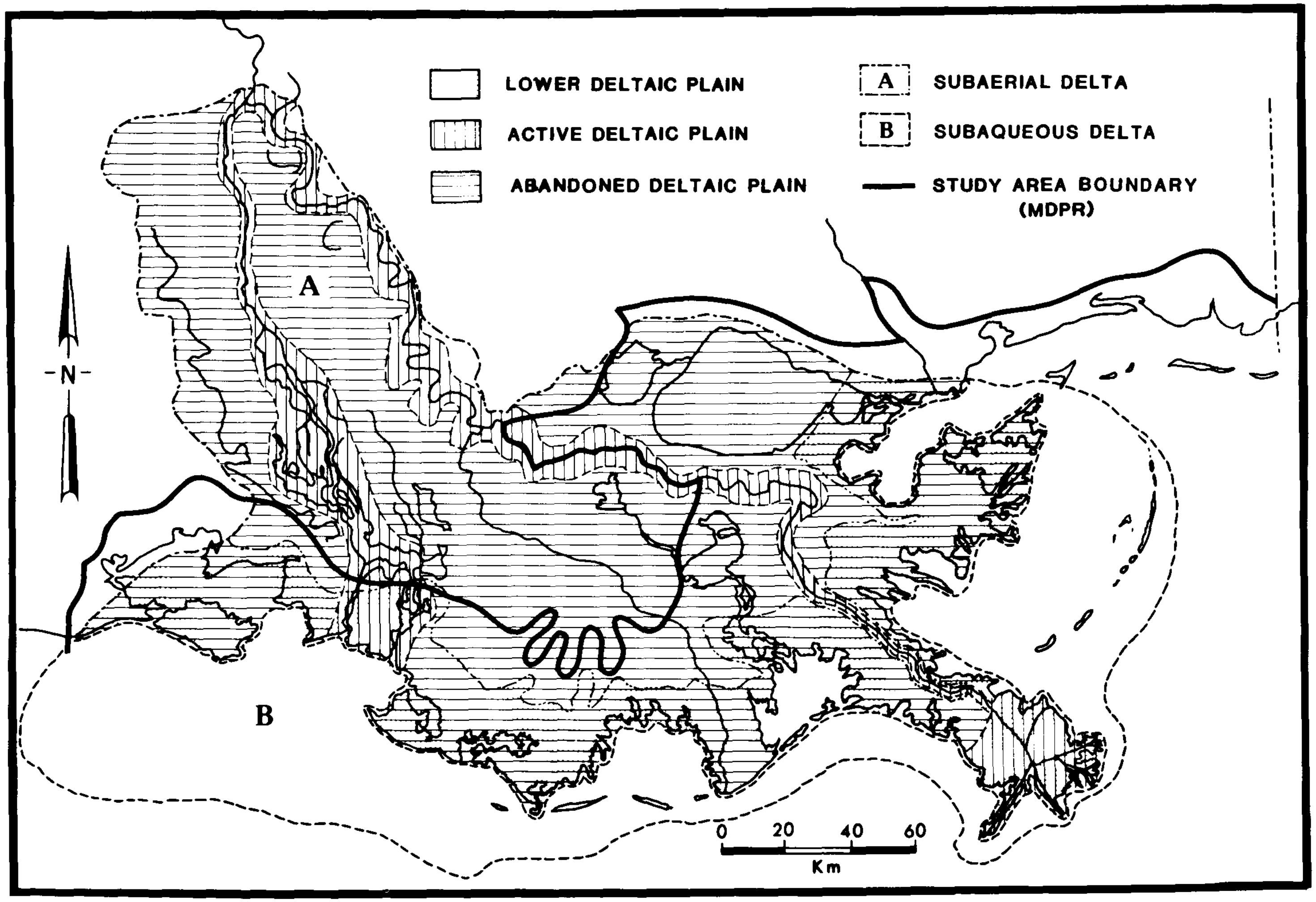


Figure 3. Geomorphology of the MDPR.

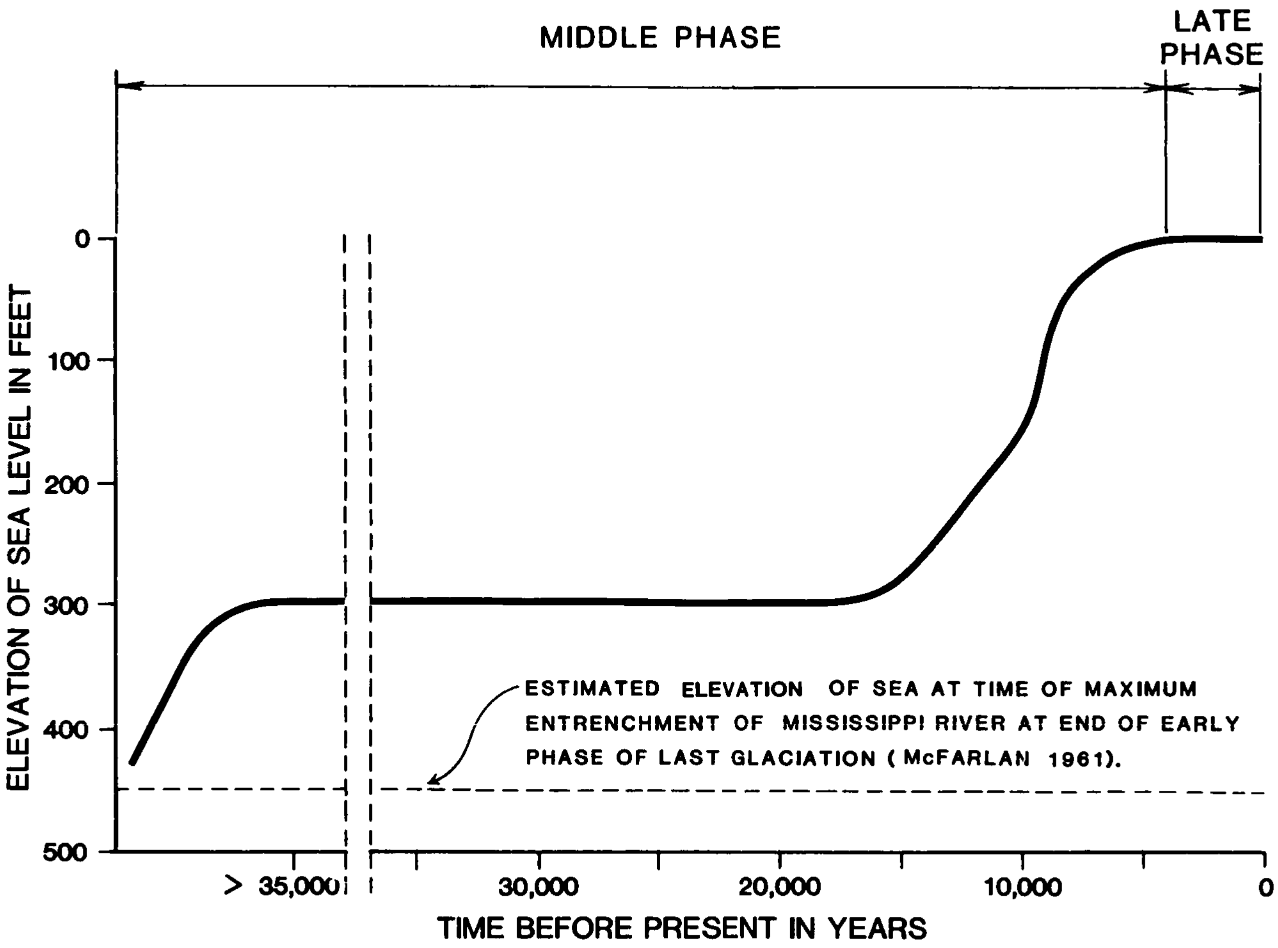


Figure 4. World sea level rise (from McFarlan 1961).

a long period when the level of the world's oceans was almost 100 m (300 ft) lower than it is today. While sea level was low, a gigantic trough (the Mississippi Trench) was eroded offshore of the present MDPR, across the Prairie Terrace Formation (the present Continental Shelf). As melting continental glaciers caused sea level to rise, riverborne sediments from the Mississippi drainage began filling the trench, and the modern deltaic plain began to develop. The rate of increase in sea level gradually diminished until sometime between 3,000 to 5,000 B.P., when it stabilized at nearly its present level (see Figure 4).

During the period when sea level was rising, and since its relative stabilization, river sediment has been deposited along the nearshore portion of the Continental Shelf. The magnitude of this riverine transport can be appreciated by multiplying the annual sediment load of the river, about 142 million metric tons/yr (Roberts et al. 1980) by the 7,000 years during which the MDPR has been building.

A key element in the geologic development of the MDPR has been the process of river diversion (Kolb and Van Lopik 1958; Frazier 1967). About once every 700 to 1000 years, the main flow has been partially diverted, probably during a major flood, to a shorter, steeper path to the Gulf of Mexico. In each case, the new path gradually captured the majority of the flow and began to build its own delta lobe. It is generally agreed that there have been about seven major changes in stream dominance during the past 5,000 years (Frazier 1967), resulting in the production of a series of delta lobes (Figure 5). In the area surrounding the dominant stream, sediments accumulated over time, first forming shallow bays, then intertidal flats with higher natural levees adjacent to the channel margins.

The intertidal flats were colonized by a variety of freshwater wetland plants such as cattails, arrowhead, and bulltongue. These plants augmented the deposition of more sediment, forming true subaerial land, which was colonized by woody plants, like willows. The highest levees and stranded beach ridges from reworked sediments were colonized by upland vegetation.

The steps by which a delta system forms in the MDPR are currently being quantified in detail by monitoring the formation of the emerging Atchafalaya Delta in Atchafalaya Bay (e.g., Roberts et al. 1980). In an active delta, sediments come directly from the river, primarily during spring floods. Land is built in three ways, as can be seen in the newly-forming Atchafalaya system. The delta aggrades as sediments are deposited in shallow coastal waters (Roberts et al. 1980). Deposition may occur on older deteriorating peripheral marshes as turbid waters flow over them. Such infilling is taking place in the marshes adjacent to Atchafalaya Bay (Baumann and Adams 1982). Downdrift to the west of an active delta can induce coastline accretion as fine sediments are deposited. Recent accretion along the Chenier Plain coast is an example of this process (Wells and Kemp 1981).

Although the rate of worldwide sea level increase slowed about 3,000 to 5,000 years ago (Emery and Uchupi 1972), sea level has not remained static. Average annual sea level along the U.S. coast has been rising over the past four decades at a rate of about 1.3 cm/decade (Hicks 1981). In comparison, apparent sea level rise from tide gauge measurements along the MDPR coast is about an order of magnitude greater than this figure (over 1 cm/yr or 0.4 in/yr). Most of this anomaly is attributable to subsidence in coastal wetlands (Swanson and Thurlow 1973).

Coastal submergence critically influences the future of the MDPR because of its effects on coastal wetlands. Subsidence in the MDPR can be attributed to three interacting factors: (1) crustal downwarping and associated tectonic processes, (2) compaction of sediments, and (3) sediment dewatering (Adams et al. 1976). Marsh vegetation is sensitive to changes in water level, and most emergent wetland vegetation in Louisiana has an inundation tolerance range of

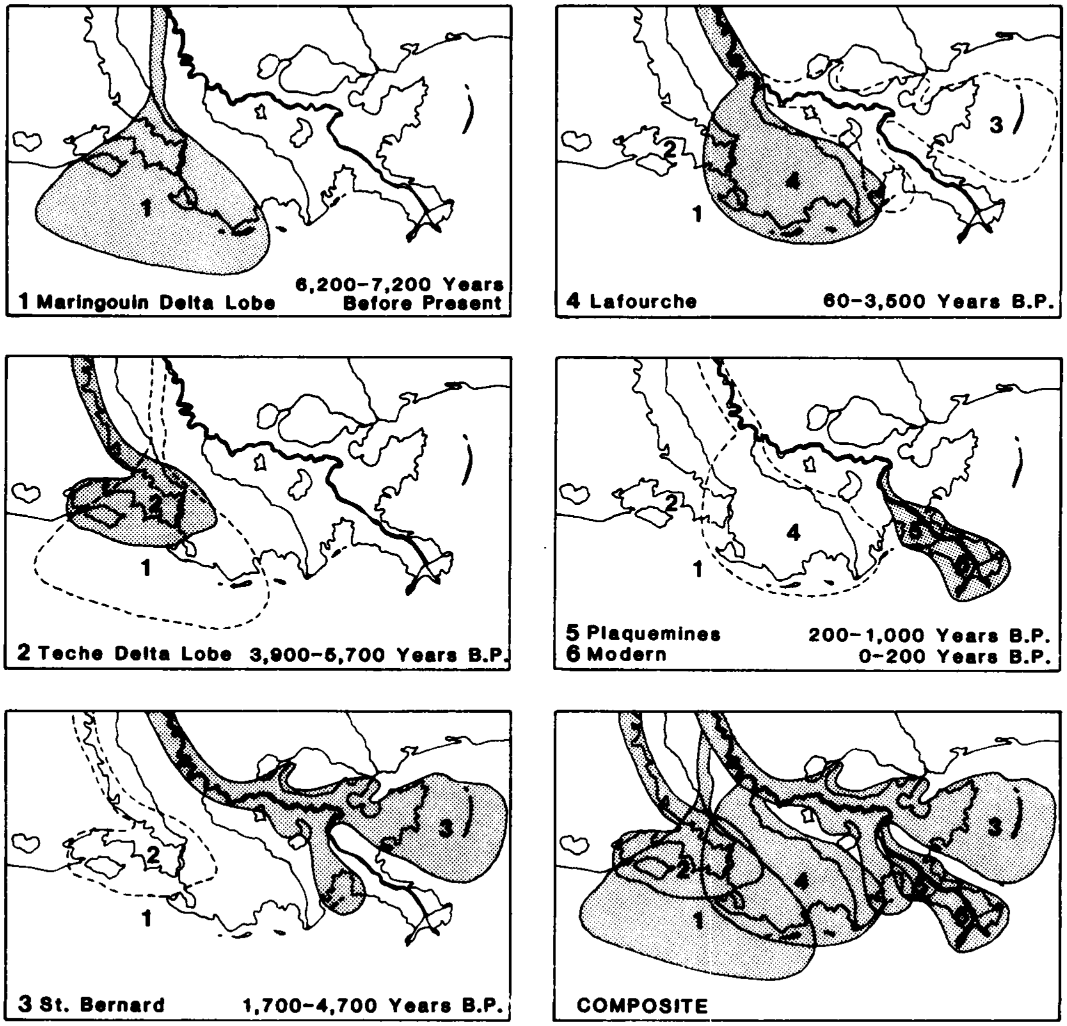


Figure 5. Major delta complexes of the MDPR (from Baumann and Adams 1982).

about 50 cm (20 inches) (Sasser 1977). Marshes rely on the deposition of sediment and organic matter to maintain their elevation above water level, and hydrologic, sediment, or salinity regime disturbances can dramatically affect marsh condition. The anomalously rapid apparent increase in sea level in the MDPR is of great importance to the future of the region. Figure 6 shows the variability in rates of elevation change along the gulf coast. Management plans should obviously take this ongoing process into consideration.

After a delta lobe is abandoned by the major distributary, resuspended sediments are the primary source for local deposition. This is also true for the present case in which Mississippi River sediments are being lost offshore. The majority of deposition occurs during winter storms associated with frontal passages and during summer tropical storms. A 5-year study (1975-1979) was done of sedimentation in the saline marshes surrounding Barataria Bay, an area artificially cut off from spring overbank flooding of the Mississippi River. Forty percent of total sedimentation took place during the winter, 40% during two tropical storms, and 20% during other times (Baumann 1980). There was a statistically significant difference between the rate of sedimentation in marshes adjacent to tidal creeks (1.5 cm/yr or 0.59 in/yr) and the rate in marshes farther inland (0.9 cm/yr or 0.35 in/yr). The subsidence rate (1.2 cm/yr or 0.47 in/yr) was 0.3 cm/yr greater than sedimentation in inland marshes, but less than sedimentation in streamside marshes. Thus, inland marshes are deteriorating. The loss of riverine sediment (because of flood control levees) and the difference in sedimentation rates between inland and streamside marshes should be considered in assessing wetland loss in abandoned delta lobes.

Geological processes in the MDPR formed traps which have collected deposits of oil, gas, and sulfur. The weight of sediments deposited over ancient salt beds in the MDPR pushed up huge pillars of salt called salt domes. Oil and gas are concentrated enough to be recovered economically only where they are trapped in geologic discontinuities. Salt domes are an important category of discontinuity in the MDPR. The salt itself is also economically important.

Caverns leached or mined from salt domes are now being used for the storage of oil. The Clovelly salt dome, near Golden Meadow, Louisiana, stores imported crude oil from the Louisiana Offshore Oil Port (LOOP) located 19 mi off the coast in the Barataria hydrologic unit. The Hackberry salt dome in Cameron Parish currently holds an oil reserve under the Federal Strategic Reserve Program. Under consideration is the storage of compressed air in salt domes to generate electricity during peak demand. In addition, a large study has been mounted to examine the feasibility of permanently storing in salt domes the current stockpile of 8,000 metric tons of high-level radioactive waste from nuclear reactors (Martinez et al. 1979; Marshall 1982).

Hydrology

Hydrologic processes integrate the entire region by regulating biological processes (especially wetland plant production), eroding and depositing sediments, modifying the climate, transporting aquatic organisms and human commerce, and disposing of wastes. Hydrology encompasses all water relations, including water budgets (inputs and losses), above and belowground storages, water quality parameters such as salinity, and flow rates.

Hydrologic processes include all interactions mediated by water movement, and almost everything that happens in the MDPR is somehow related to such processes. River water carries sediments to the region and deposits them differentially. The river water flow, rain water runoff, and ocean water inundation erode and deposit sediments. Water movements and waterborne materials, acting under the local climatic influence, control plant production, which contributes markedly to the landbuilding process.

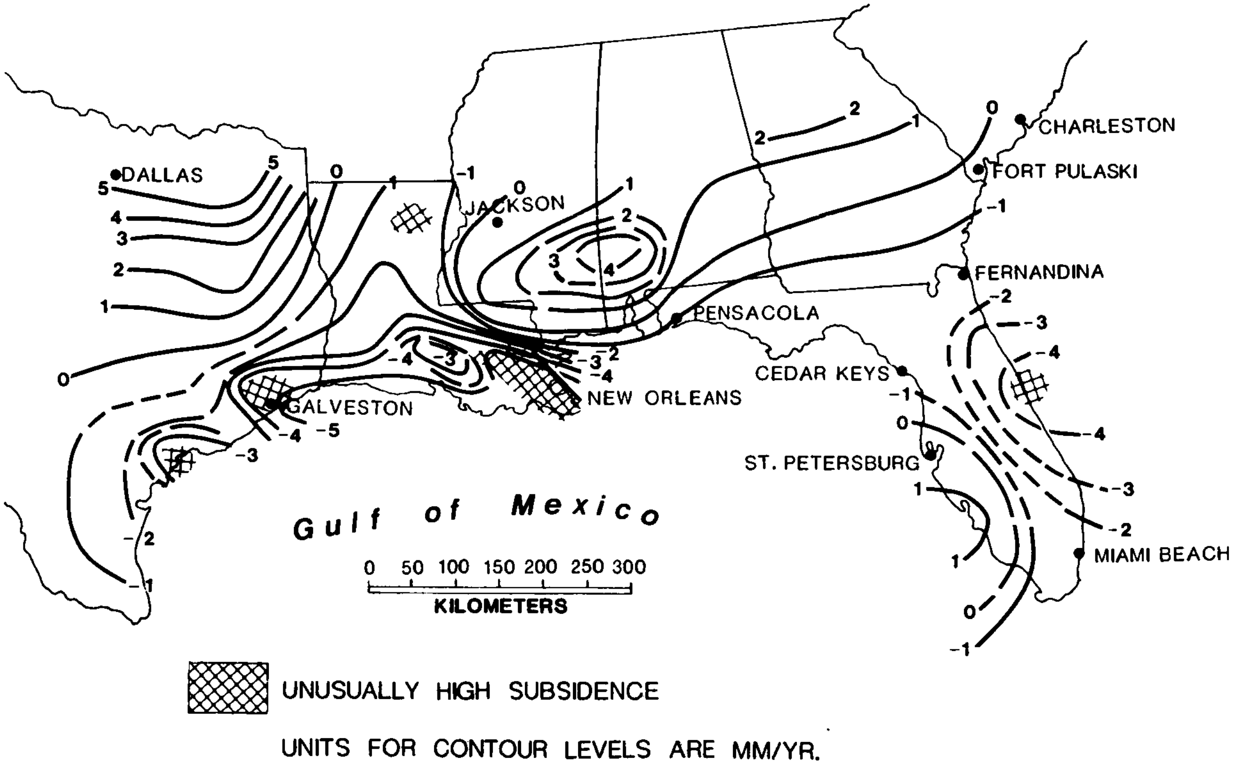


Figure 6. Recent rates of elevation change in the northern gulf coast (Holdahl and Morrison 1974).

The MDPR exists as a geologically ephemeral balance of high land, wetland, and open water. Water balance, flooding patterns, and water quality (salinity, turbidity, nutrient concentration, and pollutant levels) determine the makeup of a given habitat at a given time.

Freshwater inputs come from precipitation, surface runoff, stream and river discharge, and subsurface water. Water is lost through runoff, evaporation from open water, evapotranspiration from vegetated areas, stream drainage, and percolation (infiltration) into the soil. These interrelated activities are controlled by slope, soil type, climatic factors (precipitation, temperature, and wind regime), biological processes, marine influences (tidal patterns and storm surges), riverine processes, and human factors.

Hydrology can be divided into four main categories: riverine processes, marine processes, geomorphology and soil characteristics, and climatic factors. The influence of these is illustrated in Figure 7.

The MDPR, which contains the eighth largest deltaic plain in the world (Wright et al. 1974), is a classic river-dominated delta system. The presence of a delta at a river mouth indicates a net deposition of alluvial sediment in excess of erosion by marine energy. Compared with 34 major delta systems around the world, the MDPR ranks first in its degree of riverine dominance over marine processes (Wright et al. 1974).

Total annual freshwater discharge into the lower Mississippi and Atchafalaya Rivers from the drainage basin upstream is strongly seasonal, usually reaching a peak between February and April. The pattern is variable, however, generally having several smaller peaks throughout the year (Wright et al. 1974). The two major distributaries of the Mississippi drainage basin together discharge an average of 51,800 m^3/sec (1,830,000 ft^3/sec) of water into the MDPR, or about 2 trillion m^3/yr (58 trillion ft^3/yr) (USACE annual data). This water is discharged into the gulf at two primary sites, the modern delta (70%) and the Atchafalaya Bay complex (30%).

River water accounts for over 90% of the total input to the region. About 95% of this water and its suspended load is shunted straight to the Gulf of Mexico (USACE Annual data). Before the 1930's, overbank flooding and crevasses deposited millions of tons of silt into the Barataria and Pontchartrain basins. Levees in the lower Mississippi River system now entrain flood waters. Thus the river directly affects only the Atchafalaya and the modern delta, except when the Bonnet Carre spillway is opened to divert floodwater into Lake Pontchartrain. The spillway, built in 1931, has been opened six times to ease the pressure on the levees protecting New Orleans. During these times the river has affected both the Pontchartrain and Mississippi Sound systems.

Because of the construction of levees on the lower Mississippi River, hydrologic processes in the Barataria, the eastern portion of the Terrebonne, and the Pontchartrain hydrologic units, are dominated by marine, climatic, biological, and cultural factors. Local precipitation accounts for only 10% of freshwater input into the total MDPR, but it is the only significant source for the Barataria basin.

Marine processes are overshadowed by riverine processes in portions of the MDPR, but the Gulf of Mexico erodes and redistributes river-supplied sediments, especially in the formation of barrier islands. Compared with the other great deltas of the world, nearshore wave power along this coast is minimal, as shown in Table 1 (Wright et al. 1974). Note also that the attenuation ratio (a measure of the amount of wave energy that is dissipated offshore by the slope of the bottom) for the Mississippi Delta is much higher than that of other deltas.

Wave energy along the entire Louisiana coastline is variable with areas closest to the Continental Shelf receiving the highest wave energy; hence the modern delta receives the greatest

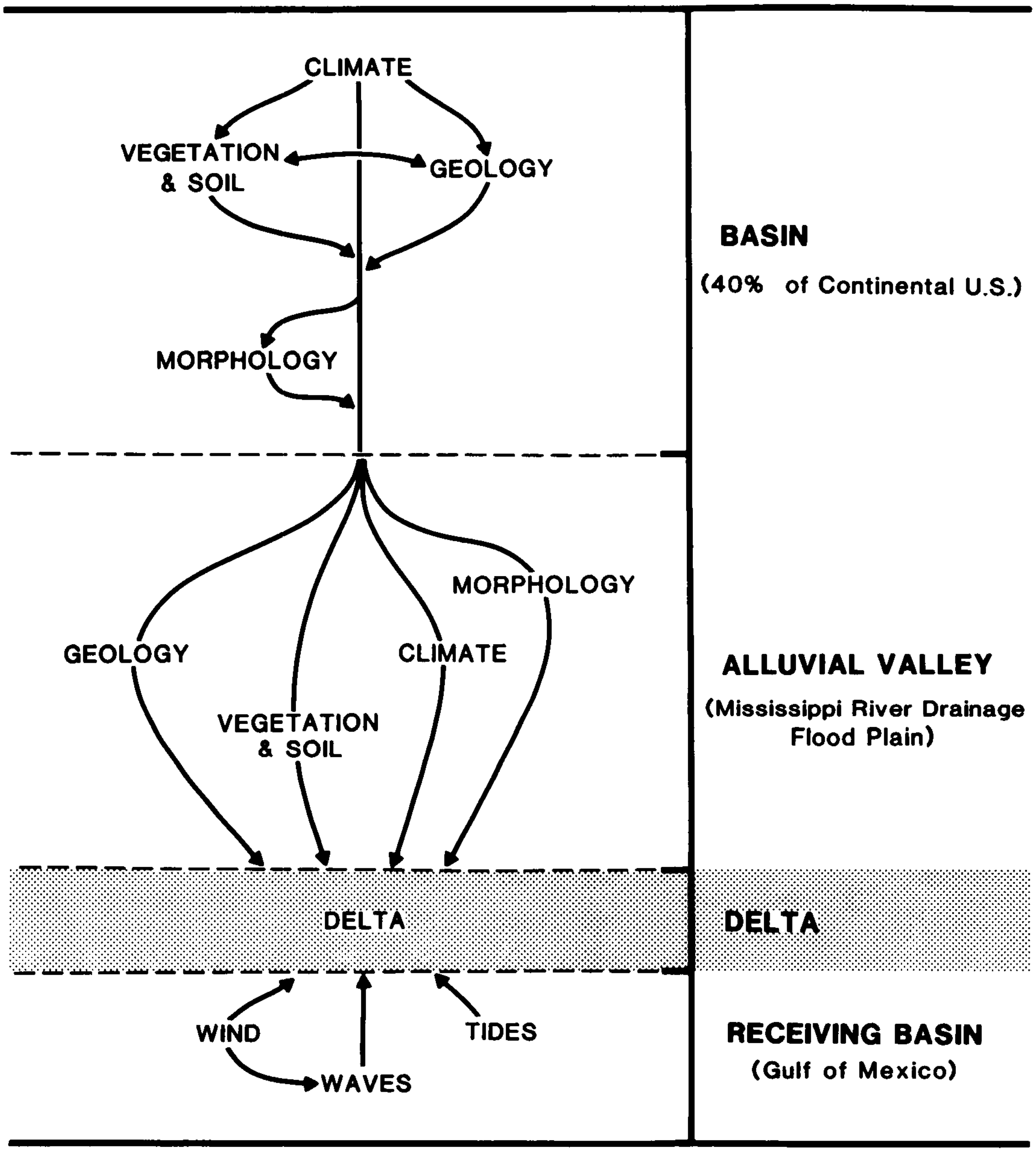


Figure 7. Physical factors influencing the development of the MDPR (from Wright et al. 1974).

Table 1. Mean annual wave power for selected delta systems (Wright et al. 1974).

Delta	Nearshore wave power (Ergs/sec x 10^7)	Wave power at 10 meters depth (Ergs/sec x 10^7)	Attenuation ratio (Column 1/ Column 2)
Shatt-al-Arab (Asia)	0.014	5.35	976.77
Danube (Europe)	0.033	49.08	1,598.63
MISSISSIPPI	0.034	181.83	5,302.78
Yangtze-Kiang (Asia)	0.127	54.68	430.55
Ebro (Europe)	0.155	180.25	1,162.90
Amazon (South America)	0.193	204.42	1,052.00
Irrawaddy (Asia)	0.193	245.50	2,028.83
Hwang Ho (Asia)	0.218	83.50	310.00
Ganges-Brahmaputra (Asia)	0.585	732.30	914.00
Chao Phraya (Asia)	0.736	220.58	1,052.00
Ord (Australia)	1.000	19.60	20.11
Niger (Africa)	2.000	174.50	70.76
Burdekin (Australia)	6.410	98.83	16.43
Nile (Africa)	10.250	128.16	12.65
Indus (Asia)	14.150	914.30	64.61
Sao Francisco (South America)	30.420	594.90	20.35
Senegal (Africa)	112.420	284.92	2.60
Magdalena (South America)	206.250	916.60	4.44

erosional stress. A general principle of delta life history is that the coastline of the most recently abandoned delta lobe regresses most rapidly (Becker 1972). The shoreline due east of the mouth of Bayou Lafourche (Barataria hydrologic unit) is eroding at a rate of 15 m/yr (Sasser et al. 1981). The typically low wave energy pattern for the MDPR changes drastically during the passage of a hurricane.

In addition to the erosional effects of wave energy, there is a pattern of littoral drift: longshore currents move sediments and organisms to the west toward Texas, as shown in Figure 8. This figure indicates that although current direction is variable near shore along the MDPR, the overall pattern is for westward-trending currents. This pattern is partly due to the general absence of westerly winds in the area, as shown below in Figure 13.

The mean tidal range along the coast is about 0.3 m (1 ft), an empirical estimate that includes both meteorological (wind driven) and astronomical tidal components. The low tidal amplitude in the MDPR results in the development of tidal flats and tidal creek networks that are smaller than those of deltas in regions having greater tides. Tidal amplitude is attenuated inland from the coast, as shown by the USACE gauge records from Barataria Bay. Two tidal components affect the inundation regime. A biweekly range cycles between tides that are equatorial (equivalent to neaptide) and those that are tropical (equivalent to springtide). A seasonal maximum tidal range occurs during solstices, and a seasonal minimum range during equinoxes.

Meteorological processes overshadow tides in the control of water level variation in the MDPR. Water-level variations lasting from less than one to several days are governed by the combined effects of tidal and climatic factors. Winter cold fronts are usually preceded by several days of strong southerly winds, which resuspend bottom sediments and flood the marshes. When the front passes, the wind shifts to the north, and the marshes drain rapidly, flushing out organic detritus.

Annual water levels show a bimodal distribution, with low winter levels reflecting northerly winds and contraction of water volume due to low temperature. The spring peak is caused primarily by a shift to strong onshore winds. The summer minimum reflects a time of weak winds and high evaporation. The peak in September is the result of strong onshore winds and some expansion from summer heating (Baumann 1980).

Variations in tidal range and wind-related water level combine to produce changes in the inundation of wetlands in the Barataria basin, which are fairly representative of the pattern across the MDPR (Figure 9).

The duration of inundation in both coastal and inland sites (in the Barataria basin for example) is largely a function of the annual water-level cycle (Figure 10). The frequency of flooding exhibits less variability than does duration of flooding. When water level is at a maximum in September, tidal range is low, resulting in the deep flooding of marshes for long periods of time (Baumann 1980). The seasonal low in frequency of flooding results in high water levels and low tide range. Flooding is more frequent in the saline marsh during December because of both a high tide range and frequent frontal passages. Frequent flooding during the summer results from the seasonal high in tide range and a low mean water level, the opposite of the conditions that prevail during September and October. Swamps remain flooded for much of the year, but they have a low flooding frequency because of the absence of tidal influence.

In addition to tides and winds, marine processes regulate salinity. The salinity regime in estuaries is constantly changing, causing osmotic stresses that exclude many marine and freshwater organisms and reduce the number of species (Hedgpeth 1967; Remane and Schlieper (1971). As land loss accelerates in the region, saline water

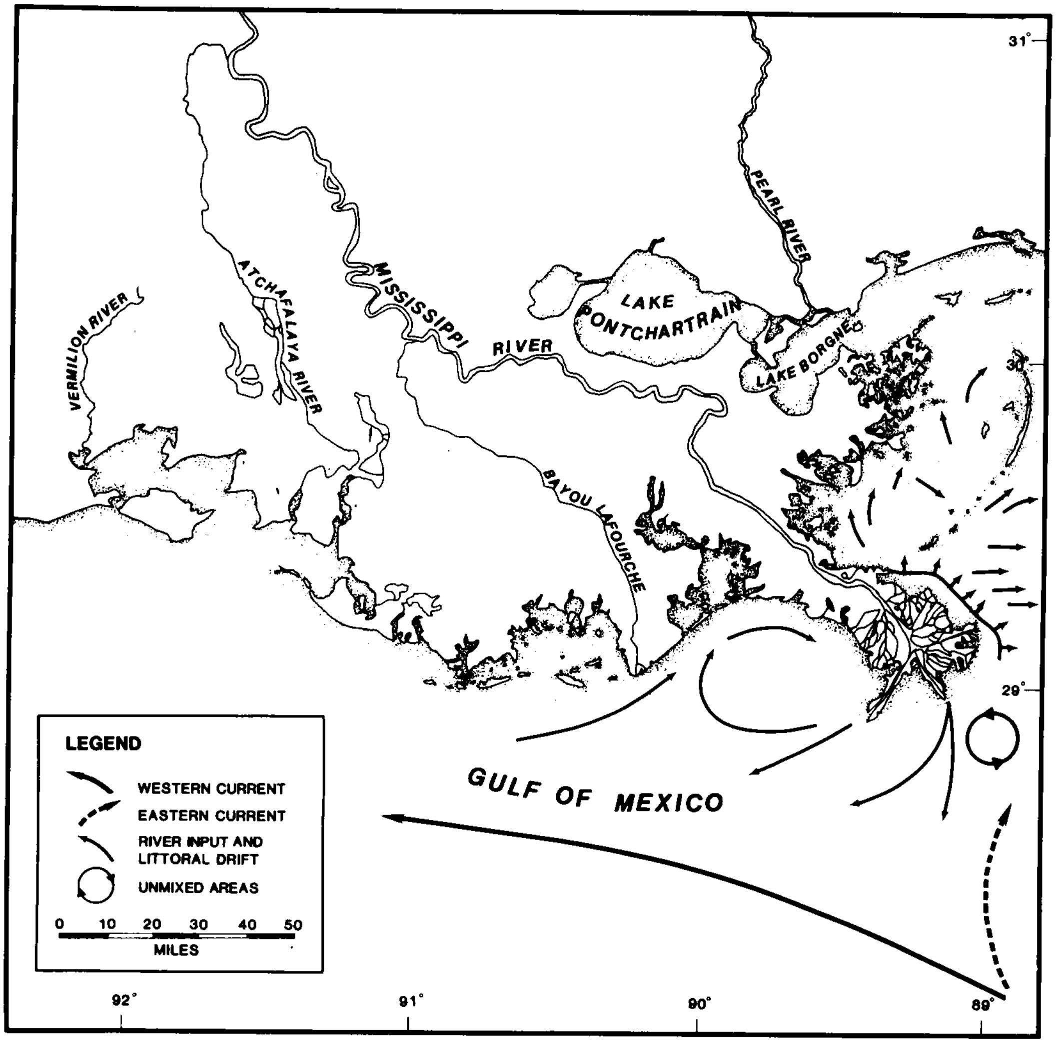


Figure 8. Littoral drift patterns in the MDPR (from USACE 1981).

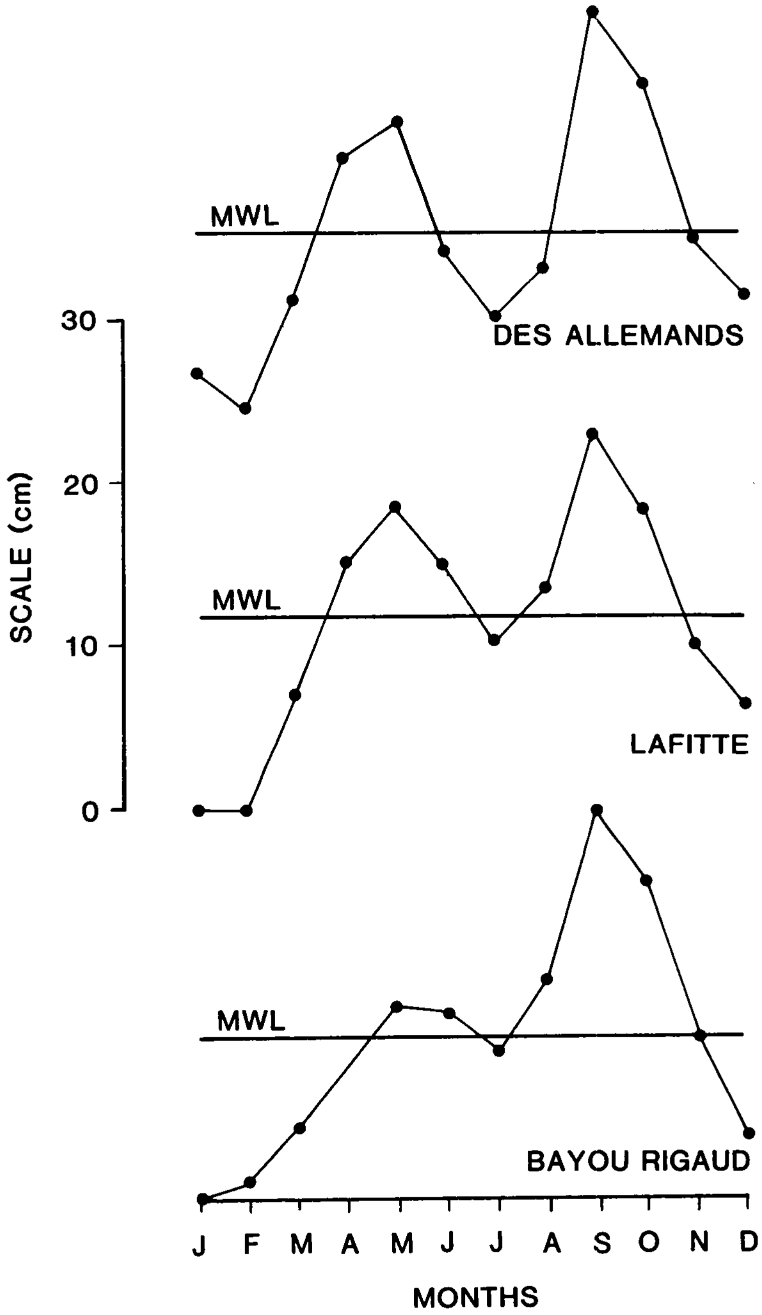


Figure 9. Seasonal variation in water level in the MDPR for an average year (from R. H. Baumann, Louisiana State University, unpublished data).

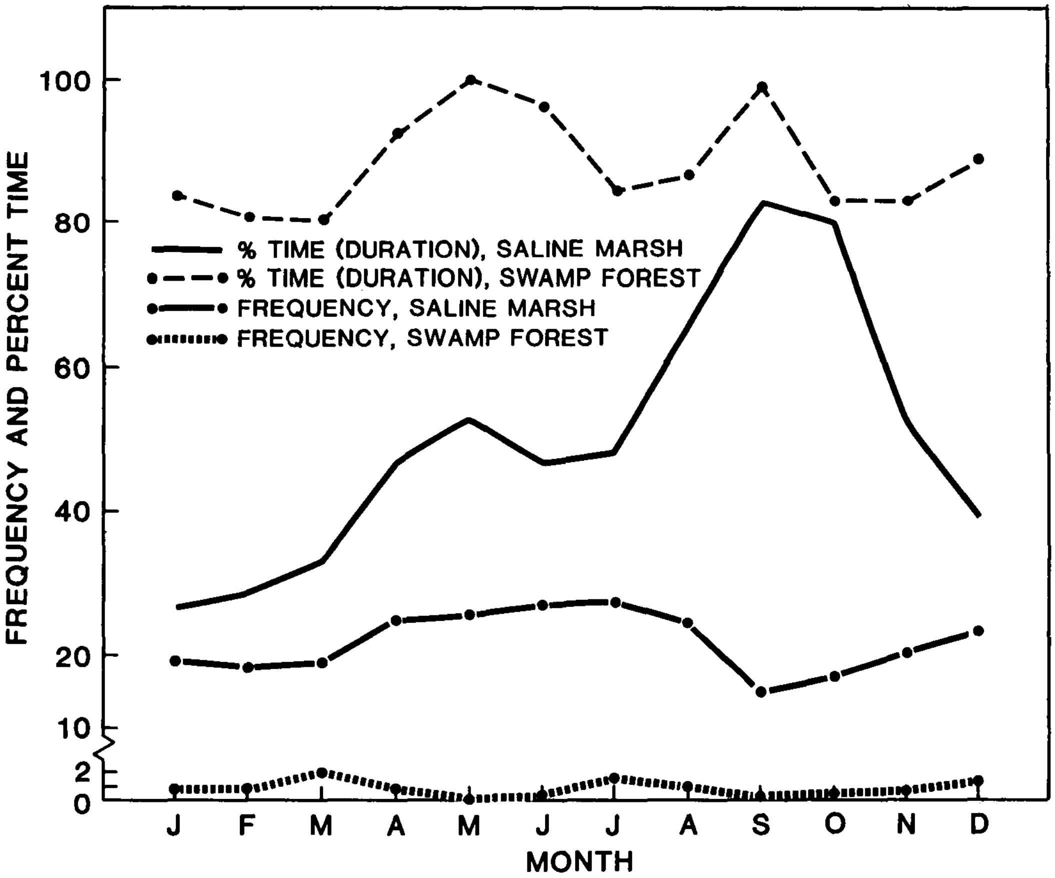


Figure 10. Frequency (per month) and duration (% hr/month) of flooding episodes in the salt marsh and swamp forest habitats of the MDPR. Note that while the frequency of flooding in the swamp forest is low, the duration of each flooding episode is high (from R. H. Baumann, Louisiana State University, unpublished data).

spreads northward affecting freshwater organisms, especially wetland plants, that are unaccustomed to osmotic stress.

The slope of land and its vegetative cover affects the rate of surface water runoff. Porosity of soils and their moisture deficits affect the rate at which water percolates through surface layers. Within the MDPR, the average surface gradient is low (about 1 cm/km or 0.6 in/mi) and the soil is saturated during most of the year. Much of the surface soil overlies a relatively impermeable clay layer. Although the dense vegetative cover that characterizes the MDPR retards water runoff, it also enhances water loss by evapotranspiration.

One of the most important regulators of hydrologic conditions within the MDPR, and also of the biological communities that characterize the region, is maritime climate (Wax 1977). Temperature, precipitation, solar energy, relative humidity, winds, and barometric pressure are all directly involved in the regulation of water level and water flow, salinity gradients, evapotranspiration, erosion of sediments, and biological productivity. The climate of the MDPR can be classified as moist subtropical with essentially no water deficit (Figure 11), in contrast to the semi-arid conditions generally present at 30 degrees north or south Latitude (Figure 11). Precipitation in the MDPR, which arises largely from evaporation in the Gulf of Mexico, overrides this latitudinal semi-arid tendency.

The subtropical location of the MDPR and its proximity to the Gulf of Mexico ensure a long growing season (236 to 240 frost-free days) and relatively small annual temperature ranges (Wax 1977). The moderating effect of the gulf is dramatically demonstrated by the presence of a thin fringe of black mangroves (Avicennia germinans) along the inshore borders of the barrier islands of Louisiana.

Evapotranspiration affects not only the availability of water, but also the rate of primary production. Rates of evapotranspiration, precipitation, and runoff have been estimated for the MDPR using water balance calculations by Sklar (1980). Actual evapotranspiration averages about 100 cm/yr (40 in/yr), while precipitation averages near 160 cm/yr (63 in/yr), resulting in a large volume of surplus water available for runoff (about 60 cm/yr or 23 in/yr).

Muller (1977) described the climate of south Louisiana in terms of eight synoptic weather types. During the warmer months, tropical weather types (those associated with the Gulf of Mexico) dominate; in cooler months, continental weather types are more common. Winds are generally weakest in the summer, except during tropical storms and briefly during thunderstorms. The strongest winter winds are associated with the passage of cold fronts.

Few occurrences in the MDPR are as dramatic as the approach of a hurricane. Such an event captures the attention of the news media for days, and stories of damaged property are always accompanied by economic loss estimates in six or seven figures. Usually there is ample warning time to prevent extensive loss of life, but in the case of Hurricane Camille in 1969, 171 people were killed in the area of Biloxi, Mississippi (USACE 1970) when they ignored warnings to evacuate. A recent study indicated that New Orleans is extremely vulnerable to hurricanes (USACE 1981). A level 5 hurricane (like Camille) could inundate major portions of the city with water 7.6 m (25 ft) deep (Baton Rouge Sunday Advocate 1982).

Hurricanes are considered natural calamities, but they produce beneficial effects on natural coastal ecosystems. For example, the extreme wind and wave energies that accompany major storms represent disordering processes that send large amounts of sediment and nutrients into coastal estuaries. This results in both short-term and long-term increases in primary productivity, although some animal populations may decline initially (Baumann et al. in

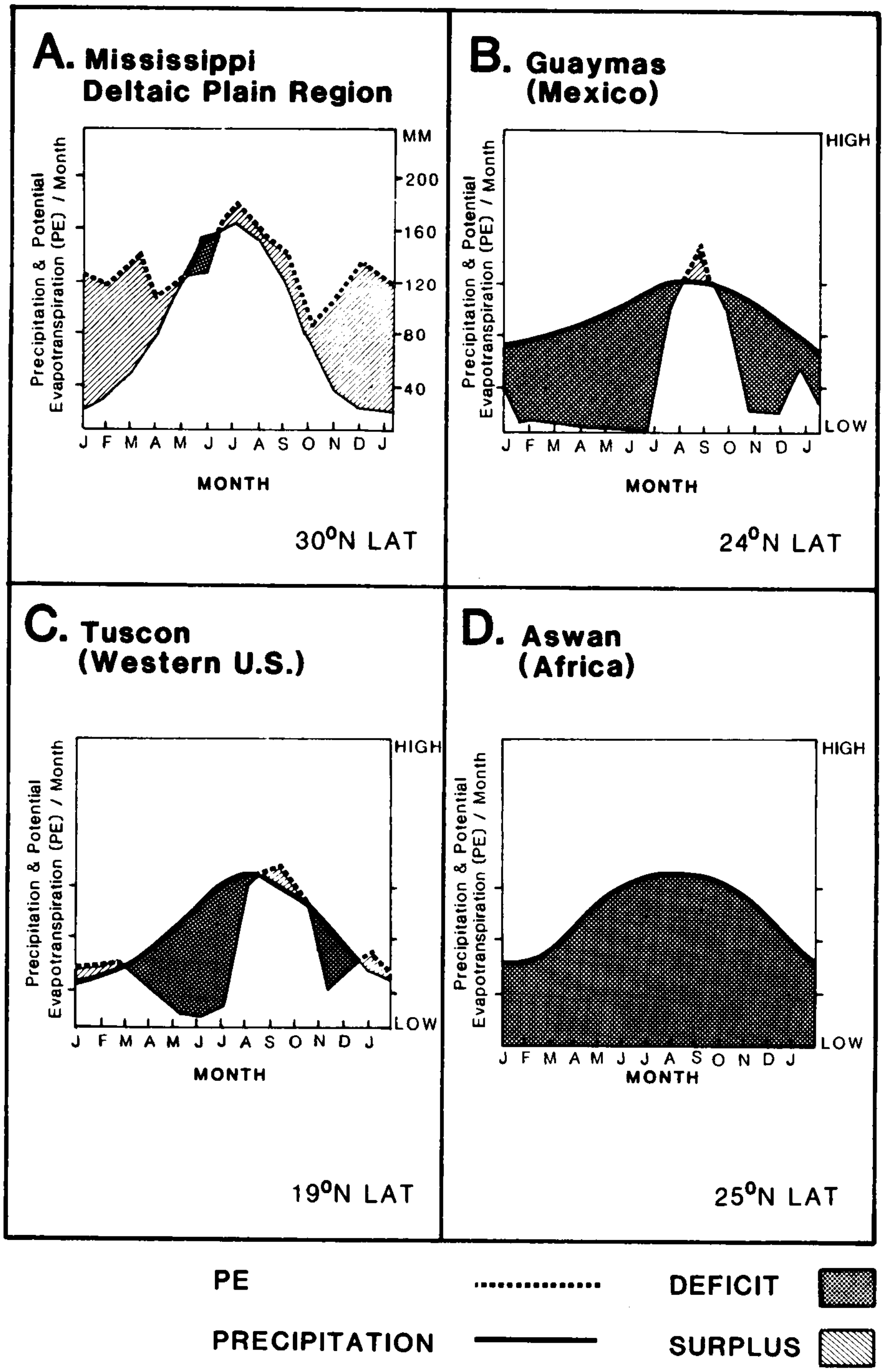


Figure 11. Precipitation/evaporation diagram for the MDPR (A) and other stations at similar latitudes. (A) (Sklar 1980) shows minimal water deficit due to the influence of the Gulf of Mexico, while stations (B), (C), and (D) (from Walter 1973) show severe water deficits.

preparation). Hurricane stress aids in the maintenance of wetland plant communities at a successional stage of low maturity and high net production. In addition, the threat of hurricane damage may discourage coastal development and indirectly prevent habitat destruction.

The pathways of hurricanes that have impinged on the gulf coast in the past are illustrated in Figure 12. Because a storm may be as wide as 200 km (124 mi), any location along the coast of the MDPR has about a 14% chance of sustaining hurricane effects during a given year (Baumann et al. in preparation).

Hurricanes and less severe tropical storms are characterized by low barometric pressure, which results in a significant rise in sea level. At the same time, onshore winds of up to 200 or more km/hr (124 mi/hr) can produce a storm surge in the MDPR as great as 7 m (23 ft) in elevation, as did Hurricane Camille, driving ocean water far inland (USACE 1970). Torrential rains that accompany hurricanes compound the flooding problem. These effects can drastically change the shape of the coastline; dunes may be washed away and new inlets may be created across barrier islands.

Major storms supply significant amounts of the total average rainfall in some areas. About 15% of the precipitation in the MDPR is related to tropical disturbances and 70% to frontal passages (Muller and Wax 1978).

The mean distribution of wind speed and direction in the MDPR during four months of a typical year is shown as four wind roses in Figure 13.

BIOLOGICAL SETTING

The biological setting of the MDPR is defined here as the broad pattern of distribution of the organismal communities that occupy the region, the processes that affect and limit their distribution, and the regional effects of these communities. The biological setting of the MDPR is affected and constrained by both the physical and climatic settings. At the same time, the physical and climatic settings are affected by the biological setting.

The regional biological setting is most appropriately visualized as it appears to an observer flying over the coastal zone at an altitude at which major plant communities can be perceived. This setting is a broad flat zone of lush emergent wetland vegetation, intersected by wooded natural levee ridges along river courses and bayous. Numerous open water bodies are turbid, algal rich, and the more inland lakes may be covered with floating plants. Flocks of wading birds and waterfowl will be seen feeding in the wetlands. Large numbers of commercial and private fishing boats will be seen plying the waters. The overall impression is one of a biologically rich and fertile region. O'Neil (1949) mapped the dominant coastal marsh communities across the Louisiana portion of the MDPR, including saline, brackish, intermediate, and fresh marshes, but excluding forested swamps. The distribution of these communities was again mapped by Chabreck (1972) and later updated by Chabreck and Linscombe (1978) and by Wicker (1980), who included Mississippi wetlands as well.

At the regional level, the biological components in the MDPR can be visualized the way they appear on high level imagery: bands of vegetation that completely cover almost all subaerial and intertidal surfaces. Such photographs exhibit roughness and color differences that indicate differences in biomass and/or productivity. This perspective indicates the relative role of biological processes in determining the topography of the regional landscape.

Organisms and topography are interrelated in several ways. The production of organic carbon by wetland vegetation results in the net deposition of peat during and after the long growing season. The carbon that remains after losses from leaching, grazing, and

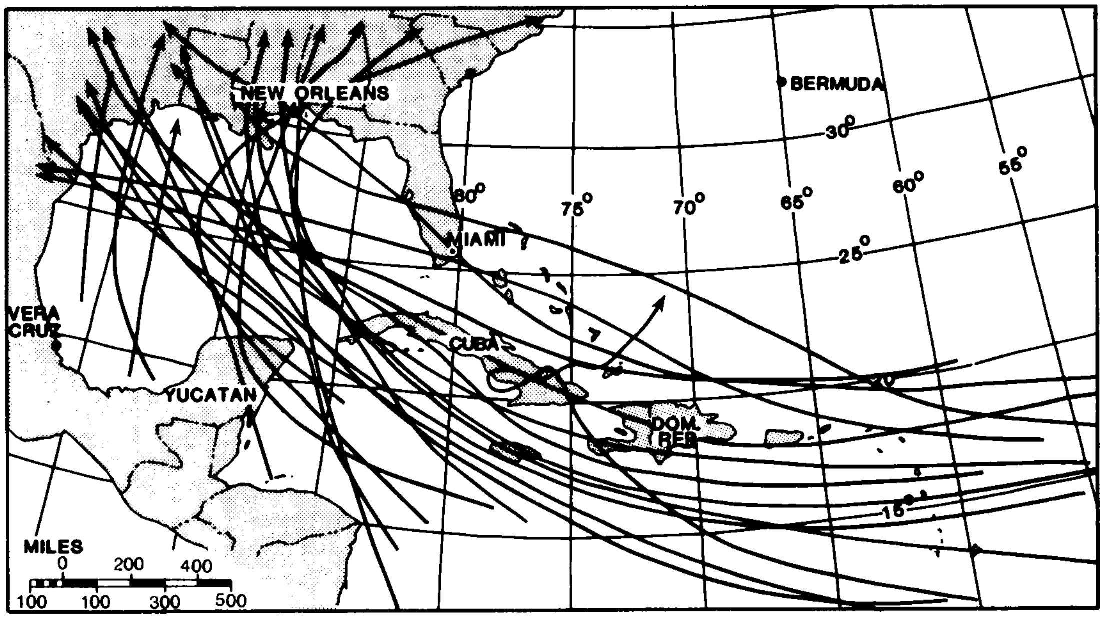


Figure 12. Tracks of Atlantic tropical cyclones recorded from 1893 to 1960 (from American Society for Oceanography 1966).

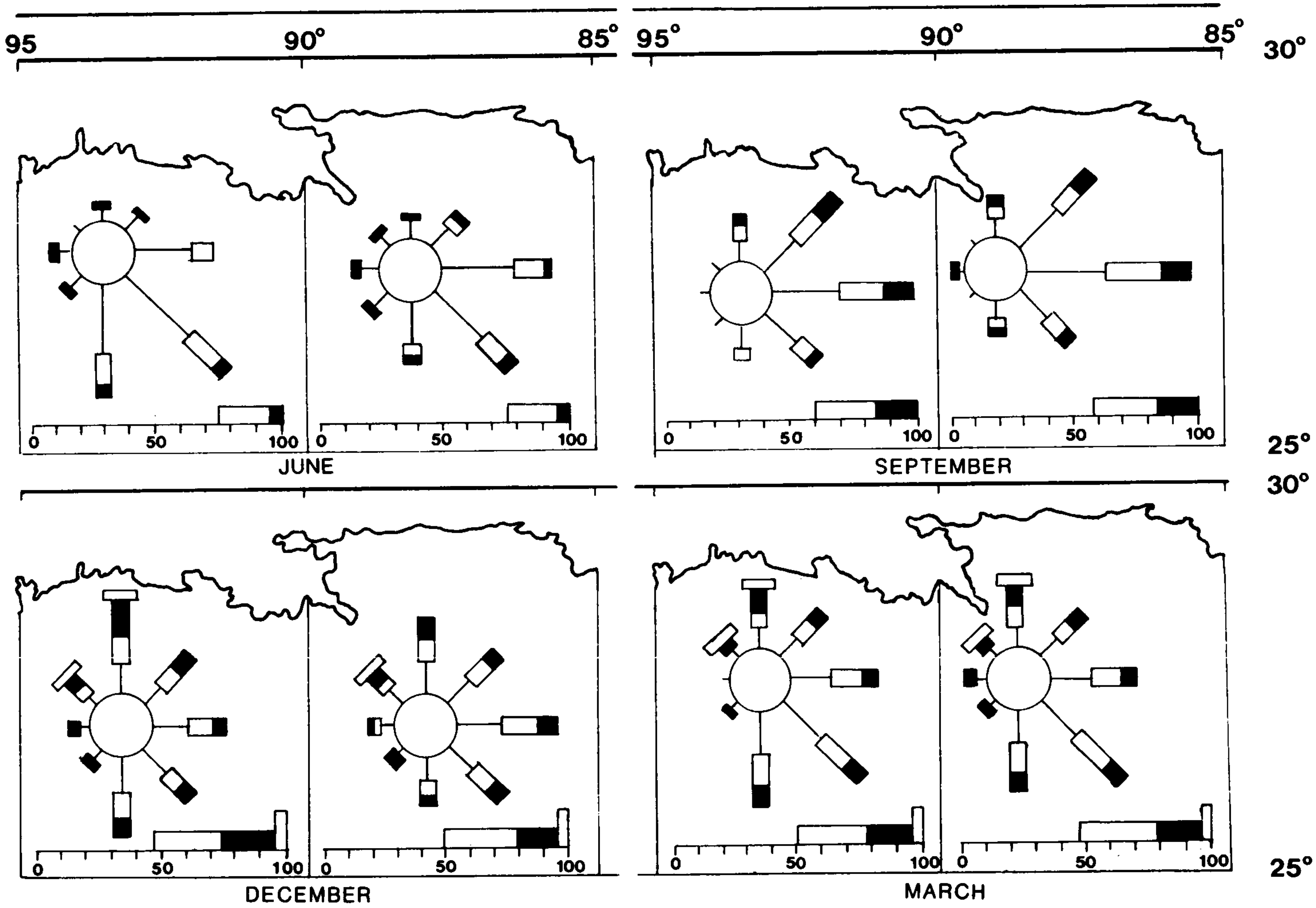


Figure 13. Distribution of wind speed and direction in the MDPR (from National Data Buoy Center 1973).

export by currents accumulates and increases marsh elevation. Higher elevation means more frequent exposure of the soil surface to air, increasing the loss rate (oxidation) of carbon and limiting further increases in elevation. Soil that is so low as to be permanently waterlogged (never exposed to air) develops an oxygen deficit that retards macrophyte production. There is presumably an optimum inundation frequency for each wetland community type that provides energy subsidies in the form of nutrients and other plant requirements that stimulate production rates. The highest plant biomass occurs along the banks of natural streams and bayous. More inland portions of the region are inundated less frequently than are coastal marshes, and they are covered by standing water for longer periods. The highest productivity levels are shown by brackish marshes, in which flushing and inundation frequencies are intermediate (Day et al. 1982).

Macrophyte vegetation in wetlands also contributes to inorganic deposition by reducing water-current velocity and increasing sedimentation rates. This current-damping effect is also important for absorbing the energy of storm surges that would rapidly erode unvegetated sediments. The root mat of wetland plants can be more extensive and contain 2 to 3 times the biomass of the aboveground portion (Stout and de la Cruz 1981) in the MDPR.

Other roles of wetland vegetation at the regional level include the enhancement of water loss through evapotranspiration and the decrease in albedo, or reflectance, both of which affect local climate (Hansen et al. 1981). In addition, the marshes in the MDPR attract a majority of the migrating waterfowl that use the Mississippi flyway.

Certain so-called pest organisms have significantly influenced the urban and agricultural development of the MDPR. For example, numerous species of mosquitoes have always affected the residents of New Orleans. The city experienced many outbreaks of malaria and yellow fever until 1900 (Lewis 1976). Water hyacinths (<u>Eichhornia crassipes</u>) were accidentally introduced to New Orleans from South America during the Cotton Exposition of 1883 (Lewis 1976). They have since spread throughout the South, where they cover freshwater ponds and canals in which nutrient levels are high, especially during the summer.

Agricultural pests, including sugarcane borers, nematodes, aphids, and fire ants reduce crop production or otherwise hinder agricultural operations. They also create an active market for chemical pesticides. These chemicals ultimately enter water, sediments, and organisms in the MDPR. Some chemicals, such as DDT and toxaphene, are persistent and dangerous to humans and to other vertebrates inhabiting the MDPR. For example, during the 1960's, the entire natural breeding population of the Louisiana State bird, the brown pelican, was eliminated by interference in its shell metabolism by some of these chemicals (Blus et al. 1979).

SOCIOECONOMIC SETTING

The economy of the MDPR is based on abundant renewable and nonrenewable natural resources and its location at the mouth of the country's major navigation system. Several studies have addressed the economic conditions and history of coastal Louisiana (Jones and Rice 1972; Renner 1976) and the MDPR specifically (Larson et al. 1980). Rates and patterns of natural resource consumption and pollution and other environmental impacts are a principal concern of this report. The research strategy employed throughout this study has been to treat economic and ecological processes as comparable phenomena that can be incorporated in the same models. Quantitative descriptions of the standard economic sectors in the MDPR (such as agriculture, forestry, mining, and manufacturing) are included as "economic habitats" along with the ecological habitats in a following section.

Natural Resources

The principal natural resources on which the economy is based can be divided into four groups: (1) petroleum and other nonrenewable minerals; (2) the soils and climate that contribute to agriculture; (3) natural habitats that produce fish, wildlife, timber, and other products and natural work services; and, (4) waterways that provide both inexpensive transportation routes and fresh water. The economic system of the MDPR is intimately connected with and dependent upon its ecological systems; it uses both the current production of these systems and the past accumulated production (in the form of petroleum and soils). Recreational use of the area is highly dependent on fish, wildlife, and other natural resources. Larson et al. (1980) provided a detailed inventory of the natural resources of the MDPR, as summarized below.

The MDPR has been the site of significant oil and gas production during the last 50 years, and oil production and proven reserves in the Mississippi Delta and Gulf waters off Louisiana and Mississippi represented about 51% of the Nation's total current production and reserves, excluding Alaska in 1979 (American Petroleum Institute 1982). A plot of oil production in Louisiana from 1938 to 1980 is shown in Figure 14. Production is shifting to deeper water (Figure 14) as nearshore State-owned and private reserves are depleted.

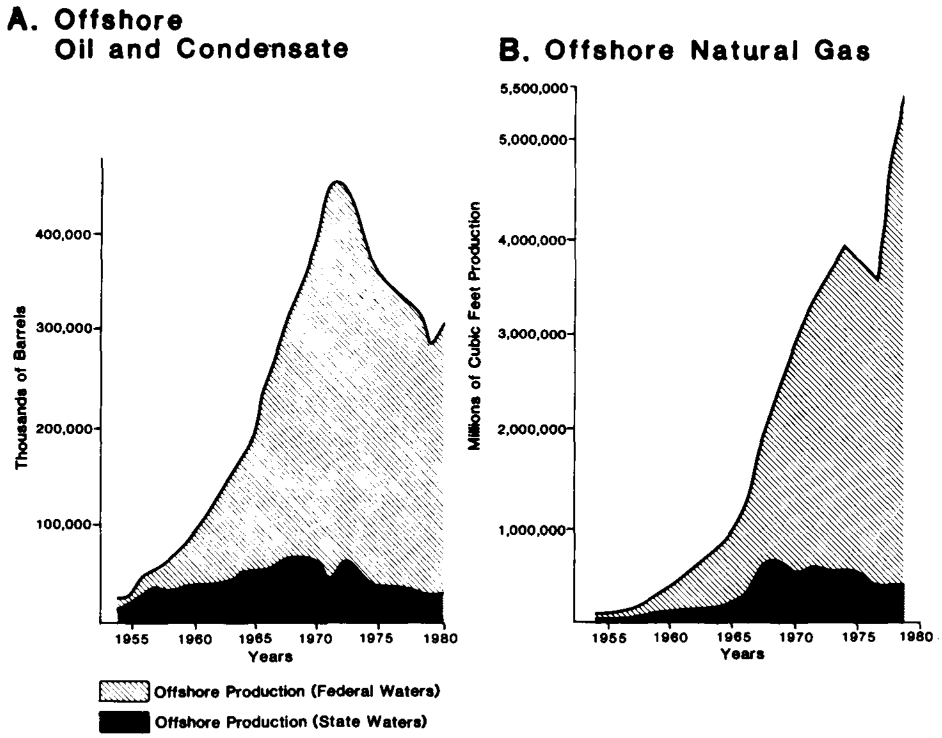
The MDPR is a difficult and expensive area in which to drill for petroleum, relative to other onshore sites such as in Texas, Oklahoma, and central Louisiana. The marshes and coastal waters preclude the use of conventional land-based transportation and drilling systems. Most of the onshore oil and gas wells have been drilled from barges moved to the drilling site through canals dredged for that purpose. Offshore wells have been drilled from huge platforms and the products transported to shore via pipelines. These pipelines are laid by barges that also require access canals through the coastal marshes. About 64,000 ha (160,000 acres) of canals and their associated spoil banks were present in 1978, the majority of which are oil and gas-related (Craig et al. 1979). Canals have been implicated as a major contributor directly and indirectly to the deterioration of MDPR marshes (Craig et al. 1979). Oil and gas mining and undisturbed marsh habitats produce economic benefits for the MDPR. Assessing the trade-offs implicit in disturbing marshes by dredging canals is a primary prerequisite to effective management (see MANAGEMENT ISSUES).

Agriculture has long been an important economic activity in the MDPR, but it has been steadily declining relative to other economic activities in the region, both in terms of employment (Figure 15) and dollar value. This decline coincides with the national trend, as farms have become larger and more industrialized, and as manufacturing and service industries have become more dominant. Agriculture, like oil production, entails certain trade-offs with natural ecosystems (see MANAGEMENT ISSUES).

The natural levees of the present and historical Mississippi River distributaries include the most fertile agricultural soil in the MDPR, and most of the agricultural activity continues to be concentrated in these areas. As the agriculture of ancient Egypt flourished on the silt and sediment deposited by the annual Nile flood, so agriculture in the MDPR has flourished on the alluvial soils deposited during centuries of spring floods.

The value of farm products in the MDPR in 1974 was about $236 million (Larson et al. 1980). The major crops were sugarcane, soybeans, livestock, tobacco, fruits, pecans, and vegetables. In addition to using soil resources, agriculture uses groundwater and results in the discharge of nutrients and pesticides into downstream habitats.

Natural habitats are defined as all habitats that are not the direct result of cultural activities. Natural habitats



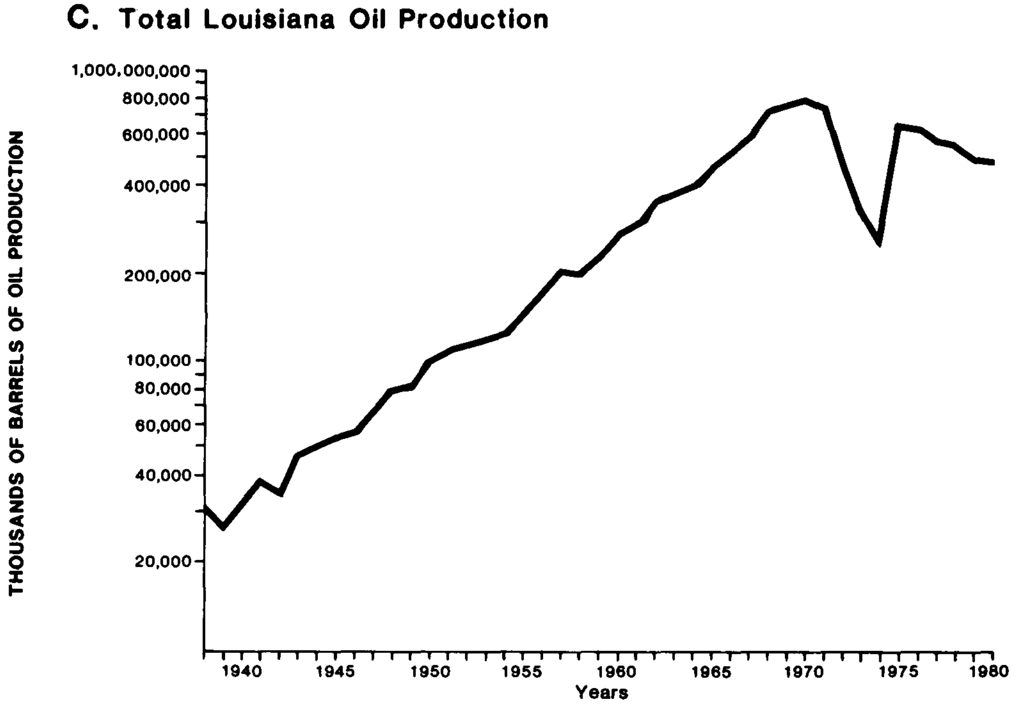


Figure 14. Louisiana offshore oil (A), natural gas (B), and total oil production (C) to present. Louisiana offshore oil and natural gas production figures from API (1982), total oil production figures from Louisiana Annual Oil/Gas Report (Louisiana Department of Conservation 1975) and from Energy Information Administration (EIA), 1976-1980.

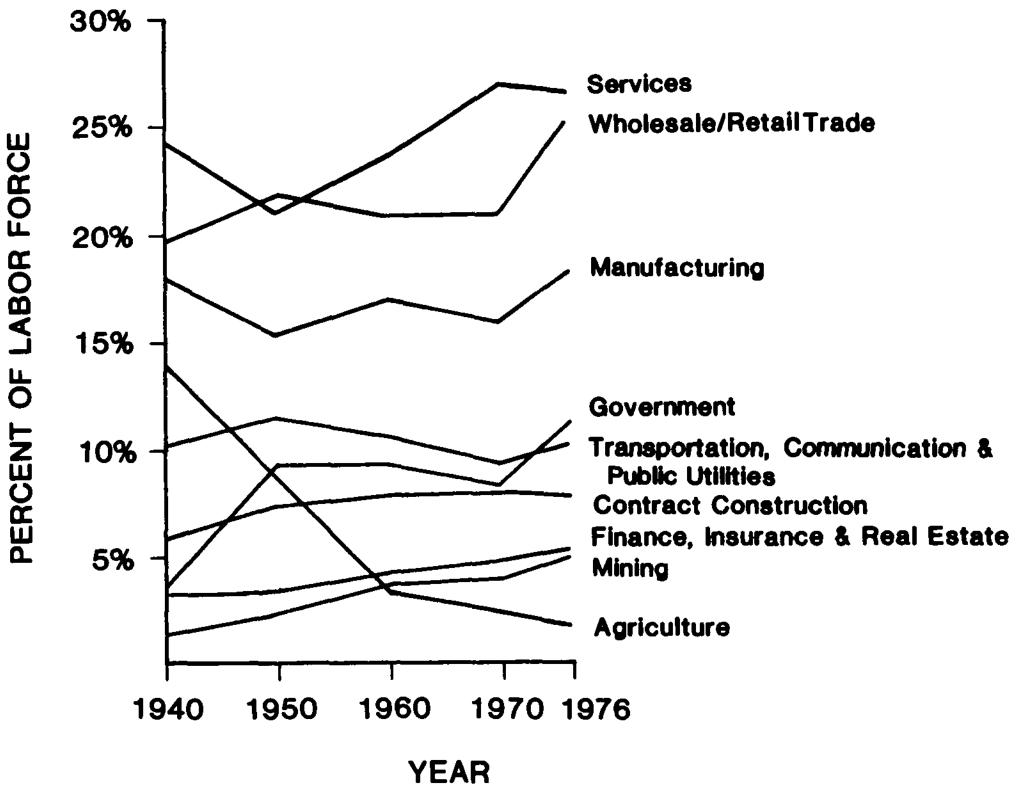


Figure 15. Employment by major industry groups as a percentage of MDPR total civilian labor force, 1940-76 (from Larson et al. 1980).

provide a spectrum of products and services to the economy. Some products, such as shellfish, fish, and furbearers, have well-defined markets, and their contribution to the economy is relatively easy to quantify (Table 2). Natural work services, such as waste assimilation, recreation, microclimate control, and flood protection, are not traded in well-defined markets so their contributions are harder to quantify. This report describes the ways in which natural and economic habitats are interconnected. Ultimately an informed management system should be based on the knowledge of those interconnections.

The connection of the MDPR via waterways to most of the United States and to the world provides an obvious economic advantage. The existence of natural waterways, built and maintained in large part by natural hydrologic processes, saves users the expense of constructing and maintaining alternative transportation. Water transport thus has a significant cost advantage over other transport modes. Figure 16 shows the major navigable waterways in Louisiana and the number of commercial vessels using them in 1978. The Port of New Orleans is the major port in the MDPR and handles more cargo than any other port in the Nation (USACE 1981). Table 3 lists the quantities of major commodities shipped on waterways in Louisiana in 1976: natural resource and agricultural commodities make up most of the waterborne shipments, indicating the importance of natural resources to the economy of the MDPR.

Waterways are also a significant source of fresh water for varied economic activities. The Mississippi River in particular is used for drinking water, for industrial processes and cooling, and as an outlet for municipal and industrial waste. Reconciling these conflicting uses is a major management concern.

Waterways in the MDPR have been modified by dredging and levee construction to facilitate transport and flood control. Levees now flank the Mississippi all the way from Cairo, Illinois, to the active delta, 113 km (70 miles) below New Orleans. The main navigation channel through Southwest Pass is continually dredged to prevent siltation from blocking transport (USACE 1981).

While flood control and navigation structures and dredging facilitate the short-term economic interests related to river-borne commerce, they inhibit some natural processes that support natural habitats. This is especially true of annual overbank flooding that should provide sediments and nutrients to maintain the growth of the delta. Given the region's dependence on natural resources, long-term regional economic viability is thus jeopardized.

Marshes in the region are in a delicate balance between sedimentation and erosion. The leveeing and dredging of the Mississippi have allowed the delta to build out to the edge of the Continental Shelf so that water and sediments are shunted out Southwest Pass, South Pass, and Pass a Loutre into deep water where it cannot build land. Sediments that were once distributed to the MDPR marshes are now lost over the shelf. This situation has been identified as a major cause of Louisiana's current land-loss (Craig et al. 1979). Along with the loss of sediment, the Mississippi is tending to take the shorter Atchafalaya route to the sea (Kazmann and Johnson 1980). The implications of this change, if it were allowed to continue, would be profound. The net loss of MDPR land could be reversed as the Atchafalaya delta expanded, even though erosion in the densely populated eastern portion of the MDPR would probably accelerate. There is a growing need to examine the probable effects of the river switch, and its overall costs and benefits. Meanwhile, the cost of maintaining the present course of the river against a natural gradient can only increase. These kinds of problems indicate the difficulty of the critical management decisions that must be made in the near future.

Table 2. Economic value (1976 dollars) of principal shellfish, fish, and furbearer resources in the MDPR, 1976 (Larson et al. 1980).

Resource	Mississippi (Gulf coast counties)	Louisiana (MDPR parishes)
Oyster	1,015,165	15,410,921
Shrimp	8,417,899	50,002,348
Menhaden	6,839,342	5,274,017
Blue crab	267,775	2,952,415
Muskrat pelts	-	43,367,528
Muskrat meat	-	1,600
Nutria pelts	-	14,781,397
Nutria meat	-	158,400
TOTAL	16,540,181	131,948,863

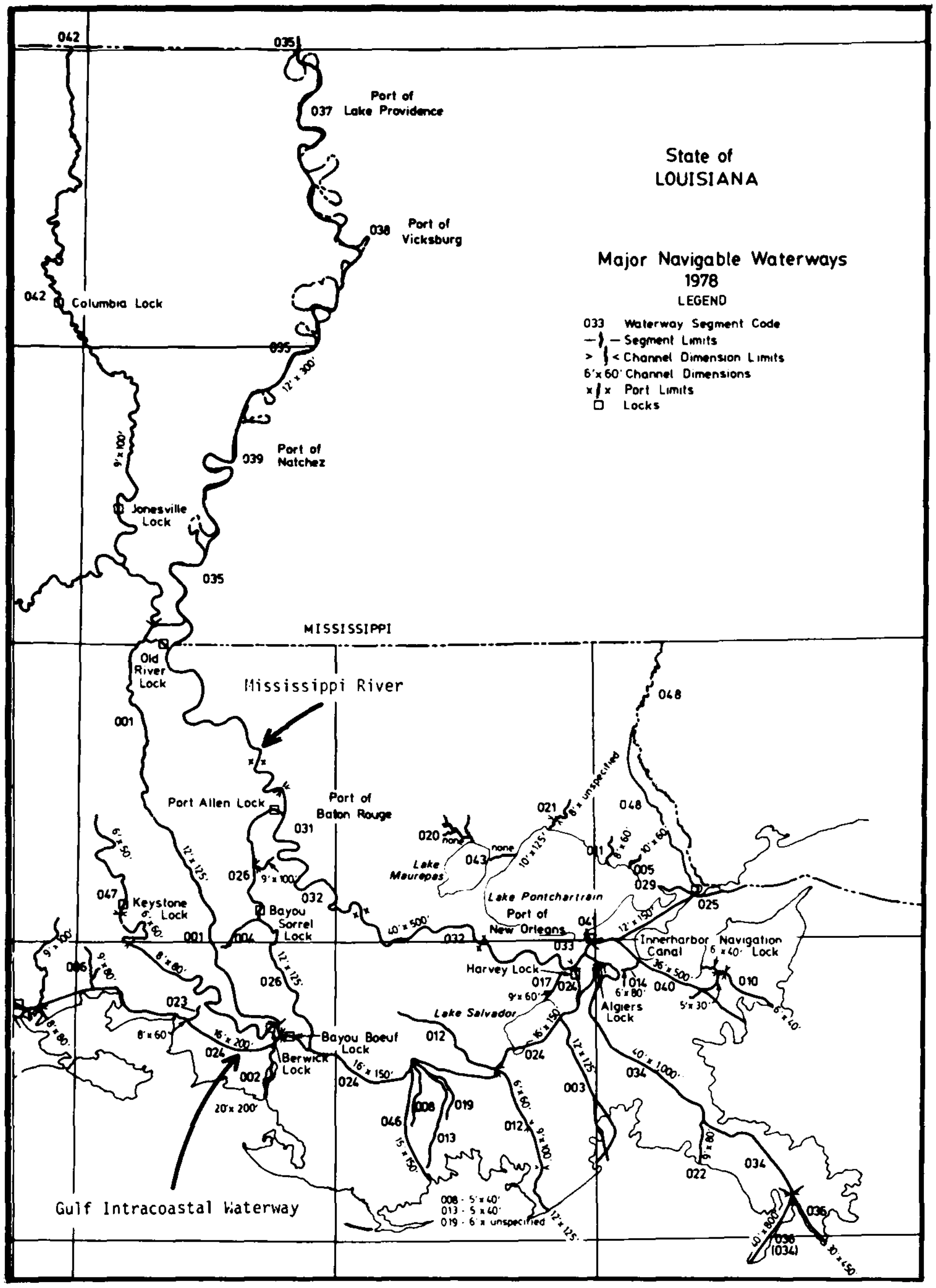


Figure 16. Major navigable waterways in Louisiana, 1978 (from Louisiana Department of Transportation and Development 1979).

Table 3. Commodities shipped on waterways, 1976 (1000 tons) (Larson et al. 1980).

Waterways	Farm products	Fish & other marine products	Metal ores	Coal	Crude oil	Non-metal ores, except fuels
Mississippi River:						
Baton Rouge to New Orleans[a]	71,061	924	10,547	7,754	55,301	10,915
Port of New Orleans	60,683	1,149	798	8,439	24,214	8,362
Mississippi River Gulf Outlet	344	83	503	635	241	1,702
New Orleans to Mouth of Passes	47,385	2,800	27,541	11,648	67,786	13,443
Gulf Intracoastal Waterway:						
Mobile to New Orleans	1,413	1,241	116	3,382	3,489	1,548
New Orleans to the Basin	599	4,429	197	296	16,706	5,351
Major Waterways:						
Morgan City to Port Allen	207	189	24	215	1,561	3,132
Bayou Teche	17	268	-	-	69	1
Houma Navigation Canal	-	133	-	-	1,232	141
Waterway from Intracoastal Waterway to Bayou Dulac	-	120	-	-	37	140
Bayou Terrebonne Waterway from Empire to the Gulf of Mexico	-	134	-	-	720	3
Bayou Little Caillou	-	4	-	-	884	-

[a] Not including the Port of New Orleans.

HABITAT DESCRIPTIONS

This section contains descriptions of each of the 20 ecological and economic habitats identified in this study, accompanied by a map showing the distribution of each habitat. The companion technical report (Costanza et al. 1983) contains detailed data on each of the 20 habitats, including energy and matter flow diagrams and input-output tables for eight of the more intensively studied habitats. Figure 17 is an example of one of the energy and matter flow diagrams from the technical report (the salt marsh habitat). Table 4 is the salt marsh input-output table that corresponds to Figure 17.

In general, the diagram shows the salt marsh habitat as comprised of four major components: surface water, shallow sediments, primary producers, and consumer organisms. The storage tank-shaped symbols represent storages, such as salts, total organic matter, and nutrients. The hexagon-shaped components are consumers (heterotrophs), and the bullet-shaped symbols represent primary producing (autotrophic) components. The entire salt marsh system is enclosed in a bullet-shaped boundary, symbolizing the fact that it is a net producing habitat, i.e., community production exceeds community consumption. Arrows coming from outside of the habitat boundary indicate inputs from forcing functions (shown as circles). These inputs regulate the habitat by providing the matter and energy that it needs to operate. The numbers shown on the arrows indicate estimated annual fluxes of matter or energy on a square meter basis (see Costanza et al. 1983).

The habitat categories used are aggregates of the more than 100 categories recently mapped in the MDPR (Wicker et al. 1980b), using a classification system based on Cowardin et al. (1979). Related habitat categories were lumped in order to limit the models to a reasonable size, and because of the lack of complete information on each specific category. Table 5 lists the areas of each of the aggregate habitats in the total MDPR for the two years, 1955 and 1978.

The amount of information available on each habitat varied considerably. Some habitats, such as cypress swamps and salt marshes, have been studied in more detail than others. This unevenness of information is reflected in the habitat descriptions and in the level of detail of quantitative information presented.

AGRICULTURE (1)

Agricultural habitat in the MDPR occupied about 98,000 ha (242,000 acres) in 1978, or almost 3% of the total area (Figure 18). Total agricultural area declined from 132,000 ha (326,000 acres) in 1955 to 98,000 ha in 1978, (Table 5), mainly as a result of increases in urban-industrial uses.

The major agricultural products in the MDPR are sugarcane, soybeans, tobacco, pasture and livestock, fruits and nuts, and vegetables. The major cultivated areas in the MDPR are the natural levees along the distributaries of the Mississippi River. These levees consist of rich alluvial soils which, in combination with a long growing season (245 frost-free days), abundant rainfall (140-152 cm/yr or 55-60 inches/yr), and easy access to low cost water transportation, support one of the most productive agricultural systems in the country (Larson et al. 1980).

Many attempts have been made to extend agricultural areas beyond the levees into low-lying interdistributary basins. However, such undertakings have required the artificial impoundment and draining of wetlands, and most of them have failed or succeeded only marginally. Large rectangular lakes, such as those near Clovelly, Louisiana (Barataria basin) testify to the effects of pumping water out of wetlands. These lakes are the remains of agricultural wetland reclamation projects (Craig et al. 1979) that were obviously expensive mistakes, both for the developer and for the natural system.

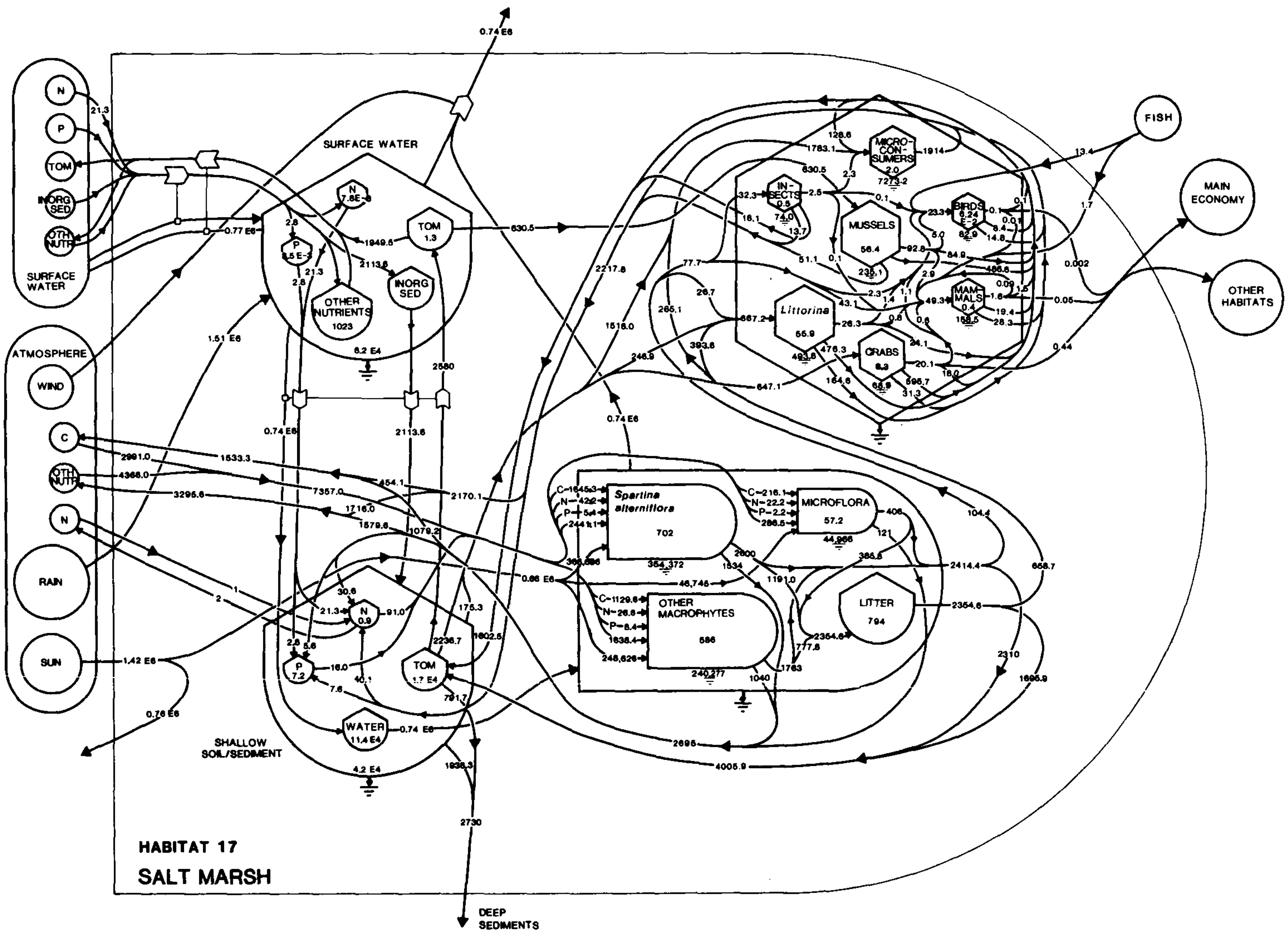


Figure 17. Example habitat level energy and matter flow diagram from the technical report.

Table 4. Example habitat input-output table from the technical report.

HABITAT 17
SALT MARSH

COMMODITIES		PROCESSES															
		SURFACE WATER 1	SHALLOW SOIL/SEDIMENT 2	MICROFLORA 3	*S. alterniflora* 4	OTHER MACROPHYTES 5	LITTER 6	MICROCONSUMERS 7	CRABS 8	MUSSELS 9	*Littorina* 10	INSECTS 11	BIRDS 12	MAMMALS 13	IMPORTS & EXPORTS 14	TOTAL	UNITS
INORGANIC NITROGEN	1	21.3 21.3 7.8 E-3	93.0 93.0 0.9	22.2 5.1	42.2 15.6	28.6 9.9		11.5	3.6	4.3	14.0	1.6	1.5	3.6	2.0 22.3	207.3 207.3 0.9	g N/m^2/yr g N/m^2/yr g N/m^2
INORGANIC PHOSPHORUS	2	2.8 2.8 3.5 E-3	16.0 16.0 7.2	2.2 0.5	5.4 2.0	8.4 3.1		3.8	0.6	0.6	1.8	0.2	0.2	0.6	2.8	34.8 34.8	g P/m^2/yr g P/m^2/yr g P/m^2
INORGANIC CARBON	3			216.1 49.6	1645.3 610.5	1129.6 419.1		317.7	20.8	20.4	65.7	9.1	6.7	13.7	1533.3 2991.0		g C/m^2/yr g C/m^2/yr
OTHER NUTRIENTS	4	1023		286.5 65.8	2441.1 905.9	1638.4 607.9		1581.0	6.4	26.8	83.1	2.8	6.4	10.6	3295.6 4366.0	7661.6 7661.6 1023	g/m^2/yr g/m^2/yr g/m^2
TOTAL ORGANIC MATTER	5	2580 2580 1.3	1602.5 5606.4 1.7 E4					1518.0	647.1 595.7	630.5 486.6	71.6 476.3	16.1	8.4	19.4	2741.2	9790.9 9790.9 1.7 E4	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
INORGANIC SEDIMENTS	6	2113.6 2113.6	2113.6 2113.6 4.2 E4								175.3				1936.3 2113.6	6340.8 6340.8 4.2 E4	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
WATER	7	1.51 E6 1.51 E6 6.2 E4	740794 740794 11.4 E4	63892 63892	366610 366610	308292 308292									1.51 E6 1.51 E6	4.5 E6 4.5 E6 17.6 E4	g/m^2/yr g/m^2/yr g/m^2
MICROFLORA BIOMASS	8			406 57.2			386.8					5.3	0.8	14.1		Σ16 406.0 406.0	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
S. alterniflora BIOMASS	9		1377		2600 702		1191.0				15.9	16.1				2600 2600 702	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
OTHER MACROPHYTIC BIOMASS	10		933			1763 586	777.6				10.8	10.9	1.5	29.0		1763 1763 586	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
LITTER BIOMASS	11		1695.9				2354.6 794	265.1			393.6					2354.6 2354.6 1686	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
MICROCONSUMER BIOMASS	12							2.0								2.0	g dry wt/m^2
CRAB BIOMASS	13							18.0	20.1 6.3				1.1	0.6	0.4	20.1 20.1 6.3	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
MUSSEL BIOMASS	14							64.9		92.8 56.4			5.0	2.9		92.8 92.8 56.4	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
Littorina BIOMASS	15							24.1			26.3 55.9		1.4	0.8		26.3 26.3 55.9	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
INSECT BIOMASS	16							2.3				2.5 0.5	0.1	0.1		2.5 2.5 0.5	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
BIRD BIOMASS	17							0.1					8.0 E-2 6.24 E-2	0.01	2.1 E-3	0.1 0.1 6.24 E-2	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
MAMMAL BIOMASS	18							1.6						0.09 1.6 0.4	4.7 E-2	1.6 1.6 0.4	g dry wt/m^2/yr g dry wt/m^2/yr g dry wt/m^2
FISH BIOMASS	19												13.4	1.7	15.1	16.1 15.1	g dry wt/m^2/yr g dry wt/m^2/yr
HEAT	20			44966	354372	240277		7273.2	68.9	235.1	493.8	74.0	82.9	158.5	648001	648001 648001	kcal/m^2/yr kcal/m^2/yr
SUNLIGHT	21			46745	386686	248626									0.76 E6 1.42 E6	1.42 E6 1.42 E6	kcal/m^2/yr kcal/m^2/yr

Table 5. Area of the habitats for the total MDPR (Wicker et al. 1980a).

Habitat		1955 area		1978 area	
No.	Description	ha	% of Total	ha	% of Total
			(2.47 acres/ha)		
1	Agriculture	131,925	3.82	97,531	2.83
2	Beach and dune	6,174	0.18	4,239	0.12
3	Bottomland hardwood	54,388	1.59	46,128	1.34
4	Brackish marsh	0	0	403,969	11.68
5	Canal	14,547	0.43	29,447	0.85
6	Cypress-tupelo	185,699	5.39	158,464	4.59
7	Fresh aquatic bed	552	0.03	6,278	0.16
8	Fresh marsh	364,477	10.57	165,245	4.79
9	Fresh open water	63,734	1.84	35,823	1.03
10	Fresh scrub-shrub	6,376	0.18	13,188	0.38
11	Mangroves	63	-	2,955	0.09
12	Flats	5,990	0.16	5,159	0.15
13	Nearshore gulf	119,279	3.38	116,569	3.38
14	Rivers, streams, bayous	36,194	1.04	37,503	1.09
15	Estuarine aquatic bed	541	0.02	14,319	0.41
16	Estuarine open water	1,762,306	51.13	1,922,123	56.08
17	Salt marsh	572,937	16.62	182,455	5.29
18	Spoil	10,539	0.31	33,576	0.97
19	Upland forest	62,928	1.81	70,690	2.03
20	Urban-industrial	48,645	1.43	102,103	2.89
	TOTAL	3,447,294	100.	3,447,764	100.

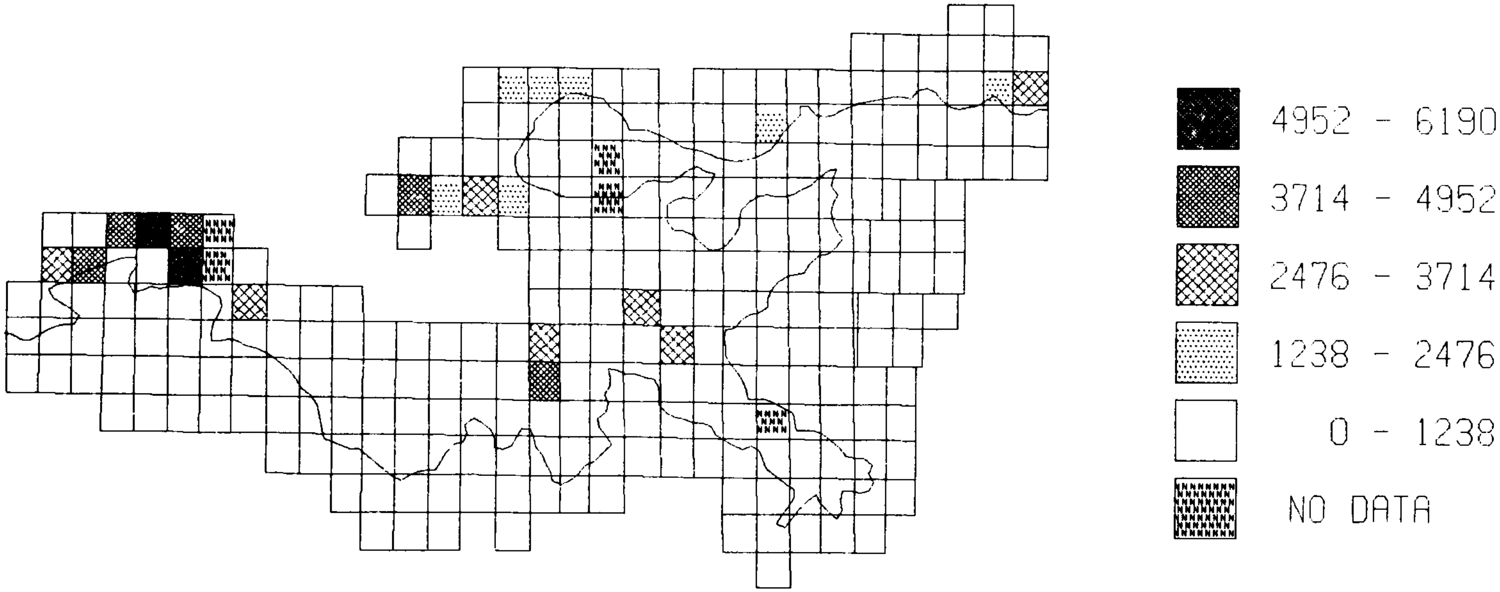


Figure 18. The distribution of MDPR agricultural habitat.

Agricultural systems can be viewed as highly managed ecosystems. These agroecosystems are maintained at low species diversity by various human activities, such as plowing, planting, cultivation, fertilization, and chemical pest control, to maximize net community production (harvestable yield). Hopkinson (1978) studied the agroecosystems of the Barataria basin from this perspective, and compared their structure and function with the natural habitats of the basin. For example, he compared the energy cost of the production of sugarcane with the production of *Spartina alterniflora* in the salt marsh. These energy budgets are shown in Table 6. They indicate that the total energy costs of both sugarcane and marsh grass are comparable, but that sugarcane energy costs must be paid in fossil fuel, while salt marsh costs are primarily sunlight and other natural work services that cost society nothing.

Details on the computations involved in this comparative budget can be found in the original reference. The absolute numbers are not as important as are their relative similarity. Sugarcane production results in a human foodstuff with high caloric content but little nutritional value, while saltmarsh production supports a detritus food web culminating in protein-rich fishery products. The implication of this computation is that productive habitats that receive large natural energy subsidies should not be converted to agricultural habitats in which fossil fuel must be used to replace the lost subsidies.

BEACH AND DUNE (2)

The beach and dune habitat represents a very small portion of the MDPR (4,239 ha or 10,467 acres in 1978, or 0.12%, Table 5). This habitat serves as a "sacrificial" barrier to storms. During calm periods sand is stored in beach dunes and then eroded during storms, thus absorbing storm energy and protecting the marshlands.

The beach areas in Louisiana (Figure 19) are characterized by gently sloping fine sand that extends several meters from the shoreline and then rises as dunes varying in height from 0.5 to 4 m (1.65 to 13 ft).

Some beaches are located on barrier islands and some line the mainland in areas unprotected by islands. Barrier islands in the MDPR are long and narrow, with very low elevation. They are separated from the mainland by shallow bays. Many of these islands represent the former margins of old delta lobes. The geologic characteristics of barrier islands have been examined more closely than their ecological roles because most of the barrier islands in Louisiana are eroding and moving shoreward. In Mississippi the barrier islands are of non-deltaic origin, but they are also subject to erosion and migration, and have tended to migrate westward (Otvos 1981).

The vegetation characteristic of the beach and dune habitat in the MDPR is described in Bahr and Hebrard (1976). The rooted vegetation closest to the shoreline of the gulf is found in the dunes. Plants here include beach morning glory (*Ipomoea pes-caprae*), morning glory (*Ipomoea stolonifera*), frogbit (*Erigeron repens*), *Heterotheca subaxilaris*, evening primrose (*Oenothera* sp.), sandspur (*Cenchrus* sp.), sea rocket (*Cakile* sp.), and sea oats (*Uniola* sp.)

Behind the foredunes there may be a meadow zone inhabited by beardgrass (*Andropogon* sp.), fingergrass (*Chloris petraea*), saltmarsh fimbristylis (*Lippea lanciolata*), frogbit (*Limnobium spongia*), pennywort (*Hydrocotyl bonariensis*), black rush (*Juncus roemarianus*), three cornered grass (*Scirpus americanus*), softstem bulrush (*Scirpus validus*), widgeon grass (*Ruppia maritima*), sandspur, morning glory, Heterotheca, sabbatia (*Sabbatia* sp.), wiregrass, dog tooth grass, and Bermuda grass (*Cynodon dactylon*).

Old dunes that have been stranded inland from the meadow zone (chenieres) and that have achieved sufficient elevation are typically colonized by trees, including live oak (*Quercus virginiana*),

Table 6. Driving energy flows of sugarcane and salt marsh ecosystems (Hopkinson 1978).

Energy input	CE kcal/m²	
	Sugarcane	Salt marsh
Group I. Natural energies		
Sunlight captured in gross photosynthesis	702	1232
Wind	891	891
Hydrostatic head of:		
Mississippi River	438	438
Bayou Lafourche	-	-
Rainwater	-	-
	2031	2561
Group II. Natural energies		
Tides	0	17
Chemical free energy of mixing:		
Mississippi River	0	374
Bayou Lafourche	0	2
Rainwater	0	-
	0	393
Group III. Purchased energies		
Seed	21	0
Machinery	104	0
Fuel	336	0
Fertilizer	280	0
Insecticide	6	0
Herbicide	29	0
Labor	489	0
	1265	0
Totals (CE kcal/m²/yr)	3296	2954

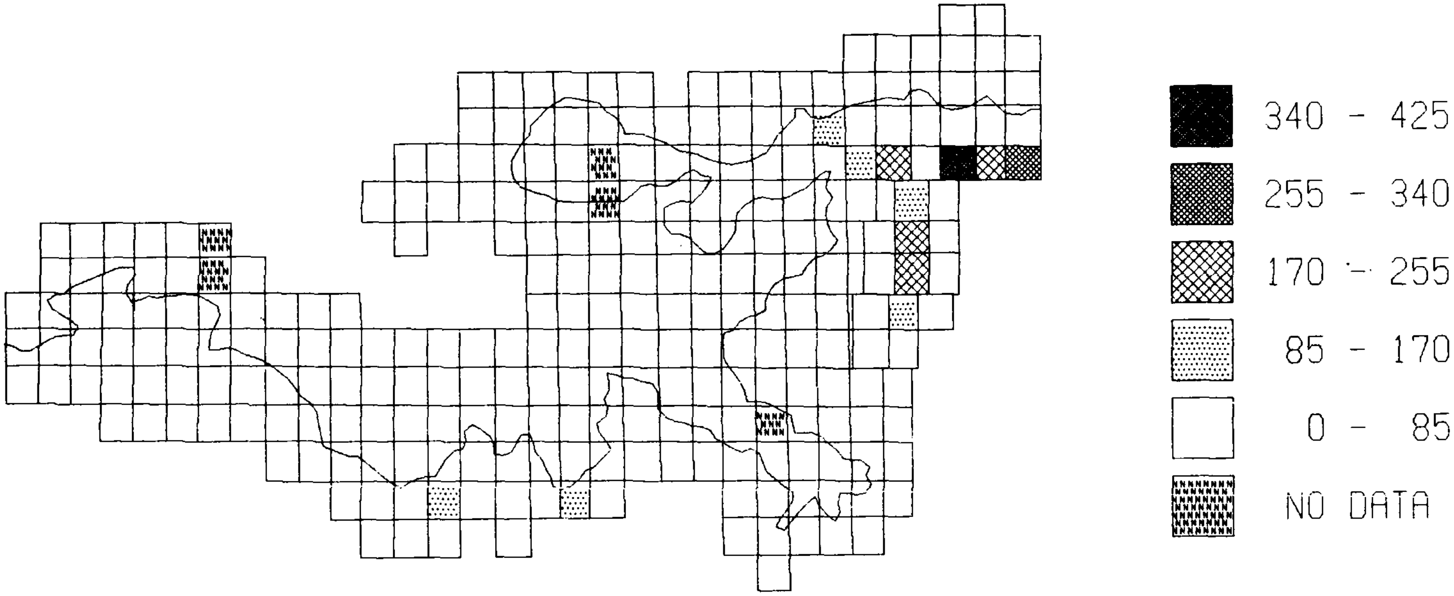


Figure 19. The distribution of MDPR beach and dune habitat.

hackberry (Celtis laevigata), Hercules-club (Zanthoxylum clava-herculis), and wax myrtle (Myrica cerifera).

Although the rate of primary production in dune areas is considerably lower than in marsh habitats, the role of dune plants in stabilizing and accumulating sediments is critical. Plant stems trap wind-blown sand that would otherwise be lost to the beach system, and the roots, which sometimes extend far beneath the surface, bind the sand together. Vegetation in the beach habitat also supports populations of rabbits and other small mammals, birds, and reptiles.

The intertidal portion of the beach habitat is the focus of rapid energy flux, but much of this activity is not apparent, because it occurs beneath the sand surface and it involves small organisms. A characteristic group of burrowing organisms feeds on the organic matter that is pumped through beach sands by tidal and wave energy. These organisms are eaten in turn by predatory burrowers and by shorebirds that feed in the swash zone. An excellent description of the dynamics of the intertidal beach community can be found in Peterson and Peterson (1979), although the comparison between high tidal energy North Carolina beaches and low energy northern gulf coast beaches is not perfect.

MDPR beaches tend to be muddy and carbonate rich. The beach intertidal community includes meiobenthic and macrobenthic fauna, the former consisting primarily of the so-called interstitial fauna, tiny crustaceans that live in the spaces between sand grains. The most conspicuous of the larger animals that occupy the lower beach are molluscs, including bivalves (e.g., Mulinia sp., Gemma gemma), gastropods, and crustacea (e.g., Orchestoidea sp., Emerita sp., Ocypode quadrata). Some benthic beach inhabitants are deeply burrowing forms that are rarely seen unless core samples are taken. These include polychaetes like Diopatra sp.; hemichordates like Balanoglossus sp.; and crustaceans like Callianassa sp. Burrowing forms are important food sources for specialized shorebirds like plovers, willets, sanderlings, and sandpipers, that forage in the swash zone during low tide. During times of inundation, the benthic fauna in the beach habitat provide food for predatory nekton, which includes members of the family Dasyatidae (stingrays), Cyprinodontidae (killifishes), Engraulidae (anchovies), and Scianidae (drums), among many others. The functional partitioning of this intertidal food source by various fish and bird groups is described by Peterson and Peterson (1979).

Besides the feeding areas of the intertidal sand and mud flats, the higher beach and dune areas are also important to birds. Migrating species like warblers use them as resting points, and shorebirds as nesting grounds. In a 1972 study of dune ridges inland from Caminada Bay (Barataria hydrologic unit), 69 species of migrating birds were identified as using the dune habitat during the spring migration period (Hebrard, unpublished data cited by Bahr and Hebrard 1976). Nesting colonies of black skimmers, Sandwich terns, royal terns, least terns, Caspian terns, gull-billed terns, and laughing gulls are all found on the barrier island beach and dune habitats in the MDPR.

Because of the vulnerability of beaches and dunes to storm erosion, and because the entrainment of the Mississippi has caused a lack of sediment enrichment in many parts of the MDPR, the erosion of barrier islands and retreat of shore lines is a serious problem. Penland and Boyd (1981) estimate that the Chandeleurs have been receding at rates of from 1 to 20 m/yr (averaging 7) or 3 to 65 ft/yr (averaging 23) during the past 60 years. It is likely that these islands will totally disappear during the next century, causing increased marsh erosion in the Pontchartrain hydrologic unit (Baumann et al., in preparation).

Although there has been some oil and gas industry activity on Timbalier Island, the only barrier island in Louisiana that has been extensively developed is Grand Isle. By 1970, more than one-third of the island had been dedicated to residential, commercial, or industrial use. Grand Isle is an important recreational area as well as the site of activity by the petroleum and sulfur industries. The Mississippi Sound islands are largely a part of the Gulf Islands National Seashore, and the mainland beaches are primarily developed for recreation.

The greater part of the Chandeleur Islands are within the Breton National Wildlife Refuge (which also includes Breton Islands). Other islands of the Chandeleur chain (Curlew, Grand Gosier, and North and New Harbor) are owned by the State of Louisiana.

Although the beach and dune habitat is not large in area, it is an important habitat ecologically and economically. Further study of the ecological relationships and methods for slowing erosion of these areas is warranted (Mendelssohn 1982).

BOTTOMLAND HARDWOODS (3)

The forested wetlands of the MDPR (Figure 20) contain two types of plant communities: bottomland hardwoods and baldcypress-tupelogum. Bottomland hardwoods (BLH) covered 46,128 ha (113,933 acres), or 1.34% of the MDPR in 1978 (Table 5). BLH forests occur in areas that are better drained than those in which cypress-tupelo are found. BLH areas typically have moist soil and short annual floodings.

Most information available on BLH in the MDPR has been collected from a site in the des Allemands area of the Barataria hydrologic unit. This site is presumably fairly representative of BLH habitat throughout the MDPR, and the following description of the des Allemands site should generally apply.

In the upper Barataria basin, the entire swamp forest (baldcypress-tupelo and BLH) is less than 1.5 m in elevation (Conner and Day 1976). Small changes in elevation in the swamp can have major effects on vegetative composition. Brown (1972) observed that a 15-cm or 6-inch) change in the swamp is as important as a 30-m change in mountainous regions. This sensitivity to elevation stems from the fact that the character of BLH forests (like all wetland habitats) is determined by hydrologic conditions. Amount of water input, seasonality, and average current speed through the habitat are all important in determining community structure, composition, and chemical cycling (Day et al. 1981).

BLH sites are flooded each year for several weeks to a few months. During the remainder of the year the water table is near or just below the soil surface (Conner and Day 1982). The des Allemands BLH site has been flooded 15-30 cm (6-12 inches) for a period of 2 to 3 months during the time of its examination (Conner and Day 1976).

The BLH plant community is more species-rich than the deep swamp (cypress-tupelo). Conner and Day (1976) reported 23 tree species in the des Allemands BLH swamp, compared with 9 species in a nearby cypress-tupelo swamp site. Bell (1974) found that species richness in floodplain forests is inversely proportional to flooding frequency.

Undisturbed BLH sites also appear to be slightly more productive than undisturbed cypress-tupelo sites. Production in the des Allemands BLH community is 1,574 g dry wt/m^2/yr (14,045 lb/ac/yr) compared with 1,140 g/m^2/yr for a nearby undisturbed baldcypress-tupelogum community (Conner and Day 1976).

BLH habitat hosts a variety of woody plant species. The red maple (Acer rubrum var. drummondii), is the most abundant tree, but maples at the des Allemands BLH site were generally small (average diameter at breast height was 5.8 cm or 2.3 inches). Oak (Quercus spp.), willow (salix nigra), elm (Ulmus americana), boxelder (Acer negundo), cottonwood (Populus spp.), dogwood (Cornus drummondii), persimmon (Diospyros virginiana), hackberry (Celtis laevigata), ash (Fraxinus spp.), and privet

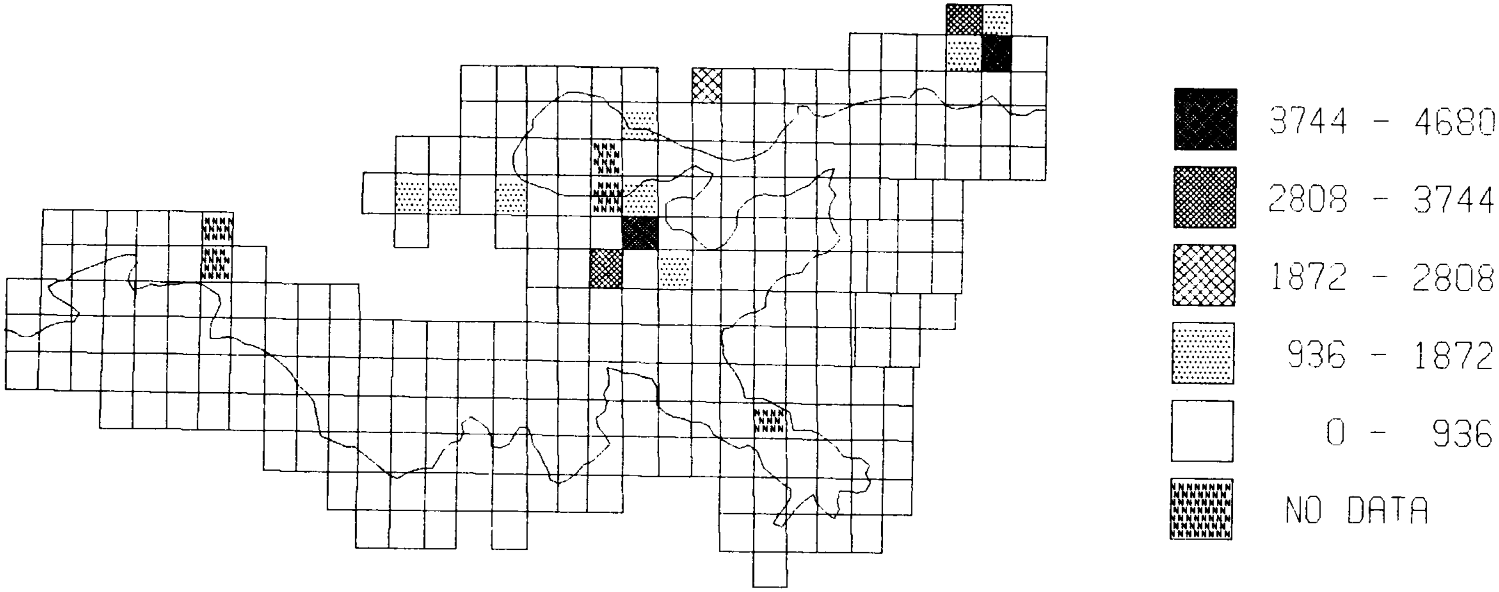


Figure 20. The distribution of MDPR bottomland hardwood habitat.

(Forestiera acuminata) are also found in the baldcypress (Taxodium distichum) and tupelogum (Nyssa aquatica) community. Herbs and vines are common along bayou banks and in any open spaces where light penetrates the canopy. Poison ivy (Rhus radicans), evening trumpet flower (Gelsemium sempervirens), green briar (Smilax spp.,), peppervine (Ampelopsis spp.,), and Virginia creeper (Parthenocissus quinquefolia) are the most prevalent vines in this area (Day et al. 1981). A complete list of species found in both Louisiana bottomland hardwood and deep swamp communities is found in Conner et al. (1975).

BRACKISH MARSH (4)

The brackish marsh is the second largest habitat in areal extent in the MDPR (as shown in Figure 21), covering 404,000 ha (997,880 acres) or 11.7% of the entire area (Table 5). While the average salinity values for MDPR salt marshes is 16 to 19 ppt, the brackish marsh is found in less saline waters, with average values ranging from 7 to 9 ppt (Rainey 1979). Since brackish marsh is defined here to include those marshes classified as intermediate by Chabreck (1972), the average salinity range for this habitat is from 2 to 9 ppt. The overall salinity range in brackish marsh varies much more widely, however, from fresh conditions to almost full ocean salinity.

The dominant brackish marsh plant is saltmeadow cordgrass, (Spartina patens), which is also found in salt marsh. Saltmeadow cordgrass grows best in waters with an average salinity of 8.6 ppt (Chabreck 1972) and it occupies about 54% of the brackish marsh community, as measured by percent cover. The brackish marsh includes some plants with lower salt tolerances than plants found in the salt marsh. Being in a slightly lower salinity, hence less stressful setting, the brackish marsh is characterized by a higher diversity of plant life. Whereas the salt marsh habitat supports only 17 plant species, the brackish and intermediate marshes contain 63 (Chabreck 1972). Saltmarsh cordgrass (Spartina alterniflora) also occurs in brackish marsh, but it covers only about 4% of the area. Other macrophytes that make up major portions of the plant community are saltgrass (Distichlis spicata), black rush (Juncus roemerianus), Scirpus spp., and several three square rushes.

Biomass and productivity studies of brackish marsh macrophytes in the MDPR have been carried out by de la Cruz (1974), Payonk (1975), Hopkinson et al. (1978b), White et al. (1978), and Cramer et al. (1981). Average brackish marsh has an estimated aboveground productivity of 2,800 g dry wt/m^2/yr compared with a value of 2,000 for the salt marsh (Costanza et al. 1983). This value for brackish marsh is higher than that for any other wetland habitat, implying that the brackish marsh occupies an optimum set of conditions. Stress levels are high enough to reduce excessive competition, while source levels, or natural work services, are high enough to ensure excellent growing conditions. "Stress" and "source" follow the usage developed by Odum et al. (1974).

When belowground production is included, brackish marsh is estimated to produce 11,300 g dry wt/m^2/yr (Costanza et al. 1983). This estimate is high compared with values usually cited for marshes, and is not very precise because of the difficulty in measuring belowground production.

Two other poorly understood parameters are community respiration and detrital export. As a result, total export to other habitats cannot be precisely quantified. By using an estimate of total net primary production (11,300 g dry wt/m^2/yr) and two of the available estimates of respiration, the brackish marsh can be calculated to be either exporting 7,300 g dry wt/m^2/yr, or importing 3,000 g dry wt/m^2/yr. Our understanding of brackish marsh dynamics is dependent upon more reliable data for production, respiration, and export.

Other biological studies conducted in the brackish marsh have included the use of this habitat by birds (Mabie

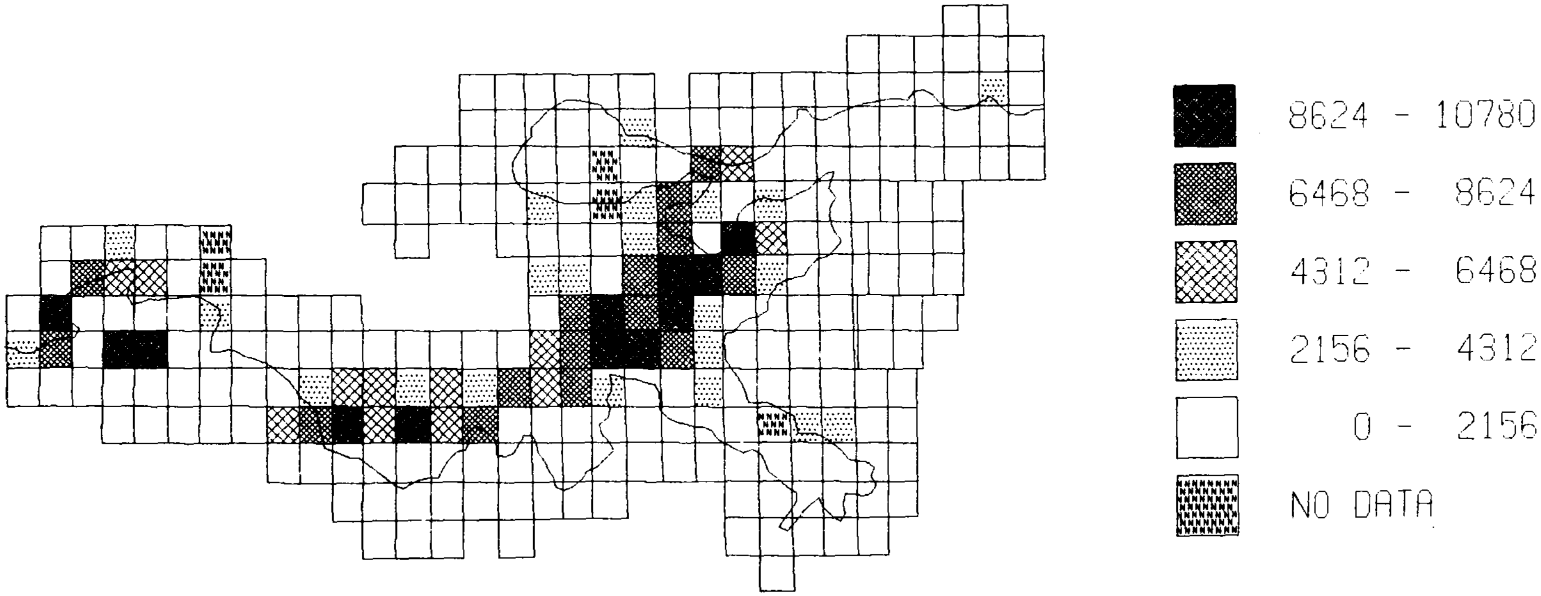


Figure 21. The distribution of MDPR brackish marsh habitat.

1976), insects (Farlow et al. 1978), and furbearers (Palmisano 1972; Fleming 1975; Robicheaux 1978; Linscombe as reported in Sasser et al. 1981). However, detailed examinations of consumers in the brackish marsh habitat have lagged far behind studies of the salt marsh.

CANAL (5)

Canals, dredged primarily for oil and gas extraction and navigation, are important man made features of the MDPR. Inventories of canal area in coastal Louisiana (Barrett 1970, Chabreck 1972, Adams et al. 1976) report that canals make up from 0.6 to 0.9% of total marsh and water area. The latest estimate is that canals covered 29,447 ha (72,739 acres) in the MDPR in 1978, or 0.85 % of the total area (Table 5).

Barrett (1970) measured 7,356 km (4,572 mi) of canals and 11,709 km (7,276 mi) of natural streams and rivers in a 28.632 square-kilometer (11.055 square-mile) area of coastal Louisiana south of the Intracoastal Waterway. This indicates that the total area of canals is approaching that of natural drainage channels.

Canals occur in fresh, brackish, and saline regions of the MDPR (Figure 22). Their hydrology and ecology differ with the type of wetland, salinity, size, and orientation to the coast (parallel or perpendicular). Canals are less productive for animal life than are unaltered natural channels. Canal dredging disturbs benthic communities, and although recolonization may occur and original biomass restored, recolonization is usually by opportunistic species of less value to the food web (Allen and Hardy 1980). Changes in substrate character, decreased oxygen supply, and decreased water exchange with adjacent wetlands are the probable factors responsible for lower amphipod and demersal fish populations in dredged canals over natural streams (Lindstedt 1978; Allen and Hardy 1980).

Higher densities of organisms were found in unaltered open water areas than in open and partially open canals in Terrebonne Parish (Adkins and Bowman 1976). Closed canals had the fewest numbers of organisms. Gilmore and Trent (1974) found benthic microinvertebrates slightly more numerous in a natural Texas marsh than in an adjacent marsh altered by channelization, bulkheading, and filling. Organisms were more than twice as abundant by volume in the natural marsh.

Lindstedt (1978) measured 60% lower numbers of amphipods, total crustaceans, and total organisms in oil field canals than in undisturbed control sites, but the effects of oil contamination could not be separated from those of dredging. Significantly fewer motile epibenthic organisms were collected in canals in oil-free control areas than in natural tidal streams. These differences may be related to the effects of the spoil banks associated with canals that prevent water exchange between marsh and water bodies.

When canals are dredged deeper than the surrounding natural streams, they tend to become stagnant and anaerobic. When viewed from the air the water in canals sometimes appears noticeably more clayey and turbid than the characteristic dark but clear water in natural water bodies.

It appears that canals do not function ecologically like natural water bodies in wetlands. Canals have been shown to double in width in 1 to 50 years (Craig et al. 1979). There is also evidence that canal networks may capture waterflow from neighboring tidal creeks. The continuing proliferation of canals in the MDPR is a major environmental issue (see ECOLOGICAL ISSUES).

CYPRESS-TUPELO SWAMP (6)

The category of forested wetlands known as cypress-tupelo swamp occupied a total of about 158,000 ha (390,000 acres) in the MDPR in 1978, or 4.59 % of the total area, shown in Figure 23. This represents a net loss of about 28,000 ha (69,000 acres) since 1955 (Table 5).

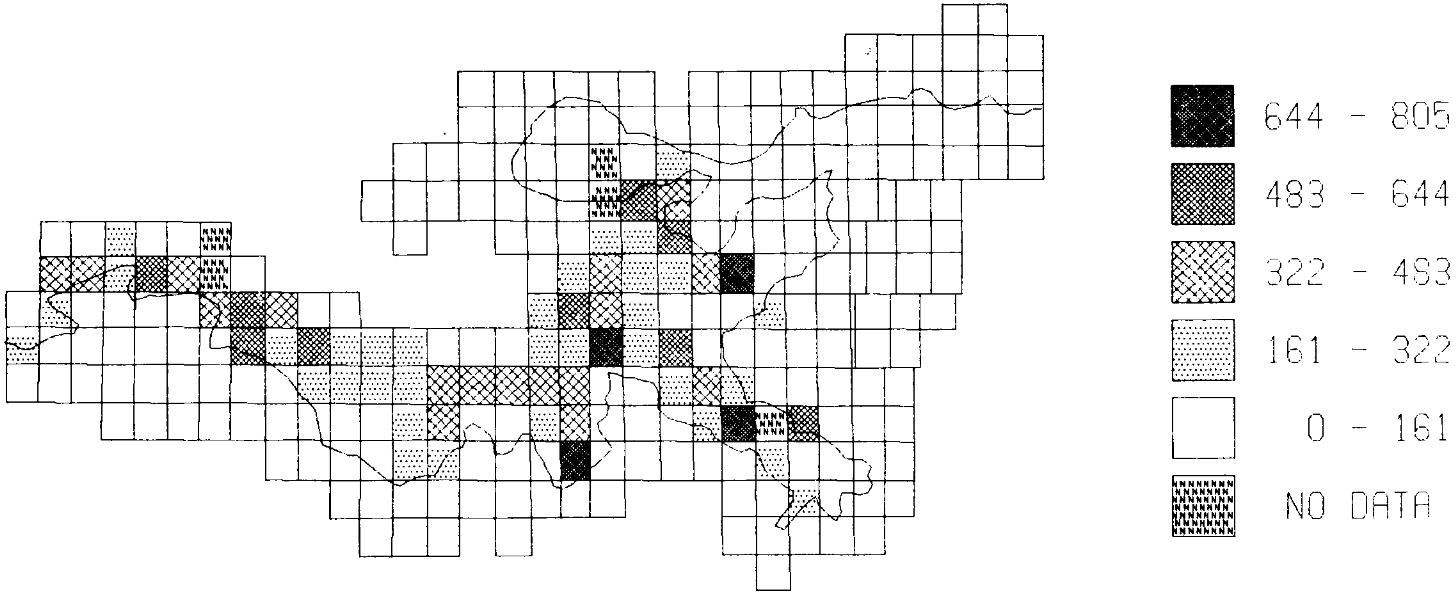


Figure 22. The distribution of MDPR canal habitat.

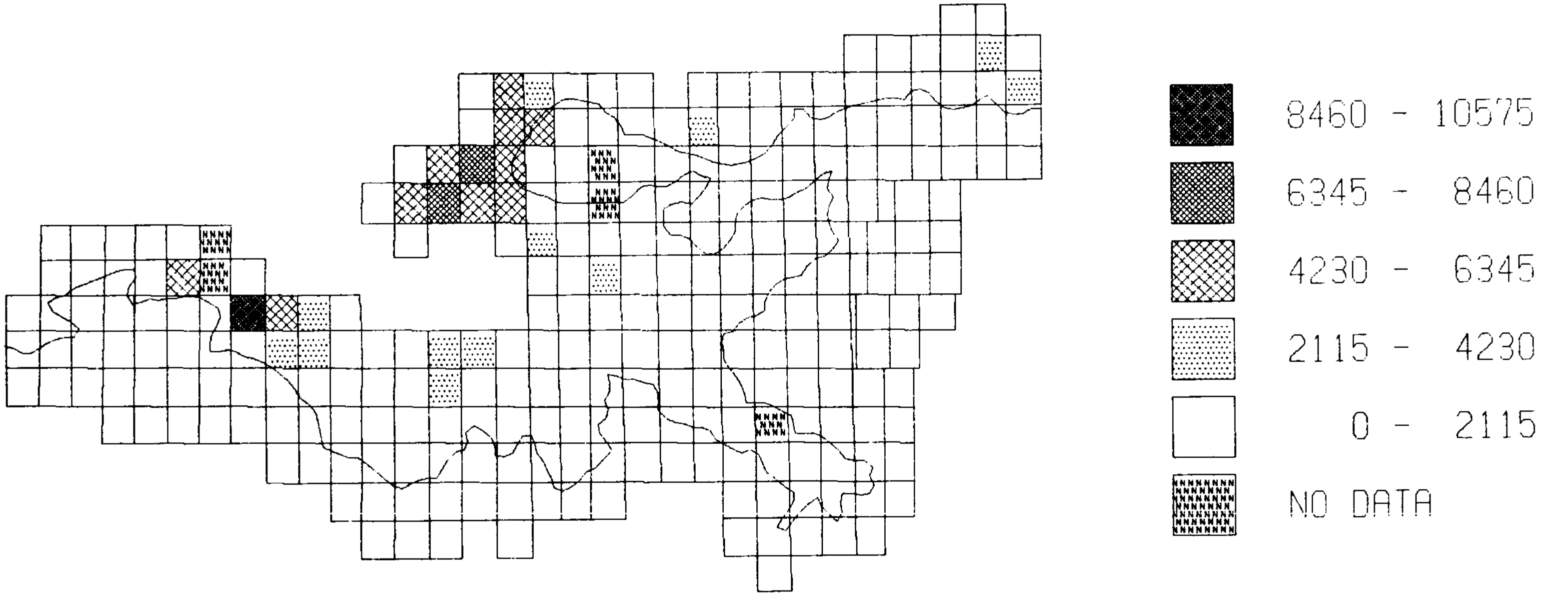


Figure 23. The distribution of MDPR cypress-tupelo swamp habitat.

Baldcypress-tupelogum swamp forests are characterized by poorly drained soils and lengthy inundations. Taxodium distichum (baldcypress) and Nyssa aquatica (tupelogum) are the dominant trees. On very poorly drained sites, baldcypress tends to dominate. On slightly raised drier sites within the swamp, tupelogum increases in abundance, and some black willow (Salix nigra), pumpkin ash (Fraxinus caroliniana), and Drummond red maple (Acer rubrum var. drummondii) occupy part of the canopy.

The presence of standing water allows the growth of floating vegetation. Duckweed (Lemna minor and Spirodela polyrrhiza), Riccia, and American frogbit (Limnobium spongia) are common (Conner and Day 1976). Herbs such as amaryllises, ferns, pennyworts, and grasses are found growing on rotting stumps and logs and other dry substrates (Conner and Day 1976).

Consumer species in the swamp are numerous and varied. Of the many insect species present, the forest tent caterpillar (Malacosoma disstria) is one of the more obvious; it often defoliates large areas of tupelogum trees in the MDPR and apparently speeds the passage of nutrients from the canopy to the forest floor in the process (Pollock and Bahr, in preparation). Omnipresent mosquito larvae are eaten by fish, and adult mosquitoes by birds, spiders, dragonflies, and water beetles. Adult mosquitoes and the microparasites they host are regulators of vertebrate populations. Important decomposers in the swamp include fungi, microbiota, and termites. Crawfish (Procambarus clarkii), harvested commercially from the swamp, are an important food item for many higher order consumers, and crawfish biomass exceeds that of all other invertebrates that live on the swamp forest floor (Sklar and Conner 1979). Large carnivores include snakes, alligators, raptorial birds (owls and hawks), wading birds, and mammals. The swamp hosts a wide variety of bird species, mainly on a seasonal basis. Amphibians and reptiles are represented by 18 and 32 species, respectively (Gosselink et al. 1979).

The information on swamp function presented below is based on measurements from the Lac des Allemands swamp in the Barataria hydrologic unit. This riverine swamp is generally characteristic of swamps in the MDPR, and it has been the site of numerous biological and hydrological studies.

Unaltered portions of the des Allemands swamp flood for about 11 months of the year. Spring high water occurs in April and May, followed by a dry summer period in July and August, when the swamp's surface water drains off completely. Inundation generally resumes in late August or September with decreasing evapotranspiration and increasing rainfall.

Water flows into the des Allemands swamp from surrounding wooded natural levee ridge lands, agricultural fields, and urban areas. Little standing water on the swamp floor infiltrates the soil, which is clayey and saturated. Most water evaporates, or runs off to downstream habitats, which are primarily swamp bayous and freshwater lakes.

During the period when the soil is flooded, surface water flows control the transport of nitrogen, phosphorus, total organic matter (TOM), and sediment in and out of the swamp. If nutrients entering the surface waters are not taken up by aquatic plants (primarily duckweed), they settle out and contribute to soil fertility. Some nutrients that wash into the swamp via water from agricultural fields are removed. Nitrogen is put into the atmosphere through denitrification, and some phosphorus is buried beneath sediments. Plant nutrient requirements are small relative to the large total quantities of nutrients present (Kemp and Day 1981). Rainfall contributes a small portion of nutrient input to the swamp surface water.

Total primary production by swamp plants was estimated at 2,038 g dry organic matter/m^2/yr (18,186 lb/ac/yr) (Conner and Day 1976.) Calculations of primary production, along with a detailed matter and energy flow diagram and input-output table, are included in the companion technical report.

Cypress-tupelo swamp productivity in the upper Barataria basin has been shown to be strongly coupled to the hydrologic regime (Conner et al. 1981). Swamps that experience regular periods of inundation and drying show higher productivity than those with very sluggish or stagnant water. Conner et al. (1981) found that an impounded swamp site showed significantly less net production 890 g dry wt/m^2/yr, than a nearby naturally flooded site 1,166 g dry wt/m^2/yr. Even higher productivity was found in an area where water level variation was artificially augmented by pumping. This area was flooded from late fall to early spring and drained the rest of the year. While flooded, water was pumped through to ensure high oxygen levels. The net production for this area was estimated to be 1,780 g dry wt/m^2/yr (Conner et al. 1981).

Swamp floor organisms have been separated into two separate communities: benthic detritus and floating communities (Sklar and Conner 1979). The former consists of dead organic material, associated microorganisms, and bacteria, as well as larger organisms feeding on detritus, including crawfish. Floating herbivores are associated with the duckweed and water hyacinths at the water surface. These include amphipods, oligochaetes, and lepidoptera. Bivalves, snails, and isopods are some examples of benthic herbivores. Primary consumers are mostly predatory insects. Snakes, turtles, alligators, birds, and mammals are the top carnivores.

FRESH AQUATIC BED (7)

The fresh aquatic bed habitat (Figure 24) consists of submerged aquatic, floating, and floating-leaved vegetation in shallow fresh water bodies. It covered only 6,278 ha (15,452 acres) in 1978 (Table 5).

Most of the fresh aquatic bed habitat consists of floating vegetation, usually water hyacinth (Eichornia crassipes) or duckweed (Lemna sp., Spirodela polyrhiza), which form dense mats on sheltered water (Wicker 1980). The distribution of these mats frequently changes in relation to physical factors, such as wind direction, flooding, and currents, and to biotic factors, such as shading, competition, grazing, and human eradication (Penfound and Earle 1948). Floating aquatic plants die and sink below the water surface every winter (Wicker 1980). Flotant freshwater marshes are included with the fresh marsh habitat rather than with the fresh aquatic bed habitat.

Submerged aquatic plants include widgeongrass (Ruppia maritima), wild celery (Vallisneria americana), several pondweeds (Potomogeton spp.), and watermilfoil (Myriophyllum spp.). Light often limits the distribution of submerged aquatic flora. The Secchi disc depth (a measurement of light penetration) of many large fresh water bodies in the MDPR does not exceed 50 cm (20 inches) (Hopkinson and Day 1979). Turbidity is thus too high to allow enough light to reach the bottom to sustain plant growth in most regions of these lakes, which reach about two meters in depth.

Little is known about the animal communities associated with submerged freshwater aquatic flora in the MDPR. Where it occurs, ducks feed on it and fish, crustaceans, and insect larvae live in it.

FRESH MARSH (8)

The fresh marshes in the MDPR can be divided into two types: flotant and emergent. It is uncertain exactly how much area is covered by each group. The total area of fresh marshes in the MDPR in 1978 was about 165,000 ha (407,000 acres) (Figure 25), compared to about 364,000 ha (899,000 acres) in 1955 (Table 5). In 1978 fresh marsh comprised only 4.79 % of the MDPR, while in 1955 it made up 10.57 %, a very significant decline.

Flotant mat is composed of an area of active root production covered by decomposing litter, floating on the surface of the water. The marsh plants

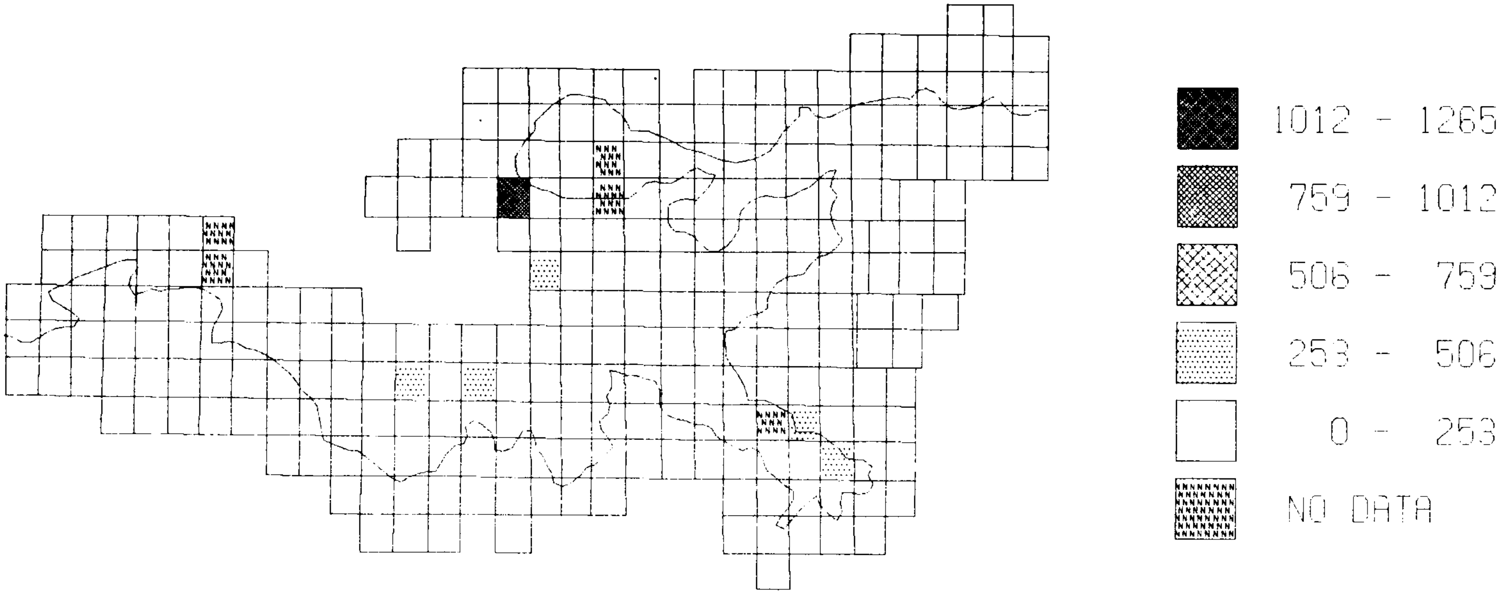


Figure 24. The distribution of MDPR fresh aquatic bed habitat.

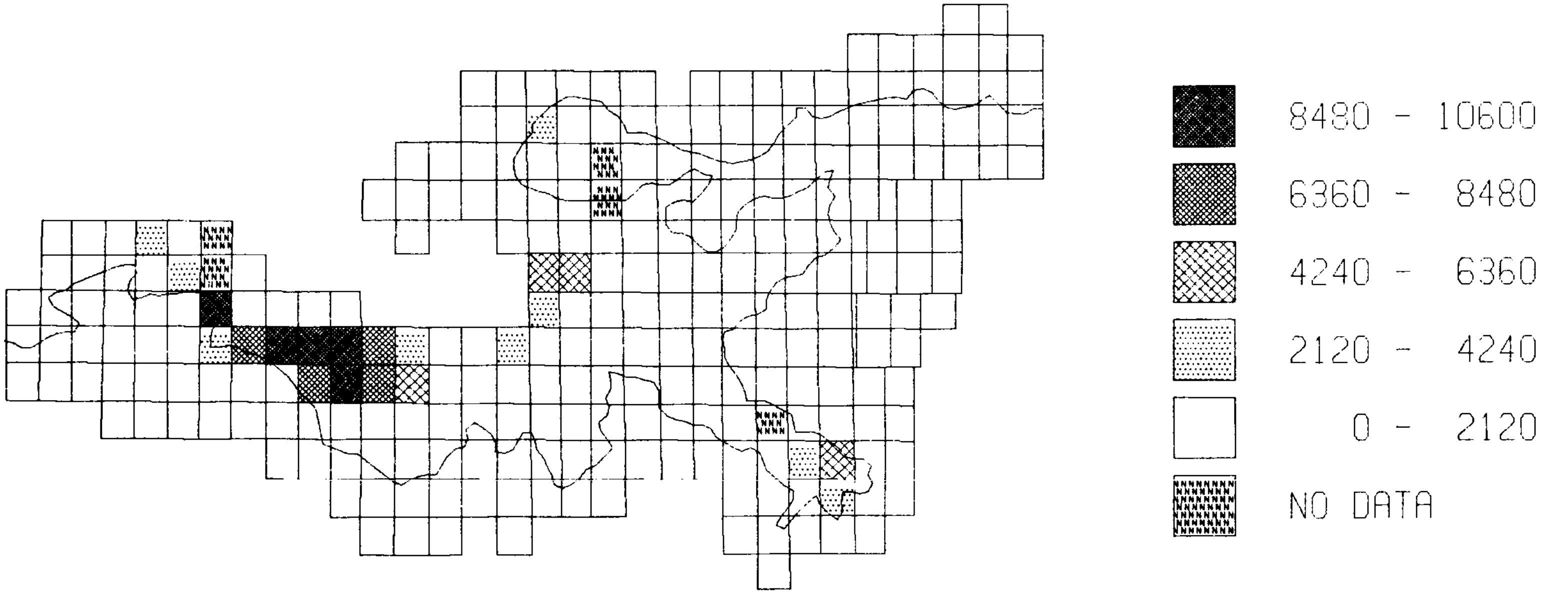


Figure 25. The distribution of MDPR fresh marsh habitat.

that live in the mat make it appear to be rooted in the soil, and the floating plant community is dense enough to support a human, but there is no mistaking it for normal marsh when one is walking on it. There are also numerous holes in the mat created by nutria, muskrats, and alligators. The depth of water under the mat averages about 1 m throughout the year. Beneath the flotant, peat accumulates over a clay sediment base, as a result of particles dropping through the water column from the overlying root mat (Sasser et al. 1981). Flotant marshes in the MDPR are usually composed primarily of Panicum hemitomom and Sagittaria communities, which also include other plant species such as alligatorweed, waterprimrose, and spikerush. During periods of high water or severe storms, sections of the mat can break off and float into surrounding water bodies.

Emergent fresh marsh includes a diverse macrophyte community made up of the same species that comprise flotant marshes. The primary difference is that the plants are rooted in the sediment.

The most important factor influencing the distribution of marsh types and vegetative communities is hydrology. The fresh marsh in the MDPR, like the other marsh habitats, is characterized by net community production, which implies peat production and export of organic matter to adjacent systems. The hydrology of the marsh is a function of inputs from rainfall and terrestrial runoff, evapotranspiration from the marsh surface, groundwater exchanges, and surface runoff. Runoff is determined by the slope of the land, marsh friction or resistance to flow, which is determined by the vegetation, and sediment characteristics. The fresh marshes are bordered upstream by swamps and upland habitats, and downstream by intermediate and brackish marshes. Exchanges of water, organic matter, nutrients, and sediments occur primarily within these habitats (Stone et al. 1978), at least in the pristine situation. In the MDPR, canals often border fresh marsh habitats (see the hydrologic model section in the technical report).

Fresh marshes are inhabited by a variety of animals. Nutria are the most abundant large herbivores, in contrast to salt marsh habitats, in which muskrats are more numerous (Bahr and Hebrard 1976). Deer, rabbits, raccoons, mice, and other upland mammals may also use these areas periodically as feeding grounds. Many species of birds, including waterfowl and wading birds, move in and out of the fresh marshes daily as well as during seasonal migrations. The fresh marsh habitat contains the highest density of alligators, and the majority of the alligator harvest comes from these areas (McNease and Joanen 1978). Other reptiles found in the fresh marsh include snakes, turtles, and lizards.

Detritivores appear to be the functionally dominant fresh marsh consumers. As is the case in the saline and brackish marshes, little (about 11%) of the net primary production is directly grazed (Gosselink et al. 1979). About 60% of the remaining plant production is consumed by detritivores, including small crustacea (amphipods and mysids) and microbial decomposers.

One of the cultural practices in the fresh marsh habitat is an annual marsh burning in the spring. This practice is common in many areas of the MDPR to encourage the production of vegetation favored by furbearing mammals, especially nutria. Burning probably stimulates short term primary production by remineralizing nutrients. It also reduces plant species richness and rough vegetation. It results in a net loss of minerals that blow away with the smoke. When a dry marsh is burned, a "deep burn" occurs that oxidizes much of the stored organic matter in the sediment, which can result in marsh loss. Data are inconclusive as to the overall influence of this practice.

FRESH OPEN WATER (9)

Inland freshwater bodies (Figure 26) include lakes, ponds, and impounded freshwater areas. These lakes are typically shallow, have depths less than

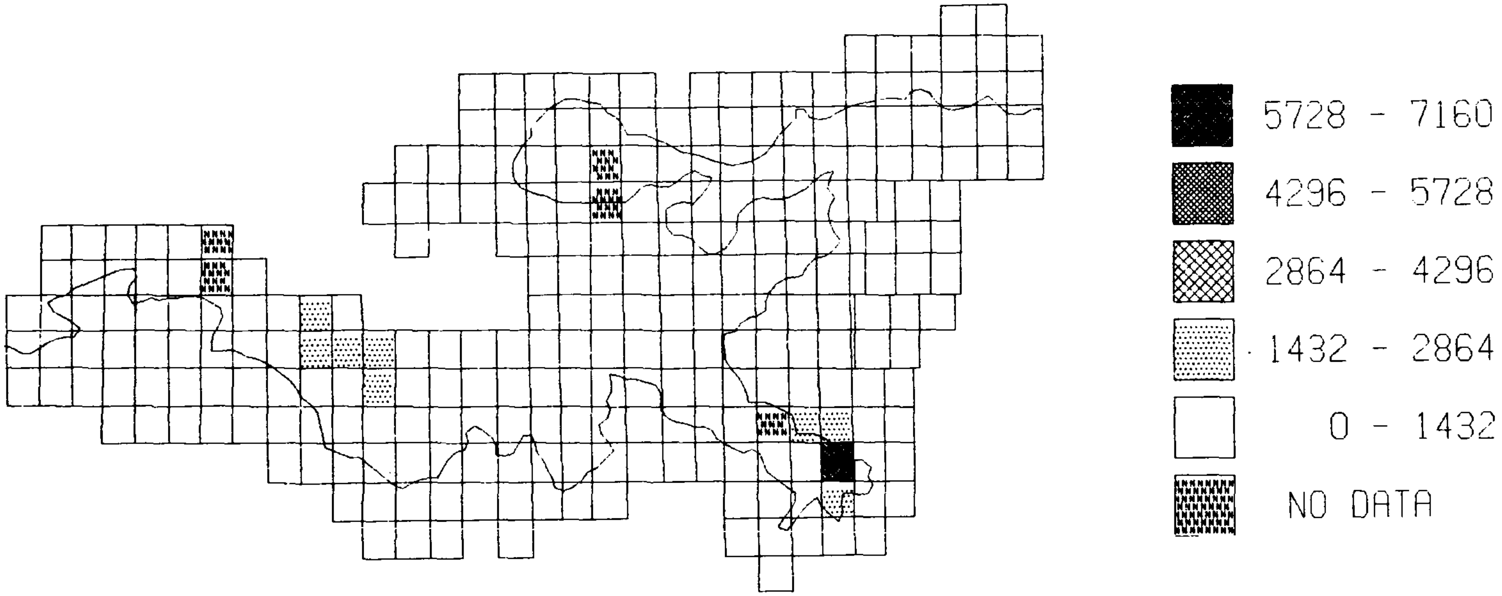


Figure 26. The distribution of MDPR fresh open water habitat.

two meters, and are bordered by cypress-tupelo swamps and fresh marshes of the Sagittaria falcata, Phragmites communis, and Typha types. The habitat covered 35,823 ha (88,485 acres) in the MDPR in 1978 (Table 5).

Lac des Allemands, in the upper Barataria basin, is described below as representative of the entire region. This lake is relatively large (62 km^2 or 23.930 mi^2) , slightly alkaline, shallow (average depth 2.1 m or 7 ft), turbid (average Secchi disc depth 0.41 m or 1.34 ft) and eutrophic, or high in plant nutrients and chlorophyll (Butler 1975). Water from the lake flows into Lake Salvador via Bayou des Allemands.

Freshwater lakes in the MDPR have been affected by human changes and land development. Nutrient loading is increasing, most dramatically in the upper freshwater regions of MDPR hydrologic basins (Craig and Day 1977; Day et al. 1977; Kemp 1978). Frequent algal blooms, aperiodic fish kills, and fish population shifts favoring catfish, gar, and shad are typical of such eutrophic water bodies (Hopkinson and Day 1979).

Nitrogen and phosphorus inflows to Lac des Allemands exceed outflows by 1.9 and 1.8 times, respectively, indicating that the lake is acting as a nutrient sink. The bottom sediments are presumably taking up the nutrients, which is presently preventing the eutrophication of downstream water bodies. At some point, however, lake sediments will become saturated and will no longer remove excess nutrients from lake water.

The dominant lake primary producers are blue-green algae (Cyanophytes) and green algae (Chlorophyta) (Butler 1975), with blue-greens the most abundant (Lantz 1970). Turbid waters prevent light penetration to the lake bottom and limit benthic primary production.

The lake ecosystem is heterotrophic, i.e., annual community respiration exceeds community primary production. Nevertheless, Lac des Allemands is very productive throughout the year. Bayous and rivers in the MDPR typically have lower primary production and respiration than freshwater lakes because of reduced sunlight caused by overhanging trees. Lac des Allemands is most productive between April and September, a period of extensive blue-green algae blooms (Day et al. 1977).

Three groups are considered to be the major components of the lake food web: zooplankton, benthos, and fish. Of the zooplankton, Cladocera and Rotifera are the most abundant in Lac des Allemands (Lantz 1970). The zooplankton feed on organic matter and phytoplankton. Chironomidae (Dipteran insect larvae) and Tubificidae (Oligochaeta) are the dominant members of the benthic macrofaunal community (Lantz 1970). The fish population is composed of many species, of which gizzard shad and channel catfish make up most of the biomass. Lac des Allemands supports a commercial catfish industry that harvests 1.12 million kilograms (2.47 million pounds) of fish annually (Lantz 1970).

Reptiles, including alligators (Alligator mississippiensis) and many species of snakes, spend much time in the fresh aquatic habitat. Amphibians, wading birds, waterfowl and mammals are also common consumers.

FRESH SCRUB-SHRUB (10)

The scrub-shrub (Cowardin et al. 1979) habitat is found in freshwater areas that are not flooded enough to support marsh (Figure 27). Broad-leaved deciduous and evergreen shrubs present here include willow, cottonwood, and wax myrtle (Wicker 1980). Altered marshes invaded by baccharis, hackberry, button bush, and palmetto are also included. Thus, both natural scrub-shrub communities and reclaimed wetlands with pioneer (invading) shrubs make up this habitat type.

The scrub-shrub habitat is small in area, ranking 15th overall. It covered 13,188 ha (32,600 acres) in 1978 (0.4% of the total MDPR), an increase of more than 6,000 ha (14,800 acres) since 1955 (Table 5). Although scrub-shrub is

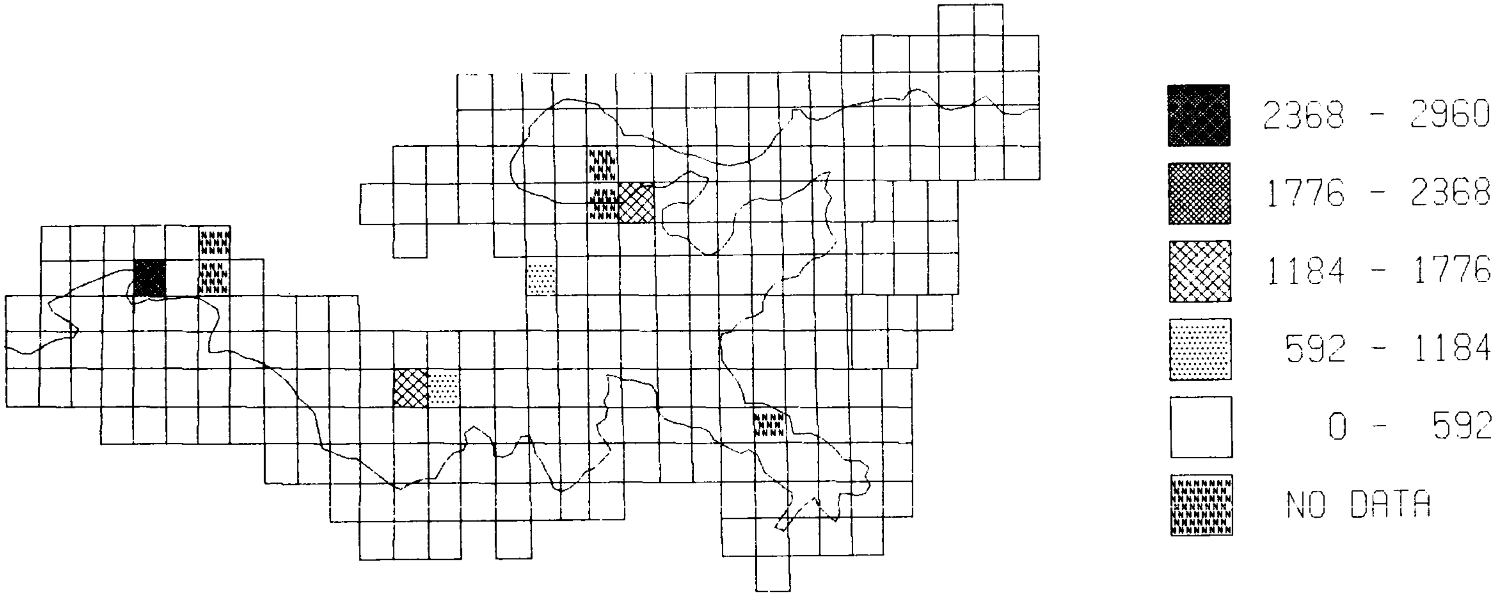


Figure 27. The distribution of MDPR fresh scrub-shrub habitat.

found in all seven MDPR hydrologic units, over 70% of this habitat exists within the Barataria, Terrebonne, and Vermilion units. All of the 4,000 ha (10,000 acres) of scrub-shrub in the Barataria and Vermilion units have developed since the 1950's as a result of human modifications to basin hydrology.

MANGROVES (11)

The black mangrove (Avicennia germinans) occupies a small area in the MDPR; only 2,955 ha (7,299 acres) in 1978 (Table 5). It occupies a fringe at the southernmost end of the region on the inside edge of the barrier islands (Figure 28). There are also stands of black mangroves on the Isles Dernieres, Timbaliers, Breton Islands, and the Chandeleurs.

Functionally, the black mangrove is an ecological analog of salt marsh cord grass that grows in similar high salinity intertidal areas, produces organic matter (most of which decomposes to detritus), and has been linked to the support of fishery species. In addition, mangrove roots and stems stabilize sediments and absorb storm wave energy, as do the stems of Spartina.

Mangroves are dominant in coastal zones at lower latitudes (e.g., southern Florida) but their range is limited to about latitude 30 deg. N because they cannot tolerate hard freezes. In the MDPR, irregular freezes every 7 to 10 years result in the dieback of the mangrove fringe. Thus, in the MDPR, this plant is at the northern edge of its range and particularly vulnerable to cultural stress. Because of its intolerance to cold, the only occurrence of the black mangrove in the north central Gulf coast is in the MDPR. One has to travel east near Cedar Key on the Florida gulf coast, or to the Texas coast near Galveston (Sherrod and McMillan 1981) before encountering mangroves again. On the Atlantic coast of Florida black mangroves occur as far north as Daytona Beach, about latitude 29 deg. N.

The distribution of mangroves within the MDPR reflects the salinity regime as well as climate; mangroves are scarce in the Mississippi Delta and the Atchafalaya hydrologic units because of high freshwater inputs to these areas, which favors other plants. Most of the mangrove acreage in the MDPR occurs in the Pontchartrain, Barataria, and Terrebonne basins.

Other than mapping, there has been little research on mangroves in the MDPR. However, there is a large body of information on mangroves in the tropics which lends insight into the mangroves of this region. The black mangrove that occurs in the MDPR, Avicennia germinans, is one of three major species that are found in the new world tropics. The other two species are red mangroves (Rhizophora mangle) and white mangroves (Laguncalaria racemosa).

Mangrove production rates as high as 3,000-4,000 g dry wt/m^2/yr have been reported. As with salt marshes, the main factors that limit productivity are nutrients, salinity, and drainage characteristics of the soil. Most of the fauna of mangrove swamps are detritivores, and much of the production is exported. Review papers on mangrove swamps have been written by Walsh (1974), Lugo and Snedaker (1974), and Kuenzler (1974).

The mangrove zone serves an additional functional role over salt marshes. The mangrove is a woody shrub that grows in the MDPR to a height of about 3 m (10 ft). It provides extremely valuable elevated nesting sites over water for a number of species of wading birds, including egrets, herons, and ibises. Pelicans formerly nested (until 1961) on North Island (Chandeleur Sound). A fairly large colony of wading birds nests in mangroves on the Isles Dernieres (Raccoon Pt. Island). Queen Bess Island behind Grand Terre Island is a tiny mangrove cay that is densely populated by pairs of nesting wading birds each spring. Unfortunately this island and many of its neighbors are diminishing in size each year because of

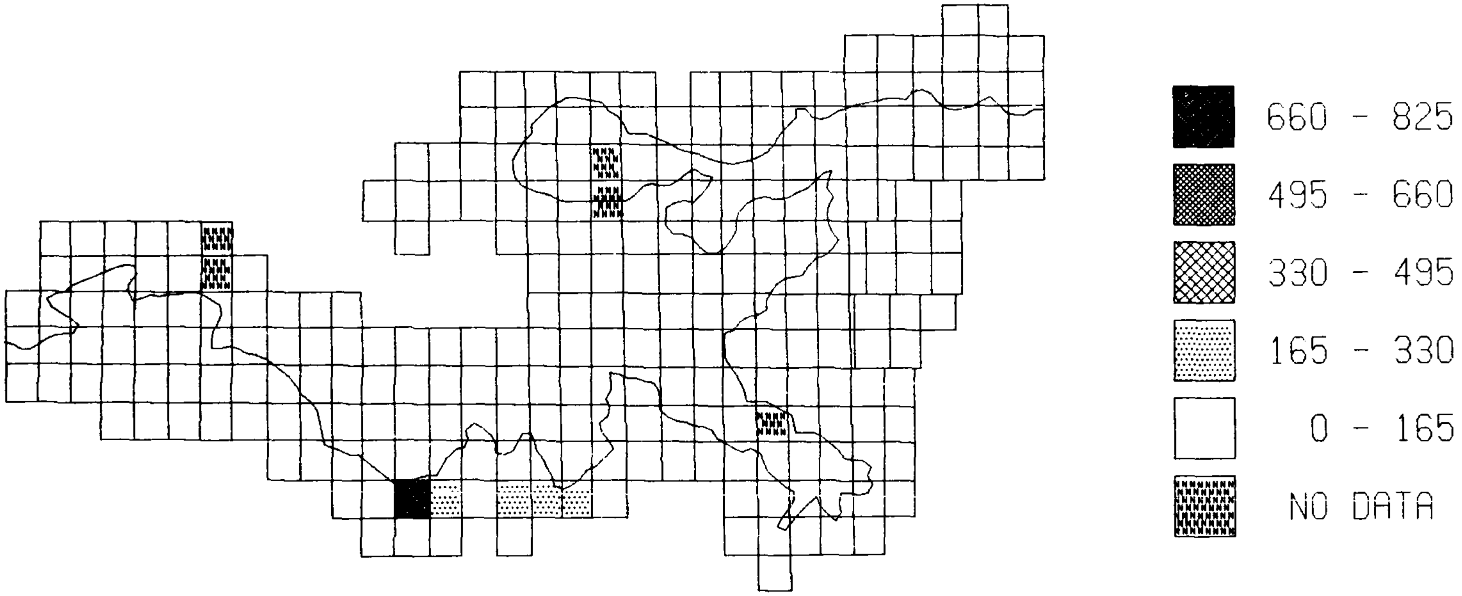


Figure 28. The distribution of MDPR mangrove habitat.

erosion, a situation that makes the remaining mangrove area increasingly vital to the welfare of these birds.

MUD FLATS (12)

Habitats classified as flats include several types of environments in the MDPR. However, 85% of the flats can be identified as one of three types: (1) unvegetated mudflats in estuarine areas, (2) unvegetated organic matter/mud deposits in estuarine and brackish areas, and (3) unvegetated mudflats in freshwater areas. The distribution of this habitat is shown in Figure 29.

Flats in the MDPR covered 5,159 ha (12,750 acres) in 1978 (Table 5). Although the area of this habitat is small, the habitat is valuable in several respects. Mudflat soils contain organisms which are involved in nutrient recycling, and the community found in this habitat supports higher level consumers. There have apparently been no studies of mudflats in the MDPR, and the role of this habitat in the MDPR is based on work done in other areas.

The most conspicuous characteristic of mudflats is the lack of macroscopic vegetation, which gives the impression that this habitat is relatively unproductive. Although no large vascular plants are found on mudflats, numerous forms of microalgae grow on and in the sediments. Most of the algae are concentrated in the top 1 cm of sediment, although living algae are found as deep as 10 cm (4 inches) (Peterson and Peterson 1979). Blue-green algae (Oscillatoria sp., Microcoleus sp., and Spirulina sp.) and diatoms are the two most common groups found on and in mudflat sediments. While the production of other habitats may be higher, much of the primary production on mudflats is consumed by benthic invertebrates in the mudflat sediments, and directly converted into secondary production (Peterson and Peterson 1979).

Blue-green algae are nitrogen fixers. Casselman (1979) measured nitrogen-fixation rates in Louisiana mudflat soils in Barataria Bay and found rates of 1.56 g N/m^2/yr (13.9 lb/ac/yr). During March, the mudflat was the site of more intense nitrogen fixing activity than that of salt marsh soils in the same area. Bacteria and fungi are also abundant on mudflats. Members of these two groups are pivotal in the process of converting detritus, which is low in nitrogen, to high quality protein-rich organic matter that can be used by deposit feeders. Wolaver et al. (1980) found that mudflats play an important role in the nutrient exchange between habitats in estuarine systems. As water flows over the mudflat during tidal flooding, nutrients are released from the sediments to the overlying water to be carried to other habitats and used by organisms in the water column. The salt marsh can apparently function as either a source or a sink for nutrients, depending upon the season (Wolaver et al. 1980). This is consistent with Casselman's (1979) results that show peak nitrogen fixing activity for different areas (mudflat and marsh soil) during different times of the year.

Microalgae associated with mudflat sediments are consumed by many species of benthic invertebrates. Both suspension feeders and deposit feeders are found in intertidal flats, and these same animals can be divided into two other groups: the infauna, burrowing organisms which live in the sediment, and the epifauna, organisms which live on the surface of the mudflat. Taken together, all of the benthic organisms are an important food source for other higher level consumers, particularly birds.

The oyster (Crassostrea virginica) is the best-known and most common epibenthic suspension feeder found in the mud flat habitat. Oysters are commercially important in the MDPR, but they are ecologically important also because they build reefs in mudflat areas. Oyster reefs help to stabilize sediments, retard coastal erosion, augment sediment deposition, provide space for a variety of epibenthic organisms and prey for shorebirds and nekton, and they recycle nutrients, especially nitrogen, in

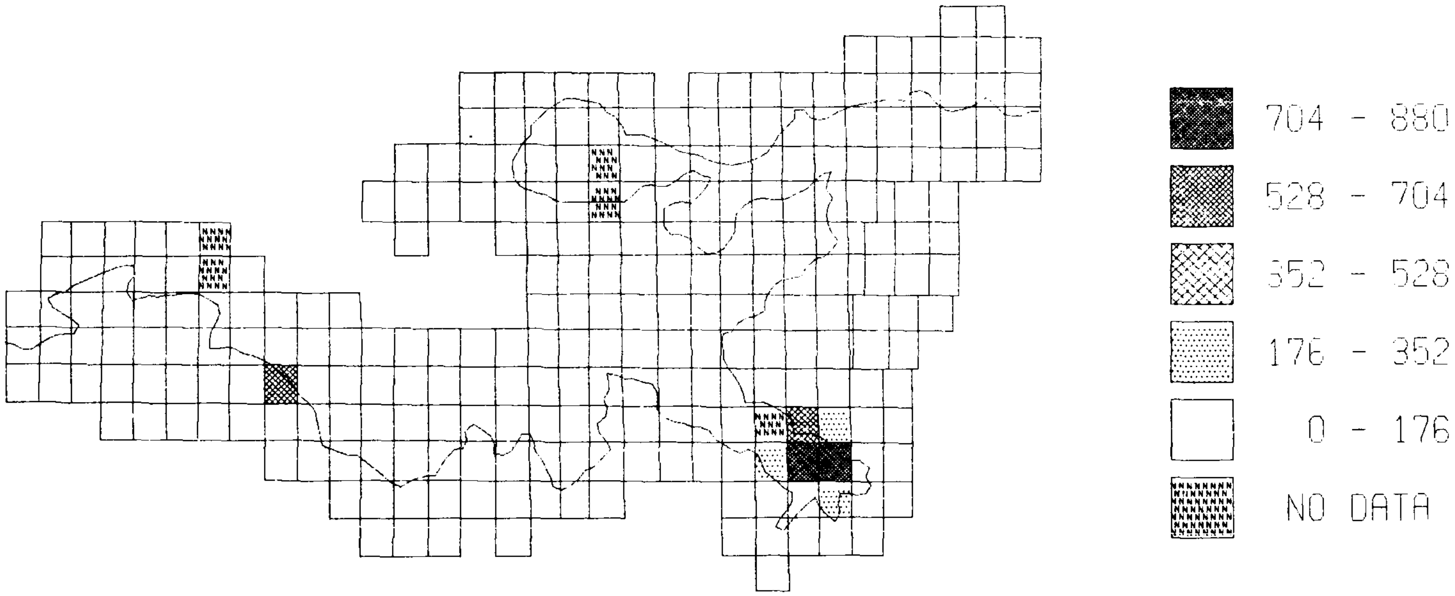


Figure 29. The distribution of MDPR mud flat habitat.

quantities and rates that can affect the local environment (Bahr and Lanier 1981; Bahr, unpublished data). Major oyster reefs are located in the MDPR from Atchafalaya Bay westward to the end of the Vermilion hydrologic unit (Figure 62). Although many of these reefs are dead, they continue to affect sedimentation patterns, and they are an important economic resource as calcium carbonate that is used in the manufacture of cement and aluminum, and for roadbuilding. Some dredged shells are used as oyster cultch, although this cultch is sometimes exported from Louisiana to other oyster growing states.

There is some controversy about the regulation of dredging clam and oyster shells from fossil beds in the Louisiana portion of the MDPR (e.g., Baton Rouge Morning Advocate, 1982a and b). The Louisiana State Government instituted in 1912 a policy whereby the Louisiana Conservation Commission (predecessor of the Wildlife and Fisheries Commission, now the Department of Wildlife and Fisheries) receives a portion of its funding in the form of royalties from the shell dredging industry, based on the volume of shells dredged (Gulf South Research Institute 1977). This royalty is presently $0.25/yd^3 of shell. Because Wildlife and Fisheries is partially responsible for overseeing the protection of fisheries resources and coastal habitats that may be affected by dredging of clam shells and/or oyster reef shells, a potential conflict of interest exists. The Coastal Management Section of the Louisiana Department of Natural Resources and the USACE will this year (1982) determine whether to grant State and Federal shell dredging permits to two applicants. The U.S. Fish and Wildlife Service has submitted a statement to these agencies recommending that reef dredging permits be conditioned to exclude the following areas: all exposed oyster reefs, the area surrounding Southwest Pass on the west end of Marsh Island, 1 mile around Shell Keys National Wildlife Refuge, and the 2-foot depth contour of the Atchafalaya Delta (U.S. Fish and Wildlife Service 1982).

Several groups of birds feed in mudflat areas; wading birds, shallow-probing birds, and deep-probing birds (Peterson and Peterson 1979). Most wading birds are fish-eaters, although some species also consume fiddler crabs and other small crustaceans that are found on mudflats. Most of these birds fish in the shallow water adjacent to the mudflat or in tidal pools on the surface of the flat. Shallow-probing birds include several species of sandpipers, plovers, oystercatchers, rails, and dowitchers. Many of these species depend on mudflat areas for most of their food. These birds are opportunistic feeders, i.e., they eat those species of infauna that are most abundant. Some birds feed on the insects and crustaceans found on the surface of the mudflat. The deeper probing birds are able to feed on larger invertebrates; these birds include willets, long-billed curlews, godwits, and whimbrels. Some birds feed on ocean beaches as well as mudflats, and the distinction between beaches and mudflats breaks down in many parts of the MDPR where the marine energy regime is low. For example, mudflats are currently building in the gulf to the west of Atchafalaya Bay, seaward of the beach habitat.

Until the mudflat habitat in the MDPR has been investigated further, little can be reported of a quantitative nature about its overall role in nutrient regulation and energy flow. The evidence suggests that mudflats may be a critical habitat for certain species of birds and may play an important role in nutrient processing in estuarine areas.

NEARSHORE GULF (13)

The nearshore gulf habitat in the MDPR is defined in this report as being limited to high salinity and relatively high energy areas (Figure 30). Thus, this habitat is found exclusively to the east of the Chandeleurs and to the south of the Mississippi Gulf Islands (in the Mississippi Sound hydrologic unit). The nearshore area to the west of the Mississippi River is defined as estuarine open water, because of its relatively low salinity resulting from the freshwater inputs from the Mississippi and Atchafalaya Rivers.

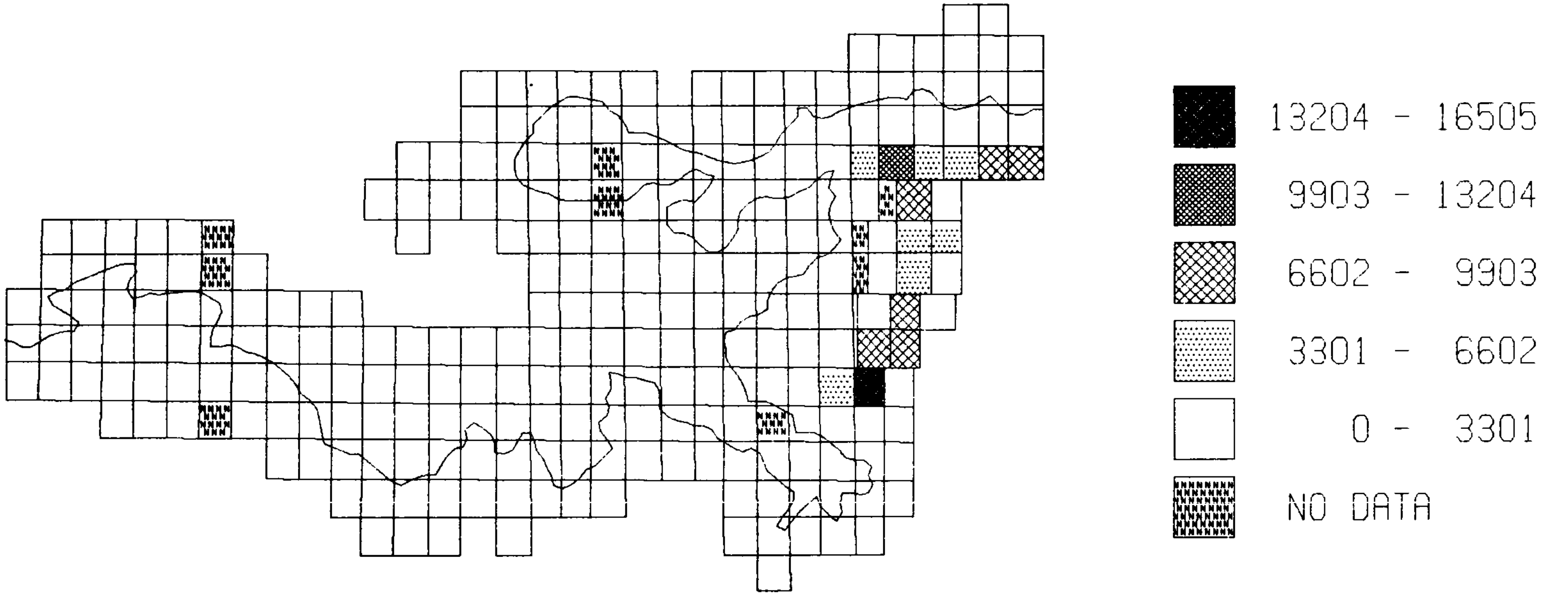


Figure 30. The distribution of MDPR nearshore gulf habitat.

Nearshore gulf is the sixth largest habitat in the MDPR, containing 116,569 ha (288,000 acres) in 1978, or 3.4% of the total land and water area (Table 5). Of this area, 65% is found in hydrologic unit II (Pontchartrain).

Ecological studies of this habitat are sparse. One of the main sources of data is a study by Franks and Associates (Franks et al. 1972) in which nutrient chemistry, benthic fauna, and nekton were investigated. Two of their six sampling stations were in the nearshore gulf.

Surface concentrations of nitrate in the nearshore gulf average 0.68 microgram atoms per liter (µg-at/l), with bottom concentrations of 0.38 µg-at/l. Nitrite was not detected in these waters. Total phosphate concentrations in surface and bottom waters averaged 1.75 and 1.78 µg-at/l, respectively. Bottom sediments at these sites were silty, containing much organic matter.

Turner and Allen (1982) examined oxygen concentrations of nearshore bottom waters and found that they were usually below saturation. Oxygen levels in summer months were especially low, and the deficit was most obvious in the shallower depths. Onshore transport of the oxygen minimum layer and oxidation of suspended organics were not believed to be responsible for these low concentrations. Rather, Turner and Allen proposed that stratification of the water column, respiration by the benthic community, and/or sinking plankton led to low oxygen levels. Respiration values of 1 mg oxygen/m^3/hr, coupled with observed stratification, could cause low oxygen values.

The major primary producers in the nearshore gulf are benthic algae, seagrasses, and sargassum (Earle 1972). The majority of the net phytoplankton found are diatoms (Franks et al. 1972). Most water column primary production is diverted to the benthic community; and most of the energy flow that characterizes the nearshore and inner shelf gulf food web passes through the benthic community to demersal fishes (Flint 1980).

Common marine invertebrates found in this area are the sea pansy (Renilla mulleri), brown shrimp (Penaeus aztecus), squid (Lollinguncula brevis), and mantis shrimp (Squilla empusa). Copepods make up the majority of net zooplankters found in the nearshore habitat. Other invertebrates studied in this area are amphipods (Stuck et al. 1980), and cnidarians (Burke 1975, 1976). The most abundant fish in the nearshore habitat are croaker (Micropogonias undulatus), longspined porgy (Stenotomus caprinus), spot (Leiostomus xanthurus), and white trout (Cynoscion arenarius) (Franks et al. 1972). The nearshore gulf is also used by menhaden for spawning (Christmas and Waller 1975). Modde (1980) reported 70 migrant species and 6 resident species of (primarily) postlarval fishes utilizing the shallow surf zone off of Horne Island, Mississippi. The resident species; including Harenguls sp., Trachinotus sp., Astroscopus sp., and Menticirrhus sp., made up the dominant component of Modde's sample, representing 42% of the total number of fishes caught. Most numerous among the migrant species were Anchoa sp., and Brevoortia sp.

RIVER, STREAM, AND BAYOU (14)

Historically, the Mississippi River and its distributaries dominated the geology and ecology of MDPR wetland habitats. Currently, artificial levees prevent annual overbank flooding in all but a few areas, such as the lower modern delta area, and limit the direct contact of river water with the wetlands. Now the Mississippi River and its major distributary, the Atchafalaya River, act primarily as transporters of moving water, sediment, organic matter, nutrients, and pollutants from the continent to the MDPR's estuarine open water areas (Figure 31).

Waters classified as rivers, streams, and bayous in the MDPR include swamp bayous, streams in freshwater marshes, and upland streams north of Lake Pontchartrain and in the State of Mississippi. These habitats covered 37,503 ha (92,634 acres) in 1978 (Table 5).

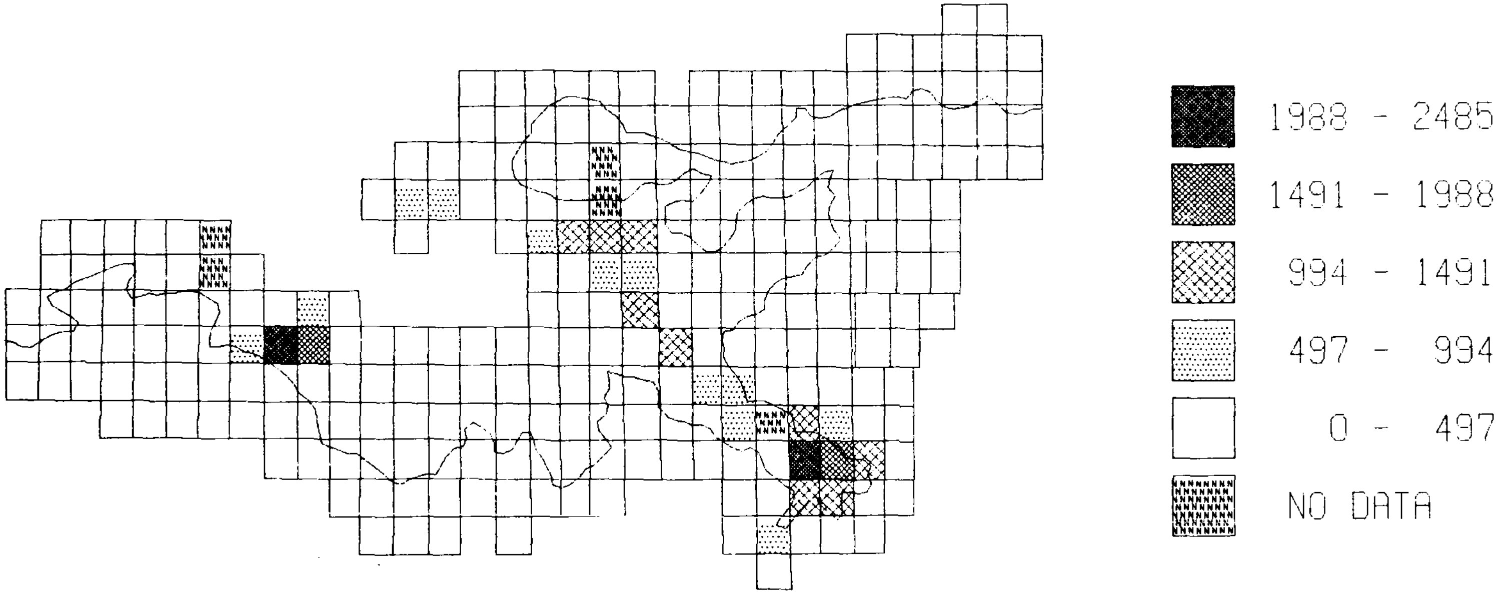


Figure 31. The distribution of MDPR river, stream, and bayou habitat.

The Mississippi and Atchafalaya Rivers combined discharge about 2.2 x 1013 cubic meters of water annually. The region's next largest rivers, the Pascagoula and Pearl, each carry about three orders of magnitude less water (1.2×10^{10} and 1.0×10^{10} m^3/yr, respectively). Smaller streams and bayous are also important transporters of water and nutrients. Most of the water flow to Lac des Allemands in the swamp forest of the upper Barataria basin is carried through swamp bayous (Day et al. 1977). The transport of organic matter from wetland and terrestrial producers to aquatic consumers is a primary functional role of natural bayous and streams. A Mississippi coastal plain stream studied by de la Cruz and Post (1977) carried between 36,000 and 538,000 kg of organic carbon per year. Greater channelization in the upper basin probably reduces the flow through natural channels and results in more rapid water movement out of the basin (Hopkinson and Day 1979).

The input of organic matter from terrestrial sources is important for river and stream habitats (Hynes 1970). De la Cruz and Post (1977) calculated an input of particulate organic matter of about 400 g/m^2/yr into a Mississippi stream. Day et al. (1981) estimated annual organic matter loading into swamp bayous in the des Allemands region of Barataria basin at 2.5% of net primary production (about 1700 g dry wt/m^2/yr).

Respiration typically exceeds primary production in rivers, streams, and bayous. Day et al. (1977) estimated bayou gross primary production at 229 g dry wt/m^2/yr and community respiration at 298 g dry wt/m^2/yr. Bayou production is generally less than lake production because of shading.

We assumed for lack of quantitative information that major rivers and bayous are similar in community composition and structure to fresh open water areas. Smaller streams take up an insignificant area and are considered a minor component of the rivers, streams, and bayou habitat.

As indicated in the description of canal habitat, natural tidal creeks are different from canals of similar width. There is some evidence that tidal creeks are themselves different from the very shallow pools of water that occur on the surface of wetlands. The latter temporary habitat is used by nursery ground, or estuarine-dependent juvenile nekton at higher densities than are tidal creeks (Day et al. 1982). This implies that the ecological or functional role of the river, stream, or bayou habitat is primarily as a conduit, or transportation route by which many nektonic animals migrate to their primary feeding areas, rather than their primary habitat.

ESTUARINE AQUATIC BED (15)

Estuarine aquatic beds (EAB), also commonly called seagrass beds, or marine meadows, are subtidal beds of rooted aquatic vegetation (Figure 32). This habitat occupied 14,319 ha (35,368 acres) in the MDPR in 1978 (Table 5). Although this area is relatively small, grassbeds may play an important role because of their value as a refuge and feeding ground for some commercially important nekton species (e.g., blue crabs, menhaden) and as a food source for waterfowl and nekton, either in its living form, or after it decomposes to detritus.

Studies of EAB in the MDPR have mostly been descriptive, i.e., mapping and identification (Eleuterius 1973; Montz 1978; Turner et al. 1980). The principal submergent macrophytes encountered in Louisiana are *Ruppia maritima*, *Vallisneria americana*, *Najas guadalupensis*, and *Potamogeton perfoliatus*. *Halodule beaudettii*, *Halophila engelmanii*, and *Cymodocea filiformis* also occur.

The main factors that limit the distribution and production of submerged grassbeds are salinity, nutrient concentrations, and light. The two species of submergent macrophytes most commonly reported in estuarine waters are eelgrass (*Zostera marina*) from temperate

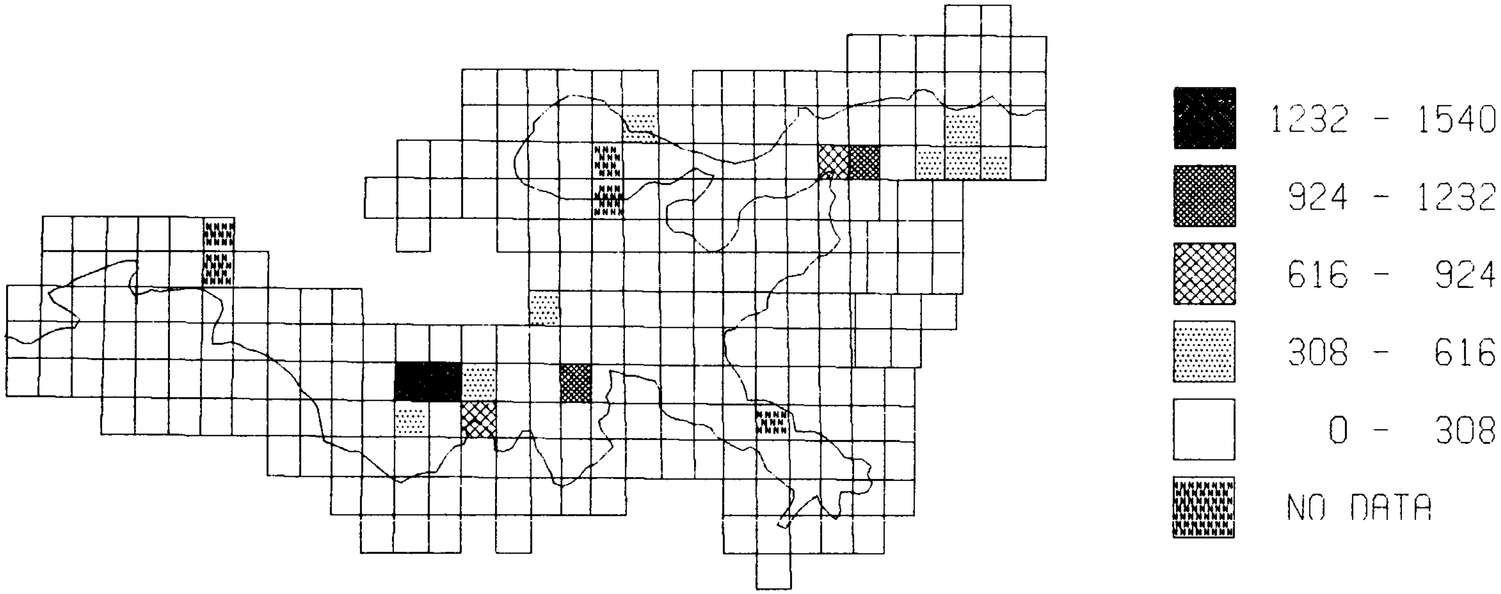


Figure 32. The distribution of MDPR estuarine aquatic bed habitat.

latitudes, and turtle grass (Thalassia testudinum) from the tropics. The salinity optimum of these species is in the range of 15 to 35 ppt. Within the MDPR, eelgrass is absent and turtlegrass is limited to higher salinity areas, such as the waters to the west of the Chandeleur Islands in the Pontchartrain hydrologic unit.

The limited areal distribution of EAB in the MDPR is undoubtedly a result of low light rather than nutrient limitation. Most coastal areas where EAB habitat occurs are less turbid than in the MDPR, and submergent macrophytes are reported in water as deep as 10 m (33 ft) (Phillips 1960). Nutrient levels in very clear waters are typically low, however, and in many areas submergent macrophytes may be limited by low nutrients. Open water areas in the MDPR are, by contrast, nutrient rich and turbid, and submergent macrophytes are therefore rarely found in waters of more than 1 m (3.3 ft) deep. This suggests that light penetration (turbidity) is the major limiting factor.

The distribution of EAB within individual hydrologic units supports this hypothesis. The Mississippi Delta, Atchafalaya, and Vermilion units have the lowest area of EAB. These zones are riverine influenced and very turbid. The Terrebonne and Mississippi Sound units, with generally less turbid waters, have the largest areas of EAB habitat. The Pontchartrain unit probably once had the largest area of EAB, but erosion of the Chandeleur Islands and increase in turbidity of Lake Pontchartrain have resulted in the reduction in area suitable for this habitat.

Although there are few studies on EAB in the MDPR, there is an extensive literature in other areas that gives insight into the role of EAB in the MDPR. Sea grasses in coastal marine and estuarine ecosystems constitute a unique shallow water community. They are widespread throughout the world, and they make a substantial contribution to overall coastal productivity (McRoy and McMillan 1979). Work has focused on the two most common species, eelgrass and turtlegrass. Annual production of submergent vegetation is extremely high, ranging from about 500 g C/m^2/yr in the temperate zones to 1,000 g C/m^2/yr in the tropics. In addition, Gentner (1977) descibed the important role seagrass plays in the uptake and transport of iron and phosphate from the substrate. Primary production in seagrass communities is divided among several components: seagrass, benthic macro and microalgae, epiphytic algae, and phytoplankton. Jones (1968) and Penhale (1977) determined that 18% to 20% of total productivity was contributed by epiphytes attached to seagrass.

In spite of the high rate of production in grass beds, only a few heterotrophs are known to utilize macrophyte tissue directly (Fenchel 1977; Zieman et al. 1979). Grazers in the water column eat phytoplankton, epiphytes, and benthic microalgae, rather than live rooted plants. The largest percentage of carbon produced by submerged vascular plants is consumed as detritus after it dies and begins decomposing (Thayer et al. 1975). The utilization of the dead particulate matter from seagrass involves a wide variety of organisms with complicated food interrelationships.

Although faunistic studies in submergent grassbeds abound, few studies have dealt quantitatively with the specific fate of seagrass-produced carbon as it passes through estuarine food webs (Kikuchi and Peres 1977). Sea grass habitats characteristically have a high density of animals residing in them and a concommitantly high rate of secondary production. Such high rates of secondary production are attributed to a high rate of detritus production, and to the seagrass itself, which serves as a refugium, for stabilizing sediments, and for creating micro-habitats (Thayer et al. 1975; Kikuchi and Peres 1977). The beds are important nursery and feeding areas for many marine nekton species (Yanez-Arancibia et al. 1979). Recently there have been indications of a considerable transport of seagrass offshore, where it may serve as food for both surface and benthic feeding organisms (Wolff 1976).

ESTUARINE OPEN WATER (16)

The area of estuarine open water habitat in 1978 in the MDPR was 1.9 x 10^6 ha (4.7 x 10^6 acres), or 56.08% of the region (Table 5). This habitat type increased in area between 1955 and 1978, largely at the expense of salt and brackish marshes.

The criteria that distinguish the estuarine open water habitat (Figure 33) from other water bodies are size and salinity. This habitat is defined as including water bodies greater than 8 ha (20 acres) with salinities between 0.5 and 30ppt (Cowardin et al. 1979). Each of these characteristics, as well as the typically shallow depth of this habitat, has ecological implications.

The estuarine open water habitat is distinguished from the river, stream, and bayou habitat in the MDPR because there are important ecological differences between large and small bodies of water. Small lakes have a proportionately higher ratio of shoreline to surface area than large lakes, and the shoreline is the site of high densities of invertebrates and nekton, intense feeding activity by birds, organic inputs from wetlands, as well as cultural activities such as fishing that impinge on the habitat. The density and diversity of organisms are typically higher at the shoreline than in the center of a lake, e.g., Roberts (1981). The edge effect, or ecotone principle, proposes that interfaces between two habitats are biologically richer and more active than the central areas of each habitat (Odum 1971).

The depth of the estuarine open water habitat is closely related to its function. The effect of wind on bottom disturbance and turbidity in this habitat is one example. Shallow lake bottoms are easily stirred up by wind. Lake Pontchartrain is only about 4.9 m (16 ft) deep and a 15 mph wind will disturb the bottom (Stone 1980a). Shallow estuaries in the MDPR have a high bottom surface/volume ratio, which increases the interactions between water column and sediments. These interactions include the various roles of the benthic community, such as nutrient recycling and providing food for nekton.

Open water also differs from small sheltered water bodies in having enough fetch to be exposed to wind energy, waves, and turbulence. The estuarine open water habitat is usually turbid because of the suspension of bottom sediments by waves. The shallowness and turbulent mixing of the estuarine open water habitat normally preclude vertical stratification. Stratification would result in low oxygen conditions in the bottom waters that would increase the incidence of fish kills in these naturally eutrophic waters.

The estuarine open water and nearshore gulf habitats are not very distinct on the basis of salinity. The estuarine open water habitat includes Lake Pontchartrain, which ranges from 0 to 16 ppt, while nearshore gulf salinities may range from 5 to over 30 ppt. Ecological differences between variable salinity coastal water bodies (estuaries) and stable salinity marine waters include relatively greater osmotic stresses on the organisms that inhabit estuaries (Remane and Schlieper 1971). This difference is not apparent when comparing the two coastal habitats in question here.

The bottom community in the estuarine open water habitat in the MDPR is typically populated with macrobenthic animals, such as bivalves and polychaetes, as well as with numerous tiny meiobenthic animals, such as nematodes, and microbenthos (bacteria and protozoa). Thus, bottom respiration (carbon requirements) are high (58 to 280 g C/m^2/yr, Roberts 1981). This implies that a large portion of the organic matter that is produced directly in the water column or that washes into open water from adjacent wetlands is processed by the benthic organisms in the estuarine open water habitat.

Most aquatic organisms (especially benthic invertebrates) have fairly

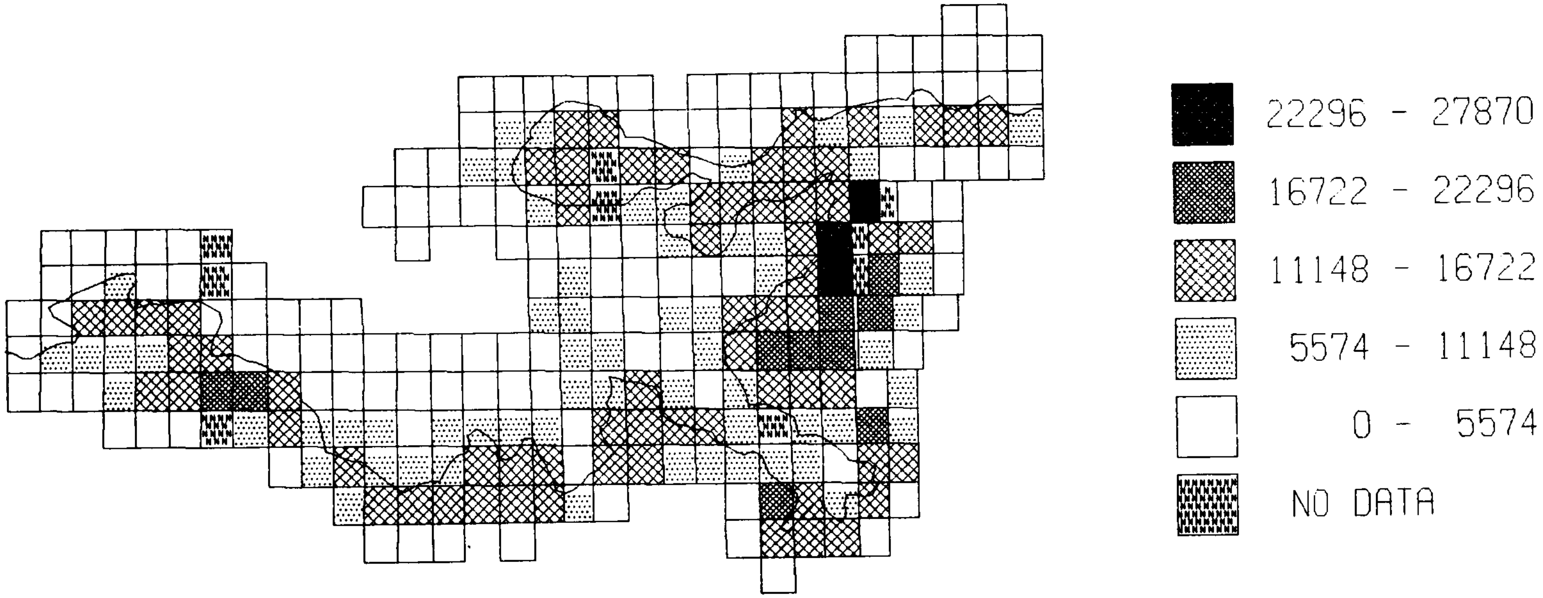


Figure 33. The distribution of MDPR estuarine open water habitat.

restricted tolerance ranges for salinity, because of the difficulty of maintaining an optimal osmotic level within their tissues. Many strategies have evolved to allow different organisms to cope with the hyposalinity of freshwater existence, and the hypersalinity of marine existence. Estuaries pose a special problem however, because they sometimes undergo drastic changes in salinity over short time periods (days or hours). Relatively few organisms have evolved to handle this variability. Estuaries have fewer species (but greater organismal abundance) than either freshwater or marine ecosystems (Remane and Schlieper 1971).

Five major groups of organisms are found in the estuarine open water habitat: (1) autotrophs (phytoplankton and benthic algae); (2) zooplankton; (3) nekton; (4) macro and meiobenthic organisms; and (5) microbial forms.

Autotrophs

Primary production in the estuarine open water habitat is often limited by light rather than by nutrient concentration. Light striking the water surface is often completely absorbed in the surface meter. Occasionally during low surface runoff and calm periods, water clarity may increase enough to allow significant production by benthic algae.

Light limitation thus precludes the development in most areas of submergent macrophyte communities (see ESTUARINE AQUATIC BED (15)). Benthic algae (especially diatoms) are also less important in this habitat than, for example, in Georgia coastal estuaries, where large tidal variations allow light penetration to the sediment surface. Most primary production in the open water habitat is the result of unicellular plants, primarily phytoplankton.

Zooplankton

Zooplankton in the estuarine open water habitat may be divided into two major classes, holoplankton (permanent members of the zooplankton) and meroplankton (larval animals that become benthic or nektonic at maturity). Holoplankton is often dominated by a single copepod (*Acartia tonsa*) that is ubiquitous and characteristic of estuaries over a wide range of latitudes. *Acartia* is well adapted to estuarine existence, in that it tolerates wide ranges in salinity and temperature. This copepod is also a cosmopolitan feeder that can filter phytoplankton while swimming, and can also feed in surface sediments on the bottom. In a benthic study of Lake Pontchartrain 8,030 individuals/m^2 of *A. tonsa* were collected in bottom samples in some areas (Sikora and Sikora 1982). Other major holoplankters are ctenophores, arrow worms, and several other species of copepods.

During the summer, total zooplankton biomass may be locally dominated at times by meroplankton. For example, the larvae of blue crabs, barnacles, and bivalve molluscs may temporarily make up most of the zooplankton community in estuaries, especially in the higher salinity areas.

Nekton

The estuarine habitat is perhaps most valuable as a nursery ground area. Immature nekton are carried inshore by favorable water currents during their peak growth period when their food requirements are highest. It has been noted that the annual movement of many of these animals occurs during spring, coinciding with the time of high organic export from marshes (Happ et al. 1977).

A study was recently made of the Barataria basin as a nursery area for a variety of nektonic species (Daud 1979; Rogers 1979; Simoneaux 1979; Smith 1979; and Chambers 1980). Chambers demonstrated that some commercially important marine-spawned nekton migrate into freshwater areas during late winter and spring as larvae, and emigrate offshore as subadults during summer and fall. These include blue crabs (*Callinectes sapidus*), croaker (*Micropogonias undulatus*), mullet (*Mugil cephalus*), menhaden (*Brevoortia patronus*), flounder (*Paralicthys lethostigma*), and the brown shrimp (*Peneaus aztecus*).

Other nektonic larvae immigrate into nursery ground areas during summer and fall, and emigrate offshore again in winter. These animals are less tolerant of low salinity water and enter the basin up to brackish water zones. The most important example from an economic standpoint is the white shrimp (*Peneaus setiferus*).

Freshwater nektonic adults utilize the basin down into intermediate salinity zones during late fall and early winter and replace the emigrating marine forms. Finally, there are some characteristic nekton that are year-round residents of the estuarine open water habitat (as well as rivers streams and bayous). A classic example is the anchovy (*Anchoa mitchelli*). These patterns are shown in Figure 52.

The estuarine open water habitat characteristically has lower nekton biomass than small creeks and ponds (see Table 20). Nekton biomass ranges from 0.32 to 1.19 g wet wt/m^2 for estuarine open water, while shallow marsh water ranges from 2.57 to 46.1 (for the same species), which implies that the nektonic organisms that use the estuarine open water are strongly dependent on surrounding wetlands.

Benthos

The benthic community in the estuarine habitat in the MDPR is not well known, in that it has been examined in detail only in Lake Pontchartrain and in less detail in Mississippi Sound. Lake Pontchartrain is probably not representative of the estuarine open water habitat throughout the MDPR, for reasons that are explained in the Pontchartrain hydrologic unit description.

The major functions of the benthic community in estuaries may be divided into four parts: (1) benthic organisms affect sediment stability and water turbidity by filtering the water and biodepositing particulate material, by burrowing through sediments, and by building reefs and depositing shells and mucus; (2) they consume oxygen within sediments and at the surface, thus regulating a number of chemical processes, including nutrient regeneration to the water column; (3) they consume carbon from sediments and the water column, and upgrade it into higher quality protein that is then available for bottom-feeding nekton; and (4) they are important socioeconomically, as a resource (meat and shell), and as biological indicators because of their tendency to concentrate various pollutants.

Five areas that have been studied in some detail are Lake Pontchartrain, Lake Salvador, Lake Cataouatche, Little Lake, and Airplane Lake. These areas span the salinity and size range of the habitat. They also show differing degrees of cultural stress; Lakes Pontchartrain and Cataouatche are severely perturbed by dredging and/or pollution of various kinds; Lake Salvador is threatened by eutrophication, while Little Lake and Airplane Lake are relatively unperturbed.

The productivity and degree of eutrophication of the water bodies in the Barataria basin are discussed below in the Barataria (IV) section of the HYDROLOGIC UNIT DESCRIPTIONS. The five areas listed differ significantly in their trophic status and productivity. (Figures 34 and 47, and Tables 14 and 18.) Of these five examples of the estuarine open water habitat, the highest productivity occurred in the most nutrient-rich (eutrophic) water body, Lake Cataouatche. Eutrophic waters also are heterotrophic, i.e., more organic matter is consumed annually than is produced (see Table 18). Gross productivity ranged from 100 g C/m^2/yr for central Lake Pontchartrain to greater than 600 for Lake Cataouatche. Chlorophyll levels also varied considerably, from less than 5 to greater than 200 mg/m^3.

SALT MARSH (17)

Salt marshes are among the most intensively studied, and best known ecological habitats in the MDPR. They comprise a significant portion of the

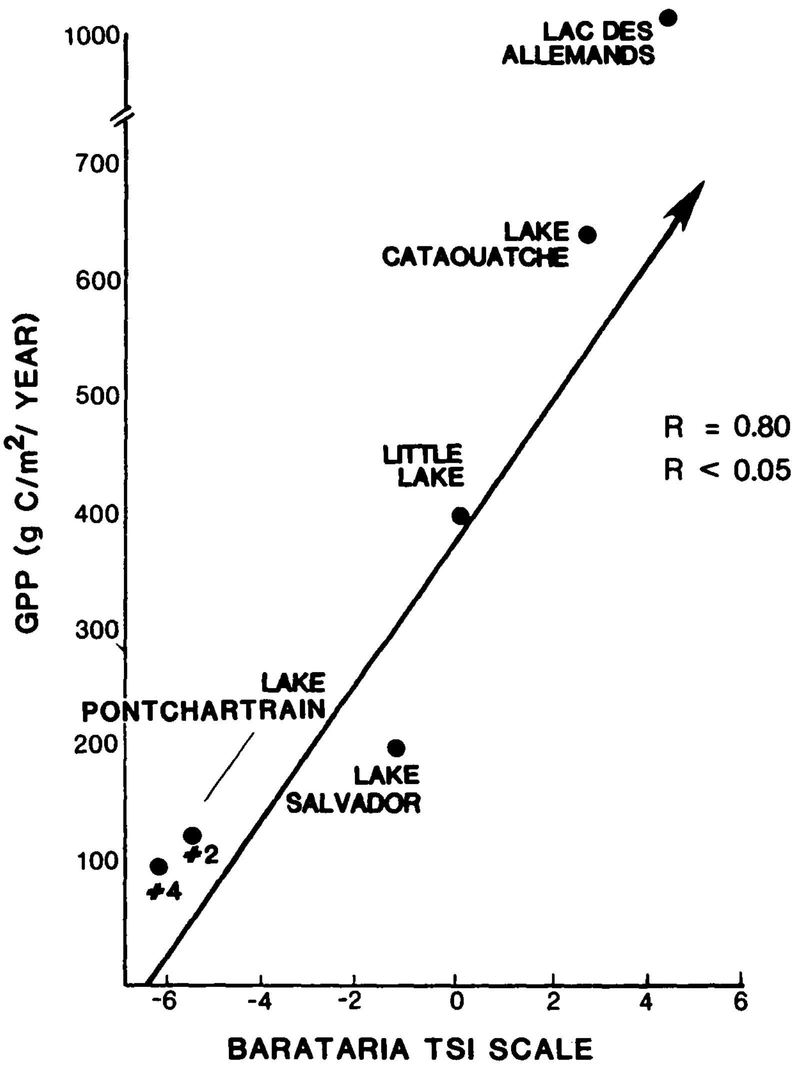


Figure 34. Gross primary production (GPP) as a function of trophic state index (TSI) for estuarine open water sites in the MDPR.

MDPR: 182,000 ha (449,540 acres), or more than 5% of the total area in 1978 (Table 5). MDPR salt marshes represent one of the largest contiguous salt marsh zones in the world (Figure 35).

There have been a number of studies of plant production in salt marshes in the MDPR (e.g., de la Cruz 1974; Kirby and Gosselink 1976; Hopkinson et al. 1978a; White et al. 1978). Studies of animal ecology and soil and nutrient dynamics in the salt marsh have also been carried out, but most of this research has examined single aspects of salt marsh function. The salt marsh ecosystem in Georgia was described in terms of an energy budget by Teal (1962), and a tentative carbon budget of the salt marsh system in the MDPR was constructed by Day et al. (1973). These studies were attempts to synthesize existing information on salt marsh function, but the absence of quantitative data on many parameters necessitated the use of many simplifying assumptions.

Much additional information on salt marshes has been developed since 1973, especially with respect to microbiological processes, but many uncertainties still remain in our understanding of the MDPR salt marsh habitat. The companion technical report (Costanza et al. 1983) contains the detailed salt marsh matter and energy flow diagram, input-output table, and accompanying documentation.

The most conspicuous feature of the salt marsh is the broad expanse of salt marsh cordgrass (Spartina alterniflora) that comprises 61% of the emergent vegetation in terms of percent cover. Other important salt marsh macrophytes are black rush (Juncus roemerianus), saltgrass (Distichlis spicata), and saltmeadow cordgrass (Spartina patens).

Various authors have studied the primary production of marsh macrophytes. A value of 2,050 g dry wt/m^2/yr was estimated for the aboveground net production of an average MDPR salt marsh. Studies have pointed out the possible significance of belowground production, however, (Valiela et al. 1976; Stout 1978; and Gallagher and Plumley 1979). It was estimated for the present study that belowground net production by marsh macrophytes contributed 5,970 g dry wt/m^2/yr, a value almost three times greater than aboveground production (Costanza et al. 1983). This estimate is not as good as aboveground production figures, however, and our understanding of salt marshes in the MDPR will be markedly improved when belowground production rates (and the subsequent fate of the carbon produced) is carefully measured. Another relatively unknown parameter in terms of marsh production is the amount of low molecular weight organic carbon that leaches out of leaves during the growing season. Current aboveground production estimates do not take this leachate into account and thus may be conservative.

Marsh microflora, particularly benthic diatoms on the mud surface, and epiphytic algae on marsh grass leaves and stems contribute significantly to the productivity of the salt marsh. It is estimated that all of these plants combined produce 750 g dry wt/m^2/yr.

The food web of the salt marsh is based primarily on detritus. Although some salt marsh grass is grazed while living by invertebrates such as insects, and mammals, most of the carbon produced by the grass is eaten after it partially decomposes in the soil and water column. For example, consumption of living producers by the periwinkle (Littorina irrorata) accounts for only 4% of the total dietary intake of this snail (Alexander 1976). Grazing of live salt marsh cordgrass is low because the grass is fibrous, high in cellulose and lignins, and low in nitrogen. The major macroconsumers in the salt marsh are crabs, mussels, snails, insects, birds, and muskrats, nutria, and raccoon. Nektonic organisms are omitted here because tidal streams are not included as marsh, and nekton are considered residents of the estuarine open water habitat.

Microbial forms are pivotal in the marsh habitat, in that they regulate in

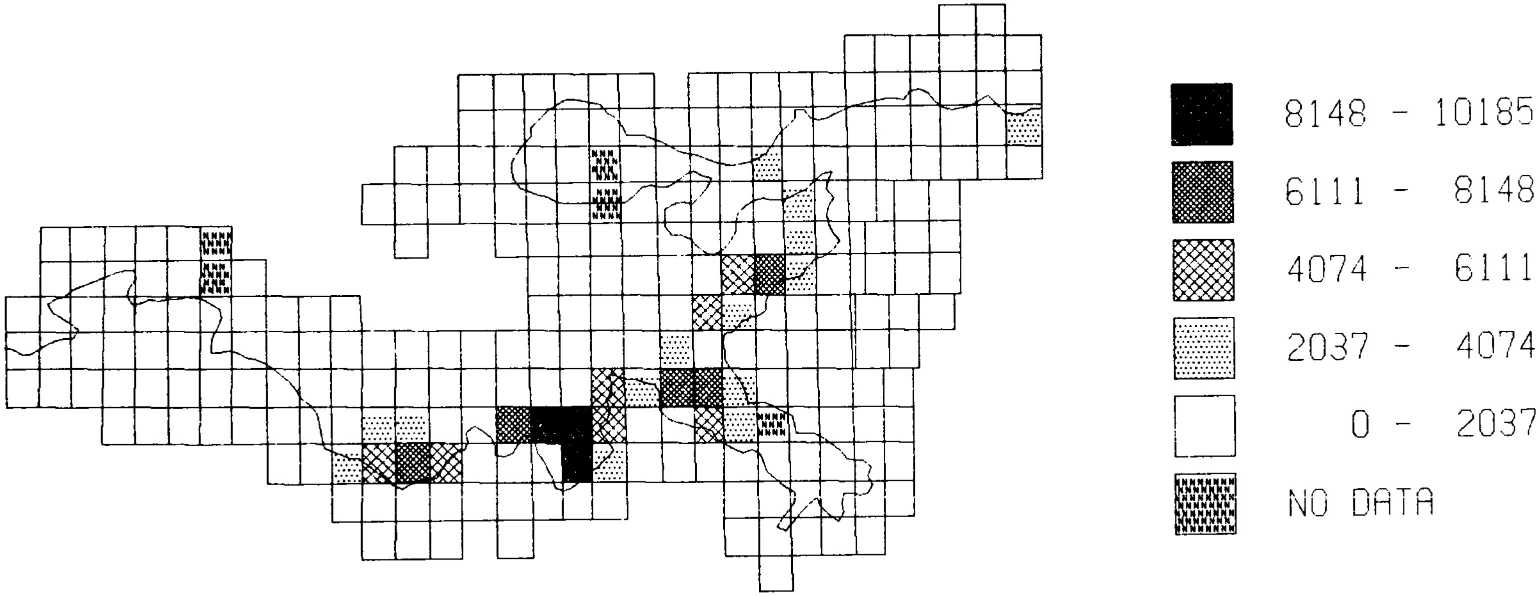


Figure 35. The distribution of MDPR salt marsh habitat.

some way almost every biological process. Microbial forms separate into two broad groups, aerobic and anaerobic. Aerobic microconsumers act as energy flow mediators. They serve to convert the relatively unpalatable cellulose from marsh grass stems and leaves into nutritious protein that supports many macroconsumers in the coastal system. It was previously thought that estuarine microbes primarily functioned as mineralizers that returned inorganic nutrients to the water column and sediments. Now it is clear that the aerobic estuarine bacteria and fungi actually compete for nutrients with the autotrophic organisms, and that the dissolved nitrogen and phosphorus they use is converted to particulate organic matter (Mann 1972). Aerobic bacteria and fungi oxidize a significant portion of the total organic carbon produced in the system, but this carbon loss is the price of enriching the remaining detritus so that it can enter the food web.

Anaerobic microbes are found in salt marsh sediments that are oxygen depleted (from about 1 cm beneath the surface to below the root zone). These organisms are instrumental in regulating sediment geochemistry, nutrient cycling, and a significant (but unquantified) portion of total estuarine energy flow. Most studies of these anaerobic forms have been gathered in other salt marshes, such as those in Massachusetts and Georgia (Teal and Kanwisher 1961; Howarth and Teal 1979, 1980).

Some of the important general roles of the complex anaerobic community are: 1) photosynthesis; 2) nitrogen fixation; 3) denitrification; 4) sulfate reduction (giving salt marshes their characteristic sulfury smell); 5) fermentation; 6) ammonification; and 7) methane generation.

The entire group of microbes has been compared to the digestive system of a cow, which uses microconsumers to turn low grade carbon (cellulose) into high grade carbon (milk and meat) Mann (1972). Unfortunately there is no good estimate of microconsumer respiration for MDPR salt marshes. It is assumed in this report that this value lies between 3,511 and 9,374 g dry wt/m^2/yr (Costanza et al. 1983). Based on this range for decomposition, the marsh may be exporting 4,650 g dry wt/m^2/yr of organic matter, or importing 1,200.

Organic matter is lost to the biotic portion of the marsh through sedimentation, or by export to streams, bayous, and/or the gulf. The loss of organic matter to deep sediments is small--about 731 g dry wt/m^2/yr. Since export of detritus has not been observed directly and there are uncertainties in the values for total net production and total decomposition, the amount of organic matter actually leaving the salt marsh cannot be estimated precisely. Additional research on belowground production, community respiration, and detrital export is needed.

Tidal flushing is the mechanism for export of dead plant material. Tidal ranges vary from 17 to 31 cm (7 to 12 in) (Table 7), although occasional hurricanes and storms cause greater surges. Tidal inundation of the marsh occurs throughout the year, but water levels are lower during the winter months because of northerly winds (Table 7). Water movement also provides an exchange of nitrogen, phosphorus, carbon, organisms and sediment between the estuary and the marsh. Water also leaves the marsh through evapotranspiration.

In addition to its contribution to the estuarine food web and many commercially and recreationally important fishery species, the salt marsh provides other commodities and services. The marsh supports fur bearing mammals such as raccoons and muskrats, and waterfowl that are hunted or trapped for food and sport. The salt marsh provides an important buffer of storm wave energy and assimilates human waste products (Mumphrey et al. 1978).

SPOIL BANKS (18)

Spoil is the term used to describe the mixture of water and sediment that

Table 7. Monthly tide levels (in cm) along the central Louisiana coast for 1958-59 (adapted from Chabreck 1972).

Month	Mean high tide	Mean low tide	Mean water level	Mean tidal range
Jan.	11.9	-10.7	0.6	22.6
Feb.	17.1	- 7.9	4.6	25.0
Mar.	18.3	- 5.5	6.4	23.8
Apr.	23.8	2.7	13.1	21.1
May	34.4	12.2	23.2	22.2
June	36.3	5.5	21.0	30.8
July	25.3	- 1.8	11.9	27.1
Aug.	25.3	3.4	14.3	21.9
Sept.	38.4	21.0	29.6	17.4
Oct.	32.3	11.9	21.9	20.4
Nov.	25.9	2.1	14.0	23.8
Dec.	11.3	-18.9	- 3.7	30.2
Avg.	25.0	1.2	13.1	23.9

results from dredging in aquatic and wetland habitats. Spoil material is commonly piled adjacent to the dredged site where it rises above the surrounding natural landscape and is called a spoil bank. The distribution of this habitat within the MDPR is illustrated in Figure 36.

Spoil banks are highly variable, depending on such factors as age, sediment type, dredging method, elevation, and location. For example, hydraulically dredged sediment that is high in clay may remain fluid for a long time, while bucket-dredged sediment from an organic rich area may be relatively consolidated. Hydraulically dredged sediment will spread out unless contained by a dike, while bucket-dredged sediment may initially remain in place without being confined. All unconstrained spoil will inevitably slump and spread out to some extent, blanketing a surface area of wetland much larger than the area dredged. Thus, the dredging of canals in wetlands creates spoil banks that are three or more times greater in area than the canal from which the spoil was removed.

A typical spoil bank in the MDPR is a linear structure resulting from the construction of an oil well access canal, a pipeline canal, or a navigation canal (Figure 37). A new spoil bank may initially rise as much as three meters (10 ft) above the surrounding wetland elevation, with a width of 30 m (100 ft) (Monte 1978). Most older spoil banks from oil access canals are lower, averaging perhaps 1 m.

Monte (1978) estimated that over 200,000 ha (494,000 acres) of spoil bank habitat existed in wetland regions of Louisiana at the time of her study. Estimates from the MDPR habitat mapping study (Table 5) indicate the presence of about 33,600 ha (83,000 acres) of spoil habitat in the MDPR in 1978, but this may be an underestimate because of the difficulty of measuring the area of spoil banks from aerial imagery.

Spoil area is rapidly increasing. For example, Louisiana receives about 2,200 permit applications yearly for various wetland modifications. The majority of the requests come from Terrebonne, Plaquemines, Lafourche, Jefferson, and St. Bernard Parishes. During 1981, 70% of all petroleum-related dredging permit requests involved saline and brackish marsh and estuarine open water habitats (Louisiana Department of Natural Resources 1982). Most of these projects create spoil banks, although many pipeline canals are backfilled after the pipe is laid.

The vegetation on wetland spoil banks usually follows a pattern of succession toward typically upland plant communities (Monte 1978). In salt marshes, the high soil salt content of newly created spoil banks retards colonization by plants other than salt marsh cordgrass. After several years as leaching decreases the spoil salt content, the bank becomes dominated by salt meadow grass. A ten year old spoil bank contains little salt and is dominated by shrubs such as eastern silverling and marsh elder. After 30 years, salt marsh spoil banks contain trees up to 25 cm (9.8 inches) diameter, including toothache trees and hackberry. Sixty-four percent of the plant species found on thirty-year-old salt marsh spoil banks are typical of upland rather than marsh habitats.

Succession on brackish marsh spoil banks follows a similar pattern, but lower initial soil salt content allows more rapid colonization by upland species. Thirty-year-old brackish marsh spoil banks are typically dominated by hackberry, toothache tree, chinaberry (Melia azedarach), and black willow, up to 10 m (33 ft) in height. Seventy-one percent of the plant species found are typical of upland rather than wetland habitats (Monte 1978).

Fresh marsh and swamp spoil bank succession proceeds even faster because of the absence of soil salts, and because seed sources are closer. Ten-year-old spoil is often vegetated by such bottomland hardwood species as cottonwood (Populus deltoides), red maple (Acer rubrum), black willow (Salix

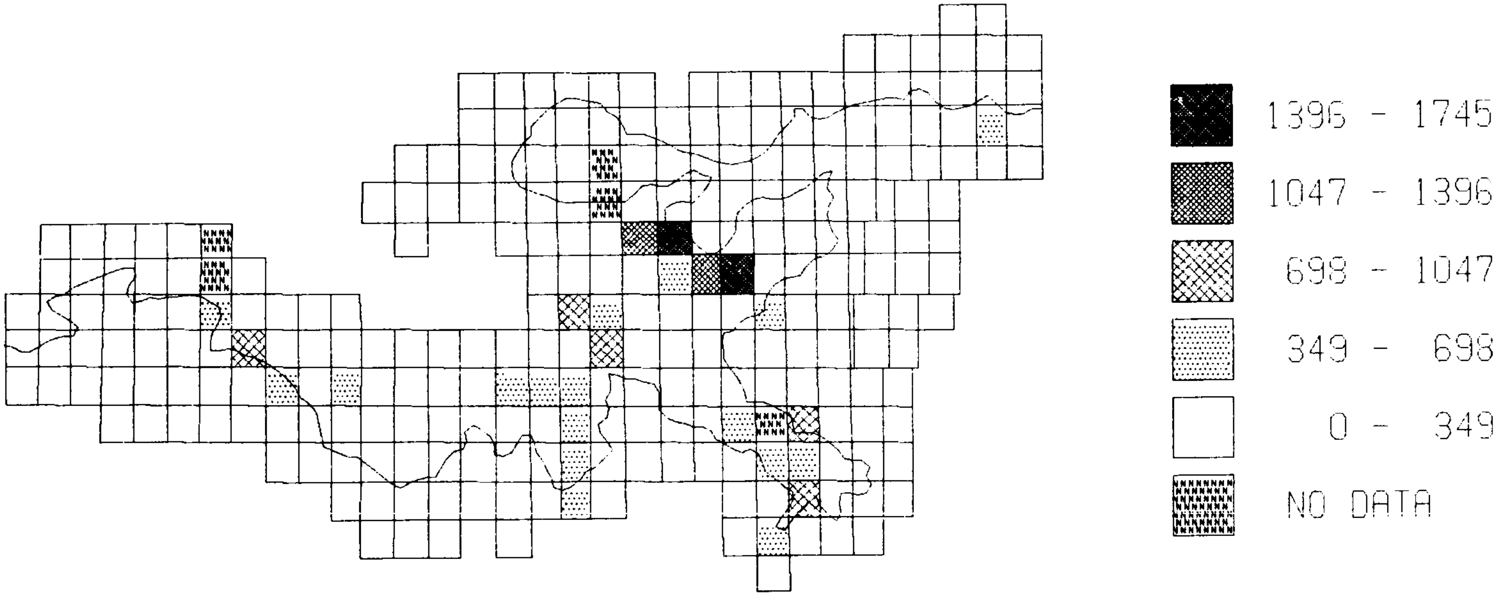


Figure 36. The distribution of MDPR spoil habitat.

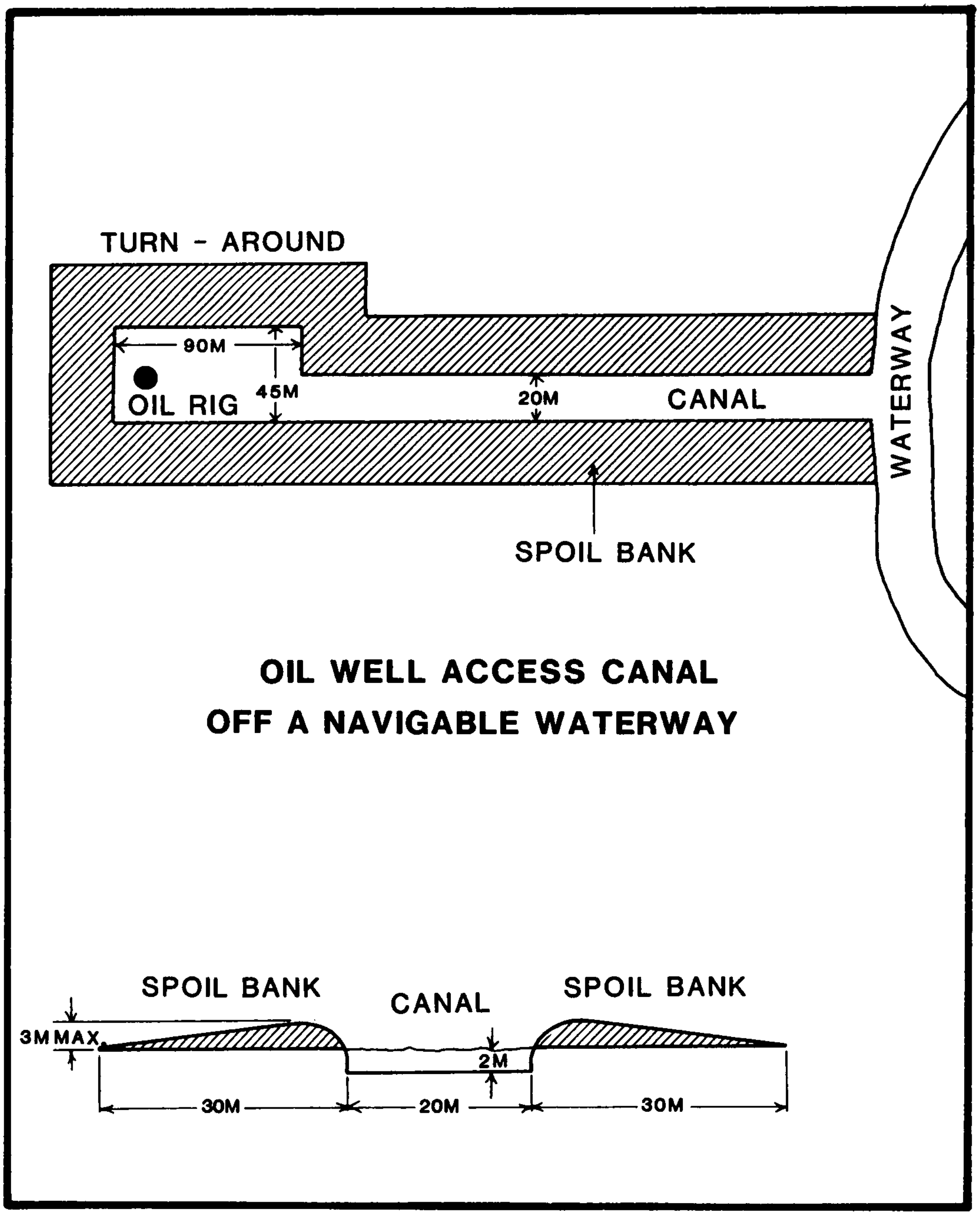


Figure 37. Typical canal configuration (from Monte 1978).

niger), and green ash (Fraxinus pennsylvanica). Monte (1978) found fresh marsh and swamp spoil banks to be dominated by 47% and 69% upland trees and shrubs, respectively, after 30 years.

During its ecological succession, a spoil bank consolidates and slumps, and some of its organic sediments oxidize and disappear. Bank elevation gradually diminishes, increasing the flooding frequency that ultimately determines the makeup of the plant community. The composition of the climax community is extremely sensitive to elevation. The highest and oldest spoil banks resemble natural levee ridge (upland forest) habitat, in terms of species composition; however they would have to survive for hundreds of years in order for the plant community to reach maturity. With a subsidence rate of about 1 m per century, this is unlikely to occur.

Because spoil banks become colonized by a variety of plant and animal species not normally associated with wetlands, some workers have described this feature as being ecologically beneficial (e.g., Monte 1978). Local increase in habitat and species diversity is far outweighed in most cases, however, by the widespread disruption of natural hydrology that spoil banks create.

The ecological impacts of spoil banks on the habitats on which they are superimposed are variable. Nevertheless, these impacts can be divided into local (direct) impacts and general (cumulative) impacts. Local impacts include the direct loss of wetlands because of sediment deposition, and the imposition of a barrier to water flow between marsh and open water. This interruption of flow can stress wetland vegetation by reducing its flushing action and nutrient acquisition, and changing its salinity regime. These changes may reduce primary productivity, as demonstrated by Mendelssohn et al. (1981). Even a few centimeters of artificial increase in elevation may interrupt water movement. Spoil banks also prevent the local export of plant-derived carbon into natural water bodies or canals.

Spoil banks in wetlands may also increase local species diversity by allowing the colonization of upland vegetation and the migration of large animals (including cattle) into the marsh. Mammals that often inhabit spoil banks include raccoons, deer, rabbits, and armadillos. Many birds use spoil banks as nesting areas, and migratory birds use them as resting areas. Increased habitat for terrestrial fauna resulting from spoil banks must be weighed against losses in wetland productivity caused by hydrological modifications. Areas of higher elevation in marsh areas may in some cases be marginally beneficial. The major problem with spoil banks in the MDPR is their effect on wetland hydrology and the negative impact this has on primary productivity.

Spoil banks are usually long, unbroken, linear elements built without regard to local patterns of water movement. Spoil banks could be constructed to have minimum impact on local hydrology, thus providing "islands" of species diversity without incurring additional ecological costs, but this is seldom if ever the case. In almost all instances the spoil is the result of a canal whose purpose is to link two points with the shortest possible transport distance, i.e., a straight line.

There are numerous dramatic examples of the inadvertent impact of spoil banks on wetland hydrology and viability. One of the best documented examples is a portion of the des Allemands swamp forest study area described by Conner et al. (1981). This accidentally impounded swamp is dying and turning into a stagnant bog.

Can this situation be changed? Studies are underway to determine the effectiveness of spoil bank modifications as follow: backfilling canals and eliminating the adjacent spoil banks, creating numerous breaks in the spoil bank to allow water movement, placing the original spoil in less harmful ways, and alternatives to canals and spoil banks in general. The results of these studies will have significant management implications.

UPLAND FORESTS (19)

Upland forests occur on the Pleistocene Terrace north of Lake Pontchartrain, in Mississippi, and on a series of narrow natural levee ridges that extend as peninsulas into wetland areas (Figure 38). This habitat occupies about 71,000 ha (175,000 acres) of the MDPR in 1978, or 2.02% of the region (Table 5).

Upland forest habitat was formerly much greater, occupying most of the natural levees. The upland forest habitat has probably been more drastically reduced, in a relative sense, in the MDPR than any other natural habitat. Most of this area has been developed for agriculture and urban-industrial use because it is the most elevated land in a region in which development has often been limited by high land.

Upland forest habitat grades into bottomland hardwood as elevation declines and flooding frequency increases on the lateral slopes of the natural levee ridges. Bottomland hardwood habitat in turn grades into swamp forest habitat with further decline in elevation toward the interdistributary basins. This gradual change is illustrated in Figure 39, which shows the spectrum of flood tolerance of various trees.

The natural levee ridges on which the remaining upland forest habitat is found are composed of Mississippi River alluvial soils. The higher soils are characteristically silty loams, which are well oxygenated. At lower elevation the soils are more clayey and firm when moist (Monte 1978). The maximum elevation of the natural levee ridges in the MDPR is less than 6 m above sea level, and most levee areas are less than 3 m (Monte 1978).

Natural climax vegetation on well-drained and undeveloped Pleistocene Terrace sites is dominated by mixed deciduous and evergreen trees that are less tolerant to flooding than are many bottomland hardwood species. These include oaks (*Quercus virginiana*, *Q. alba*, *Q. nigra*), shagbark hickory (*Carya ovata*), hackberry (*Celtis laevigata*), sweetgum (*Liquidambar styraciflua*), pecan (*Carya illinoensis*), magnolia (*Magnolia* sp.), and various pines. Some of the pine woodlands are now cultivated for lumber and pulpwood.

Ridges supporting upland vegetation are prominent in marsh zones because they support woody vegetation and they are often visibly dominated by mature (sometimes stunted and dying) live oak trees. Natural levees serve as homes and migration routes for some terrestrial animals that may venture into the marsh for food during low water. During very high tides and storm surges, the levee ridges may be the only exposed land, and they can become densely populated.

From prehistoric times until the present, natural levees have also provided human beings with the only firm living and transportation space available. The cultural pressure on natural levee ridges is intense, and undisturbed natural levee habitat is scarce. Natural levee ridge habitat includes all the old Mississippi River distributary ridges, such as the Bayou Lafourche ridge, the Metairie-New Orleans ridge and the old Bayou Teche ridge, upon which Morgan City is located.

The Caminada ridges in the lower Barataria hydrologic unit are not natural levees, but stranded beach ridges (cheniers) parallel to the coast line. Such ridges also occur in Southern Hancock County, Mississippi (Otvos 1981).

URBAN-INDUSTRIAL (20)

The urban-industrial system is not often thought of as a habitat, since human settlements have acquired the connotations of artificial and even unnatural environments. Humans and their artifacts are, however, constrained by many of the same factors that limit other forms of life. Thus this study treated the habitat in which human beings live and work as analogously as

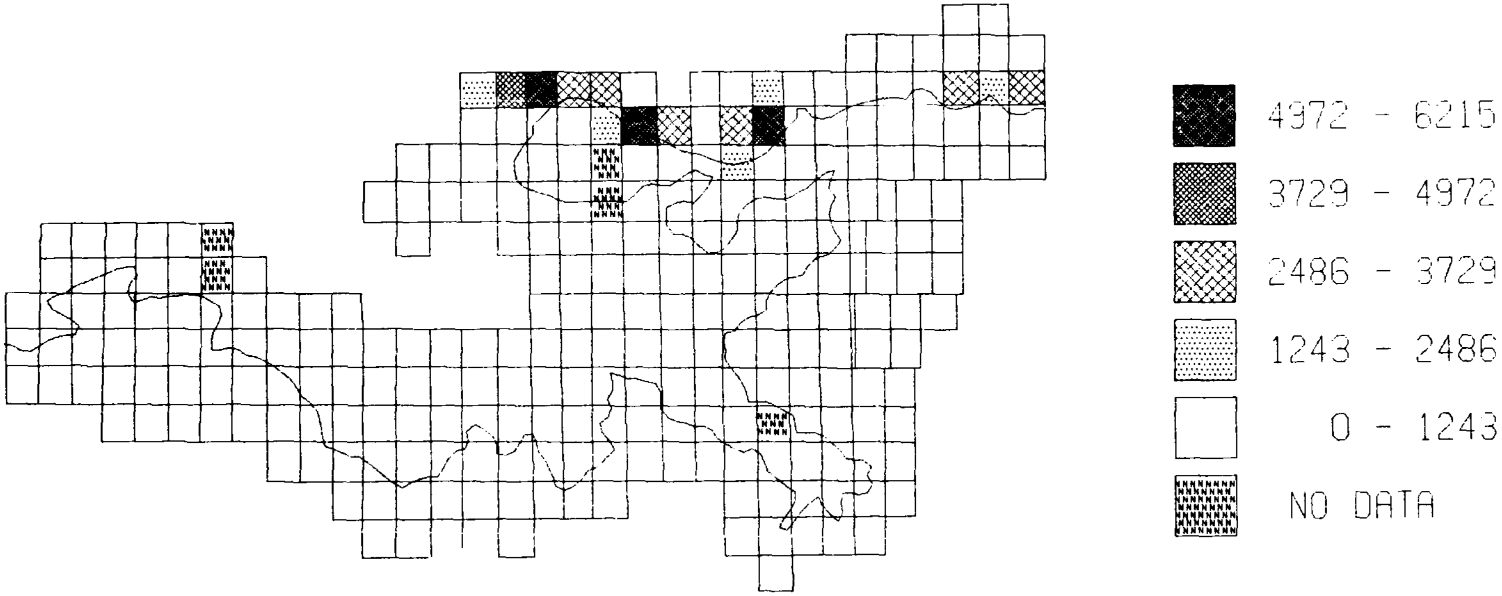


Figure 38. The distribution of MDPR upland forest habitat.

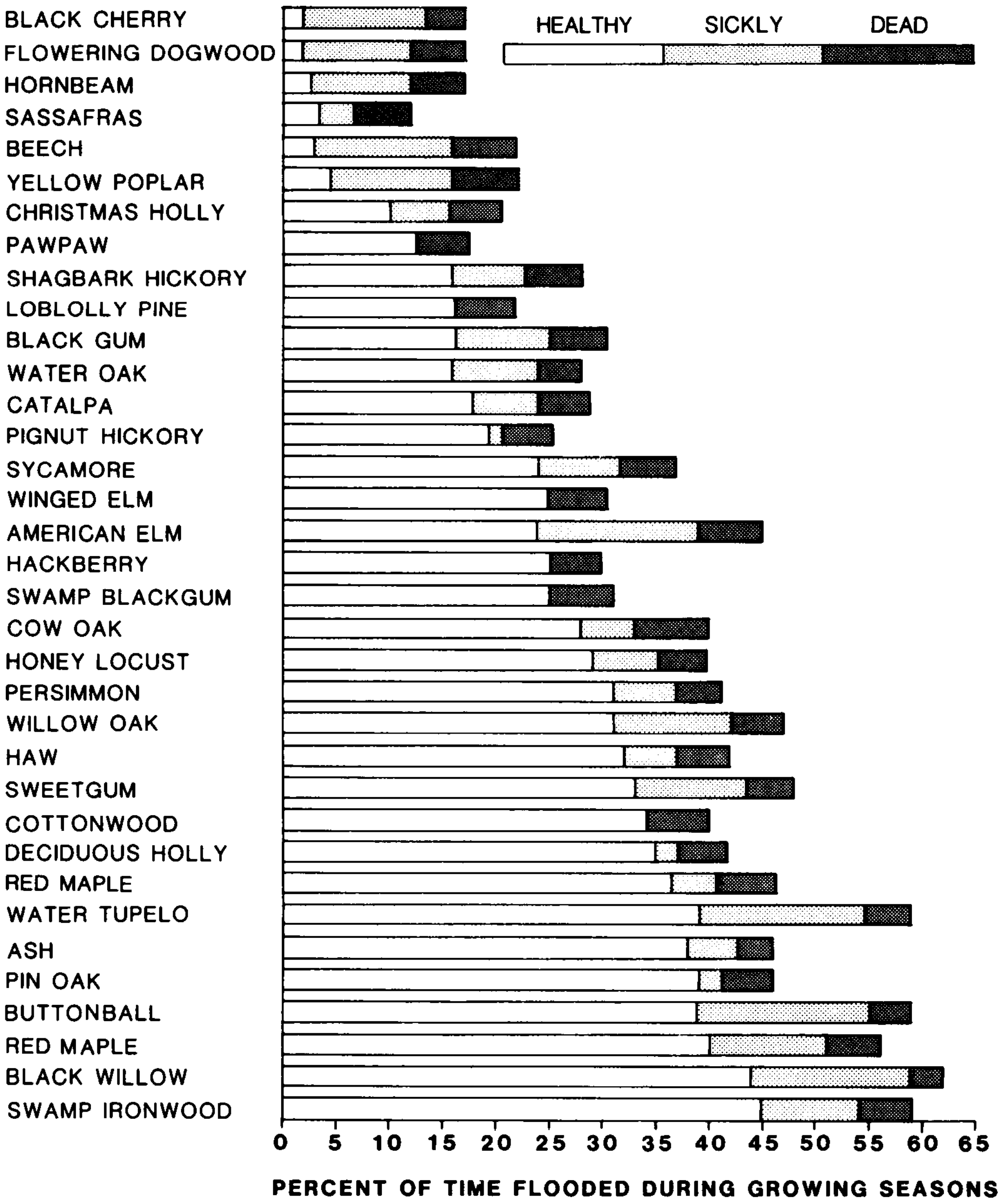


Figure 39. Tolerance to flooding during the growing season of 3-inch DBH and larger bottomland hardwood tree species of the MDPR (Monte 1978).

possible to the other "natural" habitats. Instead of plant and animal groups, the urban-industrial habitat was divided into "sectors" that produce and consume a set of commodities different from those that are important in natural habitats. In the technical report (Costanza et al. 1983) a model of the urban-industrial habitat was developed, divided into 13 major sectors.

The urban-industrial habitat covered 102,000 ha (252,000 acres) in the MDPR in 1978, or almost 3% of the total land and water area (Table 5). The distribution of urban-industrial habitat in the region is shown in Figure 40. New Orleans is the major urban center in the region, and industrial activity is concentrated along the Mississippi River corridor.

Details of the urban-industrial habitat are better known than most of the non-human habitats (Costanza et al. 1983; Larson et al. 1980). The urban-industrial system is distinct from the other habitats in that its major direct energy source is fossil fuel rather than sunlight, and it exchanges materials with other urban-industrial habitats at much longer range than the other habitats in the region.

The three major "raw materials processing" sectors in this habitat are forestry and fisheries, oil and gas extraction, and other mining (sulphur and salt mining in the MDPR). These three sectors process raw material inputs received directly from the local environment, resulting in products for use by other local sectors and for export. Oil and gas extraction is by far the dominant raw material activity in terms of dollar value, accounting for more than \$1/yr generated for each m^2 of urban-industrial land in 1978 (Costanza et al. 1983). Of the oil and gas produced, more than 70% is exported from the region before further processing. Oil and gas extraction activities will eventually wane, however. The more modest \$.015/m^2/yr generated by forestry and fisheries production represents a possibly sustainable value derived from the annual production of the local ecological systems (Bahr et al. 1982).

The major goods producing sector of the MDPR economy produces \$.26/yr worth of goods for each m^2 of urban-industrial land. The construction sector produces many of the capital goods and structures used in the region and exports about 18% of its total output. The petroleum refining, chemicals, and allied products sector is important in the MDPR, producing at an intensity of \$.69/m^2/yr; and most of its production (80%) is exported to the national market. Other manufacturing is important in the region, but a net import of about 10% of the total requirements for manufactured goods is necessary to satisfy all local users (Costanza et al. 1983).

Six sectors represent the services component of the economy, divided into transportation and communication services, utilities, wholesale and retail trade, finance, insurance and real estate services, and other services. The services sectors represent an essential component in the local economy, managing the flow of goods and information. Together they contribute \$1.67/m^2/yr to the MDPR economy.

The households and local government sectors complete the picture of the MDPR urban-industrial habitat. Households represent a major component in the economy. They consume much of the local production of the other sectors and provide labor services that are a major input to all the other sectors at an average intensity of \$2.14/m^2/yr. About 10% of the required labor services must be imported from outside the MDPR. In contrast, about 90% of government services are imported from outside the MDPR (from State and Federal governments).

Inputs to the urban-industrial habitat include fossil fuel, direct solar energy, wind, water, agricultural products, and natural products (fish, wildlife, and forest products) from the other habitats in the MDPR. The habitat produces waste water, elemental wastes, heavy metals, organic carbon, hydrocarbons, air pollutants, and solid wastes that are absorbed by the region's other habitats or exported. Summary rates of resource use and waste production by the MDPR urban-industrial

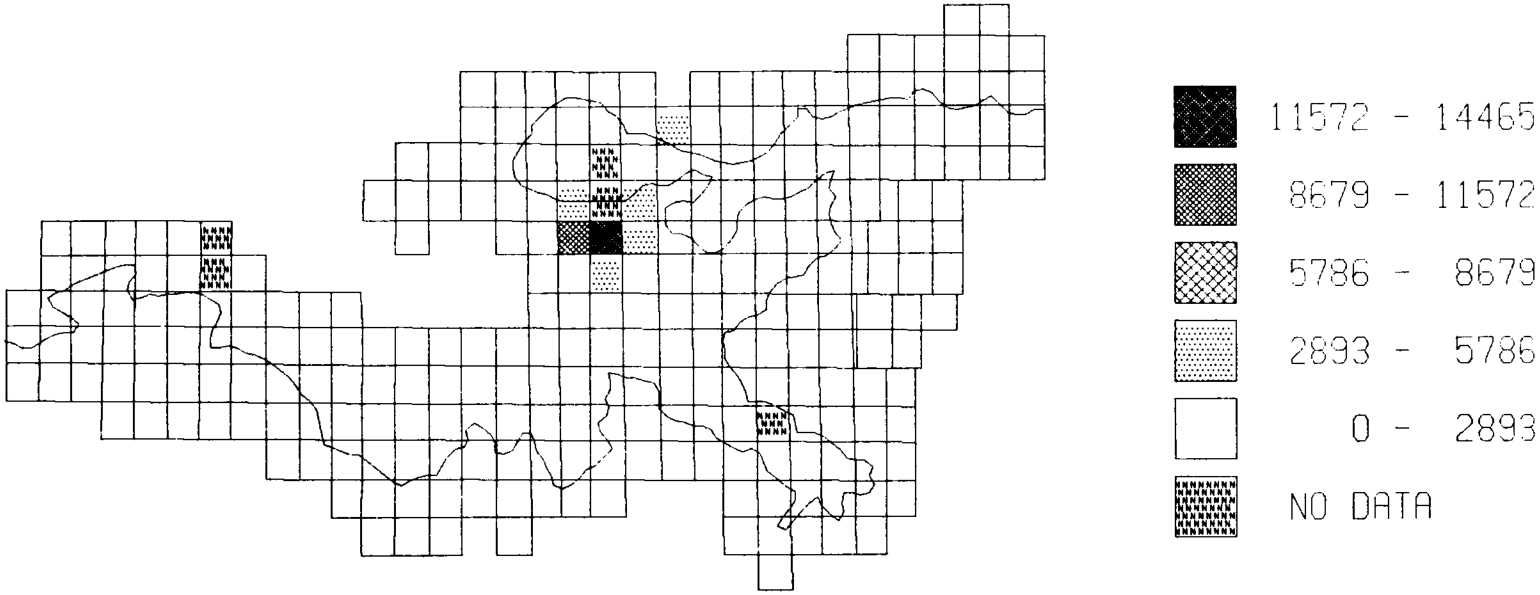


Figure 40. The distribution of MDPR urban-industrial habitat.

habitat are listed in Table 8. Additional details are given in Costanza et al. (1983).

Table 8. Summary resource use and waste production coefficients for the MDPR urban-industrial habitat (Costanza et al. 1983).

Resource or waste product	Use or production intensity for MDPR urban-industrial habitat	
Water	1.83	m^3/$
Waste water	1.69	m^3/$
Solid waste	0.46	kg/$
Air pollutants	0.51	kg/$
Elemental wastes	0.02	kg/$
Heavy metals	0.28	g/$
Organic waste	0.05	kg/$
Hydrocarbons	0.03	kg/$

HYDROLOGIC UNIT DESCRIPTIONS

At the hydrologic unit level of resolution, habitats are the functional components. The primary connections between habitats are water flows with their dissolved and suspended loads of nutrients and organic matter, natural animal migrations, harvests of economically important plants and animals, and flows of urban and agricultural waste products.

The 20 habitats distinguished in the MDPR can be grouped into three broad categories: (1) high land or terrestrial habitats, (2) intertidal or periodically-flooded habitats, and, (3) aquatic or continuously flooded habitats. Net hydrologic flows through a basin can generally be considered to pass from high land to intertidal to aquatic habitats. This means that by-products of the first two habitat groups are often "washed" into aquatic habitats and assimilated by them. This is a matter of great importance in terms of natural ecosystem functions and human perturbations of these functions.

A major feedback flow from the downstream habitats to the socioeconomic system is the harvest of marketable organisms (fishery, game, and fur species) from the natural coastal ecosystem. Also important are a broad range of non-marketed ecosystem services, such as waste assimilation, climate control, marine energy inputs to coastal production, nursery ground and migratory bird access, aesthetics, and recreation.

Money flows and purchased goods and services connect urban-industrial habitats with the external economy. Agricultural and urban habitats produce waste by-products that must be assimilated by other habitats in the coastal ecosystem.

Relative proportions of area covered by the 20 habitats differ greatly from basin to basin. The relative area of a habitat may indicate its importance in the basin in question, especially habitats in Groups 2 and 3. However, Group 1, or high land habitats, often show a functional significance greater than their areal extent would indicate, because: (1) urban-industrial, agricultural, and other socioeconomic processes tend to be concentrated in upland habitats and many waste materials are released downstream into flooded zones, and (2) any physical relief or elevation (either natural or manmade) in an otherwise flat coastal area is almost certain to affect water flows and productivity in flooded areas.

Specific hydrologic units contain unique distributions of habitats based on their natural and economic histories. For example, the Atchafalaya basin contains no salt marsh because it is a new emerging delta with large fresh water inputs.

In the following sections, each of the seven hydrologic units in the MDPR are described. Some hydrologic units (such as Pontchartrain, Barataria, and Atachafalaya) have been the subject of much scientific study over the years, while others have received less attention. These differences in both the quantity of information and the types of information available are reflected in the descriptions. For example, the Barataria basin has been the subject of detailed study on eutrophication and other human impacts. These topics are therefore emphasized in the Barataria hydrologic unit description. The Atchafalaya Delta has been the site of much study on sedimentation patterns and marsh colonization, and these topics are emphasized in the Atachafalaya hydrologic unit description. Some hydrologic units are less well understood and their descriptions are necessarily more generalized.

MISSISSIPPI SOUND HYDROLOGIC UNIT (I)

The Mississippi Sound hydrologic unit occupies the eastern flank of the deltaic plain. It is bounded on the north by the 15-ft elevation contour, on the west and southwest by the Pontchartrain hydrologic unit, on the south by the 3 mile limit, and on the east by the

Mississippi-Alabama State line (Figure 41).

The areas of each of the 20 component habitats in this hydrologic unit and changes in habitat areas from 1955 to 1978 are shown in Table 9.

The coastal plain is narrow in Mississippi, compared to its width in the remainder of the MDPR to the west. The rolling, upland DeSoto National Forest occupies much of the land north of the basin. Upland forest (habitat 19) makes up a significant proportion of the Mississippi Sound hydrologic unit, primarily because the inland boundary is defined by a relatively high elevation contour rather than by a political coastal zone boundary as in Louisiana.

The string of barrier islands in the Mississippi Sound hydrologic unit are unusually far from the mainland compared to other islands in the MDPR (Otvos 1981). These islands demarcate Mississippi Sound, the single largest habitat component of the basin (habitat 16, estuarine open water). The open water area beyond the barrier islands to the three mile limit is considered nearshore gulf habitat (habitat 13), and the Mississippi Sound hydrologic unit contains the largest portion of this habitat of the seven hydrologic units in the MDPR.

Wetland habitats consist of the marshes and swamp forests that occupy the lower Pearl River valley and surround the four bays that interrupt the shoreline of Mississippi: Bay St. Louis, Biloxi Bay, Pascagoula Bay, and Point aux Chenes Bay.

The eastern boundary of the hydrologic unit (the Mississippi-Alabama State Line) has no geological or ecological significance. The Alabama portion of Mississippi Sound (including Mobile Bay) is functionally continuous with the drainage basin described here. The western boundary of the basin is continuous with the Pontchartrain hydrologic unit, and waters from the two hydrologic units mix at the interface between Lake Borgne and Mississippi Sound.

Because of the rapid urban growth of the Mississippi gulf coast area, the urban-industrial habitat (habitat 20) is now relatively prominent in this unit. The agricultural habitat (habitat 1) is also relatively large, but it has been rapidly losing ground to urban-industrial uses in the last two decades, as shown in Table 9.

Freshwater input to the basin is normally limited to rainfall and drainage from coastal rivers. Average river inputs in cubic meters per second are as follow: Pascagoula, 378.35; Pearl, 327.72; Jourdan, 23.47; Wolf, 19.98; Biloxi, 13.97; and Tchoutacabouffa, 12.36 (Eleuterius 1978). During extreme high water stages on the Mississippi River the Bonnet Carre Spillway is opened, and Mississippi River water drains through Lake Pontchartrain and Lake Borgne into Mississippi Sound. The effect of opening the spillway may be quite significant, as shown by the widespread oyster mortality that accompanied the last opening of the spillway during the spring of 1979. Oyster production in Mississippi Sound in 1980 was lower than it had been for at least 3 decades (Deegen et al. 1981).

Geological History

The following brief description of the geological history of the Mississippi Sound hydrologic unit is summarized from Otvos (1981). The developed part of the coastline (the so-called Mississippi Gold Coast) is located on ancient beach ridges, the Gulfport Formation overlying the Biloxi Formation, that formed about 1.25 million years B.P., during the Sangomon interglacial period when sea level stood higher than at present. More recently during the late Pleistocene period of sea level decline, river trenches were eroded into the prairie terrace in the Gulf of Mexico seaward of the present location of the barrier islands. These entrenchments filled with sediments as sea level rose again in late Wisconsin and early Holocene times until it stabilized again about 4,500 years B.P. The bays along the Mississippi coast formed at this time, as sea water filled the coastal depressions, and most of the area now

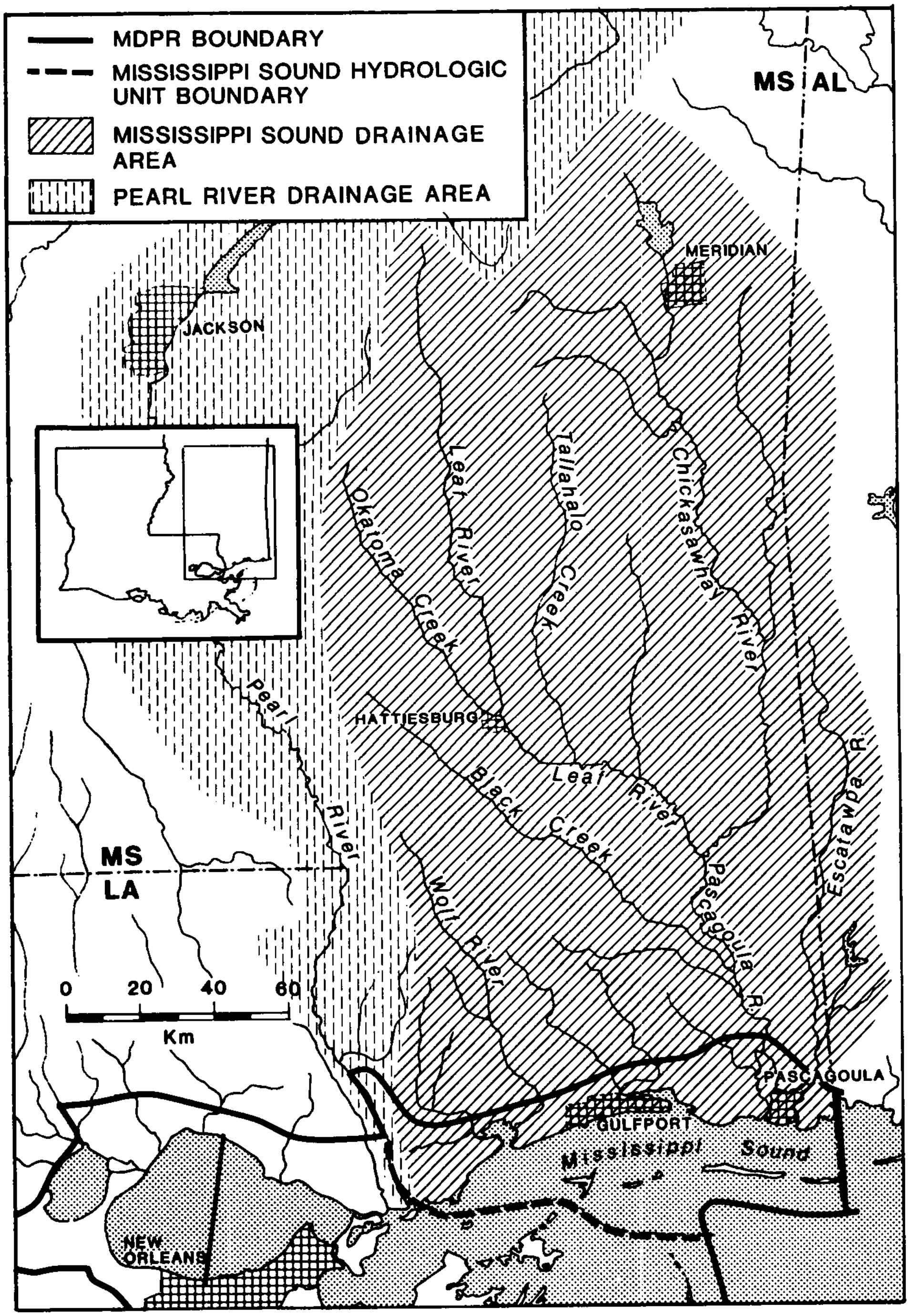


Figure 41. Map of the Mississippi Sound drainage basin showing the MDPR boundary.

Table 9. Habitat areas in hydrologic unit I, Mississippi Sound.

Habitat		Area (ha)		Change in area[a]
No.	Description	1955	1978	(1978-1955)
		(2.47 acres/ha)		(ha)
1	Agriculture	25901	10930	-14971
2	Beach and dune	2340	1973	-367
3	Bottomland hardwoods	16917	17157	240
4	Brackish marsh	(b)	14702	(b)
5	Canals	107	402	295
6	Cypress-tupelo	13547	13421	-126
7	Fresh aquatic bed	19	62	43
8	Fresh marsh	2578	1451	-1127
9	Fresh open water	389	790	401
10	Fresh scrub-shrub	214	404	190
11	Mangroves	-	-	-
12	Mud flats	248	152	-96
13	Nearshore gulf	42774	41849	-925
14	Rivers, streams	1980	1827	-153
15	Estuarine aquatic bed	537	4265	3728
16	Estuarine open water	147877	146402	-1475
17	Salt marsh	26859	10899	-1258[b]
18	Spoil banks	196	943	747
19	Upland forest	27258	31014	3756
20	Urban-industrial	6591	17686	11095
	Total	316332	316329	

[a] Due to differences in classification and resolution between the 1955 and 1978 maps, care must be taken in interpreting the area changes shown in this table. See text for a more complete explanation.

[b] Brackish marsh was not delineated on the 1955 maps, but was included with salt marsh as "nonfresh marsh." Therefore, the change in salt marsh number was set equal to the change in total nonfresh marsh.

occupied by Mississippi Sound was a full salinity system, as shown by marine foraminifera remains in sediment cores. The nearshore zone was brackish, however, especially near the mouths of the two large rivers (Pearl and Pascagoula).

The barrier islands formed following the slowdown in sea level rise about 4,000 years B.P. These islands formed from the accretion of bottom sediments that had originally eroded from the Alabama mainland. They formed a 230 km long barrier island-shoal chain that extended between Dauphin Island, Alabama, and the present Jefferson Parish-New Orleans metropolitan area.

Between about 3,000 and 2,300 years B.P., St. Bernard delta sediments from the Mississippi River prograded into the gulf to about 3-20 km south of the present Cat, Ship, and Horn Islands. This delta reduced wave energy from the west and stopped the progradation of Cat Island. After the Mississippi River abandoned the St. Bernard distributary, erosion of delta sediments led to severe erosion of Mississippi coastal marshlands. The Chandeleur Island chain formed parallel to the original delta lobe shore and has since migrated westward.

During recent times the Mississippi Sound barrier islands have been strongly affected by hurricanes, as well as by normal beach erosion and westward littoral drift. Although the islands have shown a net westward migration, new islands have formed on the east end of Mississippi Sound following the passage of hurricanes.

The Mississippi Sound Estuary

Mississippi Sound makes up the largest habitat type in the Mississippi Sound hydrologic unit. This elongated shallow estuary is bordered on the north by a series of small bays, marshes, bayous, and rivers and on the south by a chain of islands. Average overall depth is 2.97 m, with 3.5 to 6 m depths in central areas (Otvos 1981). Fresh water input is primarily through the Pearl and Pascagoula drainage basins, in addition to minor inputs from St. Louis Bay and Biloxi Bay. Mississippi River water may be introduced through Chandeleur Sound (Lytle and Lytle 1981) as well as through Lake Borgne during openings of the Bonnet Carre spillway. Marine water from the gulf enters the Sound through the island passes.

Mississippi Sound is characterized by low tide and wave energy, and highly variable salinity. There is a dominant westward littoral drift, due to prevailing SE, S, and SW winds. Much of the time the water column is uniform and well mixed, and it rarely stratifies (Eleuterius 1978).

Bottom sediments are muddy (silty-clayey) in central areas and sandy along island and mainland shores. Much of the sound is underlain with fossil oyster reefs, and the largest recent reefs exist south of St. Louis Bay, (Square Handkerchief, Pass Marianna, and Telegraph Reefs) with a total area of about 3,000 ha (7,400 acres) and a maximum thickness of 4 m (Otvos 1981).

Oysters are still common in Mississippi Sound, although oyster production has declined significantly over time. Commercial production in Mississippi Sound peaked in the early 1900's, declined and leveled off during the 1950's and 60's, and declined further in recent years. In 1979, only 41,000 pounds of oyster meat were harvested, compared to 4,680,000 pounds in 1963 (Deegen et al. 1981). The decline has been attributed to adverse salinities, reef closure in bay waters, and storm damage (Deegen et al 1981). An effort is underway to restore some of the oyster-growing potential through shell planting by the Mississippi Bureau of Marine Resources. A private leasing system has also been suggested to encourage improved management. Many natural oyster beds are closed because of increasing sewage pollution resulting from increasing coastal urbanization.

Fisheries in the Mississippi Sound hydrologic unit include finfish and shellfish, which are dominated by menhaden and industrial bottomfish (e.g., croaker and spot), shrimp, crabs and oysters, in decreasing order by volume. Industrial pet food represents a significant volume of additional finfish which are not reported. Fishery harvest also includes spotted and white sea trout, flounder, red drum, red snapper, spiny lobster, and squid (McIlwain 1981). Most of these fishery products are landed in the Port of Pascagoula-Moss Point (McIlwain 1981), but the proportion caught inside Mississippi Sound is not reported.

A large amount of sediment dredging and spoil disposal occurs in Mississippi Sound, primarily for navigation channels. Gulfport, Biloxi, and Pascagoula each have such channels extending across the sound. In 1977, the USACE was authorized to conduct a study to determine whether present and proposed dredging activities in the gulf coast area could be modified to reduce costs and improve environmental quality. This (ongoing) study is known as the Mississippi Sound and Adjacent Areas Study (MSAAS), and it includes the area from Lake Borgne to Mobile Bay (Waters 1981). A variety of oceanographic parameters are being examined (Parker 1981).

In addition, a baseline survey of the benthic community in the Sound is being carried out. Preliminary results from fall of 1980 indicate a much richer macrofaunal community than is found in Lake Pontchartrain. For example, a total of 330 infaunal taxa (benthic macrofauna) have been identified, with an average abundance of 7,090 organisms/m^2 (Vittor 1981). These animals were numerically dominated by polychaete worms and crustaceans. In Lake Pontchartrain only 31 species of macrofauna were identified in a series of detailed studies of the entire bottom community, in which total abundance was dominated by small gastropods (Bahr et al. 1980; Sikora et al. 1981; Sikora and Sikora 1982).

Industrial effects on Mississippi Sound are presumably higher at the eastern end of the estuary, near Mobile Bay. The most heavily developed of the Mississippi portion of the coast is the Pascagoula River (Lytle and Lytle 1981). A recent study of toxins in the nearshore portion of Mississippi Sound indicated that St. Louis Bay shows significantly less influence of toxic pollutants in sediments than the Pascagoula River mouth (Lytle and Lytle 1981).

PONTCHARTRAIN HYDROLOGIC UNIT (II)

The Pontchartrain basin is the largest of the seven basins. It occupies most of the coastal land and water between the Mississippi and Pearl Rivers. The entire Pontchartrain drainage basin is shown in Figure 42, which also depicts the official MDPR study area boundary. Table 10 shows habitat areas and changes from 1955 to 1978.

The most distinctive features of the Pontchartrain basin are its large estuarine open water and urban-industrial habitats. The estuarine open water habitat consists mainly of three large, shallow, interconnected waterbodies: Lakes Maurepas, Pontchartrain, and Borgne, that occupy the largest part of the basin.

The urban and estuarine open water habitats dominate the Pontchartrain basin in a functional as well as an areal sense. The urban-industrial habitat includes primarily New Orleans and its suburbs, with a small amount of additional urbanized land scattered around the basin. New Orleans is the largest urban center in the MDPR, and the only major city in the United States that is located entirely in a flood plain (Most of New Orleans is below sea level). Large (and increasing) costs are incurred to keep New Orleans dry (Wagner and Durabb 1977). Levees must be maintained, and large parts of the city must be pumped dry after every rainstorm. Why build a city on such an inhospitable site? The answer is that New Orleans was sited originally during a relatively flood-free period, and on an area of relatively high land (natural levee) as close to the Gulf and to Lake Pontchartrain as possible, to facilitate ocean, river, and coastal commerce

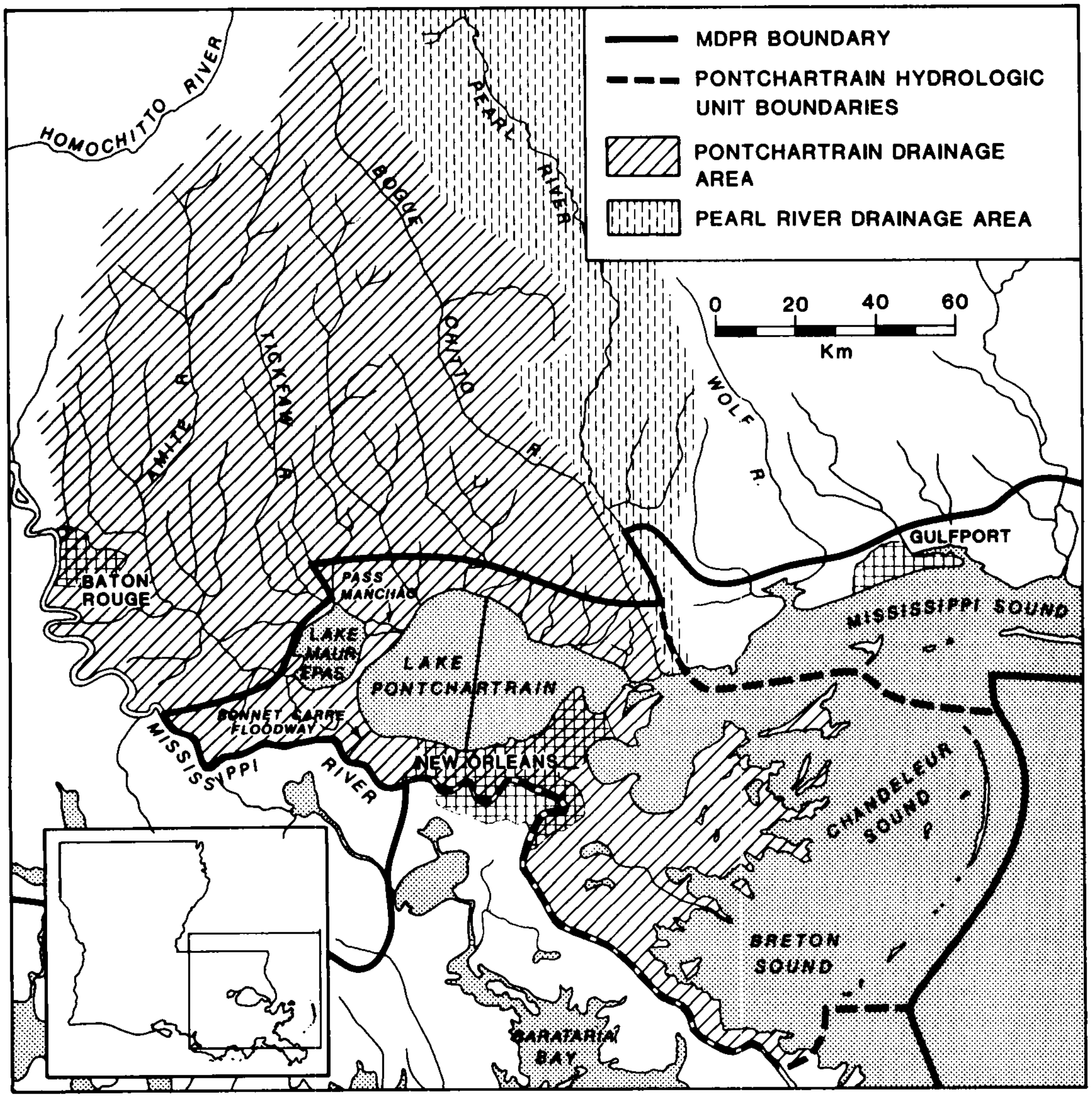


Figure 42. Map of the Pontchartrain drainage basin showing the MDPR boundary.

Table 10. Habitat areas in hydrologic unit II-Pontchartrain.

Habitat		Area (ha)		Change in area[a]
No.	Description	1955	1978	(1978-1955)
		(2.47 acres/ha)		(ha)
1	Agriculture	45008	23949	-21059
2	Beach and dune	1737	988	-749
3	Bottomland hardwoods	20986	15042	-5944
4	Brackish marsh	(b)	129487	(b)
5	Canals	3551	7366	3815
6	Cypress-tupelo	91553	73903	-17650
7	Fresh aquatic bed	409	1809	1400
8	Fresh marsh	36855	14519	-22336
9	Fresh open water	24232	1714	-22518
10	Fresh scrub-shrub	764	2460	1696
11	Mangroves	63	208	145
12	Mud flats	975	245	-730
13	Nearshore gulf	76505	74721	-1784
14	Rivers, streams	2367	1412	-955
15	Estuarine aquatic bed	-	1420	1420
16	Estuarine open water	740222	797036	56814
17	Salt marsh	185018	45793	-9738[b]
18	Spoil banks	2191	9453	7262[b]
19	Upland forest	31393	36110	4717
20	Urban-industrial	27987	55116	27129
	Total	1291816	1292751	

[a] Due to differences in classification and resolution between the 1955 and 1978 maps, care must be taken in interpreting the area changes shown in this table. See text for a more complete explanation.

[b] Brackish marsh was not delineated on the 1955 maps, but was included with salt marsh as "nonfresh marsh." Therefore, the change in salt marsh number was set equal to the change in total nonfresh marsh.

(Lewis 1976). As the city prospered it grew beyond its available high land into the surrounding wetlands.

The industrial corridor from New Orleans to Baton Rouge on the Mississippi River (taken together) is now one of the most active port complexes in the world. New Orleans' strategic location fostered its development as a major port city, but severe constraints on dry land, combined with a shift from water to rail and truck transport, reduced its competitive advantage. The population growth of New Orleans was thus slowed relative to other major U.S. cities (Figure 43).

Description of the Area

Lakes Maurepas, Pontchartrain, and Borgne are delta flank depressions, or low areas at the edge of a formerly active delta system. They are the remnants of a large arm of the Gulf of Mexico that was partially pinched off by the progradation of the St. Bernard Delta complex that was active from about 2,500 to 1,000 years B.P. (Kolb and Van Lopik 1958). The area of these lakes has increased somewhat in recent times as a result of sea level rise, shoreline erosion, land subsidence, and wetland deterioration. For example, the northwest shoreline of Lake Pontchartrain was formerly bounded by swamp forest and freshwater marsh that is now becoming open water because of a combination of the above processes.

Water quality in the estuarine open water habitat is a function of the components of the basin watershed, which extends inland to about 65 km (40 mi) east of Natchez, Mississippi. This watershed includes the large (300,000 population) and growing Louisiana State Capital city of Baton Rouge and a rapidly developing "bedroom community" fringe along the north shore of Lake Pontchartrain.

Lake Pontchartrain is a large (1,700 ha, 4,199 acres) shallow (5m, or 16 ft) well-mixed, oligohaline estuary with a turnover, or flushing time from 60 to 100 days (Swenson 1980). Although the Mississippi River does not normally flow directly into the lake, a natural crevasse site on the west side of the lake has been converted into a controlled diversion structure (the Bonnet Carre Floodway) through which excess flood water from the river has been released six times (1937, 1945, 1950, 1973, 1975, and 1979) since the construction of the floodway in 1931. When Mississippi waters are diverted into the Bonnet Carre, enormous quantities of sediment also enter, but there is no sign that the lake has become shallower during recent times (Stone 1980b). The depth of the lake is apparently maintained by wind-driven erosion that scours excess sediment from the bottom (Price 1947) and exports it to the gulf via Lake Borgne.

Fresh water (other than precipitation) enters the lake from Pass Manchac to the west, the Tchefuncte and Tangipahoa Rivers and some smaller streams and bayous to the north, the New Orleans drainage canals to the south, some marsh bayous west of New Orleans, and aperiodically from the Pearl River basin under certain wind and flood conditions.

There are indications that Lake Pontchartrain water has declined in quality in recent times (Stone 1980a and b; Turner et al. 1980; Sikora and Sikora 1982). These signs are nutrient increases without corresponding increases in primary production, population changes in nekton and zooplankton, benthic community changes, a decline in organic matter in the sediments, a possible increase in turbidity, marsh loss around the lake edge, and alarming concentrations of toxic chemicals (Stone 1980a and b; Sikora and Sikora 1982).

Nutrient concentrations in Lake Pontchartrain are not particularly high at present (0.05 mg/l PO_4; 0.41 mg/l total N), despite high phosphorus and nitrogen loading rates. Excess nutrients enter the lake via rain water from New Orleans pumped into the lake along the south shore, from the Baton Rouge area via the Amite-Comite River system and Pass Manchac, and from the communities

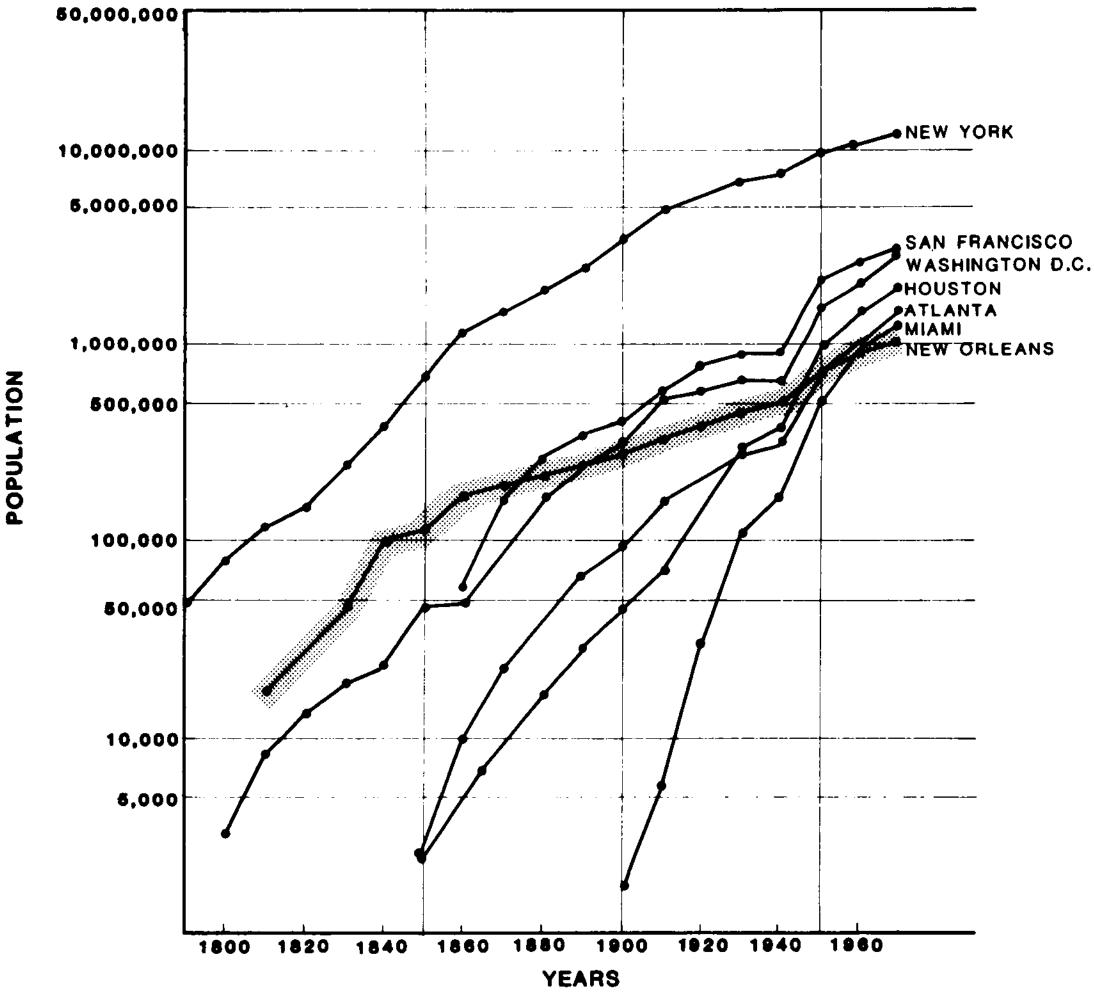


Figure 43. Population growth of major cities of the United States, 1790-1970 (from Lewis 1976).

along the shore of the lake. Evidence that phosphorus loading has increased over time is shown in Figure 44. This nutrient loading is similar to the pattern in Lake Salvador (Craig and Day 1977).

The average rate of primary production in Lake Pontchartrain does not reflect nutrient loading, however. For example, Dow and Turner (1980) estimated that only about 160 g C/m^2 is fixed in the water column of Lake Pontchartrain annually, compared with 220 g C/m^2 for Lake Salvador. If this difference is real, it may indicate that primary production in Lake Pontchartrain is being inhibited. On the other hand, excess nutrients may precipitate upon entering the lake, as seems to occur in Lake Salvador. Two possible explanations for inhibition of primary production in Lake Pontchartrain have been suggested. The first is that the turbidity of the lake may have increased recently, partly as a result of shell dredging (see below). Another possibility is that aquatic producers may be inhibited to some extent by herbicides, such as 2,4,D and 2,4,5,T, that have been detected in the lake water (Sikora et al. 1982).

There is some evidence for a recent increase in turbidity in the water of Lake Pontchartrain. One study suggests that the lake is on the average about twice as turbid as it was in 1953 (Stone 1980a). This thesis is based on overall minimum Secchi disc readings taken during four different studies beginning in 1953, which seem to indicate a clear trend (Figure 45). The possible effects of variable wind conditions during these studies have not been factored into this plot; however, it is assumed that none of the readings were taken during high wind conditions.

A combination of land clearing and increased sedimentation in the Pontchartrain basin, intensive clam shell dredging, in the lake proper during the last 30 years, along with the six Bonnet Carre floodway openings, could perhaps account for such a turbidity increase.

Another piece of information that relates to the rate of primary production in Lake Pontchartrain was presented by Roberts (1981) and Roberts and Bahr (1981). A set of aerobic respiration measurements of lake bottom samples indicated that the minimal carbon requirements of the benthic community may be greater than the estimated rate of primary production in the water column. This observation, if borne out, would indicate the dependence of the lake on carbon washed into the lake from its watershed.

The present condition of Lake Pontchartrain was recently characterized in a study funded by the U.S. Army Corps of Engineers (USACE) (Stone 1980a and b). During this study, and in a subsequent related study on the effects of shell dredging on the lake, the benthic community was examined in detail (Bahr et al. 1980; Roberts 1981; Roberts and Bahr 1981; Sikora et al. 1981; Sikora and Sikora 1982). The conclusion from these studies is that the benthic community of the lake is symptomatic of a highly stressed ecosystem. There is an unusually small number of organisms, low biomass, and low species richness, especially when compared to previous research in the lake (Darnell 1979). For example, only about seven species of macrofauna occurred in most samples, and practically no large brackish water clams (Rangia cuneata) were found in the open lake where they had been thriving as recently as 1953 (Darnell 1979).

One of the major alterations to Lake Pontchartrain is the continuing mining of fossil Rangia shells from lake sediments. Hydraulic shell dredging is allowed in almost 50% of the lake bottom area, which has been estimated to be completely scoured at least once every 1.4 to 2.3 years (Sikora et al. 1981).

In a recent study of the effects of this dredging on the lake system (Sikora et al. 1981) it was found that the bottom sediments are destabilized so much that they are too soft to support adult clams. Because these clams are dredged

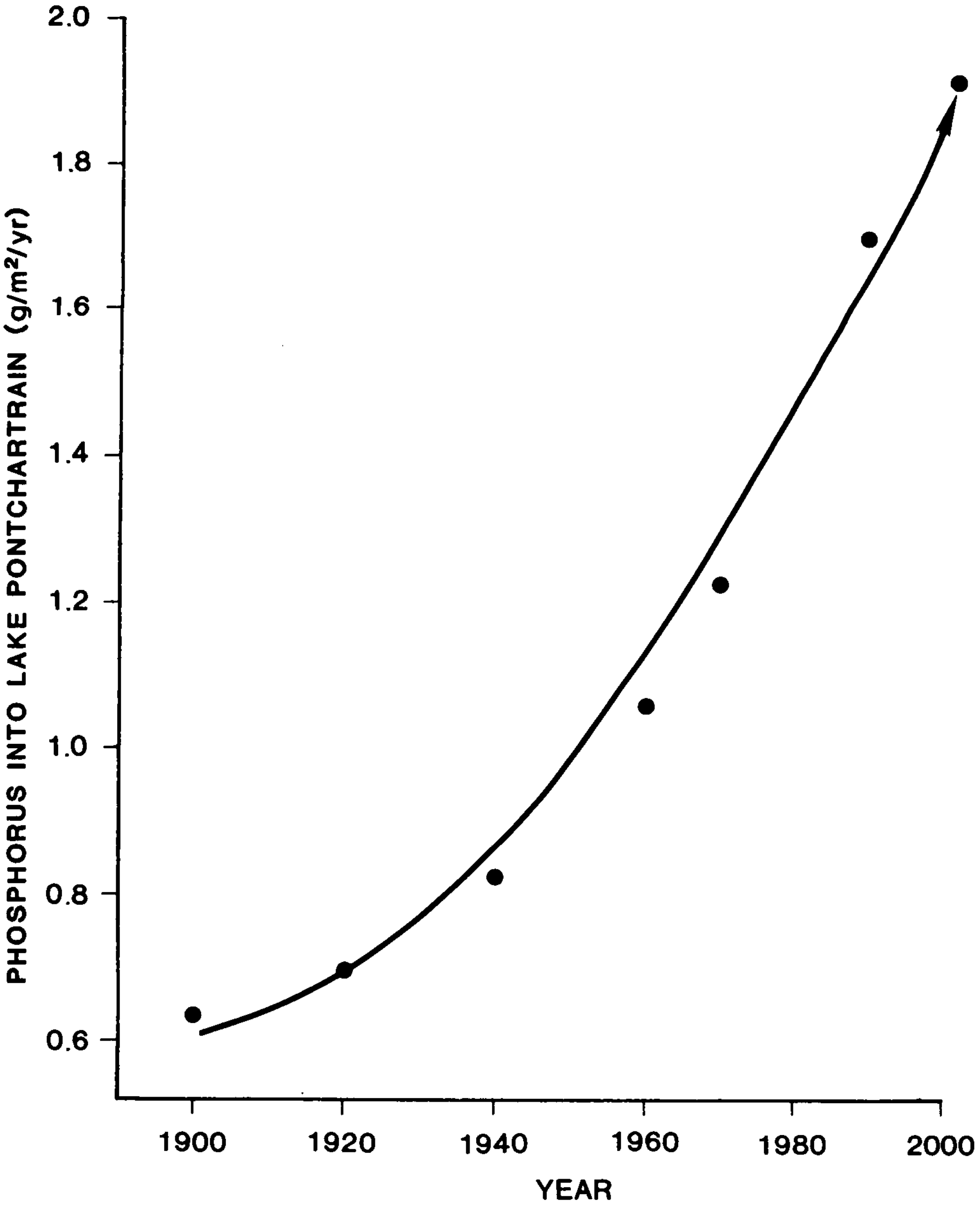


Figure 44. Phosphorus loading into Lake Pontchartrain, Louisiana, as a function of time.

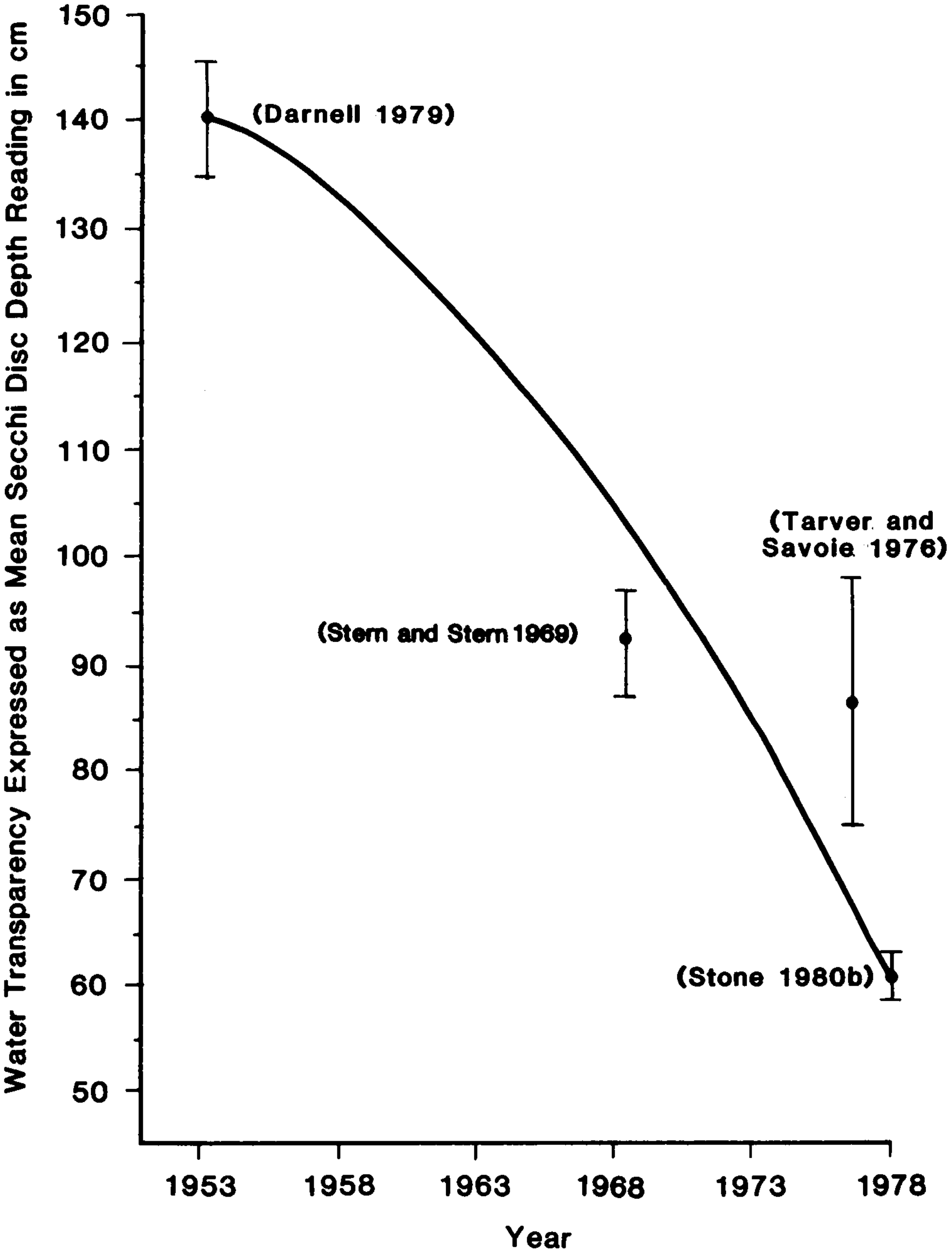


Figure 45. Water transparency (expressed as mean Secchi disc readings in cm) as a function of time for Lake Pontchartrain, Louisiana (from Stone 1980a).

as a source of calcium carbonate (and road building material) the shells are obviously not being replaced as fast as they are mined from the lake. Whereas Rangia at one time dominated the lake bottom, the most numerous macrobenthic organisms in the lake bottom in 1980 were two species of small snails (hydrobids)that seem to tolerate certain kinds of toxins present in the lake (Sikora et al. 1981).

The community of meiobenthos (animals smaller than 0.5 mm) in Lake Pontchartrain also reflect a stressed environment. These animals are relatively few in number and species richness compared with similar oligohaline estuaries (Sikora et al. 1981).

The nekton community in Lake Pontchartrain appears to have changed since 1953, when it was studied by Suttkus et al. (1954), although this change is difficult to assess. Nekton are difficult to quantify in large water bodies because of their motility, tendency to school, and differential ability to avoid trawls. Nevertheless, fishes that feed in and/or live on the lake bottom, such as flatfishes, have possibly declined (B. Thompson, LSU Coastal Ecology Laboratory, personal communication, 1982). The zooplankton community also appears to have declined in average density since 1953, and more individuals of the dominant zooplankter (Acartia tonsa) were found recently at the bottom interface than in the water column (Sikora and Sikora 1982). Nevertheless, shrimp, blue crabs, oysters, catfish, and other fishery species are still harvested from the estuarine open water habitat in the Pontchartrain basin.

Mercury, PCB's, Chlordane, Parathion, Dieldrin, and Aldrin have been found at levels far exceeding the EPA water quality criteria at the north and west shores of Lake Pontchartrain, and have been associated with the major freshwater inputs to the lake. Along the south shore high PCB, 2,4-D and 2,4,5-T levels have been recorded in lake water. Apparently Dieldrin, Diazinon, DDT, 2,4-D, and 2,4,5-T have been added to Lake Pontchartrain in significant amounts along with Mississippi River water through the Bonnet Carre Floodway (Sikora and Sikora 1982). Knowledge of the fate of these toxins within the lake is not available. A major portion is presumed to be concentrated in bottom sediments and in living organisms that feed on the bottom. This includes the majority of all of the species that use the lake (Stone 1980b). Herbicides that enter the lake from its drainage basin may partially account for the low primary productivity mentioned above.

All of this evidence adds up to a picture of an estuary that is deteriorating, and the prognosis does not look good in light of the increasing development pressure on the shorelines and drainage basin of Lake Pontchartrain.

Good water quality in Lake Pontchartrain, and in other examples of estuarine open water habitat in the MDPR, is closely related to the viability of the few remaining marshes and swamp forests that once completely surrounded the lake. These wetlands have been encroached on by the spread of New Orleans and other urban centers, logged, and cut off from the open water by flood control levees. Only a small portion of marsh and swamp remains connected to Lake Pontchartrain.

New Orleans

The second major influence in the Pontchartrain hydrologic unit is its urban habitat, most of which is occupied by the City of New Orleans. New Orleans is more than a large urban habitat; because of its strategic location and position as an active port, its functional importance transcends both basin and regional levels of organization. Lewis (1976) provides an excellent description of the major forces that have shaped New Orleans.

New Orleans was founded in 1718 by John Baptiste Le Moyne, Sieur de Bienville, on the highest land on the natural levee of the Mississippi River, 10 ft above sea level, and 30 leagues from the Gulf of Mexico. Except for the original high land, most of modern New Orleans is well below sea level by as much as 4.5 m (15 ft). Nearly 1.8 m (6 ft) of annual rainfall must be pumped out of the city and up to Lake Pontchartrain using aging pumps with limited capacity (Lewis 1976). New Orleans is therefore one of the most vulnerable of major U. S. cities to hurricane flooding.

Natural levee land that formed the original city was quickly settled, and later developments occurred in drained wetland below sea level. When swamps and marshes were drained, the soil oxidized, compacted, and sank, resulting in severe problems for residents in parts of New Orleans including both Orleans and Jefferson Parishes (Earle 1975). Much wetland "reclamation" has occurred since World War II, and despite its high cost, development continues. For example, there are long-standing plans to develop the New Orleans East area, one of the last marsh areas remaining adjacent to Lake Pontchartrain (see Figure 43). Recent population growth has occurred along the north shore of Lake Pontchartrain. The Lake Pontchartrain causeway, completed in the late sixties, has greatly accelerated this growth. Additional expansion has occurred westward into Jefferson Parish, on the West Bank, and further up the Baton Rouge corridor. A decade ago some planners stated that New Orleans had already exceeded its optimum size (Earle and Gagliano 1972).

Early New Orleans residents were often plagued by mosquitoes, both salt marsh species and freshwater forms that spread yellow fever and malaria. The mosquito problem is presently held in check with a major control program that relies heavily on aerial spraying of malathion.

Many modern residents are concerned about the quality of their drinking water, drawn from the Mississippi River downstream from the heavily industrialized corridor south of Baton Rouge. A statistically significant correlation between mortality from bladder cancer and consumption of drinking water from the lower Mississippi has been documented (Page et al. 1976). Other studies have indicated the presence of mutagens and carcinogens in the treated drinking water (Dowty et al. 1975; Pelon et al. 1979).

New Orleans dropped from the second largest city in the nation in 1835 to the nineteenth largest in 1970, (Figure 43) largely because of the space constraints and a shift away from waterborne transportation. There are plans to develop additional marsh and swampland but these projects are expensive, e.g., draining the land, providing ongoing flood protection, and about a 50 percent increase in building costs over high land construction. In addition, the natural value of the marshes is lost. Major management decisions center on the conflicting costs and benefits of urban expansion versus the long term values of wetlands and estuaries. Should the remaining marsh and swamp areas near the city be drained and developed, or should development be shifted to the more distant Pleistocene uplands on the north shore of Lake Pontchartrain? These issues cannot be resolved without an accurate estimate of the value of the natural systems that would be lost by continued development.

MISSISSIPPI RIVER DELTA HYDROLOGIC UNIT (III)

The Mississippi River Delta hydrologic unit is limited to the extreme end of the major distributary of the river, and occupies the area known as the modern bird's foot delta. The sediments composing this unit are the most recently deposited of any portion of the MDPR. Accretion of the modern delta has spanned the breadth of the coastal shelf, and because there is no more shelf on which to build, much of the sediment load flows over the edge of the shelf break and is permanently lost to the deltaic system. More land could be built locally among the major passes were it not for artificial levees, sills, groins, and continuous dredging by the USACE to maintain navigation channels.

Hydrologic unit III includes the area enclosed by the artificial levees on either side of the lower river (below New Orleans). Urban-industrial, cypress-tupelo, and other terrestrial habitats are therefore included as part of this unit. The areas of all habitats in the Mississippi River Delta hydrologic unit in 1955 and in 1978 are compared in Table 11.

The largest non-water portion of the Mississippi River Delta hydrologic unit is freshwater marsh habitat, comprising only 6% of the entire unit. Fresh and brackish marsh together comprise about 9% of the total area. Except for the two narrow levee areas on either side of the river, where most development has occurred, hydrologic unit III is mainly a network of fresh and brackish water marsh habitat heavily laced with distributary streams and bayous, and surrounded by estuarine open water. The influence of the Mississippi River on this unit is shown by the dominance of fresh and brackish marsh that occupies an area of formerly open gulf water.

At the local level, the greatest cultural influence on the modern delta is the artificial confinement of the Mississippi River through much of the hydrologic unit. The primary influence on this area, however, is the Old River Control Structure 500 km upstream which prevents the river from abandoning its present course. If the river were to change course and move to the Atchafalaya basin, the modern delta would quickly erode and the shoreline would retreat landward.

The main navigation channel from the open Gulf of Mexico through the sill of sediment that is deposited in the mouth of Southwest Pass is continually dredged. A navigable channel 12 m (40 ft) deep and 159 m (500 ft) wide is presently maintained from the open gulf to Baton Rouge, 370 km (230 mi) upstream from the Head of Passes. The feasibility of increasing the depth of this channel to 55 ft is currently under consideration (at an estimated original cost of 0.5 billion dollars), (USACE 1981). Spoil banks from channel dredging in the modern delta presently equal about 1% of the total area of the hydrologic unit. (See SPOIL BANKS Section of this report.)

BARATARIA HYDROLOGIC UNIT (IV)

The Barataria hydrologic unit is a classic interdistributary delta basin. It is bound by natural levees of Mississippi River distributaries that grade from high land down into a central delta flank depression occupied by a series of lakes. All of the habitat types are represented, with a fairly even distribution of the major types (Table 12). The basin is complete, i.e., there are no natural water bodies that connect it to other coastal hydrologic units, with the exception of the Gulf of Mexico.

Because the Barataria hydrologic unit is the most intensively studied in the MDPR (e.g., Day et al. 1973; Conner and Day 1976; Hopkinson 1978) this section includes the most detailed of the hydrologic unit descriptions.

Description of the Area

This unit is located between the natural levees of the Mississippi River and Bayou Lafourche (Figure 46). The artificial closing of the Bayou Lafourche distributary in 1904 by the USACE and the completion of the manmade levee system along the Mississippi River have effectively eliminated overbank flooding of river water and sediment into the basin. Presently, most fresh water that comes into the system is precipitation, which averages 156 cm/yr (61 inches/yr) (Sklar 1980). There is an extensive network of interconnecting water bodies that allows transport of water, materials, and migrating organisms throughout the basin.

The rate of water movement through the basin is a function of tidal range (approximately 0.3 m, or 1 ft, at the coast), wind, precipitation, and the mild slope of the topography from the

Table 11. Habitat areas in hydrologic unit III, Mississippi River Delta.

Habitat		Area (ha)		Change in area[a] (1978-1955) (ha)
No.	Description	1955	1978	
		(2.47 acres/ha)		
1	Agriculture	37	81	44
2	Beach and dune	277	37	-240
3	Bottomland hardwoods	2595	3247	652
4	Brackish marsh	(b)	10386	(b)
5	Canals	1291	1270	-21
6	Cypress-tupelo	1615	279	-1336
7	Fresh aquatic bed	-	1099	1099
8	Fresh marsh	54266	16397	-37869
9	Fresh open water	7890	16658	8768
10	Fresh scrub/shrub	955	504	-451
11	Mangroves	-	1	1
12	Mud flats	2193	3434	1241
13	Nearshore gulf	-	-	-
14	Rivers, streams	26345	26287	-58
15	Estuarine aquatic bed	-	293	293
16	Estuarine open water	171046	185279	14233
17	Salt marsh	-	-	10386[b]
18	Spoil banks	866	3491	2625
19	Upland forest	-	54	54
20	Urban-industrial	1979	2058	79
	Total	271355	270855	

[a] Due to differences in classification and resolution between the 1955 and 1978 maps, care must be taken in interpreting the area changes shown in this table. See text for a more complete explanation.

[b] Brackish marsh was not delineated on the 1955 maps, but was included with salt marsh as "nonfresh marsh." Therefore, the change in salt marsh number was set equal to the change in total nonfresh marsh.

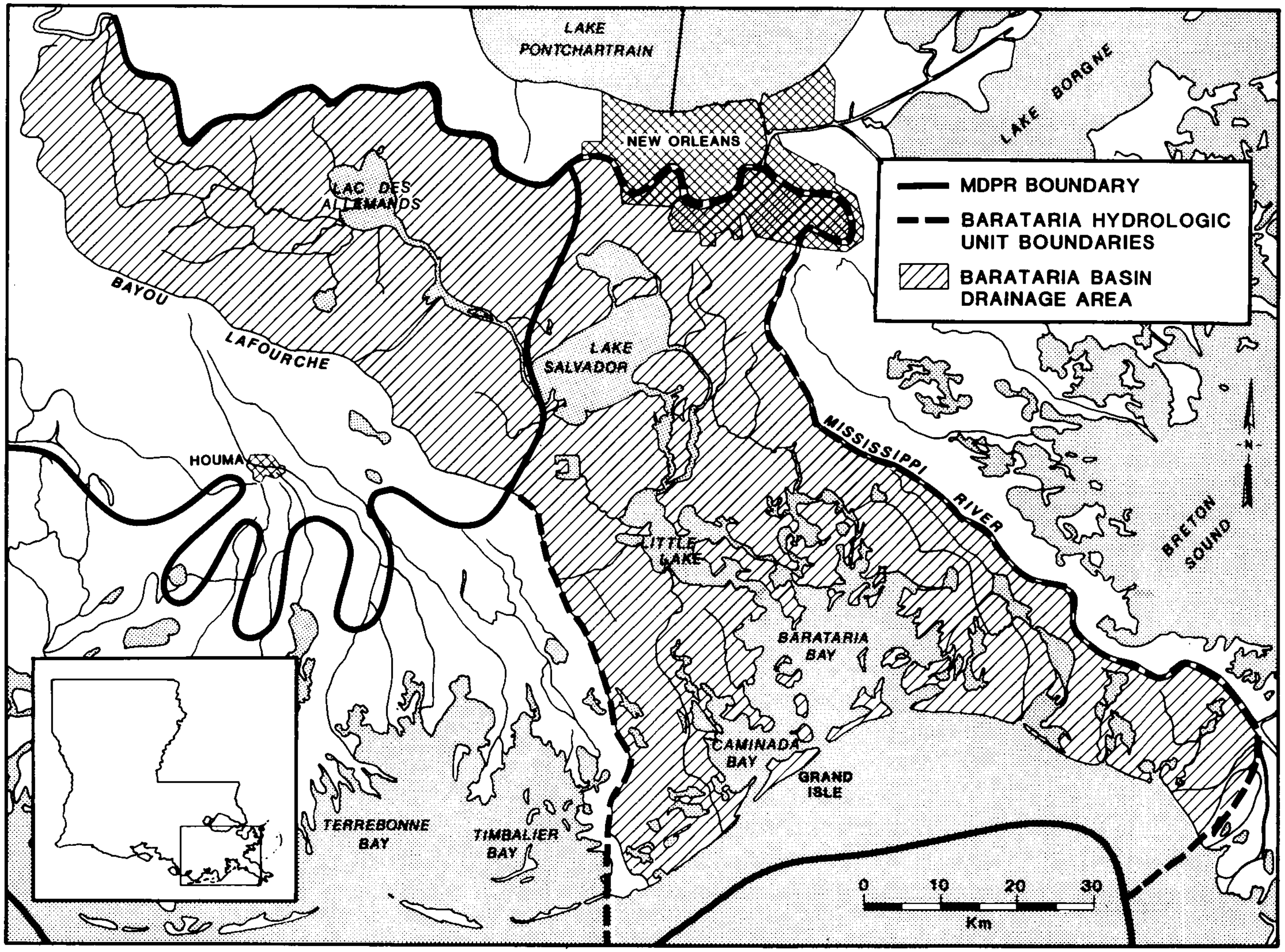


Figure 46. Map of Barataria drainage basin showing the MDPR boundary.

swamps to the gulf (approximately 1.0 cm/km, or 0.4 inches/mi). These conditions create sluggish bayous and promote overland sheet flow of water through the wetlands. Although Mississippi River water no longer flows directly into the Barataria basin, southeasterly winds, when they occur, blow river water from the Southwest Pass of the modern delta back into the lower basin via the tidal passes. (Day et al. 1973).

Wetland vegetation varies from salt marsh along the coast to freshwater swamp at the upper end of the basin. Slightly more elevated areas of the upper basin support a bottomland hardwood forest community. Seaward from the swamp forest, maidencane and cattails predominate in the freshwater marshes. Further south, intermediate and brackish marshes also support a wide variety of plant species, but this variety declines closer to the gulf. Descriptions of each of these plant communities are included in this report. Additional information can be found in Day et al. (1973), Conner and Day (1976), Bahr and Hebrard (1976), Day et al. (1977), and Hopkinson and Day (1979).

The areal extent of each habitat in the Barataria hydrologic unit is listed in Table 12. The boundary of the MDPR does not coincide with the natural boundary of the total Barataria drainage basin (Figure 47). Much of the forested wetland and adjacent uplands, a small area of fresh marsh, and some fresh aquatic areas were not included in the study area that was the source of the measurements in Table 12. The total area of the Barataria basin in 1975, by five major habitats, was estimated by Hopkinson (1978) and is shown in Table 13. The following description includes the entire basin, which is 207,000 ha (511,300 acres) greater than the area of the Barataria hydrologic unit given in Table 12.

Dominant Forcing Functions

The Barataria basin was formed during the past thousand years by sedimentation from the Mississippi River through Bayou Lafourche. The basin received fresh water and sediment during annual overbank flooding, but since the leveeing of the river in the 1930's, the only direct freshwater input has been rain, and riverine sediments and nutrients are no longer available to nourish wetlands. The only deposition of sediment comes from sediments eroded from adjacent waterbottoms, which are insufficient to maintain an elevated marsh surface. The Mississippi River affects the basin via the Gulf of Mexico, by decreasing nearshore salinity and stimulating nearshore primary productivity.

The Barataria basin has well-developed barrier islands compared with areas such as Chandeleur Sound, Terrebonne Bay, and Atchafalaya Bay. The barrier islands provide some protection from wave energy. Hurricanes and lesser storms still exert a powerful influence on the basin, however, in the form of storm surges. The marine environment also provides the characteristic salinity gradient of the estuary, and the nearshore gulf is the habitat for the many migratory organisms that use the basin.

Biological processes mediate the physical forces that impinge on the basin, e.g., wetland plants colonize mudflats and slow the rate of erosion; organic matter from plants contribute a large portion of the soil throughout the basin; benthic organisms such as oysters and clams produce carbonate shells that help to stabilize water bottoms and beaches.

Human activity has also become a major force in the Barataria hydrologic unit. The leveeing of the river during the 1930's deprived the basin of annual inputs of sediments, water and nutrients. The subsequent sediment starvation of wetlands, subsidence, erosion, and salinity intrusion into the lower basin are undoubtedly responsible for a major portion of the observed wetland loss (Craig et al 1979). Salt water intrusion causes wetland loss when it results in the rapid dieback of freshwater wetland plants, and erosion occurs before salt tolerant plants can recolonize the area. Canal construction, upland runoff, and impoundments have also affected the rate of wetland loss, water

Table 12. Habitat areas in hydrologic unit IV, Barataria.

Habitat		Area (ha)		Change in area[a] (1978-1955) (ha)
No.	Description	1955	1978	
		(2.47 acres/ha)		
1	Agriculture	13772	14118	346
2	Beach and dune	802	423	-379
3	Bottomland hardwoods	10449	7735	-2714
4	Brackish marsh	(b)	79483	(b)
5	Canals	4274	7903	3629
6	Cypress-tupelo	15784	11652	-4132
7	Fresh aquatic bed	28	669	641
8	Fresh marsh	106688	19388	-87300
9	Fresh open water	25392	1700	-23692
10	Fresh scrub-shrub	-	1660	1660
11	Mangroves	-	601	601
12	Mud flats	161	26	-135
13	Nearshore gulf	-	-	-
14	Rivers, streams	716	314	-402
15	Estuarine aquatic bed	-	2283	2283
16	Estuarine open water	175406	232682	57276
17	Salt marsh	108942	65358	35899[b]
18	Spoil banks	3007	8985	5978
19	Upland forest	1580	963	-617
20	Urban-industrial	8279	19622	11343
	Total	475280	475565	

[a] Due to differences in classification and resolution between the 1955 and 1978 maps, care must be taken in interpreting the area changes shown in this table. See text for a more complete explanation.

[b] Brackish marsh was not delineated on the 1955 maps, but was included with salt marsh as "nonfresh marsh." Therefore, the change in salt marsh number was set equal to the change in total nonfresh marsh.

Table 13. Land and water areas in the total Barataria drainage basin in 1975 (from Hopkinson 1978).

Land category	Area (ha)	
	Land	Water
Swamp	97,954	2,202
Fresh marsh	87,789	67,240
Brackish marsh	55,036	48,264
Salt marsh	63,356	82,144
Upland	124,634	
Total basin[a]	628,619	

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[a] This figure includes the entire Barataria drainage basin area, which is larger than the portion included in the MDPR. See Figure 47.

quality, wetland and aquatic productivity, and increased salinity intrusion (see ECOLOGICAL ISSUES).

The Barataria hydrologic unit has the second highest population (after the Pontchartrain unit) in the study area (Hopkinson 1978). This basin is bordered by one of the world's largest concentrations of chemical plants (Hopkinson 1978) and has the largest area of agricultural land of the seven hydrologic units within the MDPR (14,000 ha, or 34,600 acres). Urban and agricultural runoff, sewage, and some industrial wastes enter the wetland and aquatic systems of the basin, where they must be assimilated.

The major impacts of human activities are the result of (1) eutrophication caused by increased nutrient loading from urban and agricultural areas; (2) wetland loss resulting from river entrainment, land development, canals, navigation channels, impoundments, salinity intrusion, subsidence and sea level rise; and (3) toxic substances from wastewater plants, industry, hazardous waste sites, agricultural runoff (both fertilizers and herbicides), and herbicides used on aquatic weeds, especially water hyacinth.

Eutrophication

Eutrophication is the natural or artificial addition of nutrients to water bodies, and the effects of these added nutrients on the ecosystem. Although eutrophication may be a natural process, it is often accelerated by human activities. Eutrophication typically results in changes in water quality and algal blooms, leading to the establishment of undesirable species, the destabilization of natural communities, and periodic anoxic (low oxygen) conditions (Craig and Day 1977).

Waters of the upper and mid basin (Lac des Allemands and Lake Cataouatche) are strongly eutrophic (Seaton and Day 1979). These conditions are linked to increasing total runoff from upland areas into basin waters. The concentration of nutrients and suspended sediments in upland runoff, and the total volume of runoff, are both increasing because of the clearing of forested land for agriculture and the conversion of agricultural land to urban and industrial uses. Urbanized area is projected to almost double by 1995 (Hopkinson and Day 1980a). The relationship between upland runoff and eutrophic conditions in the MDPR has been demonstrated in a number of studies (Day et al. 1977; Craig and Day 1977; Hopkinson and Day 1979; Seaton and Day 1979; Stone 1980a).

In addition to total nutrient loading, canal density has been linked to eutrophication, by directly shunting agricultural and urban runoff from the uplands into water bodies. In the past, runoff from the natural levees flowed slowly through wetlands before entering Lac des Allemands and other water bodies in the upper basin. The evidence for a relationship between canals and reduced water quality in the upper basin is increasing. Canals consistently have more turbid water than natural streams, in addition to higher nutrient levels. Gael and Hopkinson (1979) showed a positive relationship between the density of canals and the trophic state (an index of the degree of eutrophication) of water bodies in the Barataria basin (Figure 47). Kemp (1978) showed a marked increase in the Nitrogen: Phosphorus ratio of water flowing out of drainage canals compared with water flowing from swamps, especially after heavy rains (Figure 48). A low N:P ratio indicates that nitrogen is being biologically removed from the water (in this case by denitrification). This indicates that the swamp forest habitat assimilates nitrogen and improves water quality.

Seaton and Day (1979) and Witzig and Day (1982) developed a numerical trophic state index (TSI) for the Barataria basin, based on the data collected over a 2-year period (Table 14).

All stations with a positive index were classified as eutrophic or hypereutrophic. These stations were characterized by relatively high chlorophyll,

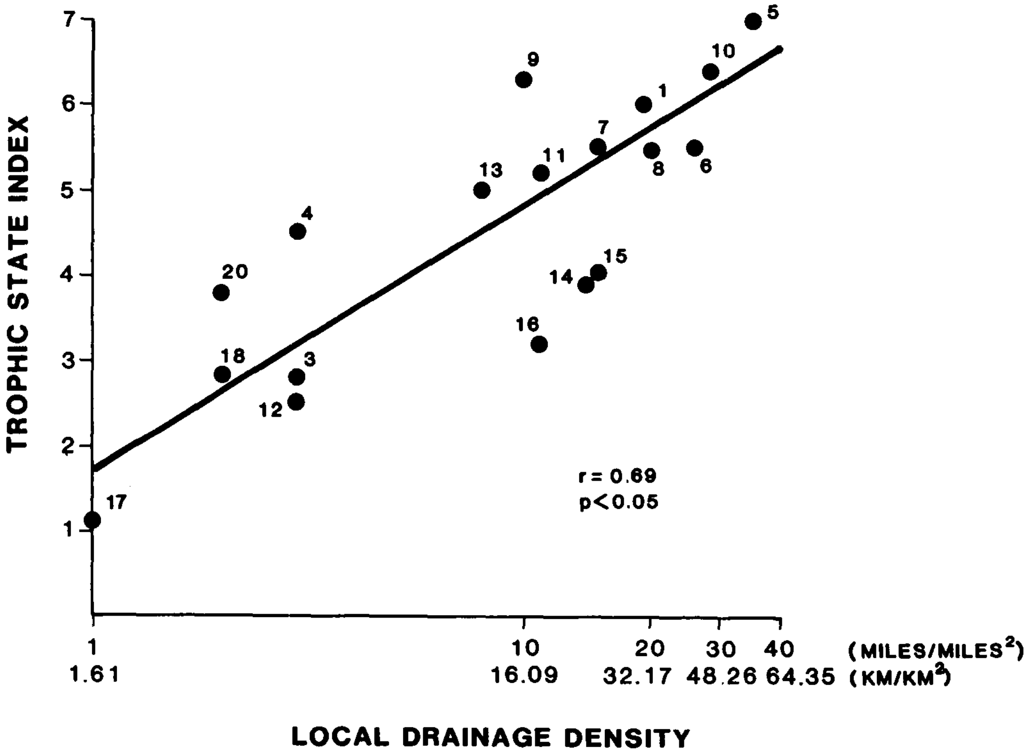

Figure 47. Local drainage density (km canals/km^2) vs. trophic state index.

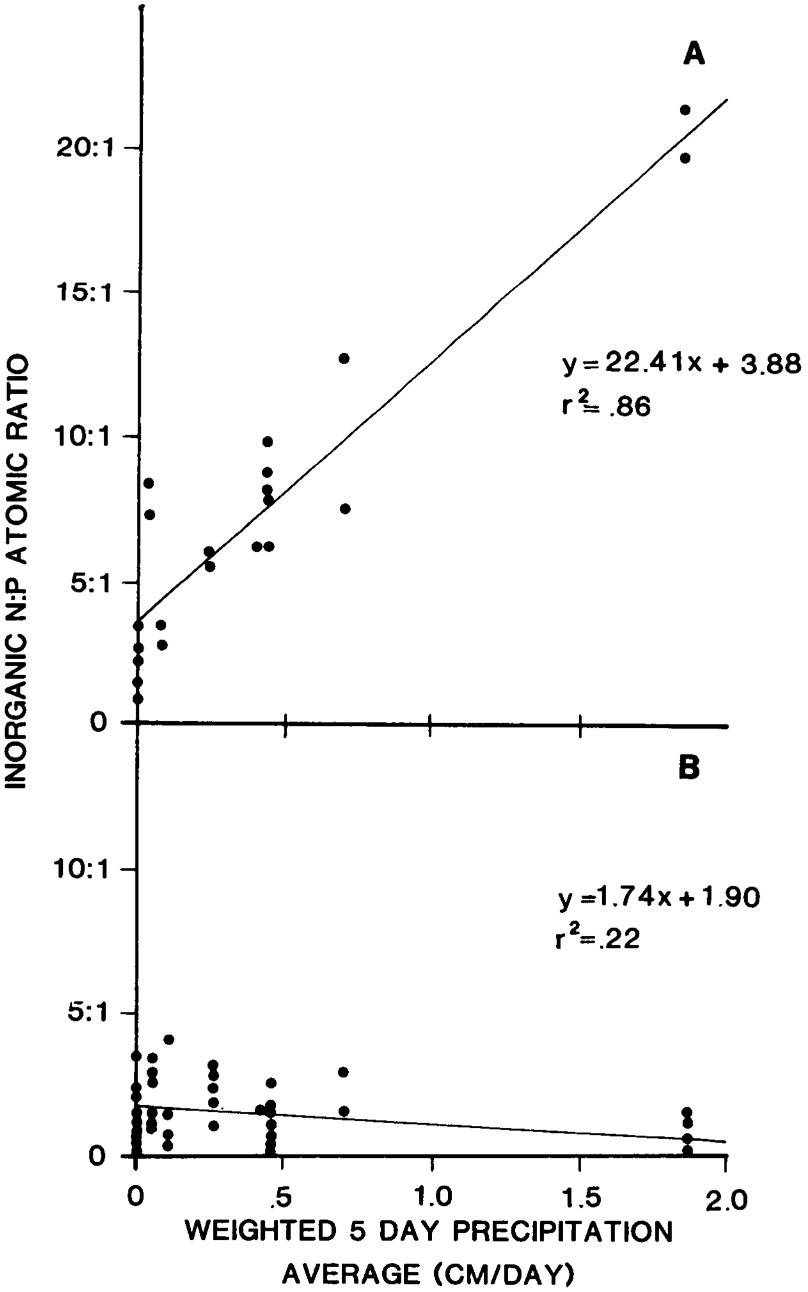

Figure 48. Inorganic nitrogen:phosphorus ratios vs. rainfall in the Barataria basin (from Kemp 1978).

Table 14. Trophic state classification of Barataria basin, Louisiana (Seaton and Day 1979).

Station no.	Name	TSI score	Trophic group[a]
25	Caminada Pass	-4.8	M-O
17	Bayou Rigolettes	-4.3	M
24	Barataria Bay	-3.8	M
12	Lake Salvador	-3.3	M
18	Bayou Perot	-2.8	M
21	Little Lake	-2.7	M
16	Bayou Barataria	-1.8	M
23	Barataria Waterway	-1.6	M
3	Natural swamp stream	-1.4	M
22	John-the-Fool Bayou	- .6	M
20	Oil and gas field	- .4	M
4	Bayou Chevreuil	.6	E
8	Recreational canal	.7	E
13	Lake Cataouatche	.7	E
11	Bayou des Allemands	.9	E
14	Bayou Segnette	1.6	E
15	Gulf Intracoastal Waterway	2.1	E
9	Bayou des Allemands	2.6	E
10	Burtchell Canal	2.7	E
1	Bayou Citamon	3.7	E-H
7	Lac des Allemands	3.8	E-H
6	Bayou Chevreuil	4.0	E-H
5	St. James Canal	6.4	H

[a] O=oligotrophic, M=mesotrophic, E=eutrophic, H=hypertrophic

nutrient, and turbidity levels. All were located in the upper freshwater portion of the basin, or adjacent to the natural levee in the New Orleans area, and all were strongly impacted by urban and/or agricultural runoff. Stations with a negative index were generally mesotrophic; they had clear water and relatively low nutrients and chlorophyll levels. Most were in the lower basin where there were no direct introductions of upland runoff.

Rates of Wetland Loss

A number of studies have been conducted on wetland loss (conversion of wetland to open water or spoil banks) in the Barataria basin (Adams et al. 1976; Craig et al. 1979; Turner et al. (1982). These studies have shown that (1) the greatest wetland loss is in the saline and brackish marshes (Table 15); (2) wetland loss is apparently related to canal density; and (3) the rate of wetland loss is accelerating.

Adams et al. (1976) studied land changes for a number of sites in the Barataria basin; a positive relationship was found between canal density and wetland loss (Table 16).

The same pattern is true for the Louisiana coastal zone as a whole (Craig et al. 1979). Turner et al. (1982) recently examined the relationship between canals and wetland loss for each basin of the MDPR using the USFWS habitat maps (Wicker et al. 1980b). Wetland loss in the Barataria basin is accelerating, as indicated by a comparison of rates from 1890-1960 and 1960-74 (Table 15). This trend of accelerating wetland loss has recently been documented for the MDPR (Gagliano et al. 1981). The area occupied by canals in the Barataria basin also seems to be increasing (Table 17).

Impoundments

Beginning in the late 1800's and continuing until the 1970's, impoundments have been created for agriculture or urban development in fresh and brackish marshes. Impoundments include areas diked and pumped dry, areas diked without pumping, and areas partially leveed with reduced connection to nearby water bodies. There are numerous wetland sites within the Barataria basin that are partially or totally impounded, and cut off from free movement of water, dissolved and suspended matter, zooplankton, and nekton. Many of these sites were created inadvertently as a result of cumulative effects of projects in the wetlands (e.g., construction of canals with spoil banks).

An example of accidental impoundment is an area of swamp west of Lac des Allemands that has been almost completely impounded by road embankments, and by the spoil bank from dredging Bayou Chevreuil (see Hopkinson and Day 1980b; Conner et al. 1981) Studies have shown that this impounded area does not dry out as natural swamp does; it has much lower water turnover, and lower primary and secondary productivity; and its wildlife habitat value has decreased. Virtually no fish were found in the stagnant water in the area.

Many of the impounded areas in the Barataria basin were originally constructed as a means of floating out timber. Some of these areas have been enlarged, and new impoundments have been created by the placement of dredged spoil material from channelization, road construction, and canals constructed for pipelines, drainage, and petroleum access.

Former wetland areas that have been diked and are maintained as dry land for residential purposes or other uses are near or below sea level. The elevation is lowered because of the compaction of soils and the oxidation of peats after the land was pumped dry. Because of the high costs of keeping such land dry, many sites were abandoned and now are open water ponds, being too deep to support emergent vegetation. Other areas of marsh have been diked but have not been continuously pumped and are impounded marshes. In addition to these sites, a number of areas adjacent to the natural levees of the Mississippi River and Bayou Lafourche have been impounded

Table 15. Wetland loss in Barataria basin (Craig et al. 1979).

	Gagliano & van Beek (1970) 1890-1960 (ha/yr)	Adams et al. (1976) 1960-74[a] (ha/yr)
Salt marsh	337	394 - 519
Brackish marsh	372	535 - 1,593
Fresh marsh	77	366 - 566
Total rate of marsh loss	785	1,290 - 2,679

[a] Lowest and highest annual values found at a number of test sites.

Table 16. Relationship of wetland loss in the Barataria basin (% marsh per year) and human activities as estimated by canal density (% total marsh area) (Adams et al. 1976).

Activity	n	Range	Canal density[a] mean (S.D.)	Wetland loss[b] mean (S.D)
Light	3	0 - 1	0.34 (0.35)	0.007 (0.024)
Light-moderate	2	1 - 2	1.31 (0.11)	0.093 (0.071)
Moderate	1	2 - 3	2.0 (-)	0.084 (-)
Heavy	1	> 3	2.81 (-)	0.105 (-)

Equation of best fit:

wetland loss = 0.074 + 0.01(canal density) $R^2 = 0.69$

[a] Chabreck 1972.

[b] Adams et al. 1976.

Table 17. Summary of inventory results of wetland loss for the Barataria basin.

Area	Canal area/ marsh area (times 100)	Methodology	Reference
Barataria basin (2,427 mi^2)	2.6	Photomosaic	Adams et al. (1976)
Barataria basin (2,025 mi^2)	1.1	Points counted by helicopter from preselected transects	Chabreck (1972)
Barataria basin (to Intracoastal Waterway, 1,370.5 mi^2)	1.0	Map measurement with various dates and scales	Barrett (1970)

to extend the natural levee for agriculture.

An undetermined area of marsh land has been affected because of the construction of canals. The topography and hydrology of the marsh have been most altered in the vicinity of dense canal networks associated with major oilfields such as Venice, Leeville, and Lafitte.

Hydrological changes

Hydrology has been altered in three ways. (1) Upland runoff enters water bodies rapidly and directly via canals, bypassing wetlands that would otherwise receive it. (2) Water exchange between different parts of the basin is speeded up because of the construction of new canals or the deepening of natural channels for the mid Barataria basin. (3) Water flow over wetlands is blocked because of spoil placement. These alterations reduce the deposition of suspended sediments and exacerbate the existing sediment deficit in inland marshes. Because sedimentation is the single most important source of "new" nutrients to the marshes (Delaune and Patrick 1980b), a reduction of sediments leads to lower marsh productivity.

Toxic Substances in the Barataria Basin

The possibility of toxic pollution of waters and wetlands is great because of their proximity to large urban centers, extensive agricultural areas, and a high concentration of petrochemical industries. There is input from industrial plants, hazardous waste sites, pesticides from agricultural runoff, pesticides and heavy metals from urban runoff, petroleum hydrocarbons from oil exploration and production, and the spraying of herbicides for aquatic weed control. Figure 49 shows the locations of major petrochemical plants in or near the Barataria basin.

The petrochemical industries within the basin produce a variety of products such as vinyl chloride, nitric acid, hydrochloric acid, methyl-ethyl ketone, styrene, sulfuric acid, acrylonitrile, benzene, and various herbicides and pesticides (Mumphrey et al. 1978). All manufacturing processes result in waste materials as by-products. In many cases, wastes are known to have leaked into the environment (Dow and Garcia 1980). Over sixty solid waste sites, pits, ponds, and lagoons associated with industry have been located within the Barataria basin (USEPA 1980).

Agricultural runoff also introduces pollutants such as pesticides, organic material, nutrients, and sediments into receiving water bodies. Crop production is not regulated to prevent pollutants from entering water bodies (although feedlot operations are regulated). Agricultural pesticide usage (including herbicides, insecticides, and fungicides) in the Barataria basin is approximately 211,000 kg/yr (465,000 lbs/yr) (Hopkinson 1978). The percentage that reaches the wetland system is unknown. The Barataria basin is currently losing soil at a rate of 327,000 mt/yr (360,495 tons/yr) from cropland and 2,700 mt/yr (3,016 tons/yr) from pastureland (Hopkinson 1978). As waterborne erosion occurs, the soil with adsorbed chemicals is transported from agricultural areas into water bodies via runoff.

A typical moderate-sized city annually discharges 45,000 to 113,000 kg (100,000 to 250,000 lbs) of lead; 2,722 to 13,608 kg (6,000 to 30,000 lbs) of mercury; 6,804 to 13,608 kg (15,000 to 30,000 lbs) of chromium; 38,555 to 40,823 kg (85,000 to 90,000 lbs) of copper; 63,503 to 136,078 kg (140,000 to 300,000 lbs) of zinc; and over 4,536 kg (10,000 lbs) of nickel. These substances originate from automobile use, including gasoline combustion, tire and brake wear, and oil loss. Other sources of contamination in urban runoff include, rubber and metal lost from vehicles, industrial combustion product residue, and pesticides and herbicides applied to lawns and parks (U.S. EPA 1977).

Available data on toxic substances in the Barataria basin are scarce. The ability to monitor possible pollution sources is limited because there is not

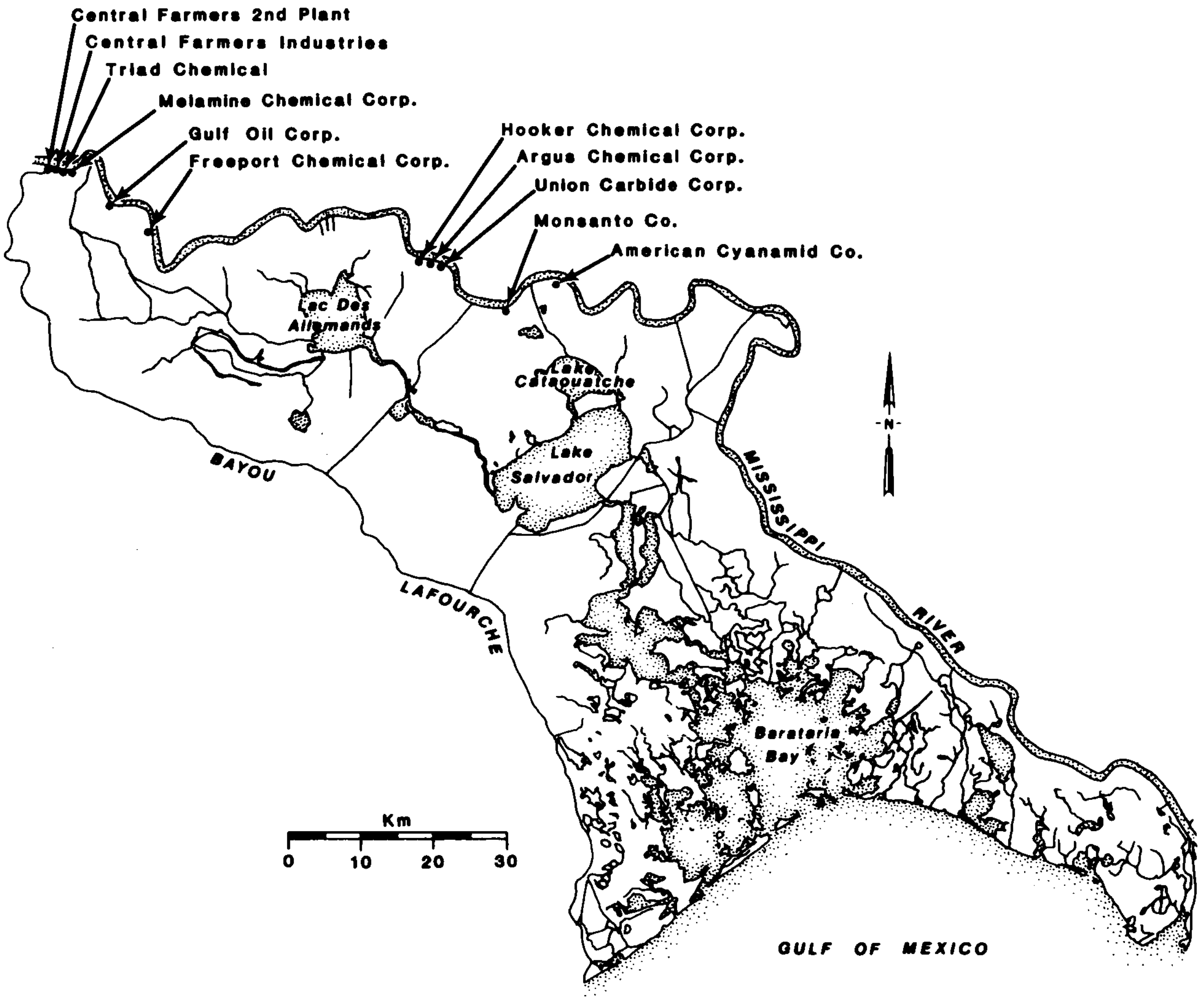

Figure 49. Locations of major petrochemical plants in the Barataria basin (from Hopkinson 1978).

adequate statutory authority. Monitoring at the State and local level is also hampered by insufficient personnel (Craig and Day 1981). Existing water quality data indicate widespread fecal coliform violations of the State criteria, the EPA criteria for aquatic life, and the USACE no-discharge criteria in Barataria Bay, the Gulf Intracoastal Waterway below Algiers, Lake Cataouatche, Lake Salvador, Lac des Allemands, and Bayou Lafourche (USACE 1980).

Prospects for the Basin

Significant economic growth has been projected for the Barataria basin uplands over the next 10 to 20 years (Hopkinson 1978), which will be reflected in changes in land use. By 1995, industrial land will increase by 4.3 times, urban and suburban land by 2.2 times, and forest and agriculture habitats will decrease by 42% and 20%, respectively. It is also estimated that almost 10,000 ha (24,700 acres) of wetlands will be "reclaimed" for various purposes (Hopkinson 1978).

These changes will exert severe environmental pressures on the waters and wetlands. Upland runoff will increase as more and more land is paved. Runoff to the upper basin will increase significantly between 1975 and 1995 (Hopkinson and Day 1980a). Unless mitigative actions are taken to lessen these stresses, there will be significant increase in environmental degradation by the end of the century.

The loading of nutrients from upland runoff has the potential for increasing the degree of eutrophication in the basin. Hopkinson and Day (1980b) estimated that nitrogen loading to Lac des Allemands will increase by 25% by 1995. Craig and Day (1977) predicted that if projected development does take place, much of the lower basin waters will be eutrophic by the end of this century. This change would cause the loss of the the area as a nursery ground for most of the fishery species that are currently harvested (Figure 50). Water bodies most seriously threatened now include Lake Salvador, Bayou Perot, Bayou Barataria, and the Barataria Bay Waterway.

Studies have shown that if upland runoff flows through emergent wetlands rather than directly into water bodies, the nutrient levels are significantly reduced. Kemp and Day (1981) studied the effect of overland flow of agricultural runoff through a swamp forest surrounding Lac des Allemands. Total phosphorus and total nitrogen were reduced by 41% and 26%, respectively, in the swamp runoff water. Hopkinson and Day (1980b) estimated that if overland flow were reintroduced in the upper basin, total nutrient loading to Lac des Allemands could be reduced by 23% for inorganic N, and 28% for P, despite increasing upland runoff. An overland flow system would also enhance wetland productivity because of the effect of added nutrients. Flooding problems would also be reduced as the backpressure on runoff of precipitation were eased.

Baumann (1980) showed that deposition is not keeping pace with subsidence in the salt marshes of the basin. He estimated that the salt marshes in the basin would disappear in about 70 years. Deterioration of inactive delta wetlands is a natural process, and nothing can completely arrest wetland loss. Several approaches have been suggested to decrease the rate of loss. Controlled diversions of the lower Mississippi River could be used to create small subdeltas (Gagliano et al. 1981). Prohibition of new canal construction and backfilling of existing canals have also been suggested as ways of lessening future marsh losses (see SPECIFIC RECOMMENDATIONS FOR MDPR MANAGEMENT).

There are approximately 100,000 ha (247,000 acres) of swamp forest in the upper Barataria basin. For the first time in many years, significant numbers of cypress trees are now being harvested. The timber is being selectively cut and then removed by helicopter, with relatively minor environmental disturbance. It is not known whether regrowth will occur, because cypress seeds need

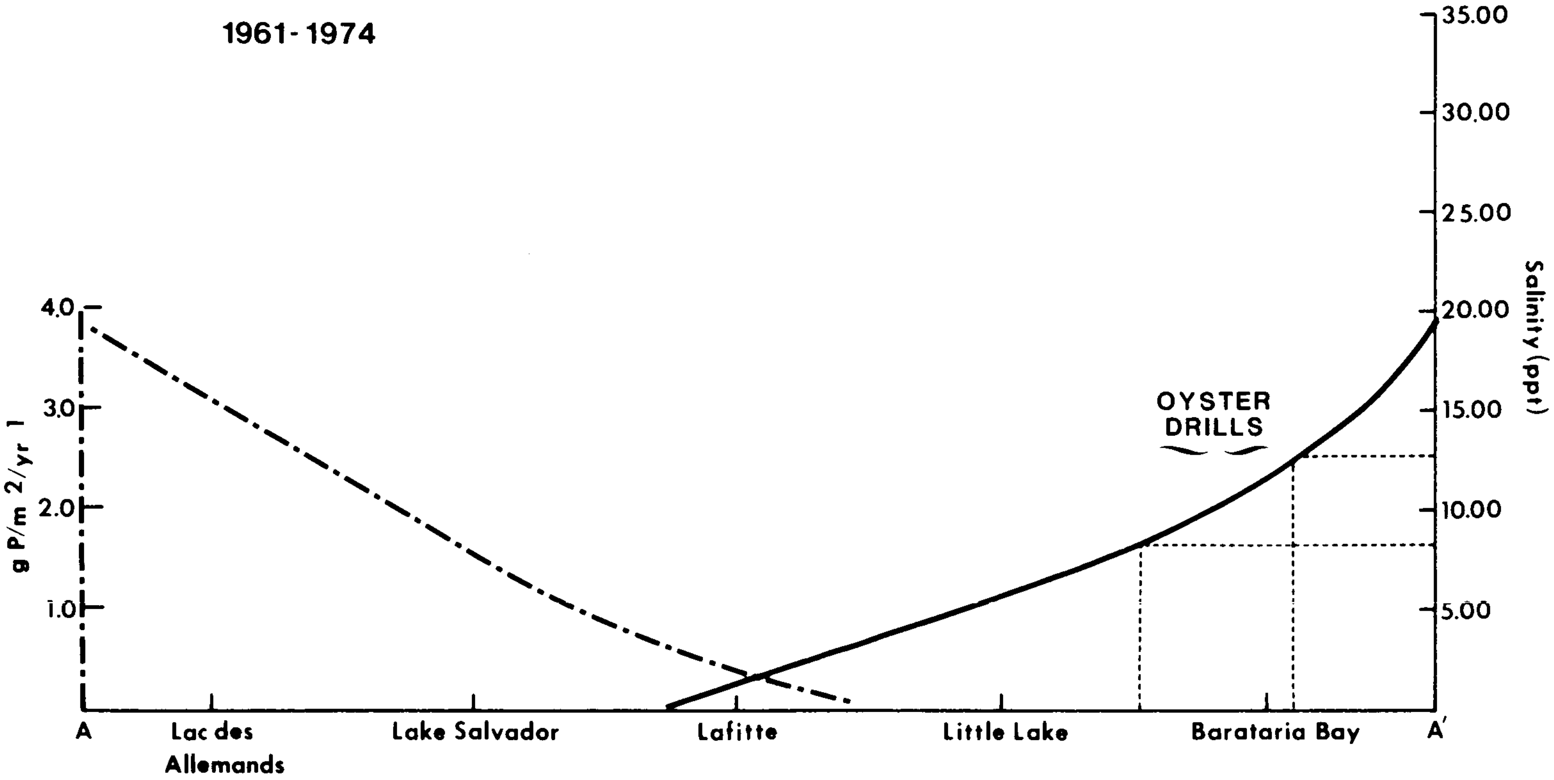

Figure 50. Phosphorus loading rates and salinity levels at various locations in the Barataria basin with the limit of oyster production indicated by oyster drill activity (from Craig and Day 1977).

moist but unflooded soils to germinate. The seedlings will survive only if there is a prolonged dry period. Because the timber land is subsiding, it is flooded for increasingly longer periods of time. In 1981 the most prolonged drought since the 1920's occurred and the survival rate of seedlings that germinated was low. These signs indicate that if the swamp is cut, there may not be another crop without a large replanting effort by the timber companies.

Natural Renewable Resources Productivity

There have been a number of studies of aquatic primary production in the Barataria basin and the adjacent Gulf of Mexico (Table 18). Stations in the upper basin (Lac des Allemands, Lake Cataouatche) show high levels of productivity with a pronounced seasonal pulse, are strongly heterotrophic (they produce less organic matter than is consumed), and they are eutrophic. Waterbodies in the lower basin (Little Lake, Airplane Lake) are less productive, lack any consistent seasonal trends, and are trophically balanced (P=R) to slightly autotrophic. Plankton productivity in the nearshore gulf is strongly increased by the discharge of the Mississippi River. Production studies in the Barataria system are summarized in Day et al. (1982). The trends from the upper to the lower basin are: (1) decreasing heterotrophy, (2) decreasing upland runoff, and (3) decreasing wetland to water ratio. This implies that outside sources of organic matter (from upland drainage or wetlands) become less important in terms of community metabolism from the headwaters to coastal waters. The upper basin is characterized by an obvious seasonal pattern; the lower basin lacks this pattern. Chlorophyll data taken at 23 stations throughout the basin (Table 18) also support the division of the basin into two parts, in that average chlorophyll levels in the upper basin are 2 to 5 times higher than the levels in the lower basin.

These results indicate that the factors controlling productivity change from the upper to the lower basin. In the upper basin, nutrient loading from upland runoff clearly controls both the timing and the magnitude of production. In the lower basin, a combination of water clarity and depth is important.

Salinity, turbidity, and primary productivity in the nearshore zone of the Barataria basin are directly related to the influx from offshore of Mississippi River water (Sklar 1976). This influx comes from westward drifting river water that enters Barataria Bay through the passes. Surface productivity about 11 km (7 mi) offshore from Grand Terre Island peaked in April during maximum river discharge, whereas the minimum occurred in September, when river discharge was low (Figure 51). Surface measurements of annual net productivity were generally higher in turbid coastal waters off Barataria Bay than in the clearer gulf waters further offshore. Total annual production of 266 g C/m^2 (measured from August 1974 to September 1975) was estimated for the nearshore area off of Barataria Bay (Sklar 1976). Happ et al. (1977) measured a mean chlorophyll of 7.6 mg/m^3 in these offshore waters.

With the tremendous expanse of periodically flooded marsh and swamp in the Barataria basin (304,000 ha, or 44.5% of the total basin, Table 13) one might expect these wetlands to play a major role in maintaining or augmenting productivity of the estuarine system. In the past 10 years, considerable data have been collected that quantitatively and qualitatively show the importance of allochthonous inputs of carbon from adjacent wetlands and upstream habitats into water bodies.

An annual organic carbon budget for Barataria basin was constructed (Day et al. 1982) by a combination of direct and indirect measurements of ecosystem fluxes (Table 19). All aquatic habitats are strongly dependent on allochthonous organic inputs from adjacent watersheds, and upstream habitats are significant sources of organic matter for downstream habitats.

Table 18. Aquatic productivity and mean annual chlorophyll in Barataria basin from freshwater bayous to offshore areas. NDP = net daytime photosynthesis; NR = nighttime respiration; GP = gross production; NCP = net community production.

Habitat (Distance from gulf)	Chl-a (mg/m^3)	NDP[b]	NR[b]	GP[b]	NCP[b]	Reference
Bayou Boeuf (106 to 120 km)	25	316	446		-130	Day et al. 1977
Lake des Allemands (98 to 108 km)	65	1418	1868	3286	-450	Day et al. 1977
Lake Cataouatche (70 to 78 km)	50	876	1205	2222	-350	Hopkinson and Day 1979
Lake Salvador (55 to 70 km)	12	402	602	1058	-198	Hopkinson and Day 1979
Little Lake (30 to 44 km)	10	639	753	1307	-117	Hopkinson and Day 1979
Brackish-saline (15 to 30 km)	10	940	910	1850	0 to + 54	Allen 1975; Day et al. 1973
Offshore[a] (0 km)	7.6	732				Happ et al. 1977; Sklar and Turner 1981

[a] Offshore value in $gC/m^2/yr$.
[b] $g\ O_2/m^2/yr$.

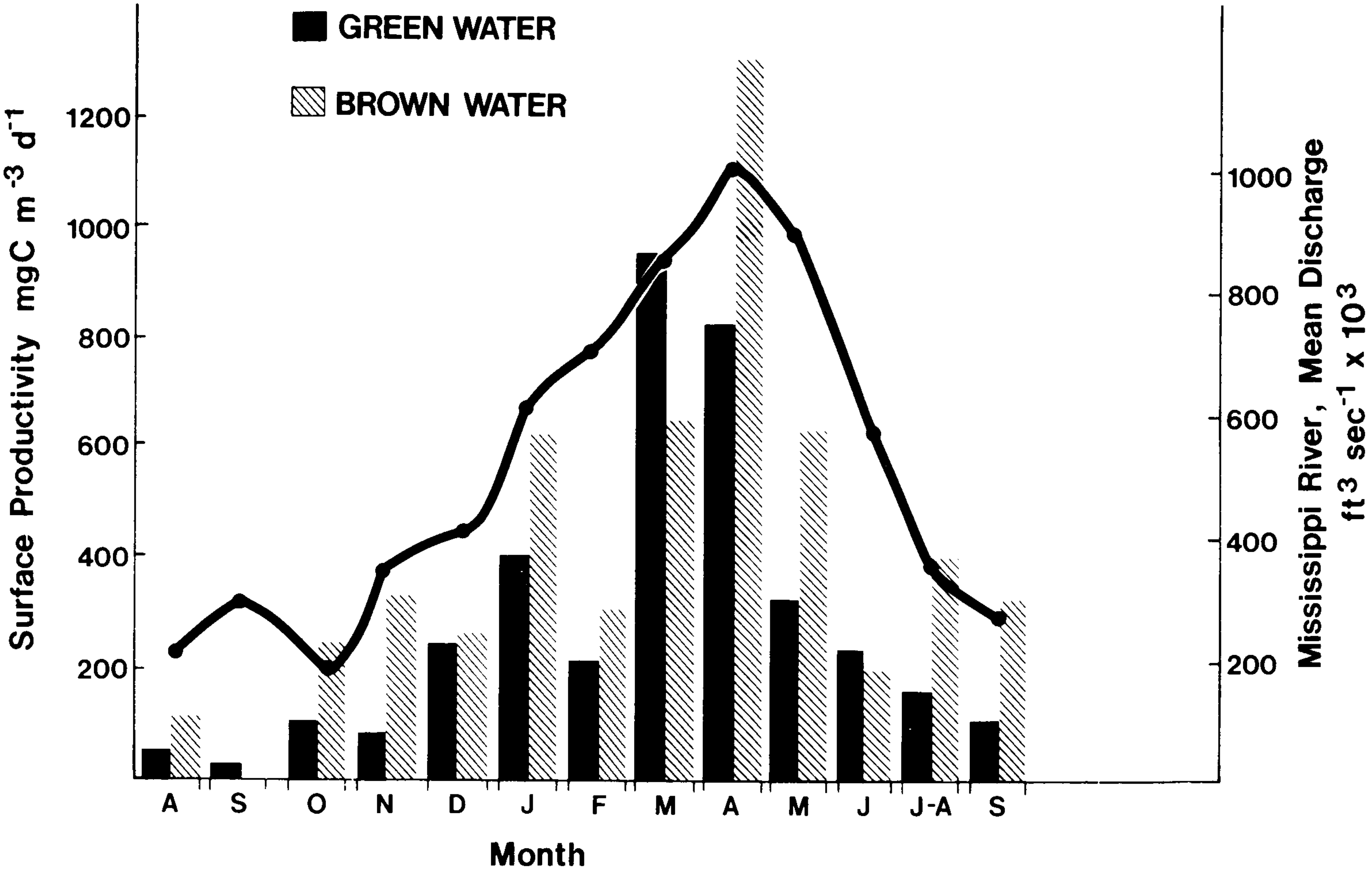

Figure 51. Productivity of nearshore waters off Grand Isle, Louisiana, and Mississippi River discharge measured over one year (August 1974-September 1975) (from Sklar 1980).

Table 19. Annual organic carbon budget for Barataria basin (all carbon flows in g C/yr E12) (see Day et al. 1982 for details).

Habitat	Area[a]	Net production	Export	Respiration	Sedimentation
Des Allemands swamp	10.30	69.94	1.75		
Des Allemands aquatic	0.65	3.15	0.65	4.04	0.21
Lake Cataouatche wetlands	2.20	19.75	1.58		
Lake Cataouatche aquatic	0.37	1.10	1.04	1.52	0.12
Fresh wetlands	4.20	37.72	3.01		
Fresh aquatic	1.90	2.59	2.21	3.91	1.17
Brackish wetlands	5.50	115.22	14.97		
Brackish aquatic	4.83	10.49	10.41	12.43	4.83
Saline wetlands	6.34	67.52	20.26		
Saline aquatic	8.21	26.23	12.38	25.55	18.97
Nearshore Gulf of Mexico	15.00	39.90			

[a] Area: m^2 E8.

The portion and total quantity of wetland primary production exported to adjacent water bodies is lowest in the headwater areas and greatest in the salt marsh. Approximately 2% of produced carbon is exported from the swamp forest; 30% of salt marsh net production is exported to adjacent water bodies. Total and areal organic carbon loading also increase in a downstream direction. Total loading increases from about 1 x 10^{10} to 20 x 10^{10} gC/yr (swamp to salt marsh), and areal loading from 110 to 246 g C/m^2/yr (swamp to salt marsh). Production and allochthonous carbon inputs exceed respiration and sedimentation in all aquatic habitats of Barataria basin. Precipitation exceeds evapotranspiration by about 33% on an average annual basis, which results in a runoff surplus (Sklar 1980). Rainwater surplus is a driving mechanism that links upstream and downstream habitats.

The Role of Marshes and Estuaries in Fisheries Production

Louisiana has the greatest area of coastal wetlands and the largest commercial fishery in the United States (Bahr et al. 1982). Coastal wetlands are thought to play an important role in supporting fisheries (Turner 1977; Bahr et al. 1982). Gunter (1967) called the area around the Mississippi delta the "fertile fisheries crescent." Many of the references that suggested a positive relation between wetlands and fishery production failed to describe the specific manner in which wetlands enhance fisheries production. Studies in the Barataria basin illustrate the way fish species use wetlands.

Eight species make up 80% to 95% of the nekton of the lower Barataria basin (Gunter 1936, 1938a, 1938b; Perrett et al. 1971; Wagner 1973; Sabins and Truesdale 1974; Chambers 1980):

bay anchovy (Anchoa mitchilli)
croaker (Micropogonias undulatus)
sea catfish (Arius felis)
striped mullet (Mugil cephalus)
spot (Leiostomus xanthurus)
menhaden (Brevoortia patronus)
silverside (Menidia beryllina)
penaeid shrimp (Penaeus spp.)

The bay anchovy is thought to complete its entire life cycle within the estuary. The other species spawn offshore and use the estuary as a nursery/feeding ground.

Chambers (1980) constructed a diagram showing a systematic pattern of use of the Barataria basin by different nekton groups (Figure 52). In the fall and early winter, juveniles and adults of freshwater species move southward into brackish areas as marine species emigrate. As salinities and water temperatures increase in the late winter and spring, the marine species begin their upbasin migration while the freshwater species retreat to the fresher water of the northernmost lakes. During the warmer months, mesohaline juveniles of some truly estuarine species move up to the mid-basin during periods of high salinity. They return to the lower bays and gulf in the late fall and winter as salinities decrease.

The data of Wagner (1973) and Chambers (1980) suggest that euryhaline marine-spawned juveniles migrate preferentially into low salinity waters and slowly move into higher salinity waters as they grow. Nekton biomass in lower salinity areas consisted primarily of large numbers of juveniles (Wagner 1973). By contrast, nekton biomass in the more saline areas consisted primarily of large juveniles or adults.

The results of studies from the Barataria basin show that a large proportion of nekton found in estuaries spend only a part of their life cycles in the basin. These species, especially larval and juvenile forms, seek out shallow water such as marsh ponds, tidal creeks, and the marsh edge. Data from the Barataria basin and Lake Pontchartrain showed that nekton biomass was 6.8 to 11.5 times higher in shallow water marsh areas than in open water (Table 20). Several workers on the east coast have also found that shallow tidal creeks and marsh shoals harbor dense populations of juvenile marine species

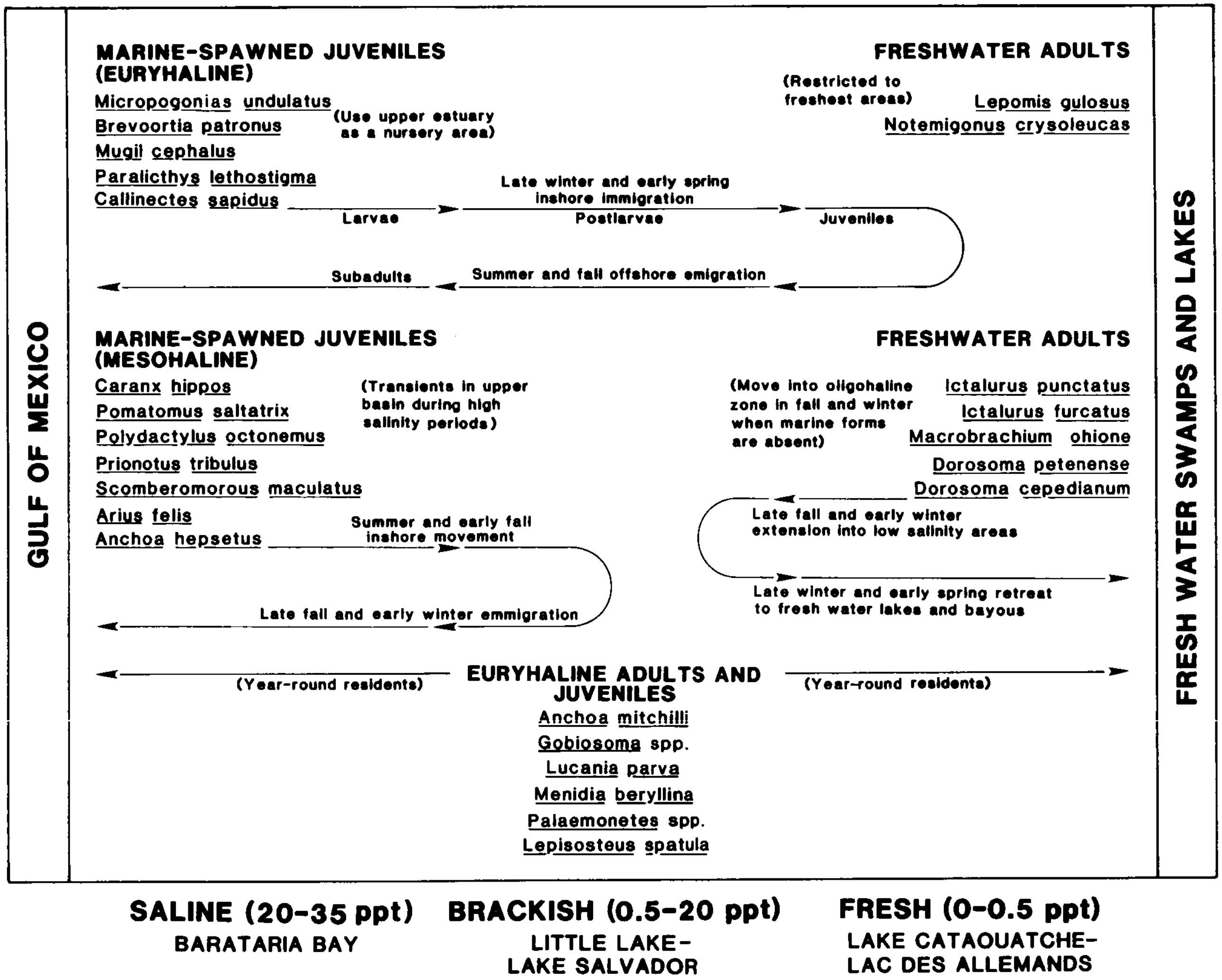

Figure 52. Patterns of estuarine use by nektonic animals (from Chambers 1980).

Table 20. Comparison of estimated nekton standing crops in shallow marsh pools and open water areas. All fish collected by otter trawl, except * = antimycin.

Area	Standing crop (g wet wt/m^2)	Reference
Upper Barataria basin, shallow water	3.41	Chambers 1980
Upper Barataria basin, open water	0.50	
Caminada Bay, shallow marsh ponds	13.8 to 46.1*	Wagner 1973
Caminada Bay, open water	1.19	
Lake Pontchartrain, shallow water	2.57	B. Thompson LSU Coastal Ecol. Lab.; pers. comm.
Lake Pontchartrain,	0.32 open water	

(Weinstein 1979, Shenker and Dean 1979, Bozeman and Dean 1980). These studies showed that young fish seek the creek headwaters.

A distinctly larger nekton biomass has been found in waters associated with marshes than in open waters of the same salinity. These two zones are only slightly different in depth. The shallow water marsh areas of the Barataria basin have the three major requirements outlined by Joseph (1973) for a nursery area: (1) physiologically suitable temperature, salinity, and other physiochemical parameters; (2) abundant suitable food with a minimum of competition at critical trophic levels; and (3) a degree of protection from predators.

TERREBONNE HYDROLOGIC UNIT (V)

Description of the Area

The Terrebonne Hydrologic Unit includes only a portion of the entire Terrebonne basin, which is bounded by Bayou Lafourche and the Barataria basin on the north and east, and by the Atchafalaya River Protection Levee and the lower Atchafalaya River on the west (Figure 53). In addition to excluding a large area that is hydrologically and functionally a part of the basin, the official boundary also excludes the major and rapidly growing urban center in the basin (Houma and surrounding smaller towns). It also excludes much of the natural levees that protrude southward like fingers into the basin, and on which most agricultural habitat occurs.

Nevertheless, as defined for this study the Terrebonne Hydrologic Unit is the second largest in the MDPR, and is distinguished primarily by its high proportion of wetland habitats (27% of the total area). The areas of each habitat in this hydrologic unit are shown in Table 21, which also shows the changes in area for each habitat between 1955 and 1978.

The functional Terrebonne basin is similar to the Barataria basin: these adjacent basins are about equivalent in area, they are both interdistributary wetland-dominated zones that receive little riverine input, and both basins are characterized by barrier islands at their seaward extremities. In addition, both basins have been especially noted for their fishery production (Lindall et al. 1979), but they are both experiencing severe problems of water quality (eutrophication and salt water intrusion) and wetland loss (Craig and Day 1977). Field measurements of marsh plant primary production performed in the eastern part of the Terrebonne basin were comparable to similar measurements from the Barataria basin (Hopkinson et al. 1978b).

The description of the central and eastern portion of the Terrebonne Hydrologic Unit is therefore applicable in many ways to the Barataria basin. On the other hand, the western flank of the Terrebonne basin is being heavily influenced by the Atchafalaya Delta development, and the trend of wetland loss and salinity intrusion has been dramatically reversed here, as illustrated by Figure 54 from Baumann and Adams (1982).

High land is in short supply in the Terrebonne Hydrologic Unit, as very little land is more than 1 m (3 ft) above sea level. The only naturally occurring high land is on natural levees (most of which is excluded in terms of the official Terrebonne Hydrologic Unit Boundary).

Major Problems

The function of the Terrebonne Hydrologic Unit has been dramatically affected by the construction of artificial waterways, especially the east-west-oriented Gulf Intracoastal waterway (GIWW) and the north-south-oriented Houma navigation canal. The latter 57.9 km (36 mi) channel was completed in 1962, and mean salinities have about doubled at Bayou Terrebonne in Houma since then (Gagliano et al. 1973). Swamp forest habitat that formerly surrounded the Pointe au Chien Ridge has been killed by the increase in salinity caused by this channel and by canals

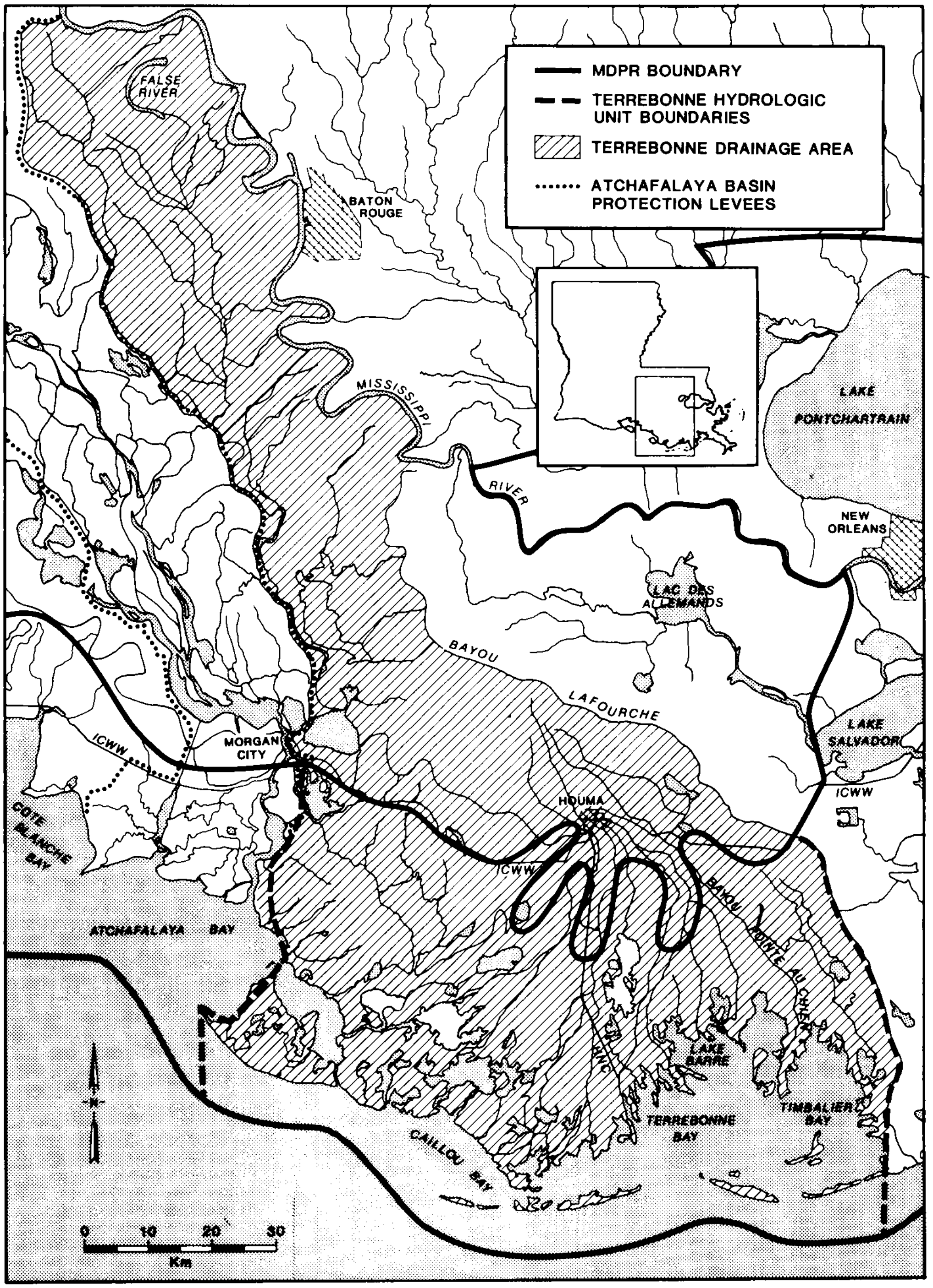

Figure 53. Map of Terrebonne drainage basin showing the MDPR boundary.

Table 21. Habitat areas in hydrologic unit V, Terrebonne.

Habitat		Area (ha)		Change in area[a]
No.	Description	1955	1978	(1978-1955) (ha)
		(2.47 acres/ha)		
1	Agriculture	5100	6639	1539
2	Beach and dune	821	611	-210
3	Bottomland hardwoods	1114	955	-159
4	Brackish marsh	(b)	92010	(b)
5	Canals	2541	6808	4267
6	Cypress-tupelo	24530	20628	-3902
7	Fresh aquatic bed	88	1844	1756
8	Fresh marsh	141691	69423	-72268
9	Fresh open water	4218	12119	7901
10	Fresh scrub-shrub	-	3235	3235
11	Mangroves	-	2133	2133
12	Mud flats	684	110	-574
13	Nearshore gulf	-	-	-
14	Rivers, streams	1406	2060	654
15	Estuarine aquatic bed	-	5461	5461
16	Estuarine open water	253139	288093	34954
17	Salt marsh	140546	57866	9330[b]
18	Spoil banks	2114	6214	4100
19	Upland forest	253	298	45
20	Urban-industrial	1278	2680	1402
	Total	579523	579187	

[a] Due to differences in classification and resolution between the 1955 and 1978 maps, care must be taken in interpreting the area changes shown in this table. See text for a more complete explanation.

[b] Brackish marsh was not delineated on the 1955 maps, but was included with salt marsh as "nonfresh marsh." Therefore, the change in salt marsh number was set equal to the change in total nonfresh marsh.

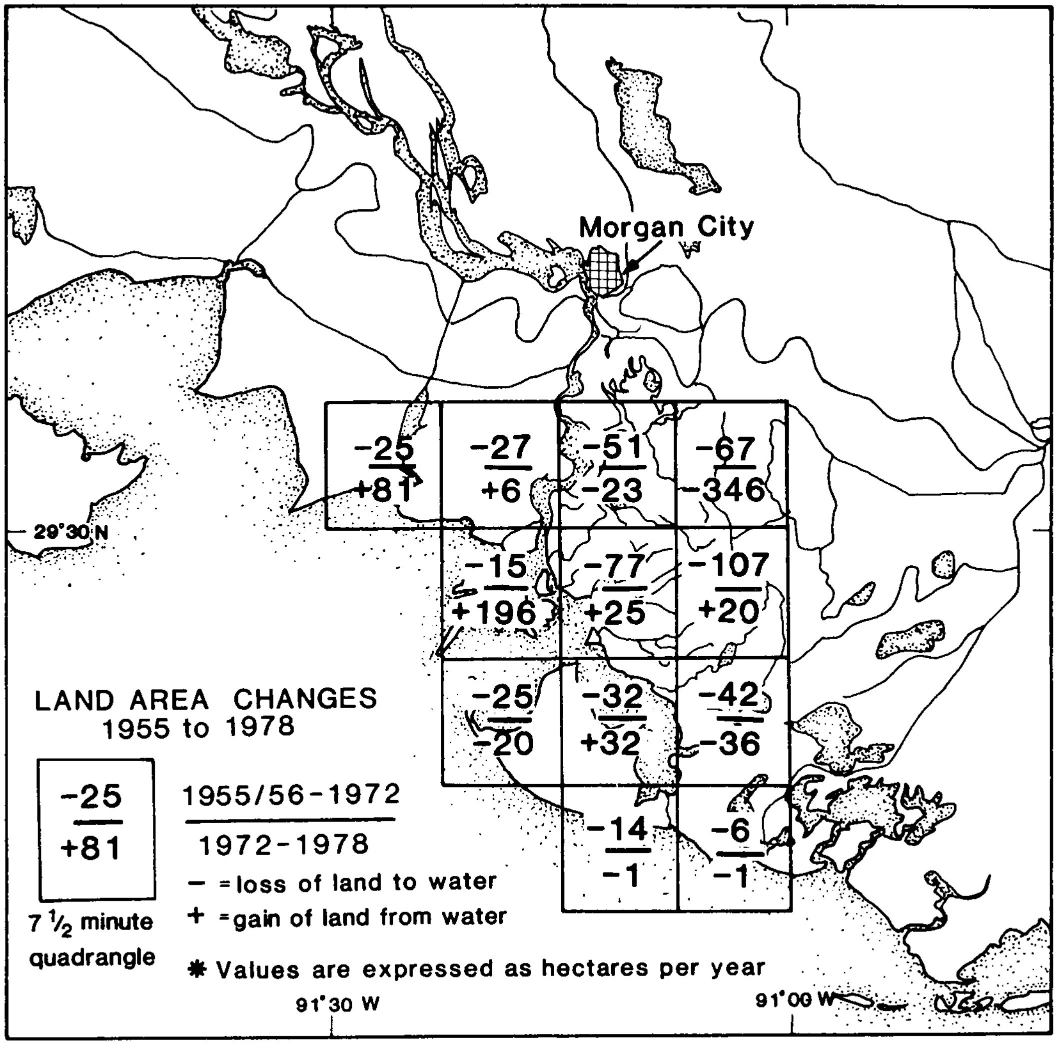

Figure 54. Patterns of land area change in western Terrebonne Parish (from Baumann and Adams 1982).

related to petrochemical production. Increased salinity in eastern and central Terrebonne basin has also induced the landward extension of the nursery ground for brown and white shrimp.

In addition to navigation canals, the Terrebonne basin has been the site of intense petroleum production activity. Terrebonne Parish has recently led the coastal parishes in terms of numbers of permit requests for marsh alteration (378 in 1981), mostly for exploration and rig access canals (Louisiana Department of Natural Resources 1982).

Oyster production has always been significant in the Terrebonne Hydrologic Unit. Large areas of formerly productive oyster ground are now closed, however, because of high coliform levels.

ATCHAFALAYA HYDROLOGIC UNIT (VI)

The Atchafalaya hydrologic unit is the only coastal basin in Louisiana that is presently undergoing net accretion--increase in land area--rather than net erosion. The Atchafalaya system is characterized by the dominance of riverine over marine processes. Abundant sediments are creating a new delta, with new habitats, and the unit does not exhibit the wetland loss that is found in the other basins.

Since the mid-1500's, the Atchafalaya River has been a distributary of the Mississippi system. Its present course to the gulf is 307 km (191 mi) shorter than the modern Mississippi River. The Atchafalaya route has a much steeper gradient than the present Mississippi route. In the 1950's, it became clear that the natural course of the lower Mississippi River would eventually follow this more direct route to the gulf (Fisk 1952).

The Atchafalaya basin is bounded by natural levees of the Teche Delta system (3,500 years B.P.) and Pleistocene alluvial terraces on the west and by the modern Mississippi and the Lafourche levee systems (1,500 years B.P.) on the east. The construction of artificial levees within the basin has substantially reduced the width of the natural Atchafalaya alluvial plain. At Morgan City, the Atchafalaya River cuts through the Teche levee system, where approximately 70% of the flow is transported southward for about 35 km (22 mi) until it discharges into Atchafalaya Bay. The remaining 30% of the flow is discharged into Atchafalaya Bay via Wax Lake Outlet--a man-made channel (Roberts et al. 1980).

The entire Atchafalaya drainage basin and the hydrologic unit boundary are shown in Figure 55. The eastern boundary of the hydrologic unit follows the east bank and protection levee of the river to the Avoca Island cutoff. It then follows the shoreline to Point-au-Fer, where it drops south to the 3-mi limit. The western boundary extends along the east bank protection levee of Bayou Sale community to the town of Burns. From Burns, the boundary follows the shoreline of East Cote Blanche Bay to Point Chevreuil. From Point Chevreuil, the boundary extends south to South Point, following the shoreline of Marsh Island to Mound Point. At Mound Point, the boundary goes south to the 3-mi limit (Wicker et al. 1980b).

These boundaries exclude areas to the east and west that are influenced by the flooding of the Atchafalaya River. Although the Terrebonne basin as a whole has a high rate of wetland loss, some areas adjacent to the lower Atchafalaya River have accreted during the past decade as a result of riverine sediment inputs (Baumann and Adams 1982). Only about 40% of the total suspended sediment load transported by the lower Atchafalaya River and Wax Lake Outlet was retained in Atchafalaya Bay during the period from 1967 to 1977. The remaining sediments, all fine grained, were transported to peripheral marshes in the Vermilion-Cote Blanche Bay complex, and offshore, where the predominantly westward-trending currents carry material to southwestern Louisiana.

Geological History

The distribution of flow between the Mississippi and Atchafalaya Rivers has not been constant. Not until 1839,

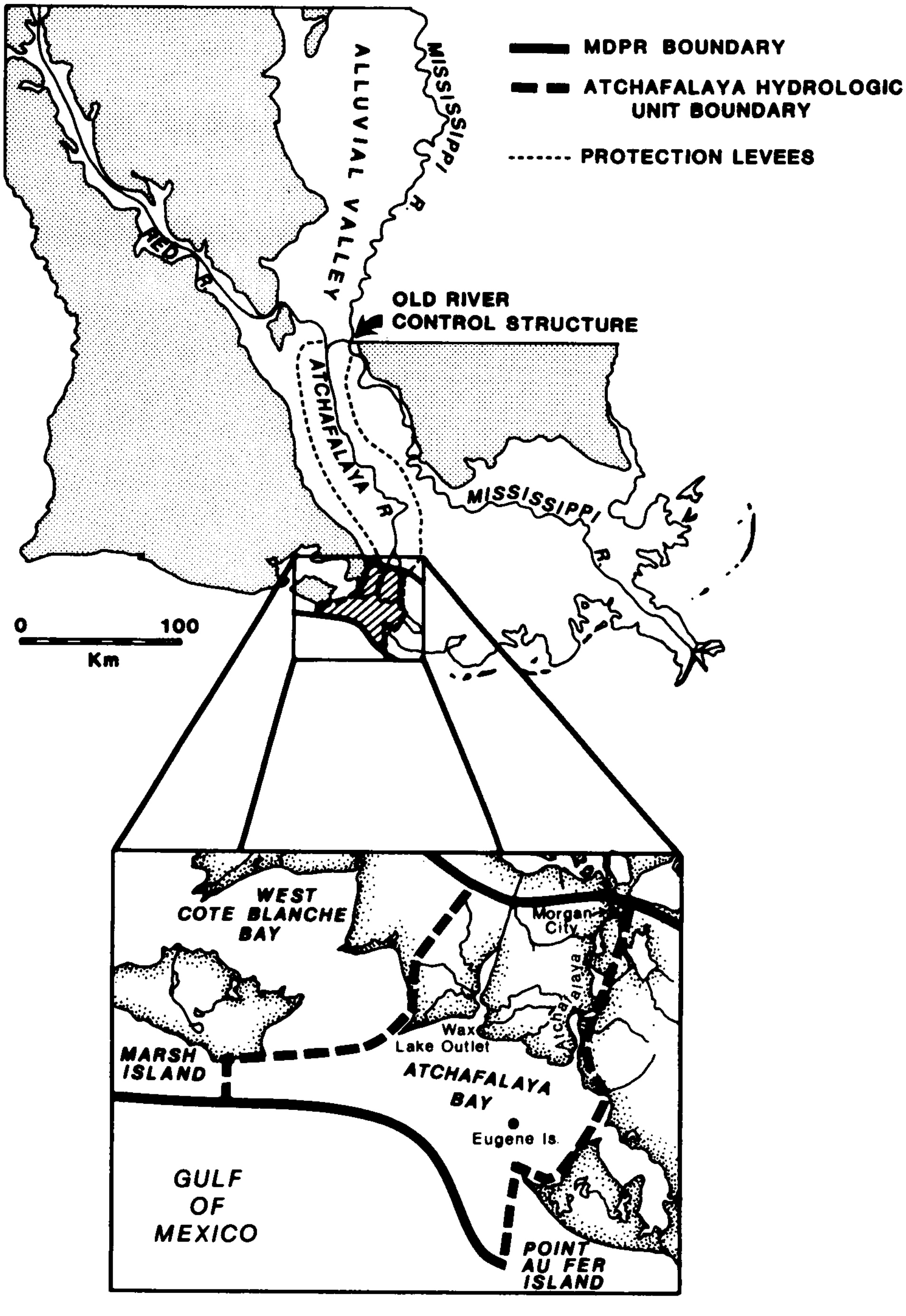

Figure 55. Map of Atchafalaya drainage basin showing the MDPR boundary.

when log jams were removed from the Atchafalaya River did the flows begin to increase steadily. In the early 1950's it was postulated that the main flow of the Mississippi River would eventually be diverted to the Atchafalaya course (Fisk 1952). To prevent this from happening, the USACE constructed a control device, the Old River Structure, at Simmesport, Louisiana (Fisk 1952). Completed in 1963, this structure was designed to limit the Atchafalaya's flow to 30% of the combined flow regimes of the Mississippi and Red Rivers. During periods of peak flow, more than 30% of the total Mississippi drainage has flowed through the structure, and peak flood stages produce most sedimentation (Roberts et al. 1980).

Recent Changes in the Atchafalaya Hydrologic Unit

Increasing sediment loads have been deposited into the lower Atchafalaya basin above Morgan City during the past 50 years or more. The Atchafalaya River flows through a system of freshwater lakes, swamps, and bayous. Most of the larger lakes in the lower basin (Grand Lake and Six Mile Lake) were filled between 1917 and 1960. With loss of the lake storage and channelization of the main streams, sediment was carried into Atchafalaya Bay in increasing volumes. From 1858 to the early 1950's, little change was noted in the bathymetry of Atchafalaya Bay (Thompson 1951). During the 1950's and 1960's, increasing volumes of silt and clay contributed to the beginning of a subaqueous delta at the mouth of the Atchafalaya River and Wax Lake Outlet (Cratsley 1975; Shlemon 1975).

By 1972, a layer of sediment about 2 m thick had been deposited in Atchafalaya Bay. In the floods of 1973-75, the large sediment load (mostly sand) increased from the average 42.6 x 10^6 metric tons/yr to 88.9 x 10^6 metric tons/yr (Roberts et al. 1980). Between 1973 and 1975, a well-developed subaerial delta emerged (Rouse et al. 1978). By 1976, more than 1400 ha (3,500 acres) of subaerial delta were present (Roberts et al. 1980). The growth of the delta from 1967 to 1977 is illustrated in Figure 56; the change in all habitat categories from 1955 to 1978 are indicated in Table 22.

Recent changes in land use reflect the rapidly increasing influence of water and sediment inputs and the economic influence of petroleum recovery.

The basin consists primarily of habitats controlled by riverine processes. Most of the hydrologic unit is made up of estuarine open water, fresh marsh, and cypress-tupelo swamp (Table 22). Major changes in habitat types from 1955 to 1978 reflect the increasing spring flooding with the concommitant sediment input (Baumann and Adams 1982). During that time period there was a complete loss of salt marsh from the area; a 140% increase in fresh marsh; an increase in fresh aquatic beds, rivers, streams,and fresh scrub-shrub habitat; and a loss in area of estuarine open water. Most of this change is related to the increase in flooding and sedimentation.

During the same period, area covered by spoil banks and canals has increased 91% and 105%, respectively, reflecting the importance of the basin as a site for oil and gas activity. Urban industrial and agricultural habitats have increased 49% and 41% in area, respectively, the former related to oil production, the latter to the lucrative market for soybeans.

The primary economic activity in this basin, based on revenues, is oil and gas drilling. The Atchafalaya River and associated channels and canals provide a transportation network to offshore oil and gas rigs. The population centers in the lower basin--Morgan City, Berwick, Amelia, and Patterson--are predominantly areas of boat-tug-barge construction, and oil rig construction, assembly, supply, and support. Before the oil boom, economic activity in the lower basin was based primarily on renewable resources (shrimping, sugar cane, and lumber), but

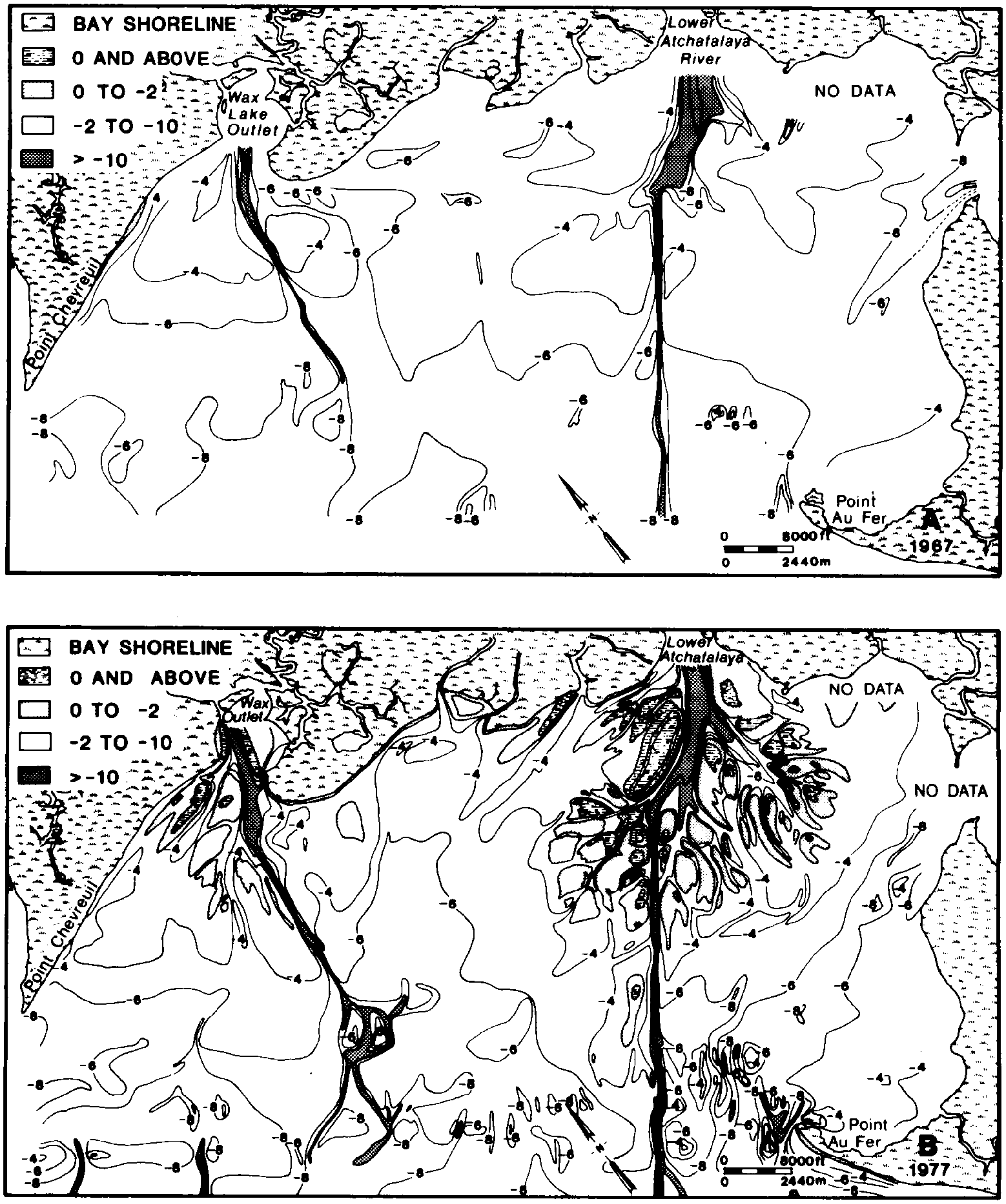

Figure 56. Bathymetric maps of Atchafalaya Bay, (1) 1967 and (B) 1977. Contours are in feet (from Roberts et al. 1980).

Table 22. Habitat areas in hydrologic unit VI, Atchafalaya.

Habitat No.	 Description	Area (ha) 1955	 1978	Change in area[a] (1978-1955) (ha)
		(2.47 acres/ha)		
1	Agriculture	742	1043	301
2	Beach and dune	-	4	4
3	Bottomland hardwoods	44	2	-42
4	Brackish marsh	(b)	-	(b)
5	Canals	825	1695	870
6	Cypress-tupelo	17185	18079	894
7	Fresh aquatic bed	7	601	594
8	Fresh marsh	9960	23855	13895
9	Fresh open water	1496	1705	209
10	Fresh scrub-shrub	69	797	728
11	Mangroves	-	12	12
12	Mud flats	1000	811	-189
13	Nearshore gulf	-	-	-
14	Rivers, streams	3046	5324	2278
15	Estuarine aquatic bed	-	1	1
16	Estuarine open water	102272	97876	-4396
17	Salt marsh	16232	-	-16232[b]
18	Spoil banks	1060	2025	965
19	Upland forest	115	163	48
20	Urban-industrial	387	575	188
	Total	154440	154568	

[a] Due to differences in classification and resolution between the 1955 and 1978 maps, care must be taken in interpreting the area changes shown in this table. See text for a more complete explanation.

[b] Brackish marsh was not delineated on the 1955 maps, but was included with salt marsh as "nonfresh marsh." Therefore, the change in salt marsh number was set equal to the change in total nonfresh marsh.

these have been overshadowed by the petroleum industry in recent years. Shell dredging in Atchafalaya Bay is still a major economic activity, although limestone from out of State is becoming economically competitive with shells (R. Dugas, Louisiana Department of Wildlife and Fisheries; pers. comm.).

The population of St. Mary's Parish rose from 48,833 in 1960 to 70,831 in 1980, a 45% increase. This increase is largely related to employment offered by the oil companies and their associated industries.

Atchafalaya Bay and Associated Wetlands

The Atchafalaya basin is strongly influenced by the seasonal flooding of the Atchafalaya River. High floods occur between January and June. The average peak flows have been about 11,300 m^3/sec (400,000 cfs) at Simmesport; the average annual flows have been 5,100 m^3/sec (181,000 cfs) between 1956 and 1975 (Figure 57). During 1973 to 1975, the river received average yearly flows of 8,800 m^3/sec (313,000 cfs) at Simmesport, with 19,800 m^3/sec (700,000 cfs) in April 1973, and 17,000 m^3/sec (600,000 cfs) in April 1975. The flows were similar for the same years at Morgan City (Figure 58). Peak flows during the flood of 1973 are suspected to have been substantially greater than reported at Simmesport because of the opening that year of the Morganza Spillway, a control structure that diverts Mississippi River flow into the lower Atchafalaya basin during high discharge periods.

Within the basin, precipitation usually has little effect on flood stage elevation or timing. The particularly high flows of 1973-75 were accompanied by similarly high levels of suspended sediment.

Suspended sediment loads in the lower Atchafalaya River averaged 41.6 x 10^6 metric tons/yr during 1967-71 (Roberts et al. 1980). During the flood years 1973-75, the load nearly doubled, averaging 86.8 x 10^6 metric tons/yr (Roberts et al. 1980). Prior to the early 1970's, the majority of the sediment reaching Atchafalaya Bay was silt and clay, because sands were being deposited until that time within the basin. The overall sediment increase to Atchafalaya Bay since the 1970's has been primarily due to an increase in the amount of fine sand, an important event in deltaic development, as it marked the shift of the locus of sedimentation downstream from the lower Atchafalaya basin above Morgan City to the Atchafalaya Bay area.

Coastal submergence is occurring in the Atchafalaya hydrologic unit, just as in the rest of the MDPR, caused by worldwide sea level rise combined with subsidence of the land and increasing river stages. The rate of sediment accumulation is more than keeping up with coastal submergence over the area, however, and land elevations are increasing.

Tidal and wind energy are also influential on the development of the emerging deltaic system in Atchafalaya Bay and the surrounding wetlands. The seasonal tidal levels at Eugene Island from 1935 to 1970 are shown in Figure 59. The astronomical tides in Atchafalaya Bay are 60% semidiurnal and 40% mixed semidiurnal and diurnal. The mean tidal range in Atchafalaya and Vermilion bays is about 0.4 m (1.3 ft), and the extreme range is 0.8 m (2.6 ft). The mean tidal range at Eugene Island is about 0.6 m (2 ft), with a 0.7 m (2.3 ft) extreme. Meteorological tides (wind tides), which are independent of the lunar tides, are also important in the shallow Atchafalaya Estuary. With a strong southeasterly wind, a wind tide may reach 0.5 m above normal; a strong northerly wind may depress water levels up to 1.0 m (Barrett 1970). Hurricane tides can have an even greater impact on water levels.

Seasonal effects on the water level at Eugene Island are as follows; high water levels due to streamflow occur during the spring (March, April, and May) and the late summer, while the high water level associated with the early fall is due to the rise of the Gulf of

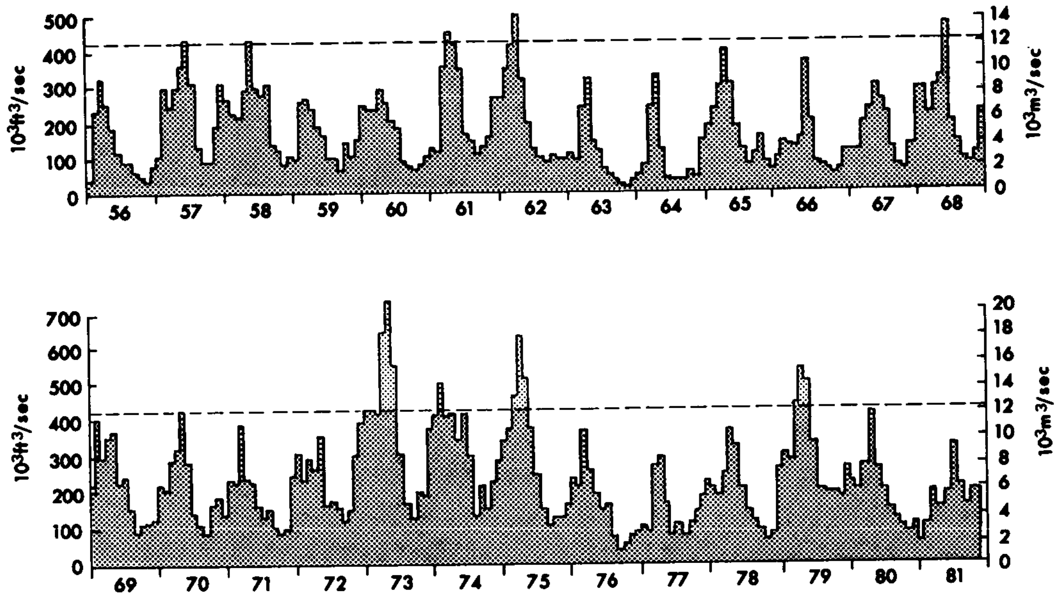

Figure 57. Mean monthly discharge for the Atchafalaya River at Simmesport, Louisiana, 1956-1975. Dotted line is average annual peak flow (425,000 cubic ft/sec) (from Roberts et al. 1980).

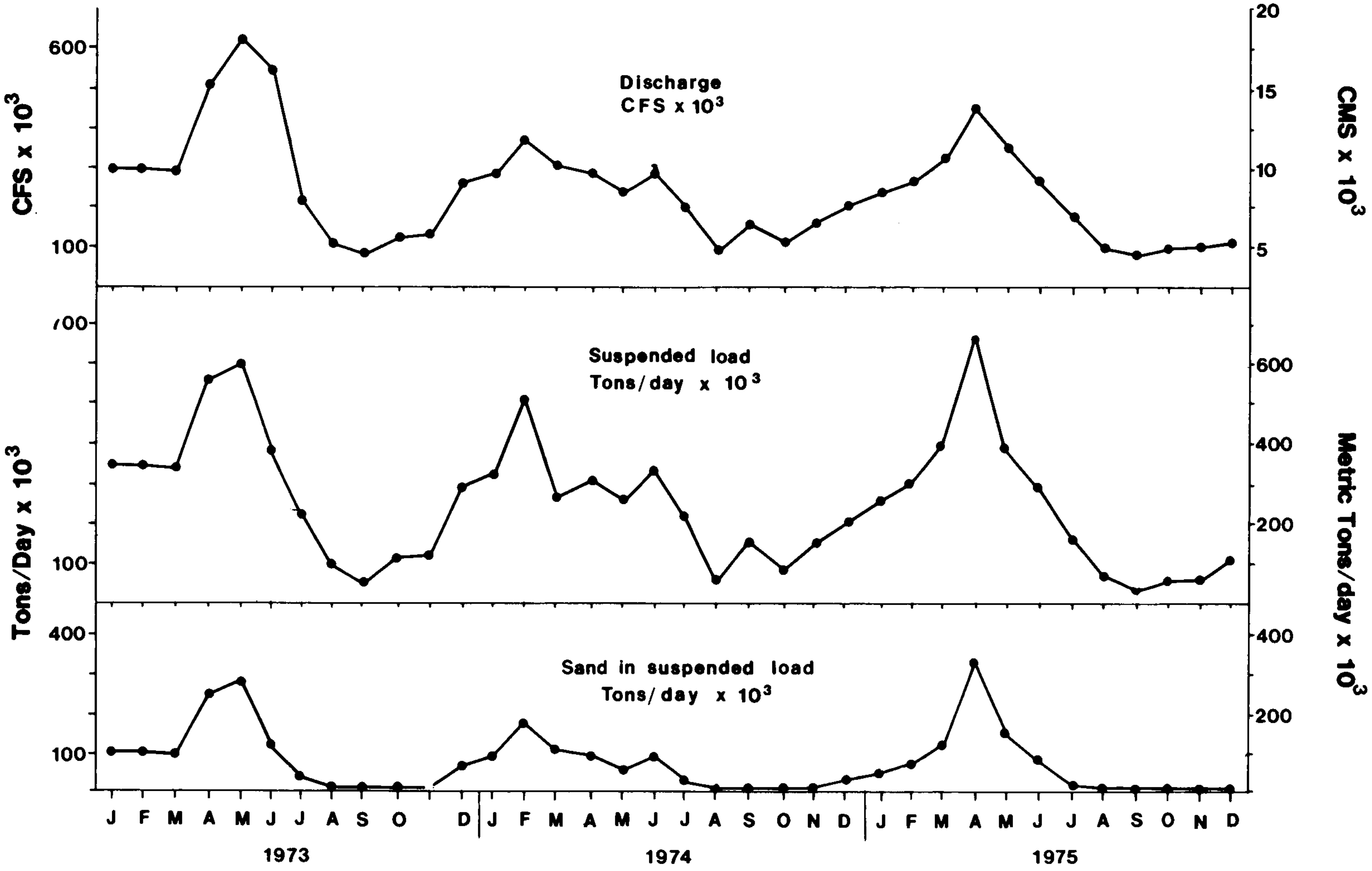

Figure 58. Mean monthly discharge and suspended load near Morgan City, Louisiana, at the lower Atchafalaya River outlet, 1973-1975 (from Roberts et al. 1980).

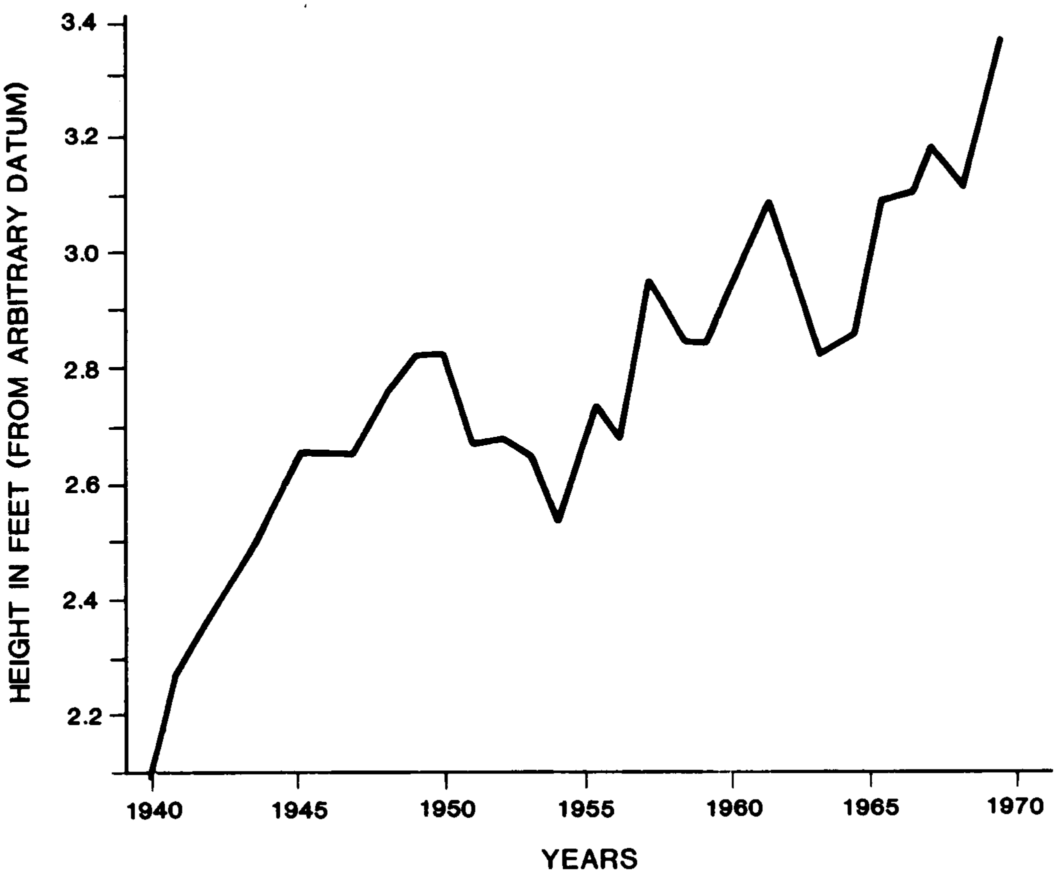

Figure 59. Annual tidal levels at Eugene Island, Louisiana, 1940-1970 (from Day et al. 1973).

Mexico at that time more than to streamflow. During the fall and winter months (October to February), streamflow is at its lowest point, and tidal ranges are highest during this time. Tidal range is lowest during spring, perhaps as a result of being masked by peak river flows. Salinity patterns reflect the influence of streamflow, with the lowest salinity during the spring floods and the highest salinity from July to September.

Like the rest of coastal Louisiana, Atchafalaya Bay is influenced by synoptic weather types. The effect of various weather patterns on water levels at Eugene Island is shown in Figure 60. Generally the winds are northerly during the winter and southerly during the summer (see Description of the Region).

Primary Production

Major habitats in the Atchafalaya hydrologic unit in 1978 included estuarine open water, fresh marsh, and cypress-tupelo forest. Since 1955 there has been a 140% increase in area of fresh marsh, with only a small increase (5%) in cypress-tupelo forest, and a small (4%) decrease in estuarine open water area. The greatest change over the 23-year period was the complete conversion of the salt marsh ecosystem, largely to fresher marsh habitats.

Primary production in the turbid estuarine bays of the Atchafalaya basin has not been well documented, although chlorophyll a concentrations have been measured. These ranged from 3-6 mg/m^3 in the delta to 15 mg/m^3 in adjacent Four League Bay (J. Day, Louisiana State University, Center for Wetland Resources; unpub. data). These values are low, compared with chlorophyll values in the Barataria basin (see Barataria Hydrologic Unit). No studies have been made of primary production in the cypress-tupelo forest in the Atchafalya. Recent studies of cypress swamps in Florida and the Barataria basin have shown increasing primary production with increased hydrologic flows and associated nutrients (Brown 1978; see Cypress-tupelo Swamp Habitat). The frequently flooded cypress-tupelo forest receives a load of suspended sediment during spring floods and may be more productive than the cypress-tupelo systems of the Barataria basin.

The most intensively studied marsh ecosystems in the Atchafalaya hydrologic unit are the marshes developing on emerging islands in the delta. Initial emergent vegetation on an accreting mud flat are arrowhead (Sagittaria sp.) and common water nymph (Najas guadalupensis) (B. Johnson, Louisiana State University, Coastal Ecology Laboratory; pers.comm.). Early island formation is mediated by the physical processes of flooding, sediment deposition scour, and erosion. Biotic factors such as root stabilization of the substrate only become important later in the deltaic developmental sequence.

After additional sediment deposition, willow (Salix nigra) becomes established on the elevated levees, and further successional changes in the island are influenced by the roots and stems. The vegetation slows the water velocity, increasing the sediment deposition and altering the chemical conditions of the sediments. Cattail (Typha latifolia) and arrowhead become established at slightly higher mean elevations in and behind the protective willow communities (Johnson et al. 1981).

As the vegetative community in the backwater of the island develops, the proportion of fine silts and organic carbon in the substrate increases relative to sand, because the community is sheltered from high velocity spring flood waters. In addition to the spring flood, the normal tidal inundation of the substrate regulates marsh development.

As the marsh becomes established, the structural complexity of the community increases, both above and below the mean water level. This results in increasing diversity of species in the marsh. The increase in community diversity appears to be inversely related to flooding stress (Johnson et al. 1981).

These pioneer marshes, once established, are not particularly productive,

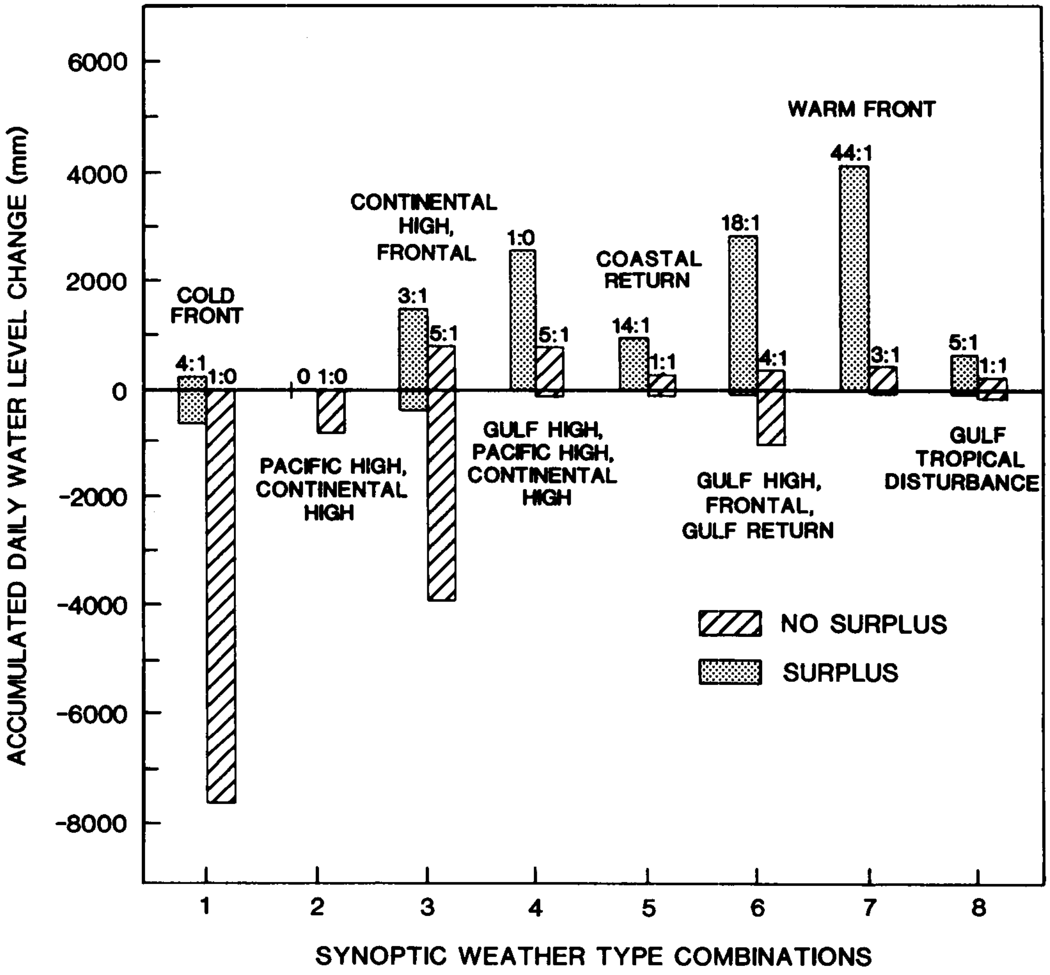

Figure 60. Effect of various weather patterns on water levels at Eugene Island, Louisiana (from Wax 1977).

compared with other freshwater marsh ecosystems (Whigham 1978). Above and below ground standing crop values range from 353 g dry wt/m^2 for Sagittaria communities, to 687 g dry wt/m^2 for Typha latifolia communities, to 660 g dry wt/m^2 for the Salix nigra community. These relatively low values may reflect the successional youthfulness of the ecosystem. Low primary productivity does not mean that emerging delta land is not heavily used by waterfowl.

VERMILION HYDROLOGIC UNIT (VII)

The Vermilion hydrologic unit is adjacent to and west of the Atchafalaya unit. From a functional and historical (geological) standpoint, the Vermilion and Atchafalaya units are closely related as they occupy the oldest portion of the MDPR, the former Teche Delta system that was active about 6,000 years B.P. (Coastal Environments, Inc. 1977). This advanced age is reflected in the coastline, which is smoother and less irregular than in younger coastal areas (Figure 61). This is said to indicate an advanced state of coastal erosion (Coastal Environments, Inc. 1977). The Vermilion Hydrologic unit is being strongly influenced by the emerging Atchafalaya Delta complex.

The Vermilion unit occupies the western extremity of the MDPR as well as the eastern extremity of the Chenier Plain. The western half of the Vermilion hydrologic unit was described in the characterization study of the Chenier Plain region (Gosselink et al. 1979). The areas of the habitats comprising the Vermilion hydrologic unit, and their changes between 1955 and 1978 are shown in Table 23.

Much of the Vermilion hydrologic unit (about 49%) is occupied by Vermilion Bay (estuarine open water habitat). This water body was described in 1969 (Dugas 1970) in terms of its ecological characteristics. Although Vermilion Bay is a part of the Atchafalaya-Cote Blanche-Vermilion complex, Dugas reported that it is somewhat distinct from the other three bays in having larger sediment grain size, more shell inclusions, and more organic matter in the sediment. This difference was presumably due to the distance of Vermilion Bay from the fine sediment outwelling from the Atchafalaya River and the presence of oyster reefs that block sediment transport.

Nevertheless, Vermilion Bay has become less saline because of the influence of the Atchafalaya. In 1966 the marshes surrounding the bay were described (perhaps incorrectly) as salt marshes (Norden 1966). They were brackish by 1969 (Dugas 1970). Average water salinity in the bay was reported as ranging from 2 to 5 ppt in 1969 (Dugas 1970). In 1979 they were partly intermediate (Chabreck and Linscombe 1978).

Vermilion Bay is quite shallow (average depth about 1.5 m or 4.92 ft) with the exception of a scour hole over 50 m (164.0 ft) in Southwest Pass to the west of Marsh Island (Juneau 1975). Water temperatures reflect the shallow depth, ranging from 10 deg. to 33.5 deg. C, or 50 deg. to 92.3 deg. F (Dugas 1970). The average sediment grain size in the nearshore zone in the Vermilion hydrologic unit is the smallest (finest) of any coastal estuarine area because of Atchafalaya influence (Juneau 1975).

Oyster reefs are not distinguished as a separate habitat in the technical report for the Mississippi Deltaic Plain Region, and were not delineated on the Wicker et al. 1980b maps which form part of the information base for this study. Reefs that are periodically (or aperiodically) exposed by low water levels are limited in their distribution in the MDPR. In the Atchafalaya and the Vermilion hydrologic units, however, oyster reefs are quite extensive, and presumably important in the nearshore habitat. A huge reef system is located directly in front of Atchafalaya Bay, and another is to the west in front of Marsh Island, as shown in Figure 62. Many of these reefs are not living because the oysters that comprise them have been killed by the increasing sediment and freshwater flow emerging from

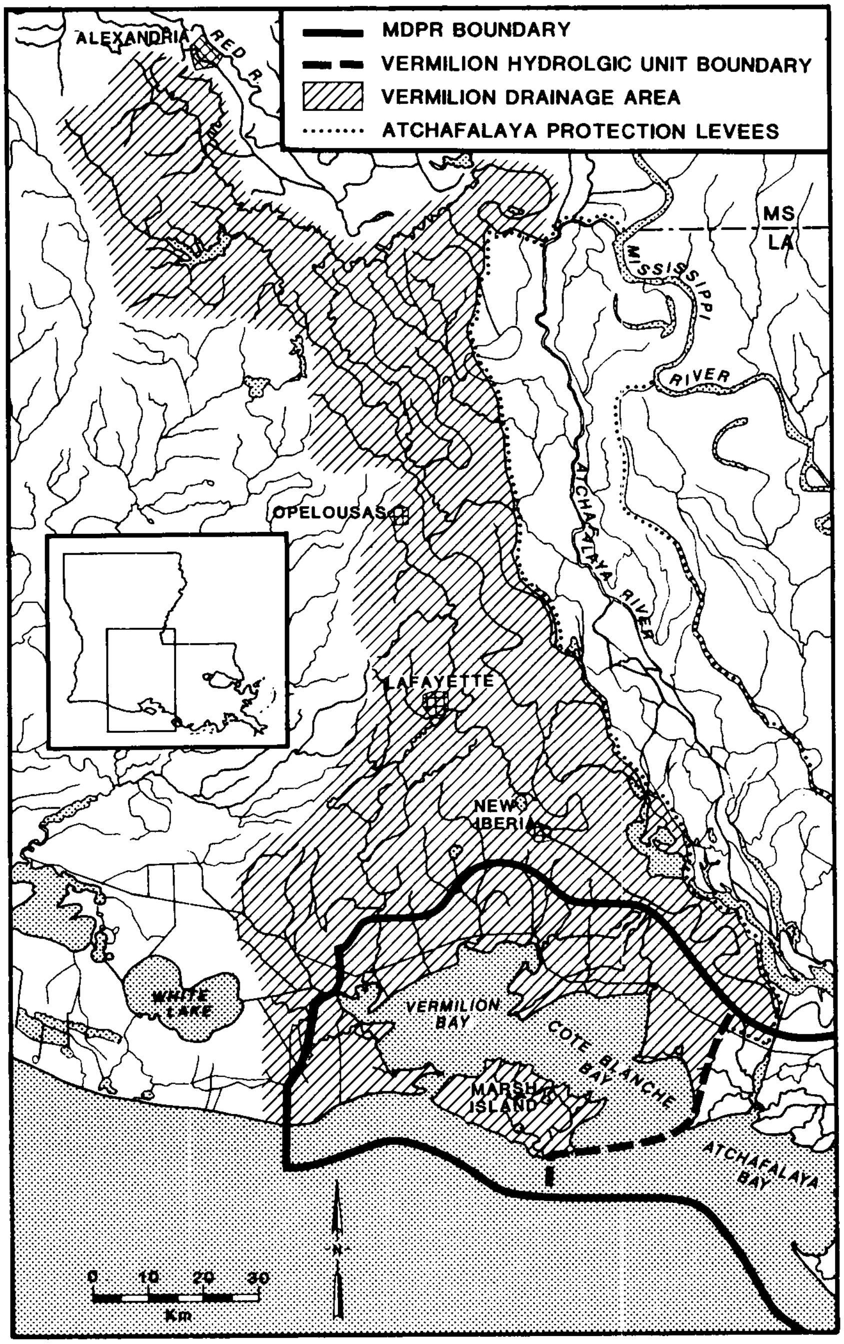

Figure 61. Map of Vermilion drainage basin showing the MDPR boundary.

Table 23. Habitat areas in hydrologic unit VII, Vermilion.

Habitat		Area (ha)		Change in area[a]
No.	Description	1955	1978	(1978-1955)
		(2.47 acres/ha)		(ha)
1	Agriculture	41366	40772	594
2	Beach and dune	197	202	5
3	Bottomland hardwoods	2283	1989	-294
4	Brackish marsh	(b)	77902	(b)
5	Canals	1956	4005	2049
6	Cypress-tupelo	21486	20503	-983
7	Fresh aquatic bed	-	172	172
8	Fresh marsh	12438	20233	7795
9	Fresh open water	117	1138	1021
10	Fresh scrub-shrub	4374	4126	-248
11	Mangroves	-	-	-
12	Mud flats	730	352	-378
13	Nearshore gulf	-	-	-
14	Rivers, streams	335	280	-55
15	Estuarine aquatic bed	4	597	593
16	Estuarine open water	172345	174754	2409
17	Salt marsh	95340	2541	-14897[b]
18	Spoil banks	1104	2466	1362
19	Upland forest	2331	2089	-242
20	Urban-industrial	2145	4364	2219
	Total	358551	358485	

[a] Due to differences in classification and resolution between the 1955 and 1978 maps, care must be taken in interpreting the area changes shown in this table. See text for a more complete explanation.

[b] Brackish marsh was not delineated on the 1955 maps, but was included with salt marsh as "nonfresh marsh." Therefore, the change in salt marsh number was set equal to the change in total nonfresh marsh.

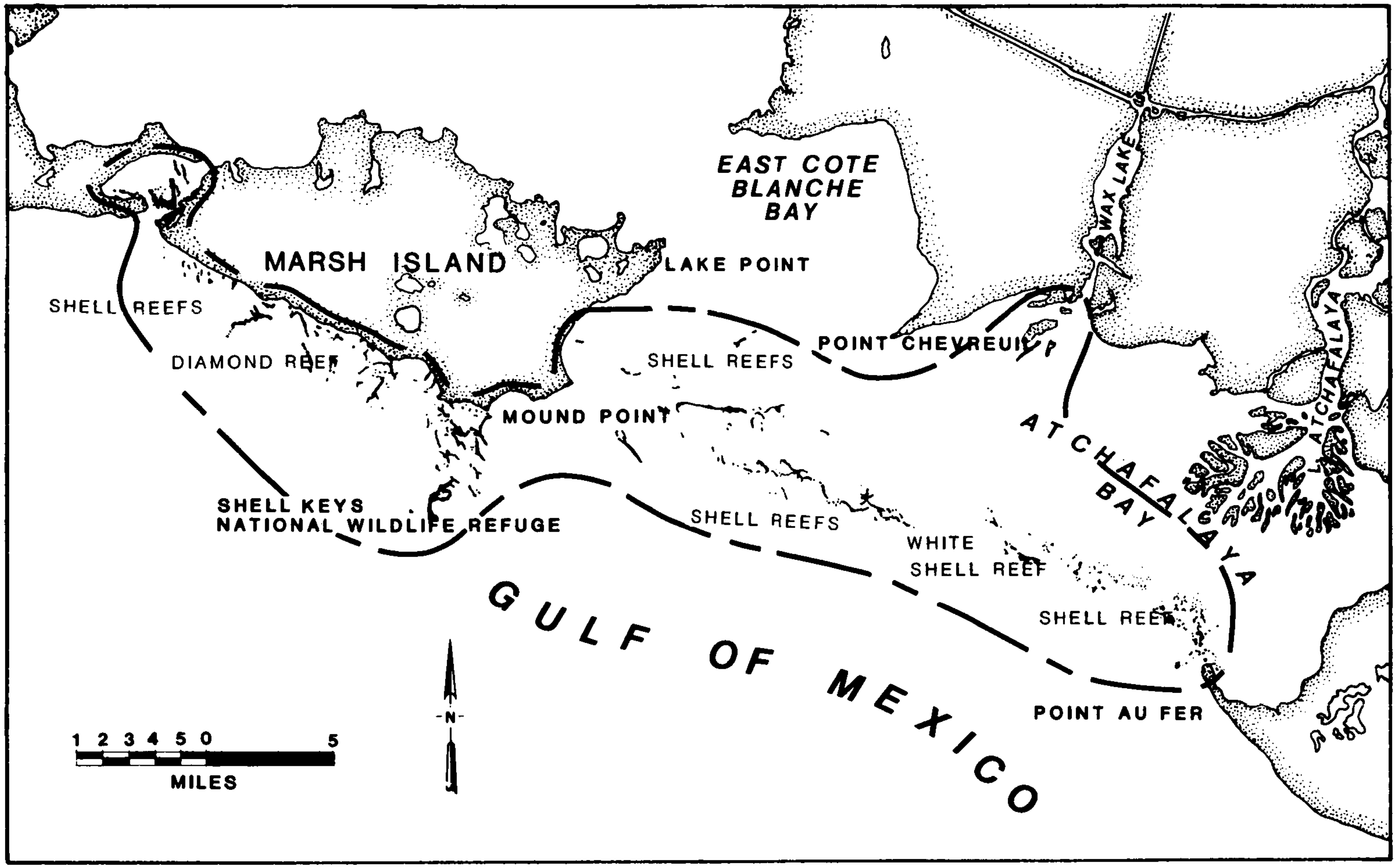

Figure 62. Oyster reef complexes in the Atchafalaya and Vermilion hydrologic units (from Chabreck and Linscombe 1978).

the Atchafalaya River, especially during and since the 1973 flood (Coastal Environments, Inc. 1977). They do attract newly colonizing spat during some years, but only those oysters that have not been subjected to prolonged low salinities grow to maturity.

These oyster reefs are unimportant for commercial harvesting because of the limited number of live oysters and because intertidal reef oysters often tend to be too stunted and difficult to harvest to be of marketable value (Bahr and Lanier 1981). Their importance is physical: as sediment traps and as barriers to tidal and wind currents. Reduced shoreline erosion within the Vermilion hydrologic unit has been attributed to local offshore oyster reefs. For example, the coastline along Marsh Island was relatively stable from 1932 to 1969 where nearshore oyster reefs were present (Adams et al. 1978).

Manmade modification of the Vermilion basin includes water control structures such as the Vermilion Locks to prevent saltwater intrusion. Fresh water is stored in the Mermentau River basin for rice irrigation, and salt water intrusion is a continuing problem. Water control structures have greatly reduced water exchange with marshes (Byrne 1977).

ECOLOGICAL ISSUES

Two particularly important open questions of estuarine ecology are the subject of a lively debate. They are: (1) what are the sources of nutrients that support estuarine primary productivity (Haines 1979; Turner et al. 1979a; Nixon 1981), and (2) what is the role of intertidal wetlands in the organic budget of estuaries and coastal waters, especially the role of wetlands in the trophic support of coastal fisheries (Turner et al. 1979b; Nixon 1980; Odum 1980).

In this section we address these issues within the context of the MDPR data base. Detailed studies have been done in the Barataria and Pontchartrain basins. Some data are from other areas and a growing amount of information is from ongoing studies in the Atchafalaya Bay area.

FACTORS AFFECTING AQUATIC PRIMARY PRODUCTIVITY

Studies of aquatic primary productivity have been conducted in all major water bodies of the Barataria basin, in Lake Pontchartrain, in several areas of the Terrebonne basin, and in the nearshore Gulf of Mexico. The problem of primary productivity in the Barataria basin serves as a general example of productivity trends throughout the MDPR.

The factors controlling productivity change from the swamp in the upper Barataria basin to the salt marsh and open gulf in the lower basin. In the upper basin, nutrient loading from upland runoff seems to be important in controlling both seasonal patterns and magnitude of production. The importance of upland runoff is substantiated by the results of Witzig and Day (1982), who showed a relationship between trophic state index (TSI) and primary production for waters of the Barataria basin and Lake Pontchartrain. Locations with a high TSI had high inputs of nutrients from upland runoff. Gael and Hopkinson (1979) reported that TSI was significantly correlated with canal density, a measure of the intensity of upland runoff. Evidence suggests that water clarity and depth control primary productivity in the lower basin (Hopkinson and Day 1979). Offshore, river flow is the dominant factor controlling productivity (Sklar and Turner 1981). Results of aquatic productivity studies from several sites in the Terrebonne basin (Allen 1975) are similar to those from the Barataria basin.

WETLANDS AND THE ESTUARINE CARBON BUDGET

Because of the great expanse of periodically flooded marshes and swamps in the MDPR, one might expect these wetlands to play a major role in controlling or augmenting the productivity of adjacent freshwater and estuarine ecosystems. Again, the most detailed evidence for this control is the result of studies carried out within the Barataria basin. Day et al. (1982) constructed an annual organic carbon budget for Barataria basin from a combination of direct and indirect measurments of carbon fluxes (Table 19).

The Barataria basin carbon budget indicates that all aquatic habitats are strongly dependent on organic matter washed in from adjacent watersheds, and upstream habitats are significant sources of organic matter for downstream habitats. The portion of wetland primary production exported to adjacent water bodies is lowest in the swamp (2%) and greatest in the salt marsh (30%). In situ production plus carbon inputs from other habitats exceeds carbon outputs from respiration and sedimentation in all aquatic habitats. Upstream production provides from 9% to 30% of total carbon inputs to the different water bodies.

The mass balance technique used to calculate the carbon budget depends to some extent on fluxes calculated by difference, so the resulting budget cannot be validated. Considerable data, however, exist to show: (1) that carbon in significant quantities is exported from the estuaries into the gulf, (2) that carbon is exported from wetlands to adjacent water bodies, and

(3) that downstream export of carbon affects primary productivity of aquatic habitats. Direct measurements of organic carbon export have been collected from Lac des Allemands to Lake Salvador (Day et al 1977) and from Barataria Bay to the Gulf of Mexico (Happ et al 1977).

Research in both the Barataria basin and in Lake Pontchartrain show that bayous, canals, and lake edges that are contiguous with wetlands are more enriched than open water areas (Cramer 1978, Seaton 1979, Witzig and Day 1982).

THE ROLE OF MARSHES AND ESTUARIES IN FISHERIES PRODUCTION

Louisiana has the greatest area of coastal wetlands (Turner and Gosselink 1975) and the largest commercial fishery in the United States (NOAA 1980). It is a commonly held belief that the region's coastal wetlands play an important role in supporting the fisheries (Lindall and Saloman 1977; Bahr et al. 1982). There is strong evidence for coupling between fisheries production and the marsh estuarine system.

Many nektonic species spend a part of their life cycle in estuaries, using them in predictable ways. Evidence suggests that larval and juvenile forms of many species seek out marsh ponds, tidal creeks, and marsh edges adjacent to wetlands. Nekton biomass in Barataria basin and Lake Pontchartrain is 7 to 12 times higher in shallow water marsh areas than in open waters (Table 20). This is also true for the emerging wetlands of the new Atchafalaya Delta (B. Thompson, Louisiana State University, Center for Wetland Resources, Baton Rouge, La.; pers. comm.). Studies on the east coast have shown that shallow tidal creeks and marsh shoals harbor dense populations of juvenile marine species (Shenker and Dean 1979, Weinstein 1979; Bozeman and Dean 1980).

Nekton community composition, biomass distribution, and migration have been studied in the MDPR (Thompson and Verret 1980). Eight species comprise 80% to 95% of the total numbers and biomass (see the Barataria hydrologic unit description). Of these species, anchovies (Anchoa mitchilli) and silversides (Menidia beryllina) spend their entire life cycle in estuaries. Croaker (Micropogionas undulatus) and menhaden (Brevoortia patronus) spawn offshore and use estuaries and marsh creeks as post larvae and juveniles. Croaker and menhaden are also important commercial species.

Correlations have been made between the presence of estuarine wetlands and commercial fisheries. Turner (1977) correlated shrimp yield (kg/ha) and intertidal wetland areas on a worldwide basis. In the northern Gulf of Mexico, he found that inshore shrimp yields were directly related to the area of estuarine emergent vegetation; but not related to the area, average depth, or volume of estuarine open water. Moore et al. (1970) presented data on the distribution of offshore demersal fish in Louisiana and Texas indicating that the greatest fish populations occurred adjacent to areas with freshwater runoff and extensive wetlands areas.

The evidence from the MDPR suggests that wetlands enhance fisheries productivity. The question of absolute dependence of nekton species on estuaries, particularly wetlands, is still open to debate. The available data indicate specific ways that commercially important nekton species use wetlands. It is highly probable that many nektonic species have evolved behavioral patterns that allow them to exploit wetlands for both food sources and habitat.

MANAGEMENT ISSUES

There are conflicting demands on the wetlands and waters of the MDPR. The region produces a major portion of both the nation's petroleum resources and its recreational and commercial fisheries. It occupies a strategic location for navigation and commerce. During the last several decades the human population and industry and commerce have greatly increased, resulting in significant alteration and apparent degradation of the natural system.

The MDPR has served as a waste repository for domestic and industrial discharges and agricultural drainage. Extensive channelization and spoil disposal have degraded wetlands. There has been an enormous net loss of wetlands. Some of the problems in the Louisiana coastal zone were recently documented by Malone et al. (1980). These include pollution, wetland loss, salt water intrusion, and others. These problems will probably intensify over time because of population and industrial expansion, and because of synergistic and cumulative effects of existing coastal modifications. Wetland loss-rates throughout the United States generally occur in proportion to population density and degree of industrial development (Gosselink and Baumann 1980).

Energy-related activities, because of their importance to the national economy, are favored by permitting agencies over the preservation of undisturbed wetland resources. The habitat base supporting renewable natural resource productivity is constantly diminishing. An unanswered management question is "What is the quantitative impact of continuing wetland alteration?" The maintenance of current levels of fishery production may very possibly depend on the present wetland area (Turner 1977, 1979, Lindall et al. 1979).

WETLAND LOSS

The MDPR is a large area of dynamic geomorphic change. Since sea level stabilized after the last glaciation, sediments from the Mississippi River have formed a broad, coastal plain of over 3.4 million ha (8.4 million acres). About 50% is inland water such as bays, lakes, and bayous; about 40% is swamp and marsh; and the remainder is upland (primarily natural levee ridges adjacent to Mississippi River distributaries).

There has been an overall gradual net land gain in the MDPR during the last 7,000 years. Within this time there have been cycles of gain and loss (see THE PHYSICAL SETTING). Since sea level rise levelled off about 4,500 years ago, the Mississippi River has occupied seven major courses and many minor ones and built seven major deltaic lobes. The river is now in the early stages of the eighth deltaic lobe, forming in the area of Atchafalaya Bay. The growth phase of a delta lobe is characterized by rapid progradation of land at the mouth of the channel. Land is also built by overbank flooding and filling in of older deteriorating marshes. As the channel lengthens and the hydrologic gradient becomes smaller, the river seeks a new, shorter course to the gulf. When a lobe is abandoned, local land-building ceases and wetland loss commences because of erosion and subsidence. The historical pattern throughout the MDPR, until recently, has been land gain in part of the region, and loss in the remainder, with an overall net gain.

Now the pattern has been interrupted. Cheap, abundant fossil fuel has given man the power to override some natural processes, especially the flow of the Mississippi River. The lower river is totally leveed, it is not being allowed to change course, and it now discharges into very deep water at the edge of the Continental Shelf, where sediments cannot contribute to land building. A description of the ongoing change (loss) in wetlands in the MDPR thus requires a discussion of the interactions among natural and cultural phenomena.

Craig et al. (1979) defined wetland loss as "the substantial removal of wetland from its ecologic role under natural conditions." Impoundment or filling of wetlands does not eliminate an area of land (i.e., by converting it to water), but it does eliminate the natural ecological function of the wetland. In this report wetland loss includes the conversion of wetland either to water or to dry land.

Before man intervened, wetland loss in abandoned delta lobes was compensated for by land building in the active delta. Now there has been a dramatic shift in the MDPR from net land gain to net loss (Gagliano and van Beek 1970; Adams et al. 1976; Craig et al. 1979; and Gagliano et al. 1981). Recent measurements show that the rate of loss is accelerating and the latest estimate is 102 km2 (39.4 mi2) annually for the MDPR (Gagliano et al. 1981). There are both natural and cultural reasons for wetland loss, both of which are summarized below (see also THE PHYSICAL SETTING).

Natural Wetland Loss

Three major natural processes contribute to wetland loss: (1) Gulf of Mexico beach retreat, (2) lateral erosion of streamside marsh shores, and (3) gradual sinking of inland marshes. Wave attack is the primary cause of shoreline retreat. Lack of sufficient sediments to offset apparent sea level rise causes inland marsh loss. Apparent sea level rise in Louisiana is due to both regional subsidence and eustatic sea level rise (see THE PHYSICAL SETTING).

Subsidence has occurred steadily during the past 130 years over the entire northern gulf coast, with a significant rate of increase during the past 25 years. From 1848 until 1959, the measured rate of subsidence from two locations in or adjacent to Barataria basin was 0.27 and 0.83 cm /yr (or 0.11 and 0.33 in/yr, respectively). From 1959 to 1971, these rates increased to 1.29 and 1.12 cm/yr (0.5 and 0.44 in/yr) respectively (Swanson and Thurlow 1973). A third location in the nearshore gulf experienced a subsidence rate of 1.51 cm/yr (0.59 in/yr) from 1959 to 1971. In the most recent analysis in the MDPR, Baumann (1980) found that subsidence in the lower Barataria basin was 1.30 cm/yr from 1954 to 1979.

Deposition of river sediment in wetlands causes aggradation that serves to counteract the effects of apparent sea level rise. Studies show, however, that in many areas sedimentation is not great enough to compensate for subsidence. Delaune et al. (1978) found that marsh sites near natural streams (streamside marshes) accrete at 1.35 cm/yr (0.53 in/yr), while marsh sites away from tidal streams (inland marshes) accrete at only 0.75 cm/yr (0.29 in/yr). They observed that much of the inland marsh in the study sites was accreting at rates less than the rate of apparent sea level rise. When compared with the subsidence rates mentioned above (1.29 and 1.12 cm/yr) it is evident that only the streamside marsh is accreting fast enough to offset the effects of subsidence. Suspended sediment must pass through the streamside marsh before it reaches the inland marsh. Boto and Patrick (1978) found that streamside marsh grass develops greater stem density than inland marsh, which enhances sediment removal. Newly deposited sediment provides nutrients that allows streamside marsh to maintain higher levels of net primary production than inland marsh (Delaune and Patrick 1980a).

Baumann (1980) observed similar patterns of accretion in his analysis of sedimentation. The accretion rate of streamside marshes (1.52 cm/yr or 0.59 in/yr) was significantly higher than inland marsh accretion rates of 0.91 cm/yr (0.35 in/yr). For all inland and streamside sites that had "aggradation deficit" (sedimentation rate less than apparent sea level rise), Baumann found a weighted average sedimentation rate of 1.12 cm/yr (0.44 in/yr). Compared with the subsidence rate of 1.30 cm/yr (0.51 in/yr), this leaves a mean aggradation deficit of 0.18 cm/yr (0.07 in/yr). Eighty percent of the marsh in the Barataria basin is experiencing an aggradation deficit. Baumann proposed that this deficit indicates that lack of adequate external sediment supply may be responsible for a large part of the marsh currently being lost in the basin.

Regional shifts in the source and seasonality of sedimentation in marshes influence marsh accretion rates. During the past 5,000 years, direct introduction of riverine sediments during spring floods supplied marshes in the active delta lobe with enough sediment to counter the effects of subsidence, and provided a surplus that enabled marsh accretion to occur. During the same time period, newly abandoned delta lobes suffered a gradual decline in direct sedimentation for several hundred years. Much of the MDPR wetland area lies in abandoned delta lobes, and the construction of levees along the Mississippi River is exacerbating the natural reduction in sediment supply.

With the exception of the Atchafalaya Bay area, most of the MDPR receives a relatively low rate of sediment input, much of which arrives during storms and hurricanes. Storm events do not introduce new sediment but rework and redistribute bay-bottom sediments. Baumann (1980) found that 41% of all sedimentation from 1975 to 1979 in Barataria saline marsh areas ocurred during the winter months; 38% was the result of two tropical storms that passed through the area, and 21% occurred during the remaining months.

Storm activity is the key to high sedimentation rates during winter months. Southerly winds increase as a cold front approaches from the northwest, raising water level in the marsh and increasing the suspended sediment load in the water. Some of this suspended material is deposited on the marsh surface. As the front passes, winds swing to a northerly direction, causing a rapid drop in water level (Baumann 1980).

Cultural Processes and Wetland Loss

A diverse array of human activities have contributed to wetland loss in the MDPR. These include canals for oil exploration, pipelines, navigation channels, recreational developments, drainage channels, and flood control. Other cultural factors contributing to wetland loss are construction of bulkheads and seawalls, highways, and impoundments. Evidence is increasing that canals are an important factor leading to wetland loss in the MDPR.

Canals are now a very common feature of the MDPR (see the canal section under HABITAT DESCRIPTIONS). Canal area (Figure 22), excluding the area of spoil deposition, is about 1.4% of the Louisiana coastal zone, or about 20,200 ha (50,000 acres) (Craig et al. 1979). Canals directly affect wetlands by excavation and spoil deposition. They indirectly impact wetlands by altering hydrology, sedimentation, and productivity. Canals have accelerated salinity intrusion causing marsh vegetation loss (Van Sickle et al. 1976). Canal spoil banks limit water exchange over wetlands and decrease deposition of suspended sediments. This exacerbates the existing sediment deficit in inland marshes. Sedimentation is also the single most important source of nutrients added to the marshes (Delaune and Patrick 1980a). Lack of sediment therefore leads to lower productivity. Craig et al. (1979) estimated that almost 70% of the total annual loss of 102 km^2 (39.4 mi^2) in the MDPR may be the direct or indirect result of canals and canal building. They also conclude that 10% of the direct loss of wetlands is attributable to canals in the Barataria basin, the area for which the best data exist. Johnson and Gosselink (1982) also estimated that canals were responsible for 10% of the direct loss of MDPR wetlands during the period from 1955-1978, and 20% if spoil bank area is included (see below).

Once established, canals tend to widen over time, especially as a result of wave action and altered hydrologic patterns (Craig et al. 1979; Johnson and Gosselink 1982). The annual increase in canal width varies from 2% to 14%, for a doubling time ranging from 7 to 50 years. As the cross sectional area and density of canals increase, the cross sectional area and density of natural channels decrease, indicating altered hydrologic patterns and the conversion of marsh to open water.

Spoil banks, the inevitable result of canal dredging, also lead to direct marsh destruction (see the spoil bank section under HABITAT DESCRIPTIONS). Spoil is usually deposited alongside the dredged area, a practice that destroys the adjacent marsh and results in a barrier to water exchange with the adjacent marsh. The ratio of canal to spoil area has been estimated to be 1:2.5 (Craig et al. 1979), indicating the importance of spoil deposition to wetland loss.

Canals also have less obvious indirect effects due to such factors as saltwater intrusion, altered sediment transport, and conversions of streamside to inland marsh. A subtle yet pervasive indirect effect of canals is a decrease in sedimentation that leads to a decline in marsh elevation. When a canal is dredged through a marsh, the canal replaces the natural channels (tidal streams) as the main route of water transport through the marsh, because canals are deeper and faster flowing (Craig et al. 1979). The streamside marsh adjacent to the natural channel is steadily converted to inland marsh, because the natural channel no longer supplies the sediments and nutrients necessary to maintain it. Once converted to the inland type, the marsh is then subjected to the sediment deficit described earlier, and will eventually be converted to open water because of subsidence. The estimated area of streamside marsh converted to inland marsh by the indirect mechanism is three to four times the area of streamside marsh converted directly to open water by canal building (Craig et al. 1979).

Several recent studies have looked at the statistical relationship between canals and wetland loss, by examining different parts of the Louisiana coastal zone and comparing their recent rates of wetland loss as a function of canal density. Scaife et al. (1982), and Turner et al. (1982) performed linear regression analyses of several variables on wetland loss rates. Data for these studies were canal densities on individual quadrangle sheets of the MDPR as shown in USFWS habitat maps compiled by Wicker et al. (1980b). These studies concluded that canals in the MDPR have been responsible (directly and indirectly) for as much as 65% or more of the total wetland loss between 1955 and 1978, and that the area of new canals added each year is accelerating in the MDPR.

Deegan et al. (1982) followed up on these studies, performing multiple regression analyses on the same data, and are somewhat more conservative in their assessment of the relationship between canal density and wetland loss. Nevertheless, the authors of the latter study concluded that from 33% to 67% of the loss of wetlands during the 23 year study period could be a result of canals. A total of 58% of the variation in wetland loss among 140 quadrangle maps was explained by a multiple regression model that included canal densities at each time, relative geologic age of the delta lobe in which the area was located, and the specific hydrologic regime of the area. By comparing the amount of land that had been lost due to the increase in canal area (Deegan et al. 1982) concluded that up to 20% of the wetland loss could be accounted for as a direct conversion to canal area.

Another recent study that examined the effects of canals on wetland loss used a different approach, that of a simulation model of land change processes in the Barataria basin (Cleveland et al. 1982). This model showed a marked acceleration of both streamside and inland marsh loss when canals were included in the simulation.

EUTROPHICATION

Eutrophication is the natural or artificial addition of nutrients to water bodies, and the effects of these added nutrients on the water body. Although eutrophication is a natural process, it has been accelerated in many cases by human activities. Severe eutrophication results in undesirable changes in water quality, destabilization of natural communities, algal blooms, a takeover by pollution-tolerant species, and frequent anoxic conditions.

Studies have shown that many of the water bodies of the MDPR are eutrophic (Craig and Day 1977; Day et al. 1977; Gael and Hopkinson 1979; Hopkinson and Day 1979, 1980a, 1980b; Seaton and Day 1979; Craig and Day 1981; Witzig and Day 1982). This is the cumulative result of natural and cultural factors. Domestic wastes are an increasing problem because of inadequate sewage treatment and population growth. Urban runoff is also a significant pollution source from cities. Asphalt and concrete increase surface runoff into storm sewers that pour nutrients (as well as toxins) into water bodies. Large quantities of nutrients from eroded sediments, fertilizers, and animal manure enter lakes via drainage canals. Wastes from industrial sites are also often sources of nutrients. Natural sources of nutrients are precipitation, excrement from waterfowl and wading birds, and organic mineralization.

The most comprehensive studies of eutrophication in the MDPR have been made in the Barataria and Pontchartrain basins. Witzig and Day (1982) developed a trophic state index (TSI) and classified the water bodies in the two basins based on existing water quality data. Their TSI uses several water quality parameters (total organic nitrogen, total phosphorus, Secchi depth, and chlorophyll a) in a multivariate statistical approach (Brezonik and Shannon 1971). Results of the TSI analyses are presented in Table 24. Negative TSI scores indicate low nutrient enrichment and positive scores high enrichment. The various stations are also assigned to one of the classical trophic categories (eutrophic, mesotrophic, oligotrophic) after the approach of Brezonik and Shannon (1971).

The waters of the two basins range from hypereutrophic to meso-oligotrophic. Generally, the most eutrophic stations are those most affected by upland runoff. It has been shown that upland runoff that flows via canals to water bodies is a cause of eutrophication (Day et al. 1977, Hopkinson and Day 1979, Kemp and Day 1981). This channelized flow contrasts with natural hydrology, where upland runoff flows slowly through wetlands before entering water bodies. The relationship of canals to water quality was demonstrated by Gael and Hopkinson (1979) who showed a significant correlation between the density of canals and the TSI. Witzig and Day (1982) correlated algal productivity and TSI. Craig and Day (1977) showed that large areas in the Terrebonne basin have been closed to oyster fishing because of domestic wastes from the city of Houma. These wastes reach the affected areas via the Houma Navigation Canal.

Eutrophication can occur in all salinity regimes, so all aquatic habitats are susceptible. The effects of eutrophication are similar in all areas, although the characteristic species recognized as biological indicators may be different. Microcystis, Anabaena, Anabaenopsis, Anacystis, and Spirulina are common freshwater bluegreen algae that are associated with eutrophic conditions. Brackish water and marine algae that indicate eutrophication tend to be small, like Monodus, Nanochloris, and Stichococcus.

In general, freshwater areas tend to be more susceptible to eutrophication, because flushing rates are lower in these areas than they are near the coast where there is tidal action. Also, the bulk of cultural eutrophication occurs in fresh or slightly brackish areas. Finally, a nutrient trapping process characteristic of brackish waters tends to reduce nutrient levels in the lower basin. This trap mechanism involves the flocculation and sedimentation of clays with adsorbed nutrients as fresh water first encounters measurable salinity. The sediments in brackish water lakes thus become repositories for excess nutrients, up to a saturation point at least. Lake Salvador may presently be acting as such a nutrient trap.

Nutrient sources to water bodies fall into point and diffuse (nonpoint)

Table 24. Trophic state classification of the Barataria and Pontchartrain basins.

Station	TSI score	Trophic group[a]
Barataria basin:		
Caminada Pass	-4.8	M-O
Bayou Rigolettes	-4.3	M
Barataria Bay	-3.8	M
Lake Salvador	-3.3	M
Bayou Perot	-2.8	M
Little Lake	-2.7	M
Bayou Barataria	-1.8	M
Barataria Waterway	-1.6	M
Natural swamp stream	-1.4	M
John-the-Fool Bayou	- .6	M
Little Lake Oil and Gas Field	- .4	M
Bayou Chevreuil	.6	E
Lake Cataouatche	.7	E
Bayou des Allemands	.9	E
Bayou Segnette	1.6	E
Gulf Intracoastal Waterway	2.1	E
Bayou des Allemands	2.6	E
Burtchell Canal	2.7	E
Bayou Citamon	3.7	E-H
Lac des Allemands	3.8	E-H
Bayou Chevreuil	4.0	E-H
St. James Canal	6.4	H
Lake Pontchartrain:		
Open Lake (Dow and Turner 1980)		
Pass Manchac	-5.2	M-O
Mid-lake	-5.5	M-O
Inner Harbor Navigational Canal	-6.3	M-O
The Rigolets	-6.2	M-O
St. Charles Parish (Cramer 1978)		
Transect 1:		
Crossbayou Canal	26.7	H
Bayou LaBranche	17.6	H
Offshore Swamp	-3.4	M
Transect 2:		
Walker Canal	1.4	E
Bayou Piquant	0.6	E
Offshore marsh	0.9	M

[a] H = hypereutrophic; E = eutrophic; M = mesotrophic; and O = oligotrophic.

categories. A point source is a location at which nutrients are released in quantity and concentration compatible with practical means of nutrient removal. A diffuse source is an area from which nutrients are released in a manner not compatible with practical means of nutrient removal. Municipal sewage effluent and industrial wastes are point sources, while urban-storm and agricultural runoff are diffuse sources. These are important concepts for management purposes because excess effort to reduce point discharges may have little effect on water quality in areas with high nonpoint discharges (Uttormark et al. 1974). The specific nutrient contributors in municipal sewage are primarily human waste and detergents. In agricultural runoff, chemical fertilizers, animal excrement, and soil nutrients are the principal sources.

In conclusion, it can be said in general that eutrophication in the MDPR is caused by two problems. First, more waste water is being generated from agriculture, domestic wastes, urban runoff and industry. Second, these waters are flowing directly to water bodies via canals that bypass the normal overland flow through wetlands.

TOXINS

The introduction of toxic materials (pesticides, herbicides, heavy metals, PCB's, etc.) into the MDPR has become an increasingly serious problem. The probability of toxic pollution is great because of the density of petrochemical industries, large urban centers, and agricultural areas adjacent to wetland estuarine ecosystems. The MDPR receives toxic input from industrial plants, hazardous waste sites, and illegal dumping grounds; pesticides from agricultural runoff; pesticides and heavy metals from urban runoff; petroleum hydrocarbons from oil exploration; and herbicides for aquatic weed control.

The petrochemical industries produce a variety of products such as vinyl chloride, nitric acid, hydrochloric acid, methyl-ethyl ketone, styrene, sulfuric acid, acrylonitrile, benzene, and a variety of herbicides and pesticides (Mumphrey et al. 1978). All manufacturing processes produce waste byproducts. In the past, chemical wastes have often been disposed of in the cheapest possible manner without regard for environmental consequences. In many cases, the wastes have leaked into the environment (Dow and Garcia 1980). The Barataria basin has 27 potential hazardous waste sites that have been identified and an unknown number of illegal dumping sites (USEPA 1980).

Although data on toxic substances are scant, they indicate severe problems, possibly a result of hazardous waste dumping. Barataria Bay was characterized by the EPA as having chronic contamination of PCB's (polychlorinated byphenyls), whose source was unknown (Cumiford 1977).

Excessive pesticide concentrations that violate the EPA criteria for aquatic life and the USACE no-discharge criteria were recorded in Little Lake-Barataria Bay, the Gulf Intracoastal Waterway below Algiers, Bayou Lafourche, Lakes Cataouatche and Salvador, and Lac des Allemands. Bayou Lafourche had pesticide violations for aldrin, parathion, 2,4-D, silvex, and lindane; Lake Cataouatche, Lake Salvador, and Lac des Allemands for 2,4-D, silvex, and lindane. These pesticides are used in the production of agricultural products and aquatic weed control. The improper disposal of unused pesticides and pesticide containers, agricultural runoff, and direct entry via application are probable routes for these pesticides into the receiving water bodies (USACE 1980).

Pesticide residues have had an effect on aquatic organisms and bird populations. The brown pelican (Pelecanus occidentalis) population in Louisiana was reduced from 50,000 in 1933 to extirpation in the early 1960's probably because of decreased reproductive capabilities due to pesticide residues (DDE, dieldrin, and endrin) in adult birds and their eggs (Blus et al. 1979). Approximately 800 birds were reintroduced during the period from 1968-1976 into the lower Barataria basin. Another die-off occurred in 1975, coinciding with unusually high endrin residues in the Barataria Bay that spring. High endrin residues were found in the pelican eggs (Blus et al. 1979). The last natural nesting colony of pelicans in the MDPR (before restocking was initiated) was on North Islands (Chandeleurs) (J. A. Valentine, USFWS retired, Lafayette La., pers. comm.).

Millions of fish, mostly menhaden, died in the Mississippi Delta area in the early 1960's of endrin poisoning that was traced to a company in Memphis, Tennessee that poured wastes into the Mississippi River. (J. A. Valentine, USFWS retired, Lafayette, La., pers. comm.). Except for these dramatic examples of pesticide-related fish and wildlife mortality, little data are available on the impact of chronic toxic input on MDPR biota.

Toxic pollution of air, water, and food has a long term cost in terms of human health. South Louisiana shows an increased rate of certain types of cancers, compared with the national average. Higher rates of cancer mortality have been statistically linked to drinking water from the Mississippi River, with its variety of chemical carcinogens, and to residence in counties where the petroleum industry is most heavily concentrated (Hoover et al. 1975; Page et al. 1976, Blot et al. 1977). A relationship between respiratory cancer and proximity of residence to wetlands in Louisiana has also been demonstrated (Voors et al. 1978).

SALT WATER INTRUSION

Salt water intrusion is a major problem in the MDPR. It leads to the death of wetland vegetation, especially fresh and intermediate types (Craig and Day 1977), and increases the rate of wetland loss (Craig et al. 1979). It also threatens municipal water supplies.

Salt water intrusion occurs naturally during the abandonment stage of the deltaic cycle, but human activity has accelerated the process. The most important factor causing intrusion is the construction of canals that increase water exchange. Major navigation canals connecting coastal and inland areas are primary factors, but any canal that establishes a new hydrologic connection contributes to salt water intrusion. Intrusion has been demonstrated for the Calcasieu basin (Gosselink et al. 1979), the Terrebonne and Barataria basins (Craig and Day 1977; Hopkinson and Day 1979; Van Sickle et al. 1976), and the Pontchartrain basin (Gagliano et al. 1973).

Van Sickle et al. (1976) reported an average rate of salinity increase of 0.009 ppt per month at St. Mary's point. Little Lake, a fresh water body early in this century, has changed to an estuary with a mean salinity of about 8 ppt. This change has induced a landward shift of brackish and saline marshes (O'Neil 1949; Chabreck 1972; Chabreck and Linscombe 1978) with a concomitant increase in wetland loss (Craig et al. 1979).

Under natural conditions, water exchange between the lower and upper parts of the Barataria basin occurred slowly through many shallow bayous and lakes and by overland flow. Saline water at the seaward end of Barataria basin formerly reached Lake Salvador only via a circuitous route through Barataria Bay via Grand Bayou or Bayou Dupres to Little Lake via La Bayou Perot or Bayou Rigolette and Barataria to Lake Salvador. Much of this route was shallow and indirect, and tended to prevent rapid water exchange.

Now, an array of straight, deep canals such as Barataria Basin Waterway, Turtle Island Cutoff, and Bayou de Familles Waterway have made new hydrologic connections within the basin. In the southwestern part of the basin, a series of petroleum and navigation canals have created new connections between western Caminada Bay and Little Lake. The Bayou L'Ours Ridge, which formerly prevented such exchange, has been breached.

Major navigation canals, such as the Barataria Basin Waterway, that directly connect waters of different salinity seem to be major factors causing salt water intrusion. The Mississippi River Gulf Outlet in the Pontchartrain hydrologic unit and the Houma Navigation Canal in the Terrebonne hydrologic unit have created similar problems (Gagliano et al. 1973; Craig and Day 1977).

MANAGEMENT RECOMMENDATIONS

The body of literature on the subject of coastal resource management is large. It is not practical in this section to propose detailed management recommendations on each activity. This section is therefore limited to a review of general management considerations that are pertinent to the MDPR region, and a discussion of some suggested approaches for the management issues covered in the preceding section.

As noted earlier, there are two general approaches to environmental management, one based on direct regulation and one based on a system of taxes and subsidies. The direct regulation approach is more popular and perhaps easier to implement when detailed information about environmental interactions is very limited. The tax and subsidy system is probably more flexible, easier to administer and less adversarial, but it requires detailed quantitative calculations of environmental disturbances that can serve as the basis for the taxes or subsidies. The companion technical report (Costanza et al. 1983) provides a data base potentially useful in this regard. The two approaches produce management recommendatons that are on the surface quite different, but which can achieve similar results. The direct regulation approach employs specific recommendations detailing what activities should be allowed or not allowed in a very "black or white" way.

The tax and subsidy approach does not disallow anything *a priori* but merely requires that the total (social) cost of all activities be paid, and that those affected be compensated. Rather than a set of specific recommendations, it employs a set of prices or costs associated with specific activities as the basis for the taxes. If the environmental cost associated with a particular activity like canal dredging is significant, and if the practitioners are required to pay this cost rather than passing it on to the local public, then they will make every effort to "economize" on environmental destruction. The revenues from the tax can then be used to mitigate the remaining damages.

In principle, the same effect can be achieved by the direct regulation approach, but this management framework is apparently operationally unable to reverse many continuing environmental problems, like wetland loss and habitat degradation. This is partly because individual projects are reviewed for permitting on a case-by-case basis that is insensitive to long term cumulative effects.

Each permitted oil access canal, dredge and fill activity, discharge permit, etc., may seem small and unimportant by itself, especially when only immediate, direct effects are considered. The long term cumulative effects of all permitted projects are quite significant, however. For example, when canals are viewed on a basin level, rather than individually, they form a network that alters the hydrologic regime of the entire basin. This enhances salt water intrusion, reduces the capacity of wetlands to assimilate nutrients, reduces coastal storm buffering capacity, reduces marsh production, increases wetland loss, and results in decreased fish and wildlife production. Because the economic benefits of each individual canal outweigh the local environmental costs, all canals are permitted and the total environment continues to degrade.

From a regulatory point of view one might aim instead for "zero net habitat loss." This management philosophy goes beyond simply minimizing the impacts of alteration, and requires that any disruption of a natural coastal habitat be accompanied by appropriate mitigation. Mitigation would involve the restoration of an equivalent area of natural habitat at another location. Any activity with demonstrable impacts in wetlands, such as canal dredging, would be permitted only if the effects were mitigated by creation, restoration, or enhancement of wetland habitat elsewhere. The functional characteristics and processes of the habitat, such as natural biological productivity, wildlife value, species diversity, water quality, and unique features would have to be maintained. Management decisions would be made with long-range, basin-wide considerations and would reinforce the natural function of the wetlands. These ideas are developed more fully in Craig and Day (1981).

The tax and subsidy approach is a natural extension of the mitigation approach, which allows the added flexibility of monetary exchange over direct barter. The obvious advantage is that revenues could be used for projects designed to yield the maximum environmental "return on investment," which may not always correspond with a one-for-one replacement of affected habitat.

CUMULATIVE IMPACTS: DIRECT AND INDIRECT

A primary prerequisite for either management approach is an estimate of the total direct and indirect impact of proposed activities. Most human activities such as construction of navigation canals, dredging and filling, petroleum exploration, discharge of agricultural and urban runoff into water bodies, have both direct and indirect environmental impacts. The direct impact of a primary activity is often easily quantifiable. For example, the amount of marsh loss due directly to a particular canal can be easily measured on a map. But with each direct impact, a series of associated indirect impacts can, in the long-term, be more severe than the direct impacts. If the total impact of an activity is to be known, the indirect impacts must also be identified and quantified.

The habitat input-output tables developed in the companion technical report (Costanza et al. 1983) are intended to provide a data base suitable for the calculation of these indirect impacts. While models based on these data have yet to be fully exercised, the estimation of indirect impacts is a primary potential use of the collected data. Indirect impacts are generally at least as severe as direct impacts in ecological systems (Patten 1982) and their quantification and inclusion in management decisions is therefore critical.

ECONOMIC-ECOLOGIC COSTS

In addition to the direct and indirect physical impacts of proposed alterations, both the direct regulation and tax and subsidy approaches require that the impacts be converted to common units. In the regulatory approach this conversion is implicit and often unacknowledged, but no less real and important. Whenever regulatory decisions are made, the act of drawing the line implicitly weights the various costs and benefits. For example, highway safety standards implicitly place an economic value on human life, and canal permitting decisions implicitly place an economic value on the affected habitat. Valuation in the tax and subsidy system is more explicit, in the form of the tax or subsidy rate itself and the calculations supporting it.

Subjective relative weights have traditionally been used in balancing economic-ecologic costs, but with the level of ecological data now available a more objective approach may be applicable. Ecologic-economic input-output models have been suggested as a means to identify and quantify the unmarketed services of the natural system and to put them on equal footing with marketed services (Daly 1968; Isard 1972; Costanza 1979). A comprehensive, detailed calculation of the value of natural habitat components could then replace the subjective weights currently in use, and allow social cost-benefit calculations, including environmental costs, to be performed with speed and ease (Day et al. 1980). This system would allow calculation of the direct and indirect changes that would result from a unit change (primary activity) in an ecosystem component. The models could produce quantitative estimates of all indirect impacts and calculate the value of the estimated change in output, broken down by short and long-term and spatial components. This calculated value could be an estimate of the present cost of the total change in value that would result from a proposed habitat alteration.

Social cost could then be compared with the social benefit estimate for the project, so that a permitting decision could be rationally made. Alternatively, the party proposing the habitat alteration could simply be charged the social cost (via a tax) and allowed to make his own cost-benefit judgment (Day et al. 1980).

The ecological input-output tables and energy flow diagrams included in the technical report (Costanza et al. 1983) are intended to serve as a data base to aid this effort. Some preliminary analysis of the data has been done (Leibowitz and Costanza 1982) but application to specific management questions must await further research.

SPECIFIC RECOMMENDATIONS FOR MDPR MANAGEMENT

A number of workers have suggested specific actions for dealing with various environmental problems in the MDPR. Many of these recommendations represent the mainstream approach to environmental management: they are intended to be incorporated in regulations, and they are based on implicit subjective analysis of indirect impacts and weightings of environmental and economic costs and benefits.

A different approach, and one potential use of the data collected in the technical report, is a more explicit, objective analysis of indirect environmental impacts and the relative weighting of these impacts using input-output models. Since these data have yet to be fully analyzed, the indirect impact magnitudes and ecological prices are not yet available. In this section, we review specific recommendations that have been made and suggest how the results of the analysis of the data collected in the technical report might be incorporated into the management process, when the results become available.

WETLAND LOSS

Two possible ways of managing the problem of wetland loss are: (1) to minimize the additional loss of wetland or (2) to build new wetland to offset losses. The most important source of sediments to build new land is the Mississippi River. Two approaches have been suggested for land building and are listed in Table 25: (1) controlled diversions on the lower Mississippi River channel, and (2) optimizing land building in the Atchafalaya Bay region.

Because canals appear to be a major factor in coastal wetland loss, prohibition or strict regulation of new canals and backfilling of old canals would have a remedial effect on continuing wetland loss. A number of recommendations have been suggested to minimize the impact of canal construction (Table 26).

Since many canals are dredged for access to drill sites, several alternatives have been suggested. These include directional drilling that would reduce the number of canals necessary, and hydroair cushion vehicles that would eliminate the necessity for canals. Information also exists suggesting that the air cushion drilling system might be economically competitive with traditional drilling rigs on barges (Table 27).

Barrier island stabilization has also been suggested to retard land loss of both islands and the wetlands they protect from storm wave activity. Structural and biological approaches can be considered. The structural approach usually involves construction of groins and rip-rap, which may stabilize one area at the expense of another. Penland and Boyd (1981) pointed out examples of the limited success of structural methods, while Leatherman (1980) and Silvester (1977) discussed the inherent problems associated with seawalls and groins. Beach nourishment (pumping sand onto the beach from offshore) is another technique that has been used, especially along the South Atlantic coast. The biological approach generally involves planting grass to stabilize dunes. This method appears to be successful at least in the short term (Mendelssohn 1982).

Barrier islands are transient features. A limited coastal sand supply has produced in Louisiana the most serious barrier island erosion problem in the United States, causing island retreat (landward migration) rates of as high as 50 m/yr, and land loss rates of 65 ha (160 acres) per year (Mendelssohn 1982).

Rational decisions concerning the various recommendations to control land loss require the comparison of economic and ecological costs and benefits. If the total (social) cost of removing a particular area of natural habitat from production were known, the effectiveness of the various mitigation techniques

Table 25. Effect of several different mitigation techniques for reducing wetland loss (Craig and Day 1981).

Activity	Reduction in wetland loss rate km^2/yr
Atchafalaya River[a]	
New delta growth	11.9
Reversal of Chenier Plain beach retreat[b]	1.1
Infilling of older marshes	4.9
Total	17.9
Controlled Diversions Lower Mississippi River[c]	1-3
Prohibition or strict regulation of new canals[d]	13-36

[a] Craig and Day (1981).

[b] This value assumes the present net rate of shoreline retreat will be arrested. The net rate of retreat was calculated as the algebraic sum of shoreline changes for each interval along the Chenier Plain as given in Adams et al. (1978).

[c] Gagliano et al. (1981).

[d] High estimate from Turner et al. (1982), low estimate from Deegan et. al. (1982).

Table 26. Recommendations to minimize the impact of canals.

Recommendation	References
Minimize new canal construction by required multiple use of existing canals and common use of pipeline canals.	Craig and Day (1981)
Restrict new canals to natural corridors, levees, or defined development corridors.	Gagliano (1973)
No construction of canals which connect (a) fresh and saline areas, and (b) the edge and center of hydrologic basins.	Craig and Day (1981); Gosselink et al. (1979)
No construction of blind-end canals or fingerfill developments.	Craig and Day (1981)
Canal depths should not exceed that of the euphotic zone (1.8-2.0 m at mean low water) except where normal turbidity results in shallow euphotic zone.	Craig and Day (1981)
Canal depths should never exceed the depth of the water body where the canal terminates.	Craig and Day (1981)
Canals should be of uniform depth or become gradually shallower proceeding inland from a central water body to insure adequate flushing. This prevents formation of stagnant pockets of water.	Craig and Day (1981)
Alignment of canals should take advantage of existing natural channels or existing artificial channels.	Craig and Day (1981); Longley et al. (1978)
Limit canals between vegetative types.	Stone and McHugh (1979)
Perform dredging operations as quickly as possible.	Gosselink et al. (1979); Darnell (1977)
Dispose of spoil with special care; place in nonwetland areas or use in marsh creation.	Craig and Day (1981); Lindall et al. (1979)
Place periodic opening in existing spoil banks to prevent impediment of water circulation.	Craig and Day (1981); Longley et al. (1978); Lindall et al. (1979)

(continued)

Table 26. (concluded)

Recommendation	References
Place water control structure on all existing water ways.	St. Amant (1971, 1972)
Plug pipeline canals on seaward side until construction finished and backfilling completed.	St. Amant (1971, 1972)
Dredging and construction should be done to minimize turbidity and scheduled to avoid time of wildlife migrations, spawning, and nesting.	Gosselink et al. (1979); Bahr and Hebrard (1976)
Backfill and refurbish canals.	Happ et al. (1976); Lindall et al. (1979);
Avoid constructing canals which shunt nutrients from urban areas directly into water bodies.	Craig and Day (1981); Gael and Hopkinson (1979); Seaton and Day (1979); Hopkinson and Day (1979)
Environmentally sensitive areas should be avoided. Examples: oyster reefs, rookeries, submerged grassbeds, etc.	Lindall et al. (1979)

Table 27. Comparison of conventional swamp barge vs. marshland air cushion drilling system (MACDS).

Process	Swamp barge	MACDS
Permit processing	Time required	Nil
Route surveys	Major	Minor
Directional drilling required	Yes	No
Support equipment	Yes	Yes
Drill depth capability	∿20,000'	∿25,000'
Time to mobilize to new site	High	Low
Major rig equipment	Old	New
Mobility	Poor	Good
Capital equipment cost	Moderate	Higher
Channel dredging required	Yes	None

mentioned above would be easier to assess. For example, rather than prohibiting canals that connect fresh and saline areas, the actual ecological cost of such canals needs to be evaluated and the information incorporated into either a regulation or a tax.

EUTROPHICATION

Eutrophication is the result of the overloading of a water body with nutrients. Eutrophication can be reduced by limiting nutrient sources and by treating runoff. Wastewater-caused eutrophication includes both point sources (e.g., domestic and industrial effluents) and non-point sources (e.g., agricultural and urban runoff). Point sources are much easier to manage because the water is more easily collected and there are standard methods available for dealing with the wastes (secondary and tertiary treatment). Mechanical treatment of waste water is expensive, however. Management of non-point sources is typically limited to reducing the levels of pollutants in runoff.

Management practices that can significantly reduce agricultural runoff and associated problems include mulching, grassed waterways, minimum tillage, minimizing pesticide applications by using pesticides only when warranted by significant outbreaks (integrated pest management), careful planning of critical areas close to water bodies, use of manure as a substitute for inorganic fertilizers, and limited use of fertilizers. These practices take advantage of the tendency of living organisms to hold water and its dissolved and suspended constituents in the soil rather than letting it run off.

Likewise, one approach to controlling urban runoff involves reducing the availability of pollutants to storm flows. This can include reducing air pollution, reducing the application of fertilizers and pesticides, improved street sweeping, periodic flushing of collection systems, separation of storm drains and sewers, minimizing exposed land surface during construction, and maintaining good vegetative cover in erodible areas (EPA 1977). Other means of controlling urban runoff directly alter the storm water path, flow rates, or loadings. Temporary storage of storm water in storage basins or ponds, and use of porous pavement can help decrease the amount of runoff entering a water body per storm. Treatment of urban runoff by standard sanitary and industrial wastewater treatment can also be utilized to lessen the impact of storm water (EPA 1977). All of these steps are costly, and a method to compare their costs with the environmental benefits they produce is essential to rational decision making.

In some new developments, the natural drainage system can be utilized in its existing undeveloped, vegetated state to slow and reduce runoff by infiltration. In these cases, leaving enough land in its natural state can be seen as an alternative to more technological solutions. Construction costs of a natural drainage system are approximately half of those of a conventional channelized and sewered system (Lynard et al. 1980). Leaving large tracts of natural land in developed areas is itself expensive, however, because it increases transportation costs. Weighing the costs and benefits of this approach to waste water treatment is not something that can be easily generalized. A site-specific analysis that adequately incorporates environmental costs is needed.

Many believe that a partial return to an overland flow regime is feasible in many locations in the MDPR, and would alleviate many environmental problems, especially in mid-and-upper basin areas. The plan would involve converting upland runoff from channels and toward overland flow by redirecting existing drainage canals into wetland areas. This would not be costly, it would not affect upland drainage systems, and it could be accomplished in steps. It would, however, require the dedication of large wetland areas as "flood control areas" and preclude them from further agricultural or urban development.

An indication that such a system can work in a mutually beneficial way, at least on a small scale, can be found in a number of crawfish ponds in swamp habitat in the MDPR. These are all impounded areas that are actively pumped to prevent stagnation. The ponds are flooded from September until the end of the fishing season (May or June) and then pumped dry. During the flooding period, water is circulated through the ponds on a regular schedule to maintain high oxygen levels. This seasonal pattern of summer drying and winter flooding closely approximates the natural hydrological cycle of the swamp. Studies have shown that these ponds maintain high water quality and swamp productivity (Conner et al. 1981; Kemp and Day 1981). The benefits of this system include: (1) improved water quality, (2) increased swamp productivity, (3) increased timber production, (4) improved wildlife habitat value, (5) increased crawfish production, and (6) reduced flooding.

SALT WATER INTRUSION

A number of management options have been suggested to reduce the detrimental effects of salt water intrusion in the MDPR. Many landowners and management agencies have argued for and sometimes implemented impoundment or semi-impoundment of wetlands as a means of reducing salt water intrusion. The idea is to surround low salinity marshs with levees built of dredge spoil to limit water exchange so as to protect the impounded zones from encroaching salt water. In the short term this approach may be effective, although quantitative studies to verify this are lacking. In the long run, however, impoundment reduces marsh grass productivity, leading to the deterioration and loss of the wetland being "protected." Impounding prevents the exchange of nutrients and sediments that are necessary for maximum plant growth and marsh accretion to offset subsidence. Two studies in the Barataria basin showed that sedimentation in streamside marshes is sufficient to maintain marsh elevation against subsidence. Sedimentation on inland marshes (like impounded marshes) is insufficient, however, and many inland marshes are slowly turning into open water (Delaune et al. 1978; Baumann 1980; Hatton 1981).

Studies have shown that hurricanes impact impounded marshes to a much greater degree than natural marshes (Ensminger and Nichols 1957; Shiflet 1963). These studies indicate that combatting salt water intrusion by limiting marsh flooding is unwise. It ultimately results in lower marsh productivity, higher deterioration and land lost, and greater susceptibility to hurricanes. Another marsh management strategy to reduce salt water intrusion is to artificially increase the fresh water input to a basin. Much less fresh water currently enters the Barataria basin than in the past, because of flood control levees along the Mississippi River. To the extent that canals in a given area have increased the rate of salt water intrusion, a restoration of as much natural hydrology as possible would help alleviate the problem. For example, some canals could be permanently closed, the cross-sectional area of open canals could be reduced with control structures, new canals perpendicular to the coast could be discouraged, and locks could be considered for major navigation channels. More information, however, is needed on the hydrodynamics and use of different canals and on the economic and ecological costs and benefits of various alternatives.

TOXIC SUBSTANCES

Probably the most immediate environmental management problem in this country is the disposal of toxic substances, since this problem has such a direct effect on human health and well being. The MDPR is a national center of the petrochemical industry, which contributes large amounts of toxic substances to the environment. Environmental legislation in place has helped to control toxic substances, but spotty enforcement, illegal dumping, and accidental releases have led to major toxic material releases, as well as to chronic releases (Page et al. 1976). The existing laws have not solved the problem, but have merely postponed it. The situation may get worse as the numerous toxic waste disposal sites begin to affect the environment, and chronic long term impacts begin to accumulate. As Stich et al. (1976) have reported:

> There is compelling evidence that points to cancer as an ecological disease. A comparison of high with low incidences of tumors in different geographic regions, along with changes in tumor frequencies among immigrant groups and the clustering of many human tumors in industrialized regions in the U.S.A. suggest a strong environmental influence in cancer induction, promotion, or both. Thus, it seems reasonable to apply ecological methodology to uncover the environmental component in cancer formation. The ecological approach may have the further advantage of being highly relevant to man, since it is economical and manageable with the presently available manpower.

A system for carcinogenic monitoring in estuaries using biological and chemical indicators has recently been developed (Stich et al. 1976). A number of microbial organisms, plants, and animals have been suggested as resident indicators of water quality. The ideal organism should detect the appearance of a specific group of chemical compounds (i.e., by appearance of tumors), have a fairly uniform distribution over a wide area, survive in contaminated waters, stay within a restricted territory, and be easy to collect in large quantities. Bottom-dwelling flatfish species whose skin tumors can be readily diagnosed and counted are good candidates for test organisms (Stich et al. 1976).

In one study, the distribution pattern of flatfish with skin tumors was mapped. The prevalence of skin tumors in lemon soles collected in uncontaminated areas was compared with sole populations inhabiting the shore around the cities of Vancouver, Canada; Bellingham, White Rock, and Everett, Washington. Tumor prevalances went from 0.0% to 58.6%, the higher values being found in areas adjacent to the cities (Stich et al. 1976).

The complementary chemical indicator system estimates the amounts of known carcinogens in environmental samples. The chemicals chosen should be representative of a larger group of carcinogenic compounds, detectable in small amounts at a reasonable cost in samples of a size suitable for collection, and reasonably stable in the environment so that transient discharges can be detected. Promising candidates for the establishment of a "carcinogenic index" are polycyclic aromatic hydrocarbons. These should be sampled in water, bottom sediments, and marine organisms, such as shellfish, that are bioaccumulators (Stich et al. 1976).

The management of toxic substances represents a clear example of how a tax and subsidy approach might be more effective than the existing direct regulation approach. If industries were taxed for their toxic substance releases and the tax rate were tied to the cumulative potential damages of the release, there would be an incentive to minimize the damage done and the taxing agency would have the funds to rectify any remaining damages. The burden of proof would shift from the regulatory agency (which must now prove a violation of regulations) to industry, which would have to prove a reduction in releases to qualify for a tax cut. The idea is similar to the "Superfund" proposal now in effect. This would give the polluting industries an incentive to reduce their polluting activities. A technology such as waste incineration would be actively pursued by industry, since it might lead to reduced costs by reducing the pollution tax. Currently, any new technology to reduce waste output only increases internalized industry costs and usually must be forced on industry.

There would, of course, be much debate over the magnitude and structure of the tax. The tax structure should be tied to the direct and indirect total (social) costs of the toxic material. There is currently much uncertainty about these costs, but a tax system does not require perfect information to be workable and effective. A tax system could also provide funding for additional research into these costs and produce more accurate taxation with time. If the environment of the MDPR and the rest of the country is to be managed effectively, more of this kind of research and the means to implement results are needed.

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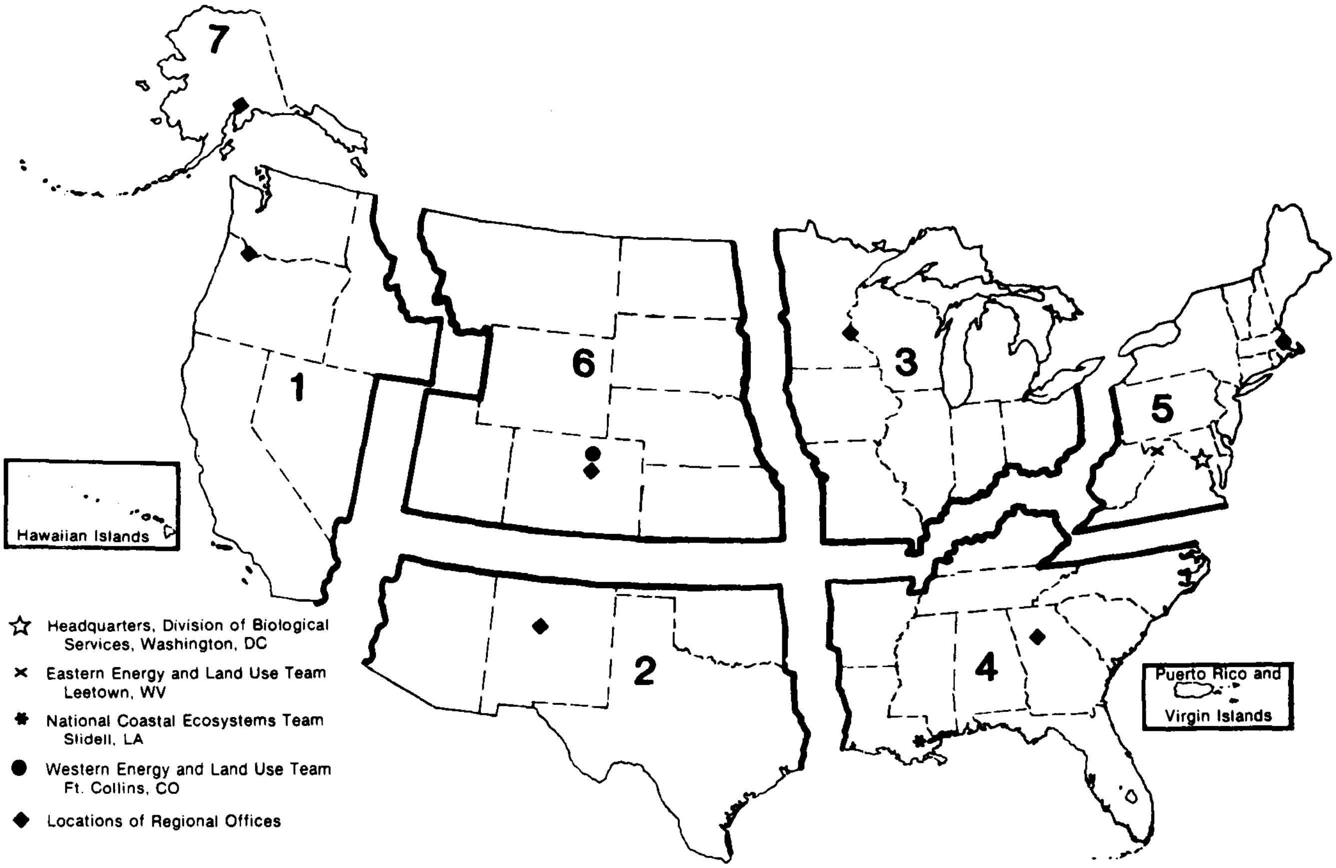

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