Journal of Coastal Research	2	3	269-284	Fort Lauderdale	Summer 1986

Changes Occurring Along A Rapidly Submerging Coastal Area: Louisiana, USA[1]

L. M. Salinas, R. D. DeLaune and W.H. Patrick, Jr.

Laboratory for Wetland Soils and Sediments
Center for Wetland Resources
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

SALINAS, L.M.; DeLAUNE, R.D., and PATRICK, W.H., Jr., 1986. Changes occurring along a rapidly submerging coastal area: Louisiana, USA. *Journal of Coastal Research*, 2(3), 269-284. Fort Lauderdale, ISSN 0749-0208.

Within the last century the Louisiana coastline began an accelerated rate of retreat primarily due to rapid subsidence. Implications of changes occurring along the rapidly subsiding Louisiana coast could be of concern worldwide, because of similar situations that may be encountered in the future if the predicted global rise in sea level occurs. The lack of sediment deposition with respect to rapid coastal subsidence cause increased submergence which in turn causes numerous habitat changes. Various human (canal cutting, leveeing, dredging, etc.) and natural processes (hurricanes, tropical storms, etc.) conjunctively influence the rate of deterioration. Landward retreat of the wetlands, in addition to causing land loss, promotes secondary effects such as saltwater intrusion, aquifer contamination, loss of freshwater marshes and disappearance of the present biota. Flooding will cause increases in salinity, waterlogging, and anaerobiosis, killing native vegetation and eventually resulting in open bodies of water.

ADDITIONAL INDEX WORDS: *Barrier islands, Louisiana, saltwater intrusion, sea-level rise, subsidence, wetland.*

INTRODUCTION

Levels of inundation and salinity in coastal marshes worldwide are predicted to rise. The relative elevation of the sea and of the coastal marshes has changed throughout time in response to two fundamentally different groups of factors, global and local. Global factors include changes in the volumes of the ocean basins due to tectonic processes and increases in the total amount of ocean water resulting from the melting of continental glaciers. The main local factor is subsidence, which primarily results from the compaction of recently deposited sediments, fluid withdrawal, and changes in sedimentation patterns. Recent global climatic modeling indicates that we are probably about to begin a period of rapid warming due to increased levels of carbon dioxide in the atmosphere (REVELLE, 1983). This climatic warming would increase melting of glaciers, leading to eustatic sea level rise. The U.S. Environmental Protection Agency estimates that the sea level will rise from 50 to 200 cm in the next century, a large increase over the 10 to 15 cm rise observed in the last century (HOFFMAN *et al.*, 1983). Little information exists on the probable response of coastal vegetation to the increased inundation and salinity that would result from this predicted rise in sea level. Louisiana's coast, especially the Mississippi River delta plain, is rapidly subsiding, both locally and regionally. Basement sinking stems from a decreasing sediment load, sediment consolidation, and tectonic activity. The meandering of the Mississippi River has created a series of overlapping lobes in the delta plain that, combined with natural levee ridges, form an elevated embankment bounding the lower interdistributary basins. Most of the research regarding coastal subsidence has been conducted in one section of this area, Barataria Basin. This basin is bound on the east by the Mississippi River and on the west by the river's most recently abandoned channel, Bayou Lafourche. The basin has been deprived of sediment by natural stream diversion and flood control measures. The water level is rapidly

[1]*This research was supported by funds from Louisiana's State Board of Regents and the Louisiana Sea Grant Program, part of the National Sea Grant Program maintained by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. 85014 received 3 May 1985; accepted in revision 14 June 1985.*

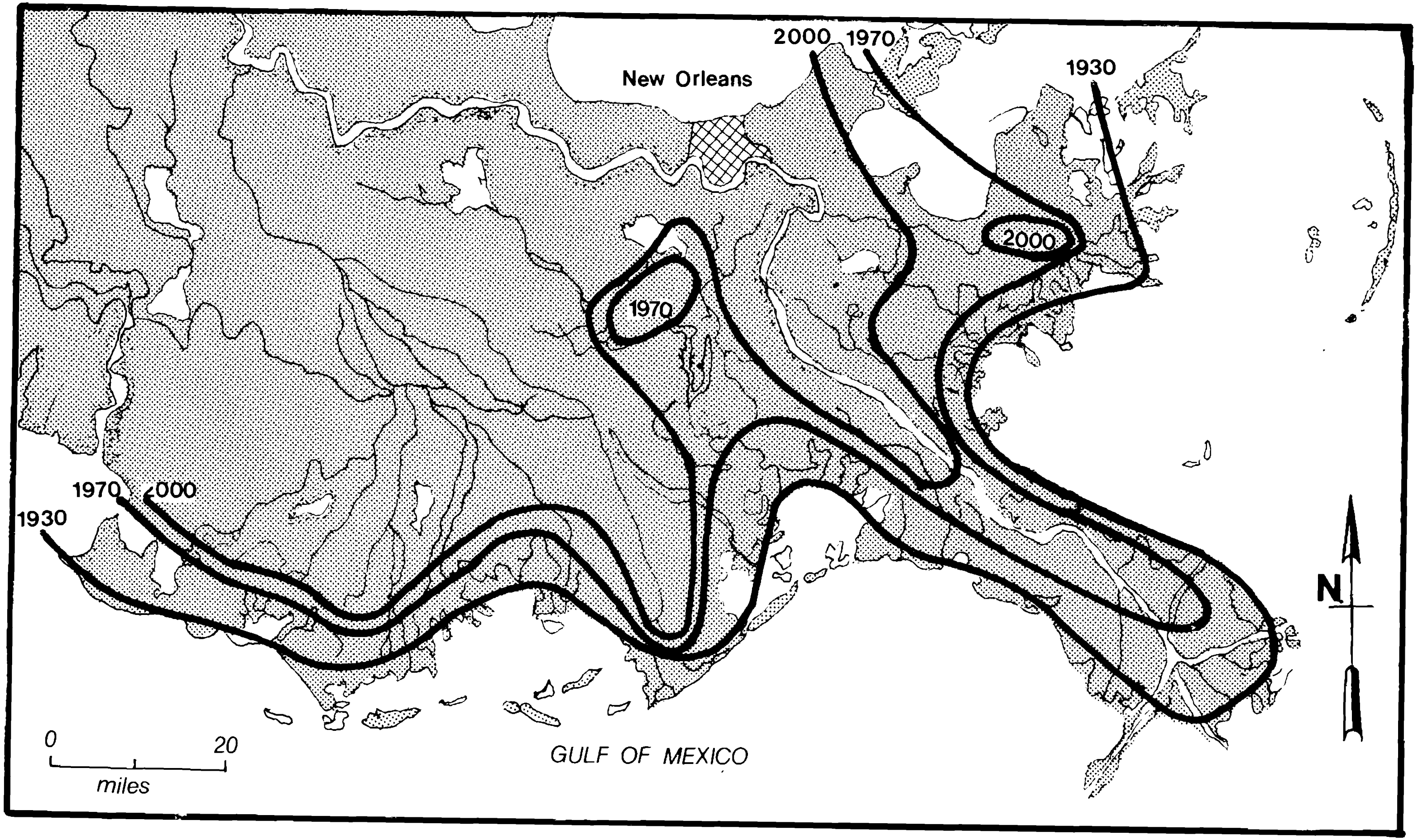

Figure 1. Fifty percent land-water isopleth over a 70-year period in the Mississippi River delta plain (GAGLIANO *et al.*, 1970).

rising in the wetland habitats of Louisiana's Mississippi River delta, primarily because of rapid subsidence (Figure 1). Salinity and water level are currently increasing in coastal marshes here, as they will soon be in coastal marshes worldwide if the sea level rises as rapidly as predicted. This paper summarizes the changes resulting from the rapid increase in apparent sea level along the Mississippi River delta plain and other portions of coastal Louisiana. These changes may be seen as a preview of the effect of the predicted increase in true sea level on other coastal regions.

LAND LOSS

Historically, the Mississippi River has undergone major natural diversions every 1,000 to 2,000 years, resulting in the formation of new delta systems. Human interaction forcing the Mississippi River flow down the current channel halted this process, causing sediment to be deposited off the continental shelf, instead of allowing the natural meander down the Atchafalaya River. This loss of sediments is a primary factor in the loss of Louisiana wetlands. GAGLIANO (1981) recently estimated that these wetlands, which cover approximately 3.2 million ha and represent 41% of all U.S. wetlands (TURNER and GOSSELINK, 1975) are disappearing at rates as high as 130 km^2/yr. Studies show that brackish marshes are deteriorating faster than any of the other wetland habitats (GAGLIANO and VAN BEEK, 1970; ADAMS *et al.*, 1976; CHABRECK *et al.*, 1968). The rate of land loss reported for brackish marshes is 1,355 ha/yr, whereas it is 701 ha/yr for saline marshes, 499 ha/yr for freshwater marshes, and 223 ha/yr for the swamp forest (CRAIG *et al.*, 1979). CRAIG *et al.* (1979) found that the wetlands in Barataria Basin are receding more rapidly than those in any other area of the Louisiana coastal zone (Figure 2). In addition, the rate at which the land is subsiding has accelerated greatly since 1940 (Figure 3). In other coastal regions of the United States, however, marsh aggradation has kept pace with increases in water level and with coastal submergence (LETZSCH and FREY, 1980). These results apply to the areas where the supply of available sediment is adequate and sea level rise is not rapid. If aggradation is less than the increase in relative sea level, the marshes will deteriorate, and land loss and marine transgression will usually occur. In Louisiana's Mississippi River delta plain, marshes are deteriorating because the sediment deposition falls below coastal submergence rates. The relative sea level is estimated to increase at a rate of increase of 1 m per century along the coast of

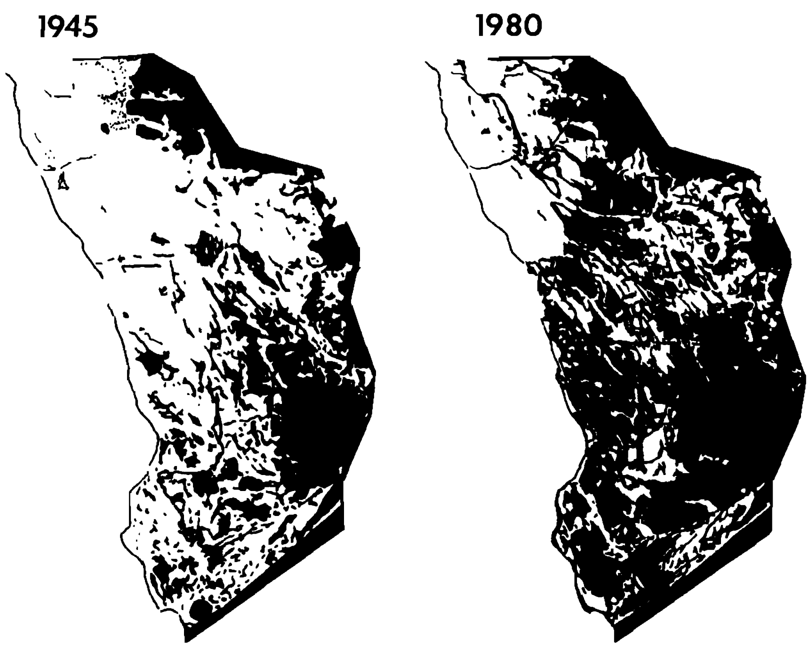

Figure 2. Change in Barataria Basin wetland area between 1945 and 1980; black is open water (after DOZIER, 1983).

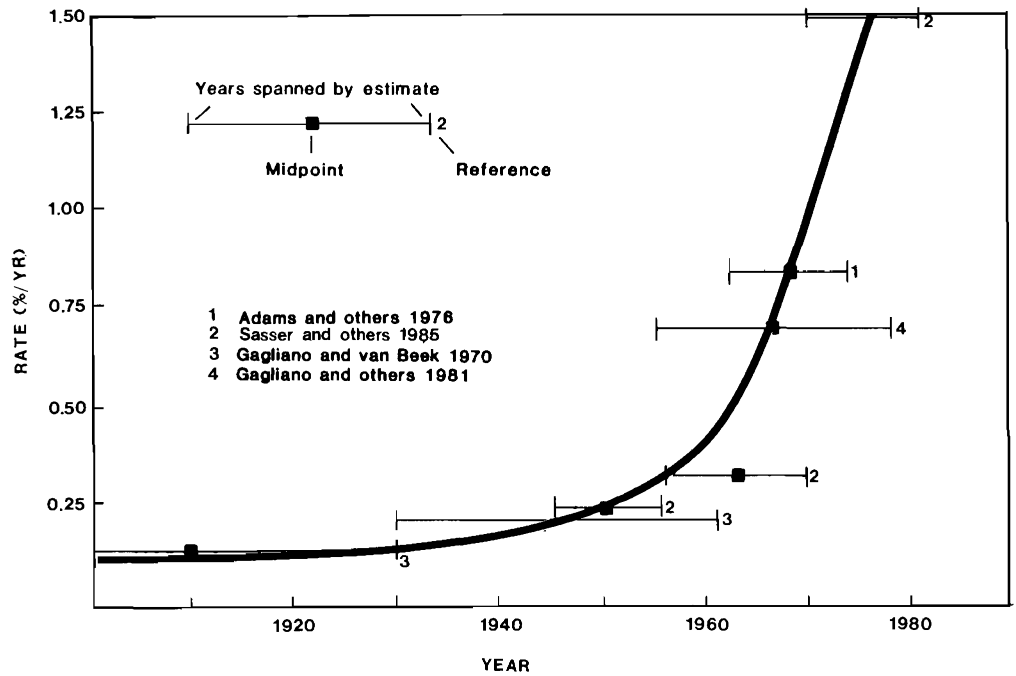

Figure 3. The accelerated wetland loss rate in the Mississippi River delta (SASSER *et al.*, 1985).

Louisiana (HICKS *et al.*, 1983), primarily because of rapid subsidence. Deterioration of the coastal wetlands began in the early nineteenth century in approximately the same period that the Mississippi River was leveed; before this, the net balance was positive (during the Holocene). Subsidence and subsequent marsh deterioration are now evident in sections of coastal Louisiana. DELAUNE *et al.* (1983a) found that the present submergence rate of 1.2 cm/yr in the East Cove area (Figure 4) of the Chenier Plain (on the southeastern border of Lake Calcasieu) is substantially greater than the average rates throughout the late Holocene. DELAUNE *et al.* (1983a) used Cs^{137} dating to establish that the submergence rate is substantially greater than the accretion rate of 0.8 cm/yr. This discrepancy is a recent phenomenon; the increases in the subsidence rate have not been fully compensated for by increases in the aggradation rate of the marsh. If the trends of the past 25 years continue, the East Cove marsh could complete its transformation to open water within 40 years (DELAUNE *et al.*, 1983a). Several factors contribute to this above-average submergence rate. Along flat coastlines such as this, any conversion of marsh to open water directly relates to the balance between submergence and vertical marsh accretion. In this region, changes in degradation appear to be correlated with human activities, particularly the construction of the Calcasieu ship channel. An additional hindrance has been the dredging and canal cutting for petroleum operations. The occurrence and rate of subsidence in Louisiana's coastal marshes directly relates to the proximity of the marshes to the rivers or streams. Streamside marshes have higher sedimentation rates than inland marshes do because they are closer to the source of sediment. DELAUNE *et al.* (1978) observed Cs^{137} profile distributions in Barataria Bay (Figure 5) and found that the accretion rate of the marsh closest to the stream was 1.35 cm/yr, whereas the inland marsh was accreting more slowly at a rate of 0.75 cm/yr. This inland marsh is slowly deteriorating into an open-water area. The distribution of Cs^{137} in a proximate lake (Airplane Lake), however, showed an accretion rate of 1.1 cm/yr. BAUMANN and DELAUNE (1981) compared rates of sedimentation in inland marshes and streamside marshes to the apparent sea-level rise and found that the streamside marshes were maintaining their relative elevation, whereas the inland marshes were not. HATTON

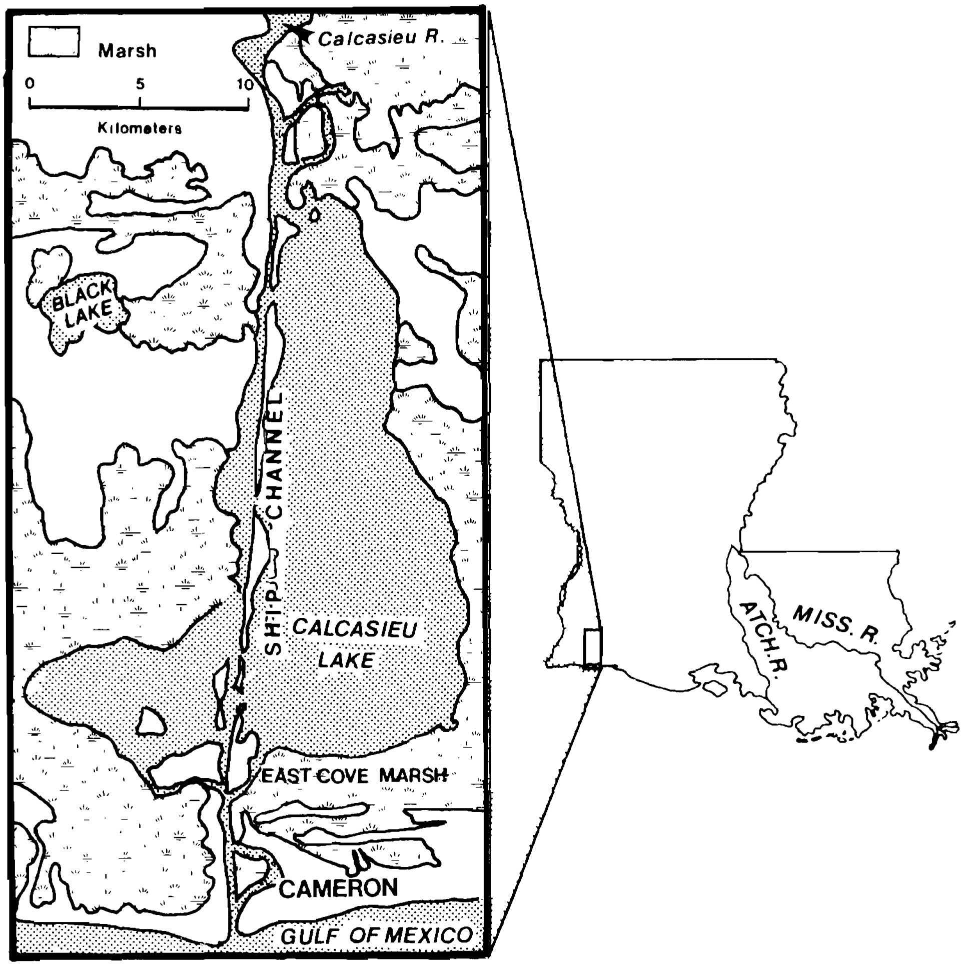

Figure 4. Location of the East Cove marsh study area (DELAUNE *et al.*, 1985).

et al. (1983) conducted a study of four different marsh types (fresh, intermediate, brackish, and saline) and found that the rates of vertical growth ranged from a maximum of 1.7 cm/yr in streamside and natural levee deposits to as little as 0.31 cm/yr in selected back-marsh areas. Mean values were 1.3 cm/yr in levee areas and 0.7 cm/yr in adjacent back-marsh areas. Thus, although there is extensive loss of marshlands in coastal Louisiana, vertical accretion is a rapidly continuing process. In general, water level data shows that the accretion rates of levee marshes are keeping pace with subsidence. The predominant back-marsh areas, however, are accreting at half the regional subsidence rate (Figure 6).

HATTON *et al.* (1983) also showed that inorganic sedimentation is the main determinant of the vertical growth rate of these marshes, although organic carbon constitutes an approximate constant mass in all soils. Mineral sediments generally accumulate at faster rates in the freshwater marshes than in the saltwater marshes; the sedimentation rates in areas adjacent to natural bodies of water are higher than in the back marshes.

An increase in apparent sea level not only affects the marshlands of coastal Louisiana, it also has an impact on the coastal wetland forest. Excluding the upper Barataria and Atchafalaya basins, there are approximately 159,800 ha of bald-cypress/water-tupelo swamps and 59,800 ha of bottomland

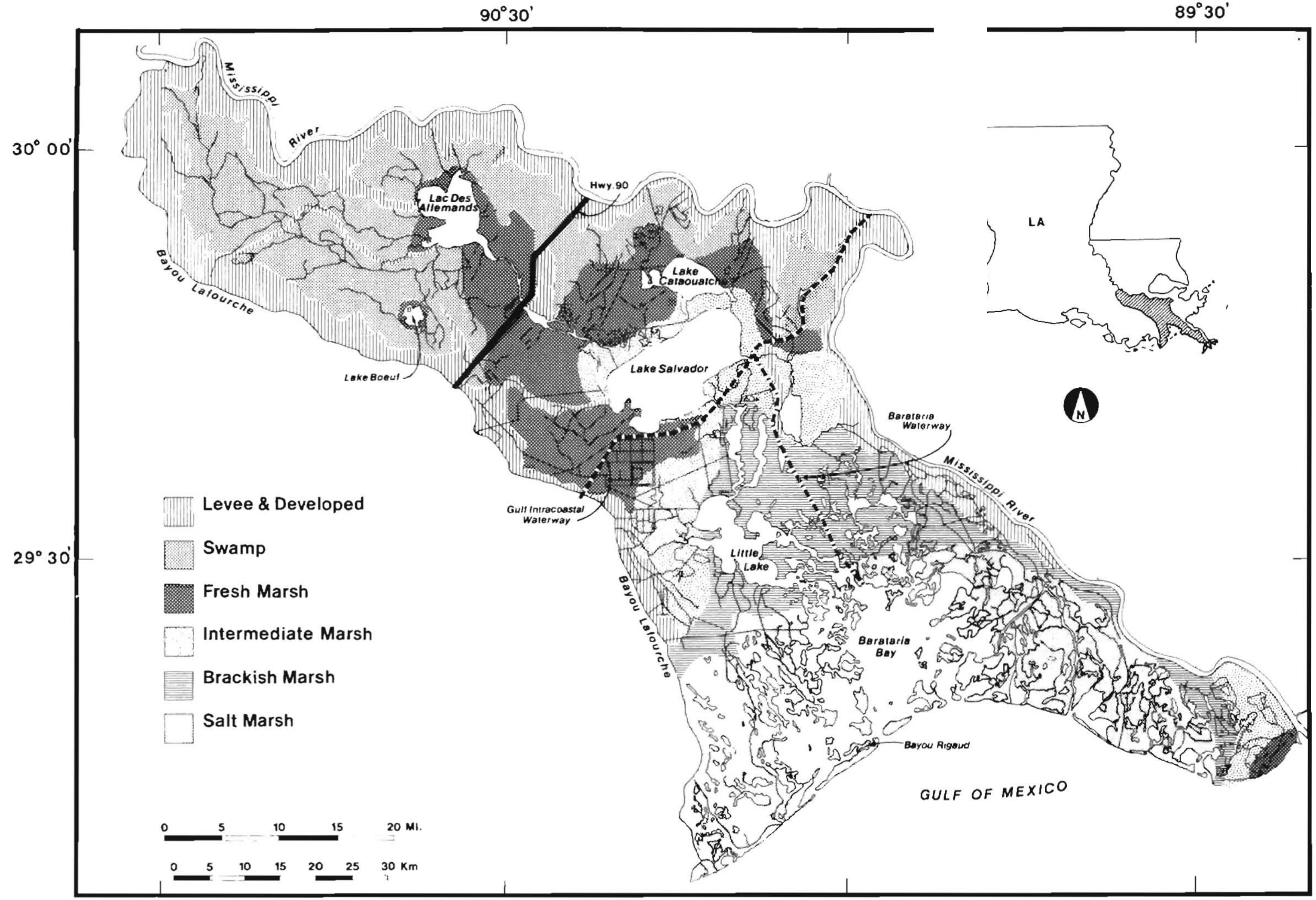

Figure 5. Barataria Basin (DAY *et al.* 1982).

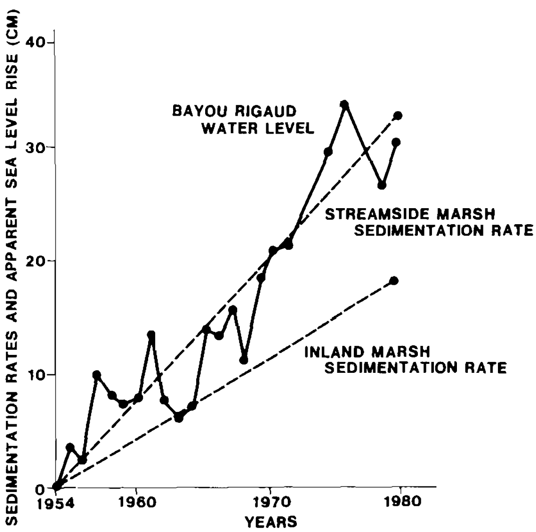

Figure 6. Apparent sea-level rise and mean sedimentation rates from streamside and inland saline marshes in the lower Barataria Bay (BAUMANN and DELAUNE, 1981).

hardwood forests in the Louisiana coastal zone (WICKER *et al.*, 1980, 1981; SCS, 1978). As the water level rises, the upland forests will eventually be replaced by bottomland hardwoods and then, as the water level continues to rise, by the more flood-tolerant bald-cypress/water-tupelo swamps. The final stage in this progression will be an open body of water (DELAUNE and PATRICK, 1985).

The impact of an increase in water level is evident in the Verret drainage basin (Figure 7). For a wetland forest to survive, it must maintain a mean elevation relative to the changing water level. DELAUNE and PATRICK (1985) determined the relationship between sedimentation, submergence, and seedling growth in the Lake Verret watershed. The tree species in the area range from bald cypress and water tupelo in the wetter areas to bottomland hardwood species in the drier areas (primarily located on natural ridges). Cs^{137} profiles of the region show that the vertical accretion rate of the swamp forest bordering Lake Verret averages 0.33 cm/yr, whereas the water-level increase averages 1.36 cm/yr (DELAUNE and PATRICK, 1985); the water level in the region is rapidly rising. The survival rates of overcup oak (*Quercus lyrata*) and bald cypress (*Taxodium distichum*) ranged from 0 to 60 %; the greatest survival rates were at the highest elevations. Neither of these species survived in a flooded area. This indicates that the increase in water level will restrict the regeneration of new species to the higher areas and ridges, which will be decreasing rapidly.

Work in Louisiana has shown that the seasonally flooded bottomland hardwoods are very productive (CONNER and DAY, 1982). The Lake Verret forest area, however, remains flooded for most of the year because of the recent rapid increase in water level. Other studies show that bottomland hardwood species are not very flood tolerant (DICKSON *et al.* 1972; GILL, 1970). Even cypress, noted for its ability to survive under flooded conditions, degenerates and gradually dies under floods of greater than 60 cm (BROWN and LUGO, 1982; HARMS *et al.* 1980; EGGLER and MOORE, 1961). The high water levels lead to anaerobiosis, which causes a variety of stresses and adversely affects many physiological activities (TESKEY and HINCKLEY, 1977).

BARRIER ISLANDS

Any alteration in the coastal barrier island system can indirectly threaten the existence of the interior wetland ecosystem. Louisiana wetlands are protected along the Gulf coast from Trinity Shoal to the Chandeleur Islands by a series of Holocene-age barrier islands, spits, and beaches. These originate from abandoned delta formations built up by an influx of coarse sediments. The Louisiana coastal Plain consists of six major delta complexes. The only two still active are the Atchafalaya and the modern Mississippi deltas; the other four are abandoned. Subsidence and marine reworking of the sediments of the abandoned deltas cause the various formations of the coastal barriers (PENLAND and BOYD, 1981).

Relative sea-level rise, coupled with subsidence and a decreasing supply of sediments, has caused extensive erosion of the barrier islands. Louisiana has lost 41% of the land area of its barrier islands since 1887; barrier island erosional rates are as high as 65 ha/yr, and the islands are migrating landward at a rate of 20 m/yr (PENLAND and BOYD, 1981; MENDELSSOHN *et al.*, 1983a,b). Figure 8 shows shoreline changes in the Isles Dernieres barrier system over an 85-year period. The erosion of this island chain and others like it has accelerated the loss of coastal marshes, contributed to the destruction of coastal property, and allowed saltwater intrusion farther inland. Sand dunes, the first line of protection against erosion, are poorly developed on Louisiana's barrier islands because of limited accumulations of eolian sands and frequent overwash.

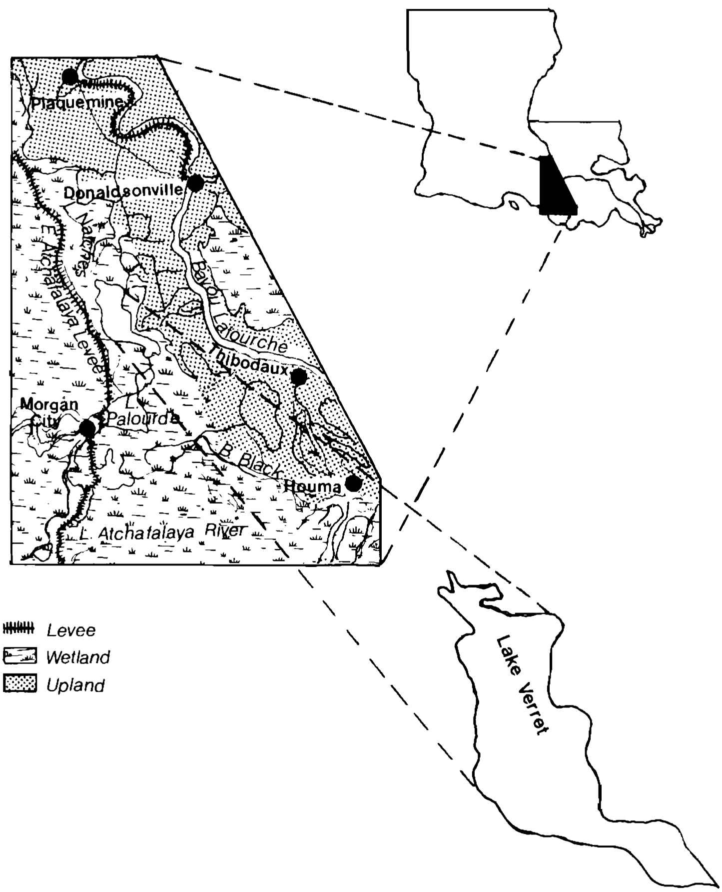

Figure 7. The Lake Verret area (DELAUNE and PATRICK, 1985).

Only 12% of these barrier islands is covered by dunes, whereas backbarrier marshes compose 54% of the total area. Marsh vegetation on the backbarrier portions of the islands binds sediment and provides organic matter for accretionary processes in addition to protecting the bayside shoreline from erosion. Backbarrier marsh vegetation may also reduce the landward migration of the barrier islands (Figure 9). DELAUNE *et al.*, (1985) verified, by measuring organic C content and bulk density, that sediments bound by the backbarrier marshes form a platform that traps additional sediment during storms that might otherwise be lost from the system. These marshes act as a foundation for the islands and a platform for sediment deposition and dune building. Thus, marsh management may more effectively reduce erosion than dune management (MENDELSSOHN *et al.*, 1985).

DELAUNE *et al.* (1985), using Cs^{137} profiles, discovered that the backbarrier marshes on Grand Terre and Grand Isle have been vertically accreting over the last 20 years at rates of 0.55 and 0.78 cm/yr, respectively, whereas submergence was an average of 1.83 cm/yr (Figure 10). These measurements and the observed relative sea-level rise of 0.14 cm/yr (HICKS, 1978) indicate that the backbarrier marshes are subsiding at a rate of 1.69 cm/yr. The aggradation deficit suggests that these marshes will become increasingly vulnerable to storms, and plant growth, the source of organic material for the marshes and the main stabilizing agent, will be subject to increasing water stress.

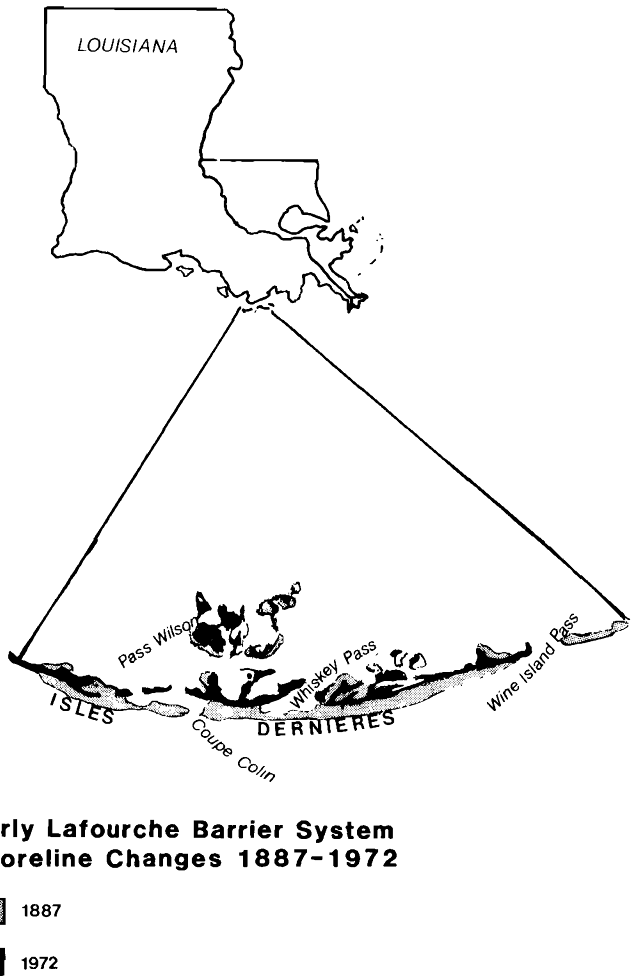

Figure 8. Shoreline changes on the Isles Dernieres (after PENLAND and BOYD, unpublished).

SALINITY AND OTHER CONSEQUENCES OF INCREASED SUBMERGENCE

As the sea level rises, salt water will extend farther upstream and inland, especially during droughts Much of the marshland vegetation, such as bald cypress, cannot tolerate salt water and will die under these conditions. Saltwater intrusion, a major problem in the wetlands, affects wetland vegetation, fauna, and freshwater supplies, and accelerates wetland loss.

DELAUNE *et al.* (1983b) observed that any modification of the natural freshwater flow could influence submergence by promoting saltwater intrusion, which degrades freshwater macrophytes and other plants not saltwater tolerant. They observed no evidence of toxic-salinity effects on marsh vegetation at that time. The salinities are well within the range tolerated by one of the dominant plants of the East Cove marsh, *Spartina patens*. Several researchers have concluded that salinity levels are partially responsible for the variation in *S. alterniflora* growth in Atlantic Coast marshes (ADAMS, 1963; BROOME *et al.*, 1975; NESTLER, 1977). The growth of *S. alterniflora* was found to decrease as salinity increased (HAINES and DUNN, 1976). All of these studies have pertained to salt-tolerant marshland species. Other inland species would also be affected by saltwater intrusion,

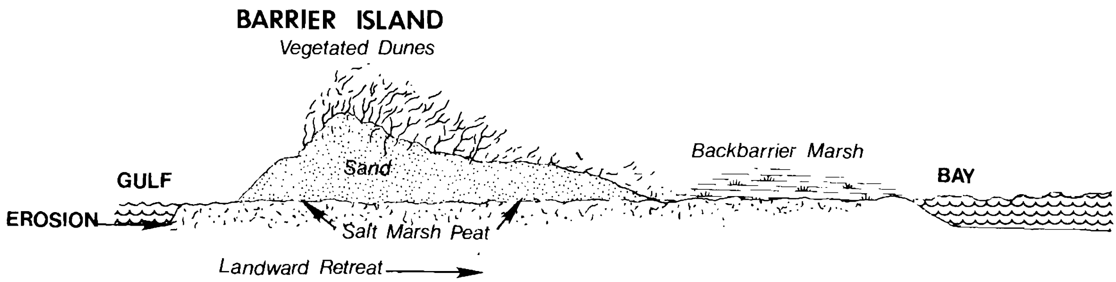

Figure 9. Cross-sectional schematic of a barrier island (DELAUNE *et al.*, 1985).

and significant dieback would result.

In a study of the effect of salinity change on oyster distribution, VAN SICKLE *et al.* (1976) discovered that oyster leases, which existed mainly in the outer Barataria Bay area in 1947, had encroached as far north as Little Lake in 1975, indicating a substantial increase in salinity over a 28-year period. In 1910 Little Lake was fresh enough to be a haven for largemouth bass (MOORE and POPE, 1910); Little Lake is now considered brackish, with salinities ranging from 4-10 ppt. VAN SICKLE *et al.* (1976) monitored St. Marys Point (in the northern part of Barataria Bay) and observed a definite increase in salinity levels; salinity increases averaged 0.009 ppt per month. Figure 11 shows changes in salinity in this area from 1894 projected through the year 2000. The presence of live *Rangia* clams in the bottom sediments of Bayou des Allemands indicates that saline waters have on occasion reached that far north (CRAIG *et al.*, 1977). A consistent drop in nutrient concentration observed along Bayou des Allemands may be due to precipitation of nutrients caused by the influx of increasingly saline waters. The oyster yield will eventually be affected by this northern migration because of the increased predation and disease accompanying Gulf waters. Increased pollution and toxic wastes could also seriously threaten the oyster harvest from this area.

Previously, water was distributed in Barataria Basin slowly and indirectly through small bayous and lakes as well as by overland flow. Recently, many straight, deep canals have been cut throughout the basin to facilitate petroleum exploration and to aid navigation. These canals create straight and direct connections between waters of different salinities and may therefore be a major factor in the landward advance of salt water. Large canals that link the saline waters of the Gulf directly with the inner marshes are particulary efficient in promoting saltwater intrusion.

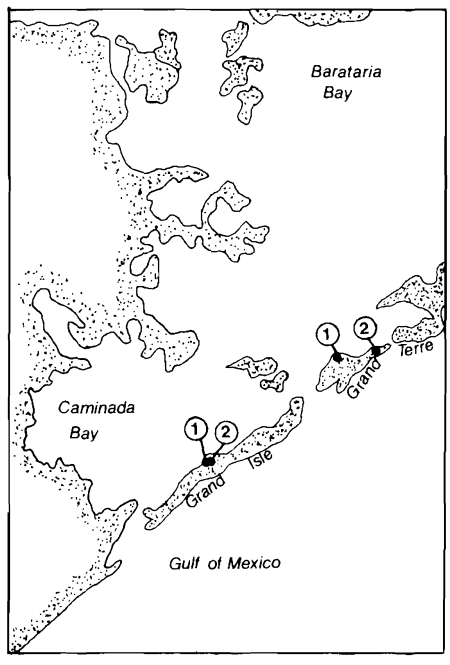

Figure 10. Barrier island study area (DELAUNE *et al.*, 1985).

The continued northward saltwater encroachment in coastal Louisiana will cause drastic changes in the less saline brackish and freshwater marshes. Substantial changes in the flora and fauna will occur, along with decreases in the fishing yield. Present coastal wildlife habitats will be damaged, and some of the local groundwater aquifers will be

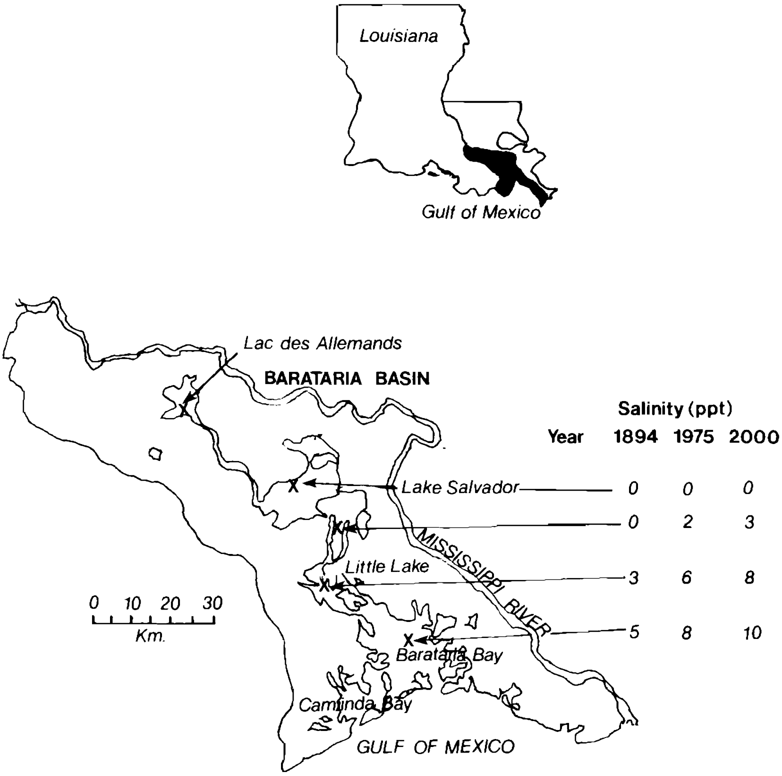

Figure 11. Saltwater intrusion in Barataria Basin (based on data from VAN SICKLE *et al.*, 1976 and CRAIG *et al.*, 1977).

contaminated with salt water. These trends, now apparent on the Louisiana coastline, are beginning to occur on a smaller scale in other parts of the United States; therefore, these studies and their recommendations for management measures should be kept in mind as similar situations must be dealt with.

Projects implemented to increase the influx of fresh water by diverting it from the Mississippi and local freshwater bayous would provide an additional source of sediment to the marshes and somewhat counterbalance saltwater intrusion. These projects would include building flood control structures resembling small-scale versions of the structure that contols freshwater influx to the Atchafalaya River (this structure was built to prevent the Mississippi River from flowing down the present course of the Atchafalaya and not as a freshwater diversion project). The Atchafalaya delta has increased from 0.51 km^2 in 1973 to 11.68 km^2 in 1979 (VAN HEERDEN and ROBERTS, 1980). Delta building resulting from freshwater diversion projects, however, would be on a smaller scale than the delta building in the Atchafalaya. DAY and CRAIG (1982) estimated that marsh restoration would only create 1-3 km^2 of marsh a year.

TURNER *et al.* (1982) hypothesized that much wetland loss in Louisiana is due to canal construction. DEEGAN *et al.* (1983) found that 25% to 39% of marsh loss over a 23-year period was related to canal and spoil construction (they also found that 9%-13% of marsh loss was due to agricultural development). Management techniques for minimizing the impact of canals on wetland loss include prohibiting unnecessary canal building, backfilling canals with previously stripped spoils, designing canals to flow down naturally occurring channels, and distributing the canal spoils evenly instead of building spoil banks. When canals cross natural streams, they should be barricaded efficiently so that they do not divert waters from them. Directional drilling may be an alternative to digging canals for the petroleum and gas industry. Also, using different types of vehicles that do not require trails or canals, such as those that ride on air cushions, should be considered.

EFFECT OF ANAEROBIOSIS ON MACROPHYTES

Two of the main factors controlling plant growth in marshes are the type of soil and its degree of anaerobiosis. Little or no free oxygen exists in flooded marsh soils, and facultative and strict anaerobic microorganisms use alternate compounds as terminal electron acceptors. Therefore, a waterlogged soil differs substantially from a well-drained soil. The amount of oxygen consumed in the sediment is greater than the amount entering the sediment through diffusion, resulting in the formation of a thin, oxidized layer overlying an anaerobic environment in the sediment. If the oxygen demand in the soil is great enough, the oxygen in the overlying water column may be depleted, and the aerobic layer will not be formed. The redox potential in these sediments is the most diagnostic parameter in measuring the degree of anaerobiosis. The following compounds, listed with their reduced forms and in sequence used, are utilized as electron acceptors when the redox potential decreases: nitrate to ammonium, manganic form to manganous, ferric to ferrous, sulfate to sulfide, and carbon dioxide to methane.

One effect of waterlogging on marsh soils, a decrease in sediment redox potential, is especially important because of the direct relationship between redox potential and the productivity of the streamside, inland, and dieback zones of *Spartina alterniflora* (DELAUNE *et al.*, 1976; MENDELSSOHN *et al.*, 1981). The sediment underlying the tall varieties of *S. alterniflora* found along the creek banks is more oxidized than that underlying the short variety found at least 2 m landward of the creek (HOWES *et al.*, 1981). DELAUNE *et al.* (1983b, 1984) found that anaerobic root respiration of *S. alterniflora* grown in a laboratory environment increased with decreasing sediment redox potential without a reduction in plant growth.

The decomposition of organic compounds under anaerobic conditions usually results in the formation of several incompletely oxidized and some potentially toxic intermediates, such as ethylene, lactic acid, ethanol, acetaldehyde, and some aliphatic acids. The organic acids are toxic in order of increasing molecular weight (RAO and MIKKELSEN, 1977). One of the toxic compounds most frequently produced under strong anaerobic conditions is hydrogen sulfide. GOODMAN and WILLIAMS (1961) observed that *Spartina* dieback was caused by sulfide toxicity, and FORD (1973) found that concentrations as low as 2.5 ppm are toxic to root growth. DELAUNE *et al.* (1983b) concluded that in a Louisiana Gulf Coast marsh, the productivity of *S. alterniflora* is mainly controlled by the accumulation of free sulfide, although the accumulation of other toxic, reduced materials (ethanol, aldehyde) produced under anaerobic conditions should not be disregarded. Sulfides are neutralized in the soil in many cases by available ferrous iron, which precipitates with sulfides as nontoxic iron sulfides.

Even though iron is sometimes beneficial, other studies show that growth in macrophytes may be affected differently by the presence of iron and other elements. *Erica cinerea* rapidly developed waterlogging symptoms in a high-iron medium, whereas *E. tetralix* grown in the same medium was unharmed. *E. cinerea* took up more iron than the other plant (JONES and ETHERINGTON, 1970), which shows a difference in resistance to iron between two species of heath plants. In another study, JONES (1972) concluded that *Festuca rubra* was adversely affected by applications of up to 200 ppm of manganese, whereas the growth of *Carex nigra* was stimulated under the same conditions. Except in isolated studies such as these, the toxicity of these soil-produced phytotoxins and their effect on *Spartina* and other marshland flora have not been researched. Many of the elements that were harmless under oxidized conditions may prove to be toxic when reduced.

Root oxygenation is an important factor in the growth of macrophytes in the wetlands. Wetland plants use a few major mechanisms to adapt to anaerobic respiration. One is a well-developed aerenchyma cell system, which serves as an oxygen conduit to the root system in plants such as *Spartina* (ANDERSON, 1974). Another mechanism wetland plants use is ethanol diffusion out of the roots when alcohol fermentation exists, such as in rice under reduced conditions (BERTANI *et al.*, 1980). In 1971, MCMANMON and CRAWFORD proposed a theory explaining how flood-tolerant plants could avoid an accumulation of lethal ethanol. They suggested that nontoxic malate accumulates in the plants instead of ethanol. The malic enzyme is missing; therefore, malate is not converted to pyruvate, and ethanol production is precluded. LINHART and

BAKER (1973) found that within a single population of *Veronica peregrinai* differential accumulation of malate under flooded conditions corresponded to microhabitat distribution. It has been hypothesized that other substances, such as lactic acid, pyruvic acid, succinic acid, glycerol, shikimic acid, glycolic acid, glyoxalic acid, a-ketoglutaric acid, olanine, ethylene, g-amino butyric acid, glutamic acid, serine, and proline, may serve as nontoxic alternatives to ethanol (CRAWFORD, 1978; MENDELSSOHN *et al.* 1981). Although this hypothesis seems to be a valid one, many researchers have found evidence to contradict it (HOOK *et al.*, 1971; KEELEY and FRANZ, 1979; DAVIES, *et al.* 1974; SMITH and APREES, 1979).

In addition to the reduction of soil compounds and the anaerobic environment, wetland macrophytes must also adapt to different concentrations of salinity. In experiments on tillers of *Agrostis stolonifera*, AHAMAD and WAINWRIGHT (1976) observed no difference in the response of inland and spray-zone plants to salt treatments and an anaerobic environment, whereas these were significantly repressed in salt marsh plants. The responses of each ecotype to salinity and anaerobiosis paralleled the relative intensities of these in their natural habitats. ROZEMA and BLOM (1977) found that although *Agrostis stolonifera* and *Juncus gerardi* had depressed malate dehydrogenase levels when subject to NaCl treatments, their activities under saline conditions were significantly higher when flooded than when aerobic. ROZEMA and BLOM (1977) found that *Glaux maritima* has a similar inverse relationship with salinity and Positive one with flooding. The growth of *Spartina alterniflora* was found to decrease when the salinity in a nutrient solution was increased (GOSSELINK, 1970; HAINES and DUNN, 1976). NESTLER (1977) observed that the growth of *S. alterniflora* was inversely related to interstitial water salinity in a salt marsh in Georgia, and that elevated interstitial salinity in the high marsh zone can reduce transpiration and increase respiration in *Spartina*, thereby reducing photosynthesis and forming a weaker plant. LINTHURST and SENECA (1980) discovered that aeration enhanced uptake of certain nutrients, especially at higher salinities.

Plants have different mechanisms of responding to salt stress. The glycophytes (salt-intolerant plants) tend to exclude Na from the xylem by sequestering it in their roots and stems. Halophytes (salt-tolerant plants) accumulate ions in their vacuoles in order to maintain the necessary osmotic adjustment for life under saline conditions. When the control mechanism of glycophytes is overloaded, Na concentration increases in the leaves and growth decreases (FLOWERS *et al.*, 1977).

In the Louisiana marshes, saltwater intrusion greatly impacts the fresh, intermediate, and brackish marshes (to different degrees). Saltwater intruding from the Gulf of Mexico has changed the distribution of vegetation in the marshes: saline vegetation has expanded greatly, brackish and intermediate vegetation have shifted farther inland, and freshwater vegetation has been greatly reduced (CHABRECK, 1981). The exact mechanics of the impact that saltwater has on the different marsh types are not fully understood, but two results that often follow saltwater intrusion are (1) death of the original macrophyte population and, in cases where saltwater intrusion is too rapid to allow revegetation by more salt-tolerant plants (2) marsh degradation into open water.

SUMMARY

In the past century, the Louisiana coastline has been retreating at rates estimated as high as 130 km^2/yr (GAGLIANO, 1981), and this rate of deterioration is accelerating. This situation, currently unique to Louisiana, provides a good case study and opportunity to gather valuable information that can be applied to other regions that may be subject to this kind of deterioration in the future. The main factor causing the rapid rate of retreat in Louisiana is the low level of sedimentation, which has resulted from efforts to force the Mississippi River down its present channel, depriving wetlands of sediment needed to maintain their elevation relative to sea level. Human activities, such as canal cutting, dredging, and water table depletion have further accelerated degradational processes. Environmental factors impeding marshland maintenance are tropical storms, hurricanes, and other highly erosional natural phenomena. These forces are also rapidly deteriorating the Louisiana barrier islands, which presently provide the coast protection from the erosional forces of the sea and storms. The rapid deterioration of the barrier islands is exposing mainland marshes to more of the erosional power of the sea.

As the eustatic sea level rises, and problems similar to those in Louisiana become more widespread, landward retreat of wetlands in other coastal areas around the world will also increase. And, as in Louisiana, the submergence of coastal marshes and wetland forests will cause secondary effects, such as saltwater intrusion, aquifer contamination, loss of freshwater marshes, disappearance of the present biota, and land loss.

In addition to land loss, the accompanying influx of salt water into previously fresh, intermediate, and brackish marshes greatly impacts wetland ecosystems. Salinity increases in the marshes may kill native vegetation, and if the change is too abrupt to allow revegetation, open bodies of water may result. As salt water intrudes farther inland, the brackish marshes will be pushed farther landward, and the freshwater marsh areas will be reduced. Many locations in Louisiana, such as the New Orleans metropolitan area, are surrounded by levees for flood protection because of their minimal relative elevation above sea level. This leveeing will halt the landward migration of the receding marshes, thus accelerating the rate of wetland disappearance. Water-level increases will affect the higher wetland forest areas that are not seasonally subject to flooding, causing waterlogging, anaerobiosis, changes in redox potential, and other consequences. This Louisiana case study illustrates how coastal wetlands with submerging marsh areas are adversely affected by interrelated primary and secondary factors.

LITERATURE CITED

ADAMS, D.A., 1963. Factors influencing vascular plant zonation in North Carolina salt marshes. *Ecology*, 44:445-456.

ADAMS, R.D.; BARRETT, B.B.; BLACKMON, J.H.; GANE, B.W., and MCINTIRE, W.G., 1976. Barataria Basin: Geologic processes and framework. Louisiana State University, Center for Wetland Resources, Baton Rouge, La. *Sea Grant Publication* No. LSU-T-76-006.

AHAMAD, I. and WAINRIGHT, S.J., 1976. Ecotype differences in leaf surface properties of *Agrostis stolonifera* from salt marsh, spray zone and inland habitats. *New Phytology*, 76, 361-366.

ANDERSON, C.E., 1974. A review of structure in several North Carolina salt marsh plants. *In*: R.J. Reimold and W.H. Queen (Eds.), *Ecology of Halophytes*. New York: Academic Press, 307-344.

BAUMANN, R.H., and DELAUNE, R.D., 1981. Sedimentation and apparent sea level rise as factors affecting land loss in coastal Lousiana. *In*: D.F. Boesch (Ed.), *Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences and Options*. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-82/59, 1-13.

BERTANI, A.; BRAMBILLA, I., and MENEGUS, F., 1980. Effect of anaerobiosis on rice seedlings: growth metabolic rate and fate of fermentation products. *Journal Experimental Botany*, 31, 325-331.

BROOME, S.W.; WOODHOUSE, W.W., and SENECA, E.D., 1975. The relationship of mineral nutrients to growth of *Spartina alterniflora* in North Carolina: I. Nutrient status of plants and soils in natural stands. *Soil Science Society of America Proceedings*, 39, 295-301.

BROWN, S. and LUGO, A.E., 1982. A comparison of structural and functional characteristics of saltwater and freshwater forested wetlands. *In*: B. Gopal, R.W. Turner, R.G. Wetzel, and D.F. Whigham (Eds.), *Wetlands Ecology and Management*. Jaipur, India: International Scientific Publications, 109-130.

CHABRECK, R.H., 1981. The effect of coastal alteration on marsh plants. *In*: D.F. Boesch (Ed.), *Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences and Options*. U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-82, 92-98.

CHABRECK, R.H.; JOANEN, T., and PALMISANO, A.W., 1968. Vegetative type map of the Louisiana coastal marshes. *Louisiana Wildlife and Fisheries Commission*, New Orleans, Louisiana.

CONNER, W.H. and DAY, J.W., 1982. The ecology of forested wetlands in the southeastern United States. *In*: B. Gopal, R.E. Turner, R.G. Wetzel, and D.F. Whigham (Eds.), *Wetlands Ecology and Management*. Jaipur, India: International Scientific Publications, 69-87.

CRAIG, N.J.; DAY, J.W.; KEMP, P.; SEATON, A., and SMITH, W.G., 1977. Cumulative impact studies in the Louisiana coastal zone. *Report to Louisiana State Planning Office*, 92.

CRAIG, N.J.; TURNER, R.E., and DAY, J.W., 1979. Land loss in coastal Louisiana (USA). *Environmental Management*, 3(2), 133-134.

CRAWFORD, R.M.M., 1978. Metabolic indicators in the prediction of soil anaerobiosis. *In*: D. Nielson and J.G. McDonald (Eds.), *Nitrogen in the Environment, Vol. 1*. New York: Academic Press, 547-563.

DAVIES, D.D.; K.H. NASCIMENTO, and PATIL, K.D., 1974. The distribution and properties of NADP malic enzyme in flowering plants. *Phytochemistry*, 13, 2417-2425.

DAY, J.W., Jr.; HOPKINSON, C.S., and CONNER, W.H., 1982. An analysis of environmental factors regulating community metabolism and fisheries production in a Lousiana estuary. *In*: V.S. Kennedy (ed.), *Estuarine Comparisons*. New York: Academic Press, 121-136.

DAY, J.W. and CRAIG, N.J., 1982. Comparison of the effectiveness of management options for wetland loss in a coastal zone of Louisiana. *In*: D.F. Boesche (Ed.), *Proceedings of the Conference of Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options*. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-82/59.

DEEGAN, L.A.; KENNEDY, H.M., and NEILL, C., 1983. Natural factors and human modifications contributing to marsh loss in Louisiana's Mississippi River deltaic plain. Department of Marine Sciences. Louisiana State University.

DELAUNE, R.D.; BAUMANN, R.H., and GOSSELINK, J.G., 1983a. Relationships among vertical accretion, coastal submergence and erosion in a Louisiana Gulf Coast marsh. *Journal Sedimentary Petrology*, 53(1), 147-157.

DELAUNE, R. D.; PATRICK, W. H., and PEZESHKI, S.R., 1985. Survival of coastal wetland forests: Sedimentation vs. submergence. *New Forest* (In Review).

DELAUNE, R.D.; PATRICK, W.H., and BRANNON, J.M., 1976. Nutrient transformation in Louisiana salt marsh soils. Louisiana State University, Baton Rouge, Louisiana. *Sea Grant Publication* No. LSU-T-76-009.

DELAUNE, R.D.; PATRICK, W.H., and BURESH, R.J., 1978. Sedimentation rates determined by Cs^{137} dating in a rapidly accreting salt marsh. *Nature*, 275(5680), 532-533.

DELAUNE, R.D.; SMITH, C.J., and PATRICK, W.H., 1983b. Relationship of marsh elevation, redox potential and sulfide to *Spartina alterniflora* productivity. *Soil Science Society of America Journal*, 47, 930-935.

DELAUNE, R.D.; SMITH, C.J., and PATRICK, W.H., 1985. Sedimentation patterns in a Gulf Coast barrier island backside marsh: Response to increasing submergence. *Earth Surface Processes*, (In Press).

DELAUNE, R.D.; SMITH, C.J., and TOLLEY, M.D., 1984. The effect of sediment redox potential on nitrogen uptake, anaerobic root respiration and growth of *Spartina alterniflora*. *Aquatic Botany*, 18, 223-230.

DICKSON, R.E.; BROYER,T.C., and JOHNSON, C.M., 1972. Nutrient uptake by tupelo gum and bald cypress from saturated or unsaturated soil. *Plant and Soil*, 37, 297-308.

DOZIER, M.D., 1983. Assessment of change in the marshes of southwestern Barataria Basin, Louisiana, using historical aerial Photographs and a spatial information system. M.S. thesis. Louisiana State University, Baton Rouge. 102pp.

EGGLER, W.A. and MOORE, W.G., 1961. The vegetation of Lake Chicot, Louisiana, after 18 years of impoundment. *Southwestern Naturalist*, 6, 175-183.

FLOWERS, T.J.; TROKE, P.F., and YEO, A.R., 1977. The mechanism of salt tolerance in halophytes. *Annual Review of Plant Physiology*, 28, 89-121.

FORD, H.W., 1973. Levels of hydrogen sulfide toxic to citrus roots. *Journal of the American Society of Horticultural Science*, 98, 66-68.

GAGLIANO, S.M., 1981. Special report on marsh deterioration and land loss in the deltaic plain of coastal Louisiana. Presented to Frank Ashby, secretary, Louisiana Department of Wildlife and Fisheries. Coastal Environments, Inc., Baton Rouge, La.

GAGLIANO, S.M.; KWON, H.J., and VAN BEEK, J.L., 1970. Deterioration and restoration of coastal wetlands. *Twelfth International Conference on Coastal Engineering*, Sept. 13-17, Washington D.C.

GAGLIANO, S.M.; MEYER-ARENDT, K.J., and WICKER, K.M., 1981. Land loss in the Mississippi River deltaic plain. *Transactions Gulf Coast Association of Geological Societies*, 31:295-300.

GILL, C.J., 1970. The flooding tolerance of woody species: a review. *Forestry Abstracts*, 31, 671-688.

GAGLIANO, S.M. and. VAN BEEK, J.L., 1970. Geologic and geomorphic aspects of deltaic processes, Mississippi delta system. Hydrologic and Geologic Studies of Coastal Louisiana, *Report No. 1., Coastal Resources Unit* Center for Wetland Resources, Louisiana State University, Baton Rouge.

GOODMAN, P.J. and WILLIAMS, W.T., 1961. Investigations into 'dieback' in *Spartina townsendii* Agg.III. Physiological correlates of 'dieback'. *Journal of Ecology*, 49, 391-398.

GOSSELINK, J.G., 1970. Growth of *Spartina patens* and *Spartina alterniflora* as influenced by salinity and source of nitrogen. *Coastal Studies Bulletin*, 5, 97-110.

HAINES, E.B. and DUNN, E.L., 1976. Growth and resource allocation responses of *Spartina alterniflora* Loisel to three levels of ammonium, iron and sodium chloride in solution culture. *Botanical Gazette*, 137, 224-230.

HARMS, W.R.; SCHREUDER, H.T.; HOOK, D.D., and BROWN, C.L., 1980. The effects of flooding on the swamp forest in Lake Ocklawah, Florida. *Ecology*, 61, 1412-1421.

HATTON, R.S.; DELAUNE, R.D., and PATRICK, W.H., 1983. Sedimentation, accretion and subsidence in
marshes of Barataria Basin, Louisiana. *Limnology and Oceanography*, 28(3), 494-502.

HICKS, S.D., 1978. An average geopotential sea-level series for the United States. *Journal of Geophysical Research*, 83, 1377-1379.

HICKS, S.D.; DEBAUGH, H.A., and HICKMAN, L.E., 1983. Sea level variations for the United States 1855-1980. *National Ocean Service, U.S. Department of Commerce*,, Rockville, Md.

HOFFMAN, J.S.; KEYES, D., and TITUS, J.G., 1983. Projecting future sea level rise. EPA. *U.S. GPO No. 055-000-0236-3*, Governmenmt Printing Office, Washington D.C.

HOOK, D.D.; BROWN, C.L., and KORMANIK, P.P., 1971. Inductive flood tolerance in swamp tupelo (*Nyssa sylvatica* var. *biflora* Walt. Sarg.). *Journal of Experimental Botany*, 22, 78-89.

HOWES, B.L.; HOWARTH, R.J.; TEAL, J.M., and VALIELA, I., 1981. Oxidation-reduction potentials in a salt marsh: Spatial patterns and interactions with primary production. *Limnology and Oceanography*, 26, 350-360.

JONES, R., 1972. Comparative studies of plant growth and distribution in relation to waterlogging. VI. The effect of manganese on growth of dune and slack plants. *Journal of Ecology*, 60, 141-146.

JONES, R. and ETHERINGTON, J.R., 1970. Comparative studies of plant growth and distribution in relation to waterlogging. I. The survival of *Erica cinerea* L. and *E. tetralix* L. and its apparent relationship to iron and manganese uptake in waterlogged soil. *Journal of Ecology*, 58:487-496.

KEELEY, J.E. and FRANZ, E.H., 1979. Alcoholic fermentation in swamp and upland populations of *Nyssa sylvatica* : Temporal changes in adaptive strategy. *American Naturalist*, 113, 587-642.

LETZSCH, W.S. and FREY, R.W., 1980. Deposition and erosion in a Holocene salt marsh, Sapelo Island, Georgia. *Journal Sedimentary Petrology*, 50, 529-542.

LINHART, Y.B. and BAKER, I., 1973. Intra-population differentiation of physiological response to flooding in a population of Veronica peregrina L. *Nature*, 242, 275-276.

LINTHURST, R.A. and SENECA, E.D., 1980. The effects of standing water and drainage potential on the *Spartina alterniflora* substrate complex in a North Carolina salt marsh. *Estuarine and Coastal Marine Science*, 11, 41-52.

MCMANMON, M. and CRAWFORD, R.M.M., 1971. A metabolic theory of flooding tolerance: The significance of enzyme distribution and behavior. *New Phytology*, 70, 299-306.

MENDELSSOHN, I.A.; JORDAN, J.W.; TALBOT, F., and STARKOVICH, C.J., 1983a. Dune building and vegetative stabilization in a sand deficient barrier island environment. *In: Proceedings of the Third Symposium on Coastal and Ocean Management*. San Diego, California: ASCE, June 1-4.

MENDELSSOHN, I.A.; MCKEE, K.L., and PATRICK, W.H., 1981. Oxygen deficiency in *Spartina alterniflora* roots: metabolic adaption to anoxia. *Science*, 214, 439-441.

MENDELSSOHN, I.A.; PENLAND, P.S., and PATRICK, W.H., 1985. Barrier islands and beaches of the Mississippi River deltaic plain. Louisiana State

University. *Sea Grant Publication* (In review).
MENDELSSOHN, I.A.; TURNER, R.E., and MCKEE, K.L., 1983b. Louisiana's eroding coastal zone: Management alternatives. *Journal of the Limnological Society of Southern Africa*, 9(2), 63-75.
MOORE, H.F. and POPE, T.E.B., 1910. Oyster culture experiments and investigations in Louisiana. Dep. of Comm. and Labor, *Bureau of Fish Documents* No.731.
NESTLER, J., 1977. Interstitial salinity as a cause of ecophenic variation in *Spartina alterniflora*. *Estuarine and Coastal Marine Science*, 5, 707-714.
PENLAND, P.S. and BOYD, R., 1981. Shoreline changes in the Louisiana barrier coast. *Oceans*, September.
RAO, D.N. and MIKKELSEN, D.S., 1977. Effects of butyric acids on rice seedling growth and nutrition. *Plant and Soil*, 47:323-334.
REVELLE, R., 1983. Probable future changes in sea level from increased atmospheric carbon dioxide. *In : Changing Climate, Carbon Dioxide Assessment Committee*. Washington D.C.: National Academy Press.
ROZEMA, J. and BLOM, B., 1977. Effects of salinity and inundation on the growth of *Agrostis stolonifera* and *Juncus gerardii*. *Journal of Ecology*, 65, 213-222.
SASSER, C.E.; DOZIER, M.D.; GOSSELINK, J.G., and HILL, J.M., 1985. Spatial and temporal changes in Louisiana's Barataria Basin marshes. *Environmental Management* (In Review)
SMITH, A.M. and APREES, T., 1979. Pathways of carbohydrate fermentation in the roots of marsh plants. *Planta*, 146, 327-334.
SOIL CONSERVATION SERVICE., 1978. Lake Verret Watershed, Final Revised Environmental Impact Statement. U.S.D.A. Alexandria, LA.
TESKEY, R.O. and HINCKLEY, T.M., 1977. Impact of water level changes on woody riparian and wetland communities, Vol. II: Southern forest region. *U.S. Fish and Wildlife Service*. FWS/OBS-77/59.
TURNER, R.E.; COSTANZA, R., and SCAIFE, W., 1982. Canals and wetland erosion rates in coastal Louisiana: causes, consequences and options. *US Fish and Wildlife Service*, Office of Biological Services. FWS-OB 82-59.
TURNER, R.E. and GOSSELINK, J.G., 1975. A note on standing crops of *Spartina alterniflora* in Texas and Florida. *Contributions to Marine Science*, 19, 113-118.
VAN HEERDEN, I.H. and ROBERTS, H.H., 1980. The Atchafalaya delta, Louisiana's new prograding coast. *Transactions Gulf Coast Association of Geological Societies*, 30, 497-506.
VAN SICKLE, V.R.; BARRETT, B.B., and FORD, T.B., 1976. Barataria Basin: Salinity changes and oyster distribution. Louisiana State University, Center for Wetland Resources, Baton Rouge, La. *Sea Grant Publication* No. LSU-76-002.
WICKER, K.M; JOHNSTON, J.B., and YOUNG, M.W., 1980. Mississippi deltaic plain region habitat mapping study. Habitat area data tapes. *US Fish and Wildlife Service*, Office of Biological Services. FWS/OBS-79/07.
WICKER, K.M.; JOHNSTON, J.B., and YOUNG, M.W., 1981. Chenier Plain region ecological characterization. Habitat area data tapes Louisiana Department of Natural Resources, Baton Rouge.