Biological Services Program

FWS/OBS-82/59
September 1982

Proceedings of the

Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options

Baton Rouge, Louisiana
October 5-7, 1981

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

Louisiana Universities Marine Consortium
State of Louisiana

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.

- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.

- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on an analysis of the issues, a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and to determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; geothermal, mineral and oil shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and systems inventory, including National Wetland Inventory, habitat classification and analysis, and information transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staffs, who provide a link to problems at the operating level; and staffs at certain Fish and Wildlife Service research facilities, who conduct in-house research studies.

FWS/OBS-82/59
September 1982

PROCEEDINGS OF THE CONFERENCE ON COASTAL EROSION AND WETLAND MODIFICATION IN LOUISIANA: CAUSES, CONSEQUENCES, AND OPTIONS

Edited by

Donald F. Boesch
Louisiana Universities Marine Consortium
Star Route, Box 541
Chauvin, LA 70344

Project Officer

Carroll L. Cordes
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

Performed for
National Coastal Ecosystems Team
Office of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

DISCLAIMER

The findings in this report are not to be construed as an official U.S. Fish and Wildlife position unless so designated by other authorized documents.

This report should be cited as:

Boesch, D. F., ed. 1982. Proceedings of the conference on coastal erosion and wetland modification in Louisiana: causes, consequences, and options. U.S. Fish and Wildlife Service, Biological Services Program, Washington, D.C. FWS/OBS-82/59. 256 pp.

PREFACE

The Conference on Coastal Erosion and Wetland Modification in Louisiana, sponsored by the Louisiana Universities Marine Consortium and the U.S. Fish and Wildlife Service, was held in Baton Rouge on 5-7 October 1981. The Conference was in response to a need for a current compendium of information on the causes, consequences, and options to deal with coastal land loss in Louisiana.

Patterns of wetlands deterioration in relation to natural geomorphic processes in the Mississippi River delta were described as early as the 1930's (Russell, R.J. 1936. Physiography of the Lower Mississippi River delta: Louisiana Geological Survey, Lower Mississippi Delta Geological Bulletin 8: 3-199). In the 1960's systematic comparisons of wetland areas from topographic maps indicated that the net loss of wetlands in Louisiana was 42.7 km^2 (16.5 mi^2/yr) (Gagliano, S.M. and J.L. van Beek 1970. Geologic and geomorphic aspects of deltaic processes, Mississippi delta system. Louisiana State Univ. Center for Wetland Resources, Baton Rouge. Hydrologic and Geologic Studies of Coastal Louisiana. Rep. 1. 140 pp.). Habitat mapping studies conducted in the late 1970's for the U.S. Fish and Wildlife Service and based on direct analyses of aerial imagery yielded estimates of coastal wetland loss of 18 km^2/yr in the chenier plain region of southwestern Louisiana between 1952 and 1974 (Gosselink, J.G., C.L. Cordes and J.W. Parsons. 1979. An ecological characterization of the chenier plain coastal ecosystem of Louisiana and Texas. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-78-9) and 83 km^2/yr in the deltaic plain of southeastern Louisiana between 1955-56 and 1978 (Wicker, K.M. 1980. Mississippi Deltaic Plain Region ecological characterization: a habitat mapping study. A user's guide to the habitat maps. U.S. Fish and Wildlife Service, Office of Bioloigcal Services. FWS/OBS-79/07). Furthermore, comparisons of land loss rates estimated for various intervals during this century indicate a geometric increase in this rate with time, the extrapolation of which yields a 1980 rate of 102 km^2/yr (39.4 mi^2/yr) for the Mississippi deltaic plain alone (Gagliano, S.M., K.J. Meyer-Arendt, and K.M. Wicker. 1981. Land loss in the Mississippi River deltaic plain. Trans. Gulf Coast Assoc. Geol. Soc. 31:295-300).

These revelations have heightened public and governmental concern about the causes and consequences of the astounding rates of coastal environmental change in Louisiana and have catalyzed action on various approaches to slow or reverse the rate of loss. The causes are clearly complex but involve at least the senescence of the active delta, regional and localized subsidence, leveeing of the Mississippi River, and the effects of channelization of wetlands. Man has played a major role, in consert with natural processes, in accelerating coastal land loss. The potential effects of these coastal changes on living resources, state revenues and human society are massive. The coastal wetlands of Louisiana are a major contributor to national fisheries and wildlife resources. Given the present rates of loss, several coastal parishes have life expectancies in the range of 50 to 100 years, and enormous social and economic dislocations would result.

Several structural and management approaches to stemming coastal land loss have been proposed. These range from allowing the wholesale diversion of the Mississippi River down the Atchafalaya River to promote rapid delta building to more restrictive

permitting of activities in wetlands. In recognition of the seriousness of coastal land loss, the Louisiana Legislature in its 1981 Extraordinary Session established the Coastal Environmental Protection Trust Fund to be applied for projects such as controlled river diversions, barrier island stabilization, and wetlands management. The first of these projects are scheduled to commence in late 1982.

Sound scientific understanding of the processes responsible, the effects on natural resources, and the effectiveness of mitigative approaches will be critical to the success of attempts to control land loss. It is to this purpose that the contributions in this volume are addressed.

The Conference and these Proceedings are products of a cooperative Agreement (14-16-0009-81-1016) between the U.S. Fish and Wildlife Service and the Louisiana Universities Marine Consortium related to research and informational services on "Shoreline Erosion and Wetland Habitat Modifications in Coastal Louisiana." It reflects the commitment of both of these organizations to address this most serious environmental problem.

Donald F. Boesch
Cocodrie, Louisiana
September 1982

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

Information Transfer Specialist
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
NASA-Slidell Computer Complex
1010 Gause Boulevard
Slidell, LA 70458

CONTENTS

ACKNOWLEDGMENTS

The Conference on Coastal Erosion and Wetland Modification in Louisiana was planned and conducted under the able direction of a steering committee composed of Donald F. Boesch, Louisiana Universities Marine Consortium (LUMCON); James M. Coleman, Coastal Studies Institute, Louisiana State University (LSU); Donald W. Davis, Nicholls State University; John W. Day, Jr., Center for Wetland Resources, LSU; Ted B. Ford, Louisiana Department of Wildlife and Fisheries; Sherwood M. Gagliano, Coastal Environments, Inc.; Joseph Kelley, University of New Orleans; Joel Lindsey, Coastal Management Section, Louisiana Department of Natural Resources; Dag Nummedal, Department of Geology, LSU; Robert Stewart, U.S. Fish and Wildlife Service (FWS); and Michael Wascom, LSU Law Center. In addition, Charles Adams, Barney Barrett, David Chambers, Nancy Craig, James Johnston, R. Eugene Turner and Paul Templet contributed to the deliberations of the steering committee.

Bette Wall, Mary Katherine Politz and John Hassell of LUMCON handled the logistical arrangements for the Conference. Mary Katherine Politz and Gloria Whitney of LUMCON assisted in editing and revision and prepared the typescript. Carroll L. Cordes provided patient cooperation and editorial assistance as FWS Project Officer.

Financial support for the Conference was provided by the Louisiana Universities Marine Consortium. Prepartion and publication of the Proceedings were supported by the U.S. Department of the Interior, Fish and Wildlife Service, National Coastal Ecosystems Team.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. FWS/OBS-82/59	2.	3. Recipient's Accession No.

4. Title and Subtitle
Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options

5. Report Date
September 1982

6.

7. Author(s)
D. F. Boesch, ed.

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Louisiana Universities Marine Consortium
Star Route, Box 531
Chauvin, Louisiana 70344

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
U.S. Fish and Wildlife Service
Office of Biological Services

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This volume contains 16 papers and panel discussions from a conference held in Baton Rouge, La., 5-6 October 1981. The presentations consider the causes and consequences of coastal erosion and wetland modification in Louisiana and the mitigative options available to slow or reverse the rapid rate of coastal land loss. Detailed habitat mapping studies have allowed accurate estimates of coastal habitat change and land loss through 1978. Projections from these rates of change indicate an annual rate of land loss in coastal Louisiana in the early 1980's of approximately 130 km^2/yr (50 m^2/yr).

The projected effects of wetland modification on the bountiful living resources of coastal Louisiana (fisheries, fur and hide bearers and waterfowl) are major because of the close dependence of these resources on estuarine wetlands. These changes and others related to flood protection, transportation and ownership of mineral resources are projected to have extensive social and economic consequences.

Options proposed to slow coastal land loss include major and minor diversions of the Mississippi River, barrier island and shoreline restoration and protection, hydrological management of wetlands and more restrictive permitting of dredging activities.

17. Document Analysis a. Descriptors

Louisiana, wetlands, coastal, erosion, management, causes and effects

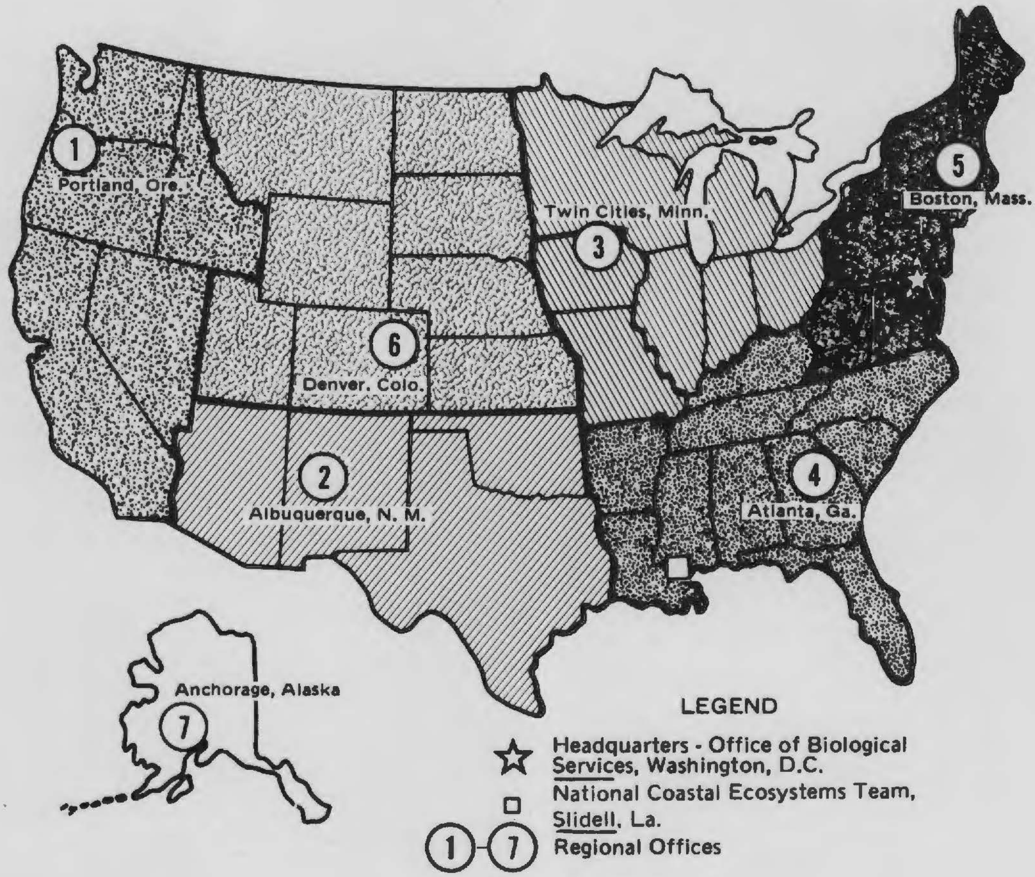
b. Identifiers/Open-Ended Terms

Wetlands, erosion, management, Louisiana

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited	Unclassified	viii + 256
	20. Security Class (This Page)	22. Price
	Unclassified	

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77)



U.S. FISH AND WILDLIFE SERVICE
REGIONAL OFFICES

REGION 1
Regional Director
U.S. Fish and Wildlife Service
Lloyd Five Hundred Building, Suite 1692
500 N.E. Multnomah Street
Portland, Oregon 97232

REGION 2
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, New Mexico 87103

REGION 3
Regional Director
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, Minnesota 55111

REGION 4
Regional Director
U.S. Fish and Wildlife Service
Richard B. Russell Building
75 Spring Street, S.W.
Atlanta, Georgia 30303

REGION 5
Regional Director
U.S. Fish and Wildlife Service
One Gateway Center
Newton Corner, Massachusetts 02158

REGION 6
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Denver, Colorado 80225

REGION 7
Regional Director
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, Alaska 99503

DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

CAUSES: CHANGES IN DISPERSAL OF FRESH WATER AND SEDIMENTS

SEDIMENTATION AND APPARENT SEA-LEVEL RISE AS FACTORS AFFECTING LAND LOSS IN COASTAL LOUISIANA

R.H. Baumann
R.D. DeLaune

Center for Wetland Resources
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

Rates of apparent sea-level rise and marsh aggradation were determined with the aid of ^{137}Cs dating, artificial marker horizons, and water level data for the lower Barataria and Calcasieu estauries. These marshes are not vertically accreting at a rapid enough rate to maintain their intertidal elevation and have been subjected to net submergence since at least the mid-1950's. This has resulted in a conversion of marsh to open water habitats.

Rates of apparent sea-level rise at the two study areas were 1.2 and 1.3 cm/yr from 1954 to present. Sedimentation rates through the same period were approximately 0.7 cm/yr over most of the area of investigation, though streamside marshes aggraded at a rate of 1.35 cm/yr. The transformation of marsh to open water will be complete in a few decades if present trends continue. A research strategy that will narrow management alternatives is briefly outlined.

INTRODUCTION

The recognition of wetland loss as a problem in coastal Louisiana is widespread, the consequences of wetland loss have been reasonably projected, and management agencies and groups appear ready to commit resources towards resolution. Until the how and why of wetland loss are understood, however, we will not know the most appropriate mitigating procedures. The how and why are the processes of wetland loss.

Wetland loss can be viewed as the inability of wetlands to maintain themselves. In subsiding environments, such as coastal Louisiana, the continued existence of marsh is partially dependent on its ability to maintain its elevation within the tidal range through vertical accretion. This must be accomplished through some combinaton of peat formation and mineral sediment accumulation. The two can be interrelated as the influx of sediments also supplies nutrients for plant growth (DeLaune et al. 1979). Increased plant growth results in more material available for peat formation and increases in stem density result in an enhanced ability to further entrap and stabilize sediment (Gleason et al. 1979). Thus, the process appears to have a synergistic effect and a reduction in sediment supply can result in an exaggerated effect.

We report in this paper the processes and rates of vertical accretion as determined by ^{137}Cs dating and by the use of artificial marker horizons, and relate them to apparent sea-level rise and marsh deterioration at two sites along the Louisiana coast. The two sites were independently studied with slightly different objectives, but the results pertaining to wetland loss were similar.

STUDY AREA DESCRIPTIONS

The two study areas are representative of the two coastal regions of Louisiana: the chenier and Mississippi deltaic plains. The site within the chenier plain is a brackish to saline Spartina patens marsh known locally as the East Cove marsh, located on the south shore of Calcasieu Lake within the Sabine National Wildlife Refuge (Figure 1). The deltaic plain site is the saline Spartina alterniflora marsh surrounding Barataria Bay (Figure 2).

Both sites have been experiencing above average land loss rates of over 1%/yr since the mid-1950's. A major difference between the two sites is their respective geologic foundation. Underlying the East Cove marsh is a 1 to 6 m sequence of Recent sediments (Gosselink et al. 1979) whereas in the lower Barataria basin, the Pleistocene surface lies 30 to 100 m below the marsh surface (Kolb and Van Lopik 1966). This difference in sediment thickness suggests that the Barataria site has an inherently greater subsidence potential. If all other factors were equal we would expect land loss rates to be comparatively greater at the Barataria site.

METHODS

Details of sampling design, laboratory procedures, materials used, and statistical analyses are provided in previous reports (DeLaune et al. 1978; DeLaune et al. in review; Baumann 1980). Discussion here will be limited to a general application of various methods and techniques as they pertain to monitoring sedimentation in Louisiana's marshes.

The numerous techniques employed to monitor sediment accretion can be divided into five broad categories: (1) surveys through time based on benchmarks or other datums; (2) calculations based on sediment budgets; (3) simple mechanical devices such as calibrated rods; (4) radiometric dating; and (5) natural and artificial marker horizons. Categories one through three are generally unacceptable for work in Louisiana marshes for many reasons, some of which have been discussed by Letzsch and Frey (1980).

Radiometric dating can provide accurate sedimentation rate information provided the substance being dated has been deposited in situ and the sedimentary sequence has not been subsequently disturbed. ^{137}Cs was the radioactive element used in the case studies discussed in this report. It was first introduced into the biosphere as a product of atmospheric nuclear testing with significant fallout levels first appearing in 1954 and peaking in 1963 (Pennington et al. 1973). By obtaining cores and measuring the ^{137}Cs activity at regular intervals throughout the core, the average sedimentation rate from 1954 to 1963 and from 1963 to the present can be determined.

Artificial marker horizons have been extensively used in monitoring studies involving a few years or less. Various substances have been employed, but most are not

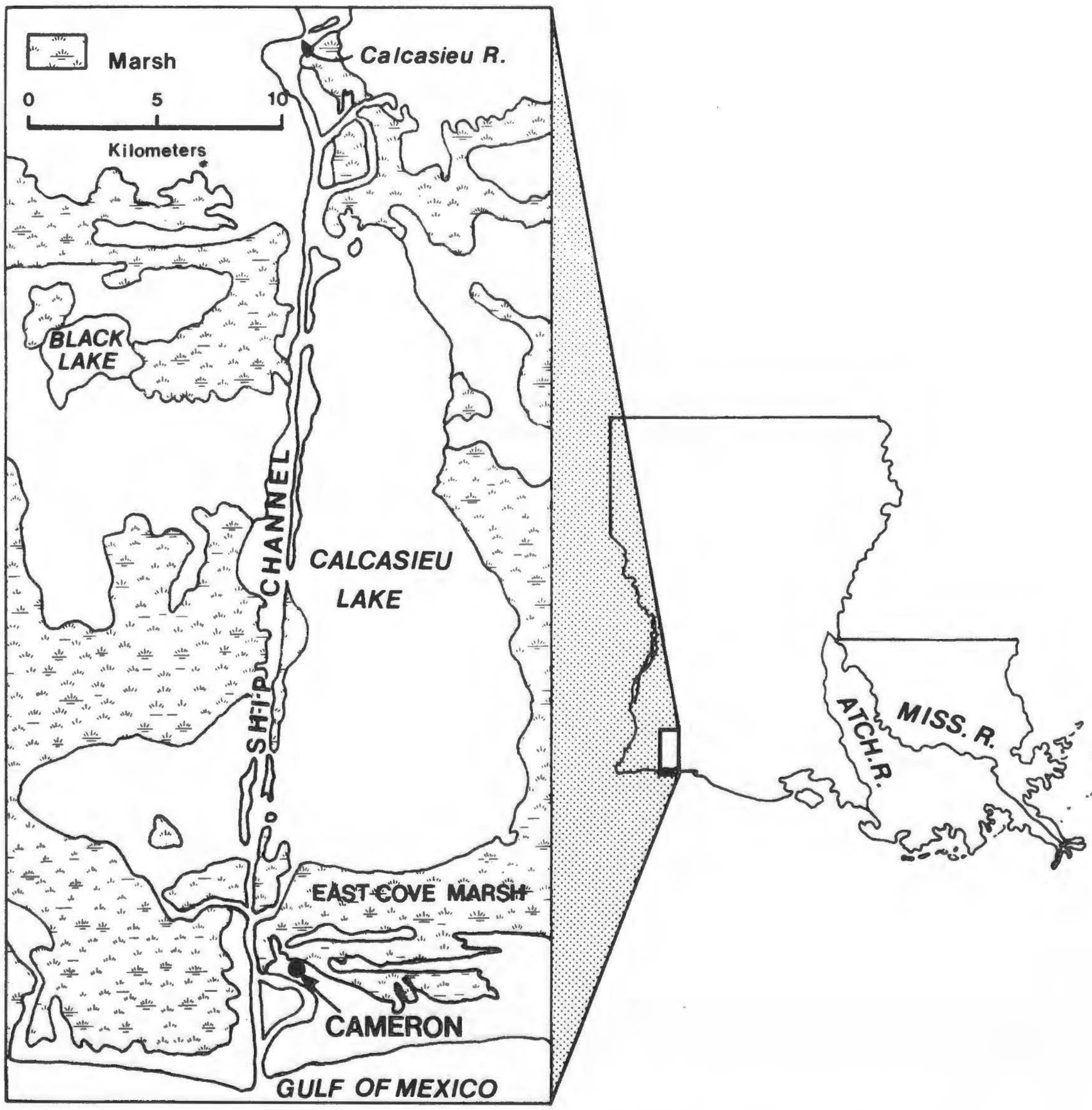


Figure 1. Location of East Cove Marsh study area.

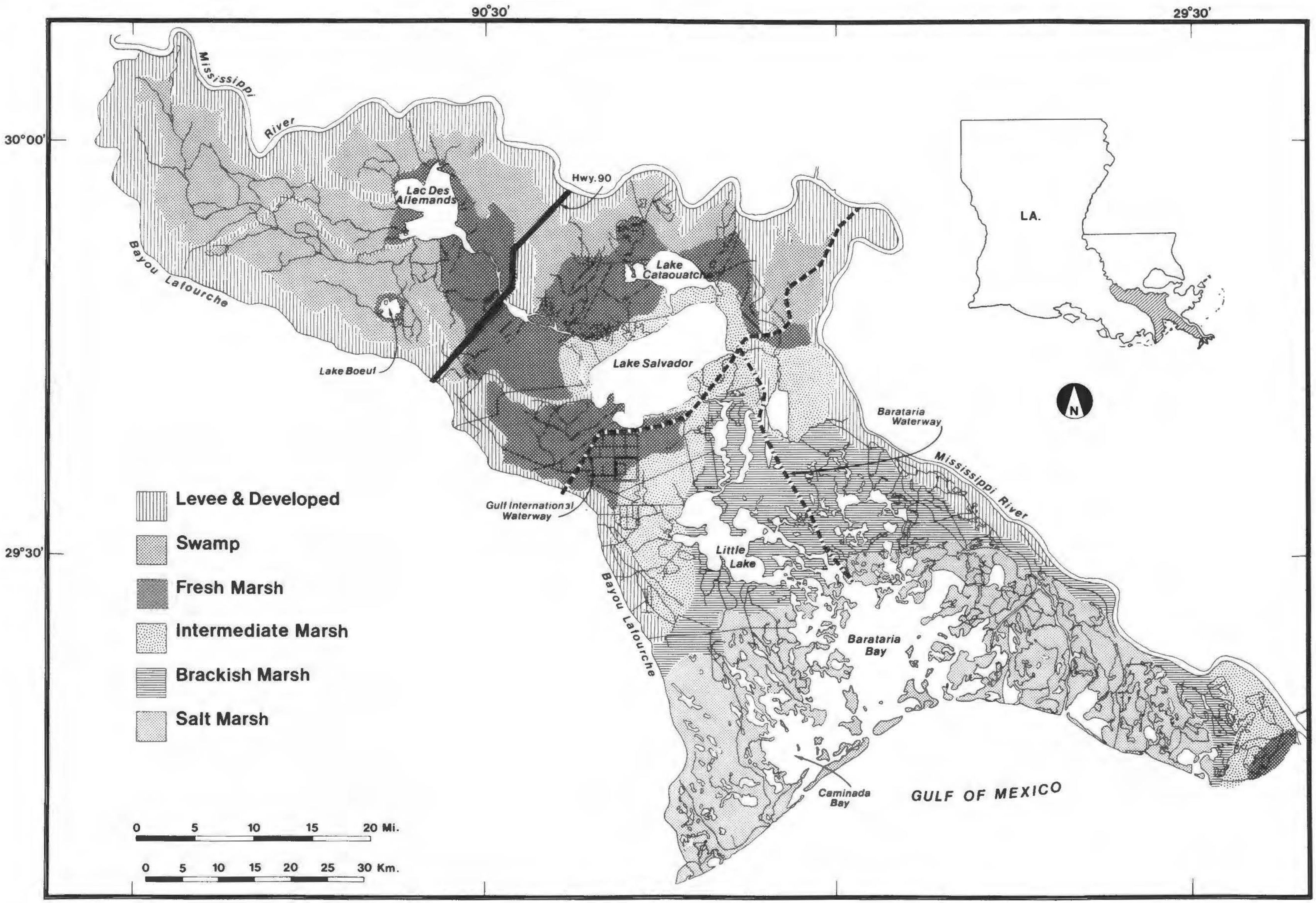


Figure 2. Location of lower Barataria estuary study area.

adequate for Louisiana's coastal marshes because of either recognizability (color) or density (sinkage) problems. White clay (Feldspar 261-F) is one substance that is easily recognizable from marsh sediments and is not subject to sinkage provided the organic content of the marsh soil is less than 30% on a dry weight basis (Baumann 1980). In Louisiana, this generally restricts its use to saline and brackish marshes.

The combination of the ^{137}Cs and artificial marker techniques provides more information than either technique alone can produce. The results of the two techniques can be compared, thereby providing an additional check on method reliability. The two techniques are compatible as some of the disadvantages of one technique are the advantages of the other. Artificial markers do not provide information on the past whereas ^{137}Cs does. Artificial markers provide information on variability of sedimentation rates through time, whereas ^{137}Cs is generally limited to providing average sedimentation rate information. Artificial markers can be sampled at any time interval desired, therefore one can obtain data on possible seasonal trends, the role of storms, etc. This frequency of sampling freedom allows one to examine processes of sedimentation more fully, but the disadvantage is that one must wait for sedimentation to occur.

Sea-level rise was calculated by linear regression analysis of tide gauge data available from the U.S. Army Corps of Engineers, New Orleans District.

Land loss rates for the Barataria site were extracted from Adams et al. (1978) and rates for the Calcasieu site were mapped and measured from available aerial photographs using the methods described by Adams et al. (1978).

RESULTS AND DISCUSSION

Barataria Site

^{137}Cs analysis showed that marshes bordering water bodies such as lakes, bayous, and ponds were aggrading (vertically accreting) at a rate of 1.35 cm/yr whereas marshes more distant from water bodies were aggrading at a rate of 0.75 cm/yr (DeLaune et al. 1978). These two types of marshes are commonly referred to as streamside and inland marshes, respectively. The difference in sedimentation rates are to be expected as streamside marshes are closer to the source of sediments. This situation is analagous to the levee and backswamp situation bordering many of the rivers and bayous of Louisiana except the scale of elevation and sedimentation rate differences are much less in the salt marshes. Density and organic carbon analysis of the core samples revealed that aggradation occurs by both plant detritus and mineral sediment accumulation (DeLaune et al. 1978).

Aggradation of the salt marsh as measured by artificial marker horizons from 1975 to 1979 was 1.5 cm $\pm$ 0.4 and 0.9 cm $\pm$ 0.2 for streamside and inland marshes, respectively (Baumann 1980). The slightly higher values resulting from the artificial marker horizon method could be due to the different time interval of sampling (5 versus 25 years), less compaction due to the shorter time interval or other unidentified reasons. Considering the natural variability in the environment, the difference in results between the two methods is quite small.

Apparent sea-level rise at the Bayou Rigaud tide gauge located near Grand Isle was 1.3 cm/yr from 1954 to 1980 (Figure 3). Apparent sea-level rise includes both the effects of subsidence of land, and a global, real rise in sea level which is referred to as eustatic sea-level rise.

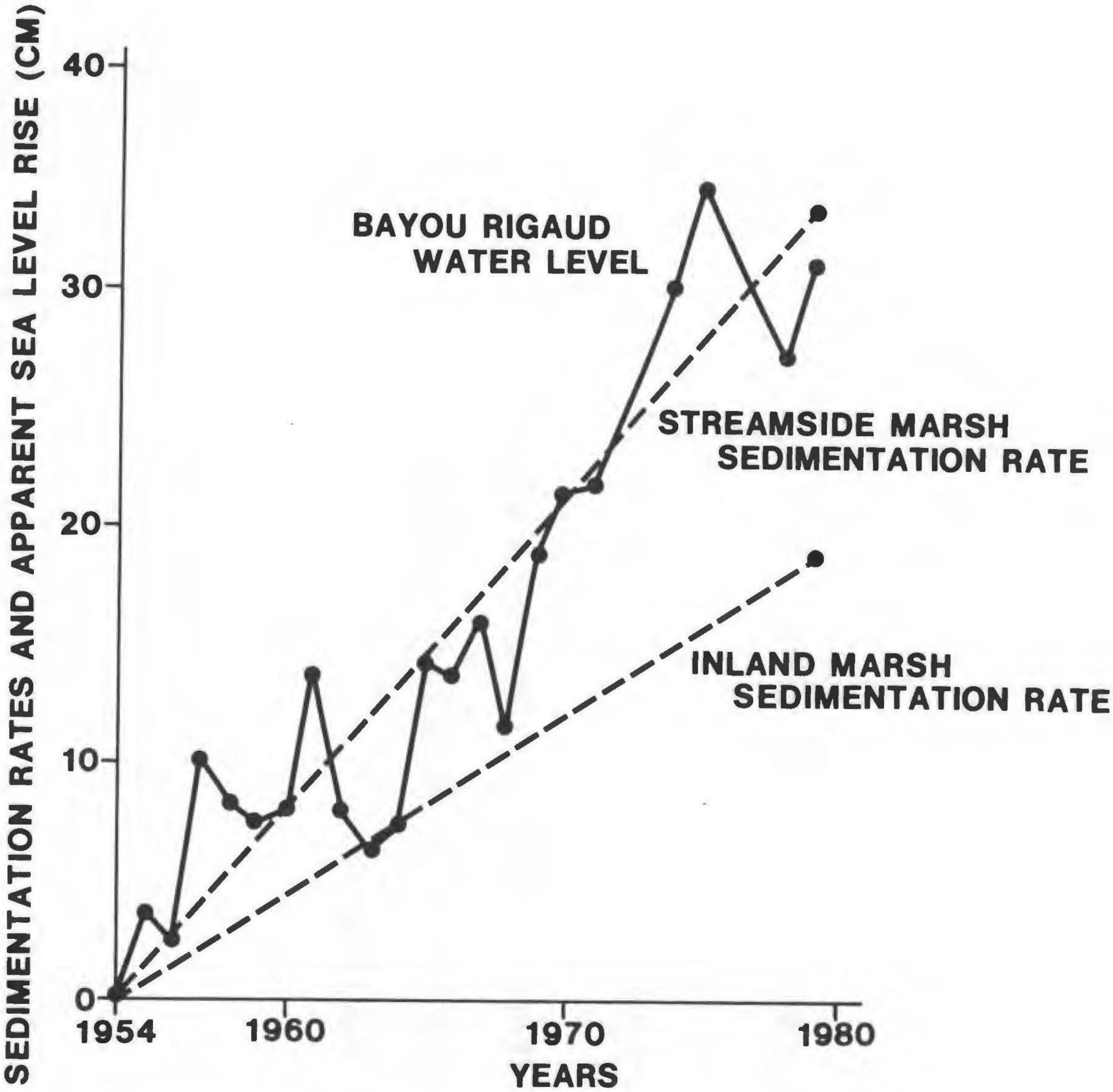


Figure 3. Apparent sea-level rise and mean sedimentation rates for streamside and inland saline marshes in the lower Barataria estuary.

If we compare the apparent sea-level rise data with the sedimentation rate data it becomes clear that since 1954 streamside marshes have kept pace with apparent sea-level rise and, therefore, are maintaining their relative elevaton within the tidal range, but inland marshes are not. Thus, through time flooding of inland marshes (representing 75% to 80% of the salt marsh area) increases and at some point the plants can no longer survive (Mendelssohn et al. 1981). Once the inland marshes begin forming into ponds and the ponds enlarge and coalesce, the streamside marshes are subject to wave attack and they begin to erode laterally.

Examining the seasonality of sedimentation (Figure 4) with the use of the artificial marker technique provides additional insights on why the marshes are not maintaining their elevation. From 1975-78 most of the aggradation occurred during the winter, but when the 1979 data are added sedimentation appears to be equally important during winter and summer.

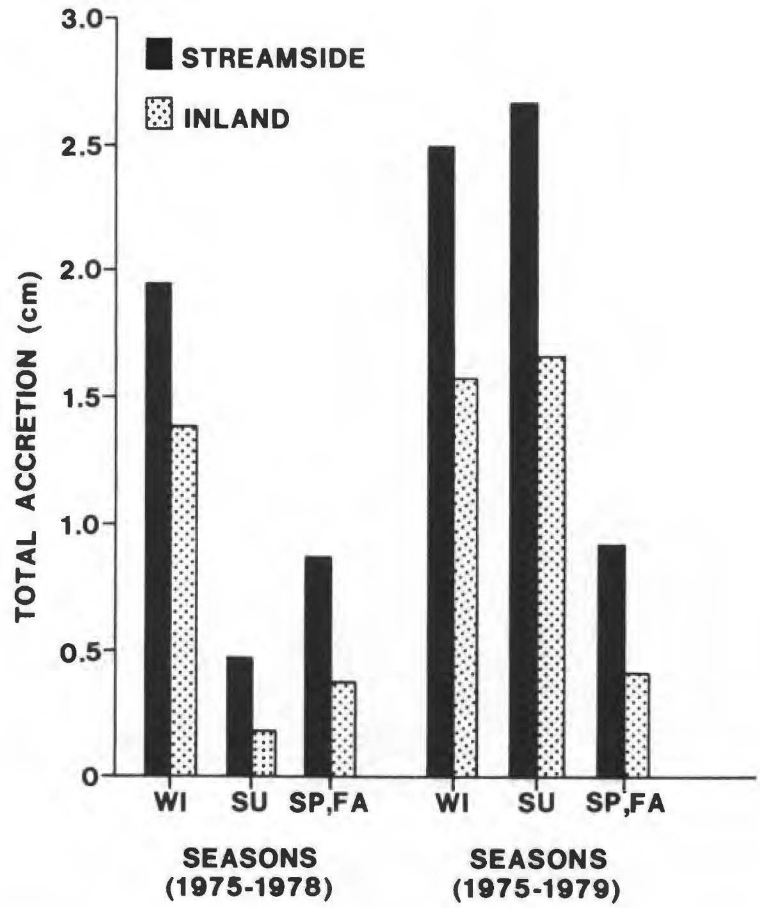


Figure 4. Seasonality of sedimentation in the Barataria saline marsh, 1975-1978 and 1975-1979. Spring and fall values have been combined. Values represent accumulated totals for the time period indicated.

The summer and winter sedimentation dominance has been related to storm events (Baumann 1980). The cyclical and repetitive nature of cold front activity is responsible for the comparatively high winter sedimentation rate. High winds re-entrain sediment in the water column with southeasterly winds preceeding the frontal passage pushing sediment-laden water over the marsh where the sediment is deposited. The reversal to strong northerly winds pushes the water off the marsh and maintains high turbidity levels in the lakes and bays (Cruz-Orozoco 1971) setting the stage for the cycle to be repeated.

Sedimentation during the summers of 1975-78 was relatively low, but increased dramatically in 1979 due to the large scale redistribution of sediments by Tropical Storm Claudette and Hurricane Bob. Thus, sedimentation rates during the summer can be expected to be normally low, but episodically high depending on tropical storm activity in this area. We expect this would also characterize the fall season, however, no major tropical storm activity occurred over the study area during the fall during the examination period.

Perhaps the most striking aspect is the lack of sedimentation during the spring when the Mississippi River is in flood and carries peak sediment loads. Even the flood of 1979, which was the second largest flood since 1950 (U.S. Army Engineer District, New Orleans 1980), did not directly result in substantial sedimentation on the study area marshes. This lack of substantial sedimentation during the spring shows that the Mississippi River is no longer a direct source of sediments to the study area.

The final aspect addressed in the Barataria example was an attempt to directly link the net sedimentation deficit to land loss rates. By combining the sedimentation and sea-level rise data with marsh elevation relative to water level data a theoretical land loss rate could be calculated. These calculations, which are outlined in Baumann (1980), indicated that the saline marsh in the lower Barataria Basin should have a maximum life expectancy of nearly a century if current sedimentation rate and sea-level trends continue in the future.

Actual land loss rates (Adams et al. 1978) indicate that maximum life expectancy is much less even after considering the direct and intentional loss of marshes via man's activities. This suggests that additional factors are also contributing to the land loss problem in the lower Barataria basin.

Calcasieu Site

Both ^{137}Cs profile distributions and the artificial marker techniques showed that the East Cove marsh has been aggrading at an average rate of 0.7 cm/yr. Sampling was not designed to compare streamside with inland accretion. The lower rate of accretion at the Calcasieu site in comparison to the Barataria site was expected due to the previously discussed regional differences in sediment supply and subsidence potential.

The accretion rate of 0.7 cm/yr is not sufficient to maintain the elevation of the marsh with respect to water level. Apparent sea-level rise as measured at the nearby Cameron tide gauge has averaged 1.2 cm/yr from 1954-80 (Figure 5). Thus, apparent sea level has been rising at nearly twice the rate of marsh aggradation during the past quarter-century.

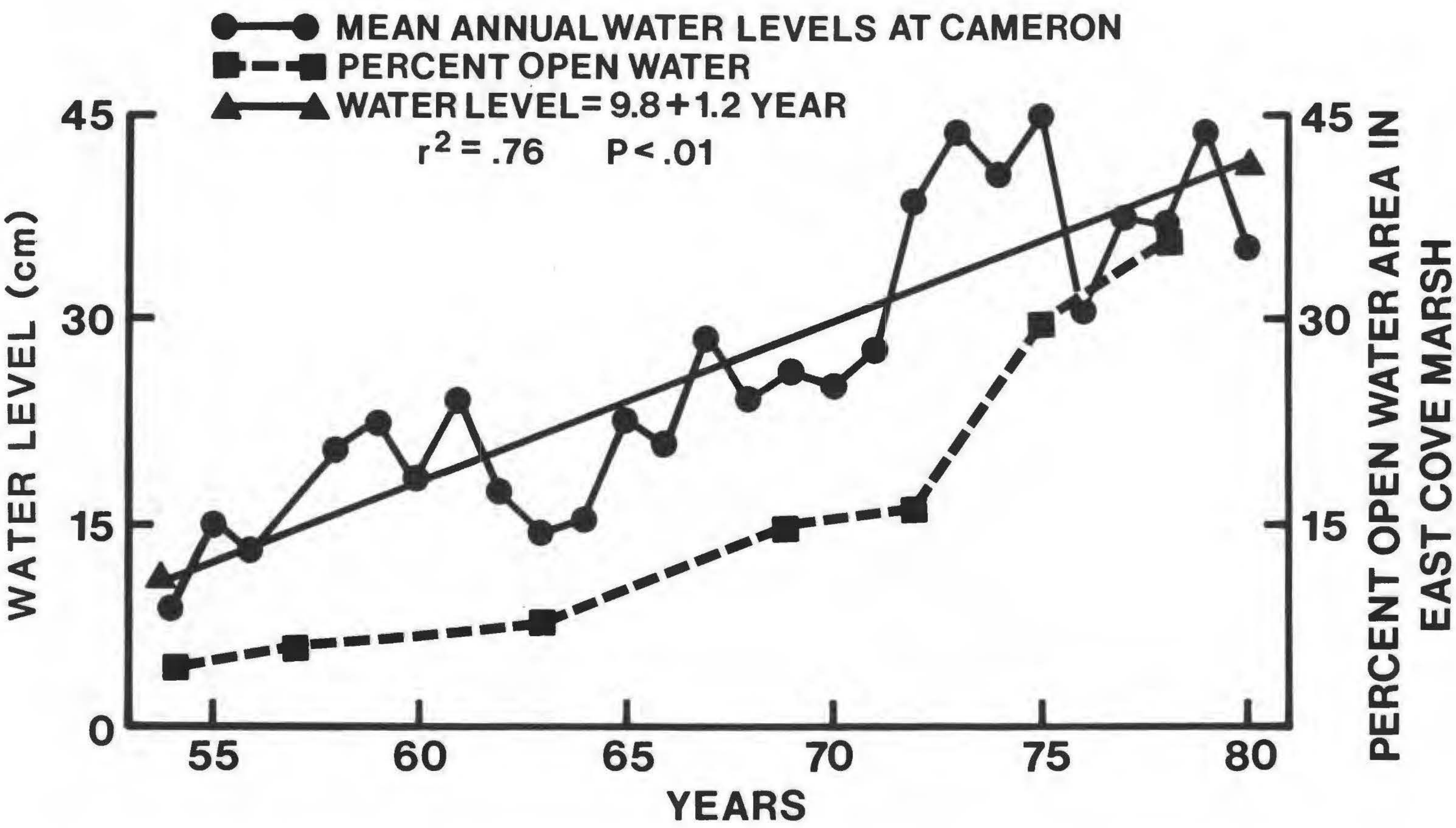


Figure 5. Relationship between apparent sea-level rise and land loss in the lower Calcasieu estuary in which there is a net deficit of 0.7 cm/yr between accretion and apparent sea-level rise. Water level based on 1929 datum.

If we assume that accretion has been fairly constant throughout the period of examination and the elevation range of the marsh is small, then the loss of marsh to open water should parallel apparent sea-level rise (Figure 5). If present trends continue, the East Cove marsh will complete its transformation to open water in approximately 40 years.

While the inability of the marsh to maintain its elevation with apparent sea-level rise appears to be an important factor that is responsible for wetland loss in the East Cove marsh, why the marshes are not keeping pace is a more difficult question to resolve. Discharge and sediment load data suggest that the Calcasieu Ship Channel has reduced the amount of riverborne sediment dispersed into the Calcasieu Lake system by debouching flows directly into the Gulf of Mexico (DeLaune et al. in review). The ship channel has also facilitated saltwater intrusion to the Calcasieu estuary which may be an additional interacting factor in wetland loss (Gosselink et al. 1979).

Probable reductions in sediment supply and saltwater intrusion may only be a part of the problem. The 1.2 cm/yr apparent rise in sea level at Cameron is high. One would expect the rate to be considerably less than at Bayou Rigaud due to the inherently lower subsidence potential, but the rates of rise at the two stations are within 0.1 cm/yr of one another. Nearby gauges depict similar rates which seem to belie any argument that the trends are aberrations due to gauge instability. The similarity in the rates of apparent sea-level rise suggests that interregional factors may be an important if not dominant factor during the past several decades.

CONCLUSIONS AND STRATEGY

In both case studies reported here, marsh aggradation has not kept pace with apparent sea-level rise. At the Barataria site, which lies within the Mississippi deltaic plain, basinal processes now dominate over riverine processes and it is apparent that basinal processes cannot maintain marsh elevation given the present rate of apparent sea-level rise. This dominance of basinal over riverine processes is characteristic of the deterioration phase of Mississippi River deltaic cycles (Coleman and Gaglino 1964).

As an initial step towards narrowing possible management options, we need to determine how widespread marsh aggradation deficits are. The two sites reported here were originally chosen partially on the basis that they were experiencing high rates of wetland loss. Thus, in addition to the small number of sample areas, the sampling is biased.

If it is found that marsh aggradation deficits are indeed a major component of land loss throughout the coastal zone, then it behooves us to examine why the marshes are not keeping pace in order to propose appropriate mitigating procedures. If the marshes are not keeping pace because canals interrupt sedimentary processes, then management solutions may be weighted towards regulatory procedures. If fluid withdrawals have accelerated subsidence rates, then we must look to reinjection where feasible and possible redistribution and control of groundwater wells. If the marshes are being sediment-starved due to levee systems, then reintroduction of sediments may help, but this solution will be geographicaly limited to a relatively narrow corridor paralleling the present Mississippi River. The possibility that all of these factors can be operating simultaneously dictates that any management plan must be flexible to deal with different causes and adaptable to change as new insights are made. But until we commit our

resources to continue to go beyond looking at effects and examine processes, we will not know what our capabilities and limitations for management are.

ACKNOWLEDGMENT

This report is a result of research sponsored by the Louisiana Sea Grant College Program, a part of the National Sea Grant College Program, maintained by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Contribution No. LSU-CEL-81-37 of the Coastal Ecology Laboratory, LSU Center for Wetland Resources.

LITERATURE CITED

Adams, R.D., P.J. Banas, R.J. Baumann, J.H. Blackmon, and W.G. McIntire. 1978. Shoreline erosion in coastal Louisiana: inventory and assessment. Louisiana Department of Transportation and Development, Baton Rouge.

Baumann, R.H. 1980. Mechanisms of maintaining marsh elevation in a subsiding environment. M.S. Thesis. Louisiana State Univ., Baton Rouge.

Coleman, J.M., and S.M. Gagliano. 1964. Cyclic sedimentation in the Mississippi River deltaic plain. Trans. Gulf Coast Assoc. Geol. Soc. 14:67-80.

Cruz-Orozoco, R. 1971. Suspended solids concentrations and their relations to other environmental factors in selected waterbodies in the Barataria Bay region of south Louisiana. M.S. Thesis. Louisiana State Univ., Baton Rouge.

DeLaune, R.D., R.J. Buresh, and W.H. Patrick, Jr. 1978. Sedimentation rates determined by ^{137}Cs dating in a rapidly accreting salt marsh. Nature 275:532-553.

DeLaune, R.D., R.J. Buresh, and W.H. Patrick, Jr. 1979. Relationship of soil properties to standing crop biomass of *Spartina alterniflora* in a Louisiana marsh. Estuarine Coastal Mar. Sci. 8:477-487.

DeLaune, R.D., R.H. Baumann, and J.G. Gosselink. In review. Relationships among vertical accretion, apparent sea level rise, and land loss in a Louisiana gulf coast marsh. J. Sediment. Petrol.

Gleason, M.L., D.A. Elmer, N.C. Pien, and J.S. Fisher. 1979. Effects of stem density upon sediment retention by salt marsh cord grass, *Spartina alterniflora* Loisel. Estuaries 2:271-273.

Gosselink, J.G., C.L. Cordes, and J. W. Parsons. 1979. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas. 3 vols. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-78/9 through 78/11.

Kolb, C.R., and J.W. Van Lopik. 1966. Depositional environments of the Mississippi River deltaic plain, southeastern Louisiana. Pages 17-61 *in* Deltas and their geologic framework. Houston Geological Society.

Letzsch, W.S., and R.W. Frey. 1980. Deposition and erosion in a Holocene salt marsh, Sapelo Island, Georgia. J. Sediment. Petrol. 50:529-542.

Mendelssohn, I.A., K.L. McKee, and W.H. Patrick, Jr. 1981. Oxygen deficiency in *Spartina alterniflora* roots: metabolic adoption to anoxia. Science 214:439-441.

Pennington, W., R.S. Cambray, and E.H. Fisher. 1973. Observations on lake sediments using fallout ^{137}Cs as a tracer. Nature 242:324-326.

U.S. Army Engineer District, New Orleans. 1980 (and earlier years). Stages and discharges of the Mississippi River and tributaries and other watersheds in the New Orleans District for 1979 (and earlier years).

ASSESSMENT OF GEOLOGICAL AND HUMAN FACTORS RESPONSIBLE FOR LOUISIANA COASTAL BARRIER EROSION

Shea Penland

Louisiana Geological Survey
Louisiana State University
Baton Rouge, LA 70803

Ron Boyd

Department of Geology
Dalhousie University
Halifax, Nova Scotia, Canada

ABSTRACT

Louisiana's coastal barrier systems are experiencing severe shoreline erosion and land loss. Between 1880 and 1980, total coastal barrier area decreased from 98.6 km^2 to 57.8 km^2, an overall loss of 41%. Coastal barrier land loss results from the natural processes of deltaic transgression and marine erosion, combined with the impact of human development. A three-stage model for the evolution of abandoned Mississippi deltas describes deltaic transgression. Sand bodies deposited during delta building are successfully transformed after abandonment into an erosional headland and flanking barriers (Stage 1), a transgressive barrier island arc (Stage 2), and a subaqueous inner-shelf shoal (Stage 3). Barrier erosion trends closely correspond to the pattern of sediment dispersal identified for each barrier evolutionary stage. Barrier islands in the erosional headland and flanking barrier stage are essentially in a state of dynamic equilibrium, due to the presence of a deltaic headland sand source. Transgressive barrier island arcs do not contain such a sediment source, and hence suffer net erosion. The principal mechanisms of transgression are subsidence combined with repeated erosion by extratropical and tropical cyclones. Coastal barrier sediment loss, hence land loss, can be attributed to the following mechanisms: (1) longshore loss into spits and tidal deltas, (2) landward loss through overwash into a subsiding lagoon, (3) offshore loss due to an inequality in offshore/onshore transport capacity, and (4) subsidence of the deltaic sand sources. Human impacts that result in accelerated coastal barrier deterioration include coastal structures, pipeline canals, and navigation channels. These manmade structures disrupt sediment transport pathways and create additional sediment sinks.

INTRODUCTION

Louisiana is faced with the most serious coastal barrier erosion problem in the United States (Figure 1). Between 1880 and 1980, the total coastal barrier area of Louisiana decreased 41%. Coastal barrier erosion and land loss results from the natural processes of deltaic transgression and marine erosion, combined with the impact of human development. The economic consequences of shoreline erosion and land loss are

Figure 1. Location map showing the distribution of coastal sand barriers along the Holocene Mississippi River deltaic plain.

seen in the destruction of commercial and residential property, the accompanying loss of valuable coastal wetlands caused by the removal of protective storm barriers, and the loss of fishery resources caused by intrusion of salt water into wetland nursery areas. A new and comprehensive evaluation of shoreline change trends along 250 km of Louisiana's barrier coastline has been made for 1922-78, using digitization of individual island areas from the U.S. Coastal Survey charts dated between 1869 and 1969 and land cover maps dated 1979.

DATA ACQUISITION

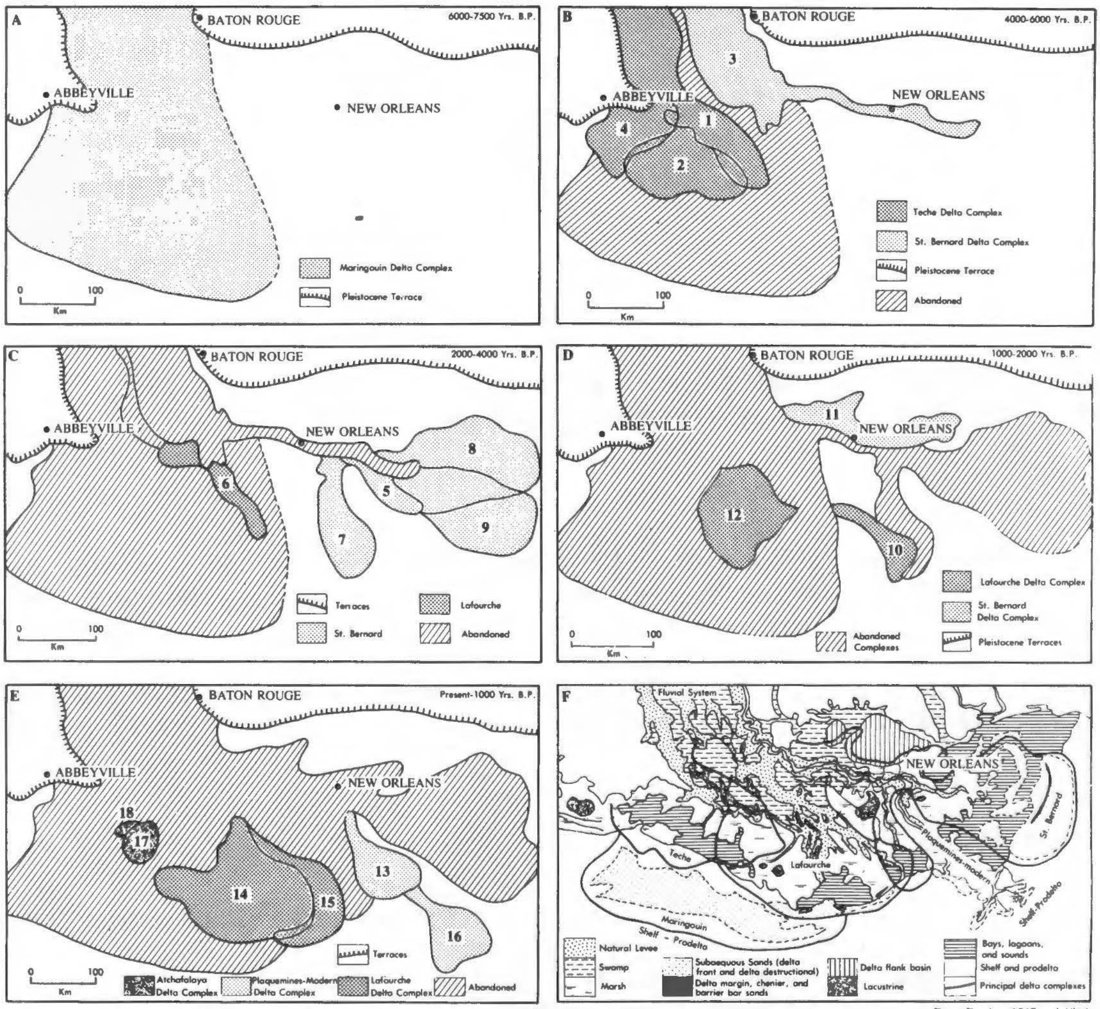
Analysis of shoreline change was based on two independent sets of data. Changes in Gulf of Mexico shoreline positions were derived by the Orthogonal-Grid Mapping System technique (Dolan et al. 1978). This technique produces a location of the high-water line for every 100 m of shoreline, based on information that has been summarized as an average rate of shoreline change over the period of data collection and expressed as areas of either accretion or erosion within 5m/yr-class intervals.

The second data set was obtained by individually digitizing the surface area of each barrier island on the Louisiana coast. This method analyzed U.S. Coast and Geodetic

survey maps for 1869-1956, together with a series of land cover maps at the scale of 1:10,000, based on 1979 aerial photography. Results are presented as a time series of variation in coastal barrier area plotted against tropical cyclone and coastal structure impacts.

GEOLOGICAL FACTORS RESPONSIBLE FOR COASTAL BARRIER EROSION

Deltaic evolution of the Louisiana coast is characterized by alternate periods of land building and land loss (Figure 2). The alternation of these two activities is determined by the balance between sediment supply and variation in relative sea level (Curry 1964). Throughout the Pleistocene Epoch, the relative sea level has undergone dramatic fluctuations, falling over 120 m and rising as much as several meters above



(From Frazier, 1967 and 1969)

Figure 2. A time series of paleographic maps depicting the evolution of the Mississippi River deltaic plain and its depositional environments (modified from Frazier 1967).

present sea level. Most of this variation may be attributed to eustatic sea-level variations related to changing volumes of ice at the polar ice caps. Since eustatic sea-level rise ceased about 3,000 to 6,000 years BP (Coleman and Smith 1964), ongoing subsidence resulting from a compaction and sinking of Mississippi delta sediments is the major cause of the relative sea-level rise, and hence land loss and coastal barrier erosion, in Louisiana.

The major factor offsetting subsidence-induced sea-level rise is sediment supplied to the coast by the Mississippi River in a sequence of well-defined deltaic depocenters (Fisk 1944; Kolb and Van Lopik 1958; Frazier 1967). During active sedimentation in each depocenter, the shoreline progrades laterally as much as 120 km seaward, with the delta plain vertically aggrading up to 5 m above mean sea level (Figure 2). Following delta switching through upstream distributary diversion, sediment supply to the delta complex quickly diminishes. Under these conditions, subsidence induced by substrate compaction and dewatering becomes the dominant coastal process and deltaic transgression begins. This period corresponds to Stage 1, erosional headland and flanking barriers (Penland et al. 1981; Penland and Boyd 1981, 1982), in which the reworking of distributary sand bodies through shoreface retreat provides the only sand source for coastal barrier generation (Figure 3). Shore-parallel transport distributes sand from the headland source into downdrift marginal spits, tidal deltas, and flanking barrier islands. While sand is being actively supplied from the erosional headland, the downdrift barrier systems in this evolutionary stage exist in dynamic equilibrium. Subsidence gradually causes this reworked distributary sand source to move below the reach of wave erosion and onshore transport. With increased age and long-term subsidence, Stage 2 occurs; this barrier system evolves into a transgressive barrier island arc, separated from the mainland by an intra-deltaic lagoon. From this point on, sand sources no longer exist for barrier nourishment, and the sediment dispersal pattern in this subsiding environment is the destruction of the subaerial barrier and the formation of a subaqueous inner shelf shoal, Stage 3. This occurs when sea-level transgression has overcome the ability of the barrier to maintain its integrity through landward migration and vertical accretion. Geological processes, therefore, interact in Louisiana to produce periods of rapid coastal progradation, associated with delta building, and rapid coastal transgression, associated with distributary abandonment and coastal barrier formation. Subsurface studies of the Mississippi River in such areas have shown the existence of several major and minor regressive-transgressive cycles in the past 8,000 years (Fisk 1944; Kolb and Van Lopik 1958; Frazier 1967). During the transgressive history of any one of the four abandoned delta complexes, the following four mechanisms are identified as controlling coastal barrier deterioration: (1) subsidence of deltaic sand source, (2) accumulation and subsiding washover deposits, (3) infilling during migration of spit complexes and tidal inlets, and (4) inequality in onshore-offshore sediment exchange.

Subsidence of Deltaic Sand Source

Following upstream diversion during the process of delta switching, the only source of sand-size sediments for coastal barrier development comes from reworked distributary sand bodies and flanking beach-ridge plains. During the evolution of an abandoned delta, these sand sources continually subside and provide a diminishing sediment supply. The maximum effective depth limit for erosion of deltaic sand sources is the base of the advancing shoreface (Figure 4). Available bathymetric data locate the base of the advancing shoreface seaward of the Bayou Lafourche headland and the Chandeleur Islands, at a depth of around 6 to 8 m. Assuming that the estimated rates of relative sea-level rise estimated between 0.6 and 1.5 cm/yr are correct (Kolb and Van Lopik 1958;

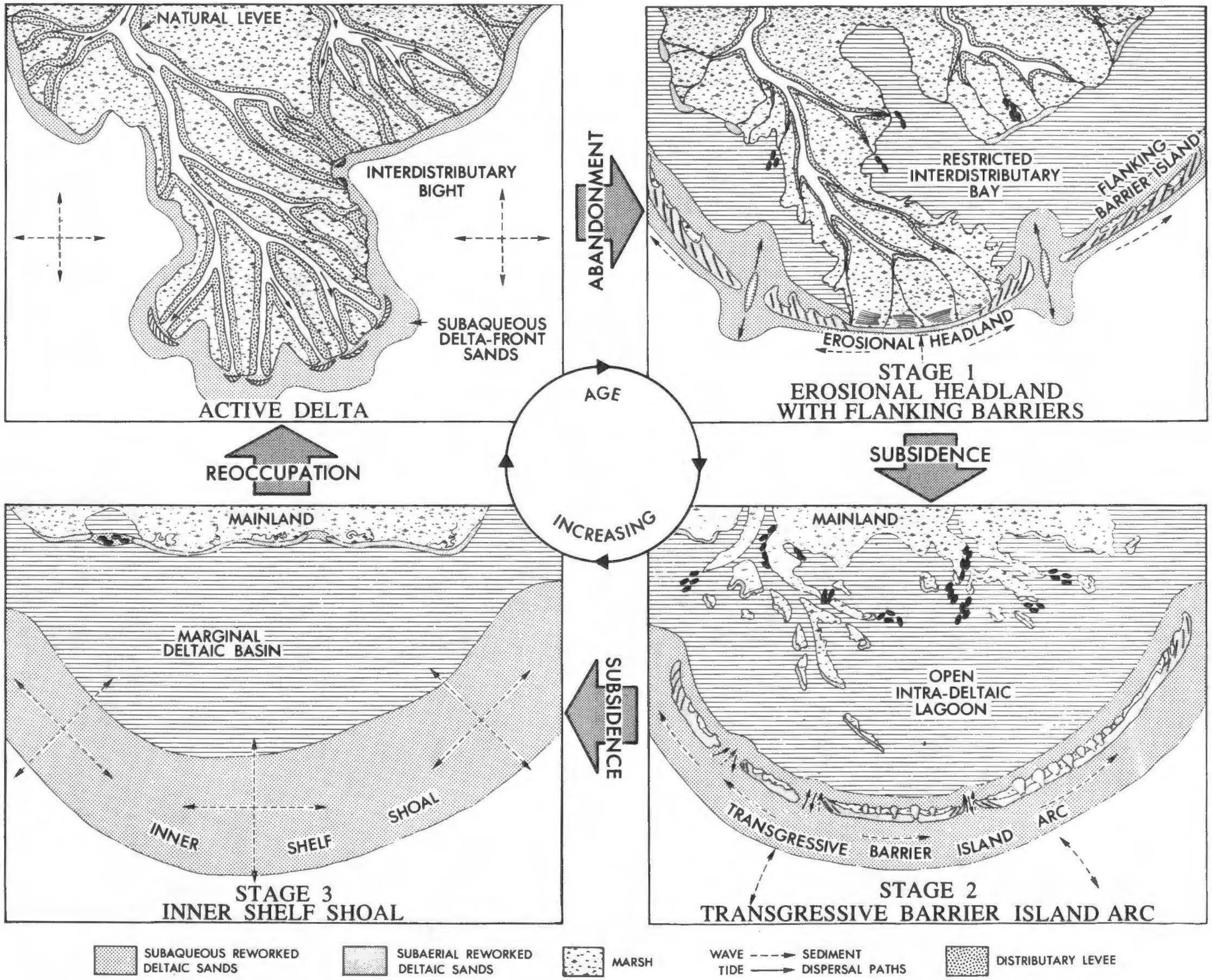


Figure 3. A model for the evolution of abandoned Mississippi River deltas and the development of transgressive coastal barrier systems.

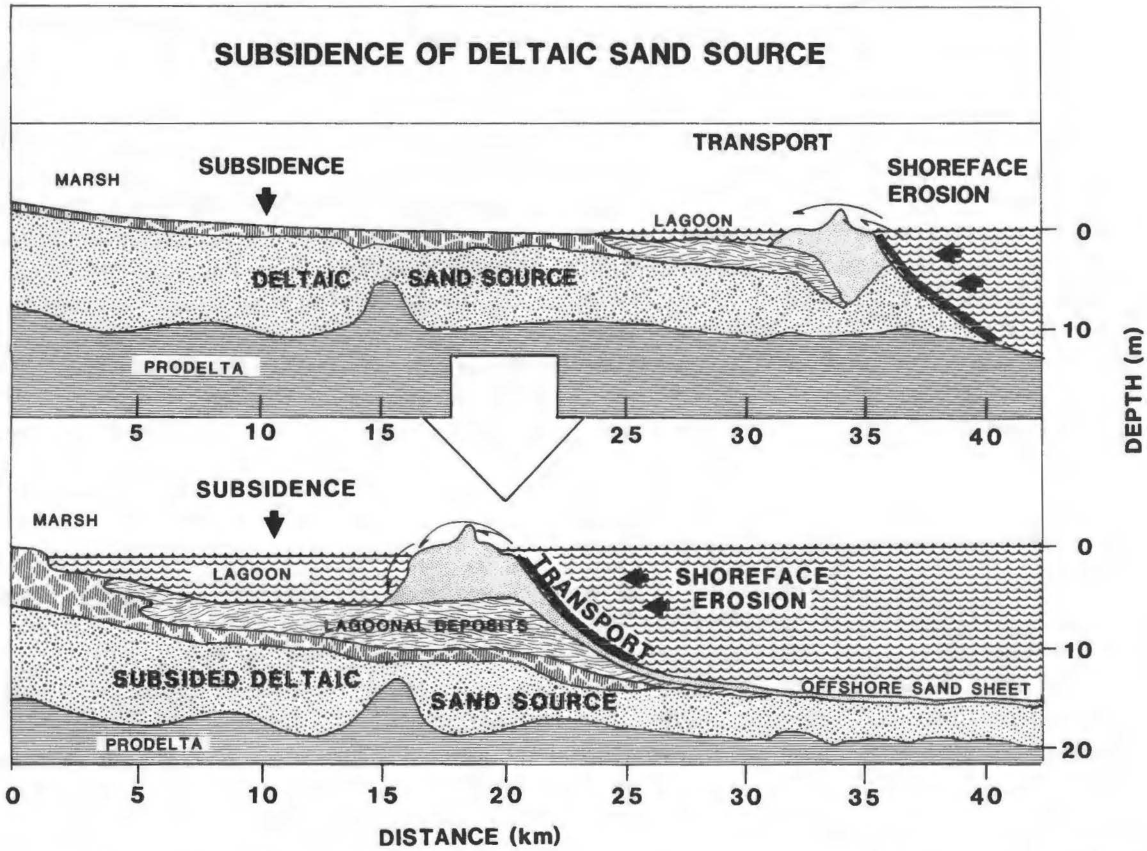


Figure 4. Subsidence of distributary sand sources is the major mechanism driving coastal barrier transgression and deltaic land loss.

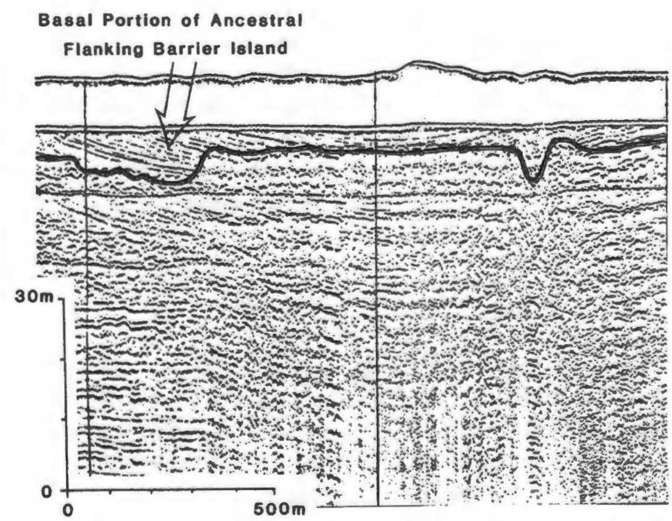


Figure 5. An offshore seismic profile showing the basal portion of a spit complex of an ancestral flanking barrier island of the Chandeleur Islands that has been bypassed by the shoreface and is now preserved on the inner continental shelf. The black line indicates the transgressive contact between the overlying sandy barrier unit and the underlying St. Bernard delta. The seismic line is shore-parallel.

Swanson and Thurlow 1973), the period of sediment supply from distributary sand bodies is effectively limited to between 400 and 1,200 years, depending on the variation in the subsidence rate over time. The rate of subsidence varies proportionally, according to the thickness of the delta; thin deltas subside slowly and thick deltas subside rapidly. Seismic data offshore from the Chandeleur Islands indicate that the St. Bernard delta complex, which was abandoned about 1,800 years BP (Frazier 1967), is no longer receiving an adequate sediment supply from St. Bernard distributary sand bodies through the processes of shoreface retreat and sediment entrainment. The upper surface of the St. Bernard delta, offshore from the Chandeleur Islands, lies two or more meters below the base of the advancing Chandeleur Island shoreface. An offshore seismic profile (Figure 5) reveals the base of an ancestral flanking barrier associated with the earlier stages of coastal barrier evolution of the Chandeleur Islands. The basal portion of the barrier has been bypassed by the shoreface and is now preserved on the inner portion of the Louisiana continental shelf.

Accumulation in Subsiding Washover Deposits

In Louisiana, storm overwash is a major process of sediment transport during barrier transgression (Boyd and Penland 1981; Ritchie and Penland 1982). Sea level is subject to frequent and dramatic elevation changes on the northern gulf coast in response to hurricane and winter frontal storms and the waves associated with them. Overwash elevations exceeding 1.7 m may be expected to occur on the Louisiana barrier coast 10-20 times/yr, causing washover sedimentation throughout more than 75% of most barrier systems (Figure 6). This sediment then is stored until again reworked by the advancing shoreface. During transgression, the site of overwash deposition in the backbarrier lagoons, such as Chandeleur Sound or Terrebonne Bay, is continually subsiding. Therefore, progressively greater quantities of sediment are required during transgression for the barrier system to remain subaerial (Figure 7). For the region of active overwash in the northern Chandeleur Islands, Penland and Boyd (1981) calculated an average shoreline retreat rate of 5 m/yr, or 500 m/100 yr. A landward advance of 500 m in the coalescing washover fans requires 2,500 m^3 of sand per meter of fan front, assuming the average water depth behind the Chandeleur Islands platform is 5 m. Using Kolb and Van Lopik's average subsidence rate of 60 cm/100 yr for the St. Bernard Delta, this washover volume will be required to increase by 300 m^3, or 12% per 100 yr. Washover sediments become permanently lost from the barrier sediment dispersal system after the depth of water into which the washover accumulation is advancing exceeds the nearshore depth of the advancing shoreface.

The Infilling of Migrating Spit and Tidal Inlet Complexes

Wave-induced longshore sediment transport is a significant factor in the development of any shoreline of an abandoned Mississippi River delta. Flanking barrier spits and islands are supplied with sand transported alongshore by waves from erosional headland sources. The configuration of the Bayou Lafourche headland (Caminada-Moreau coast) indicates that sediment is transported alongshore, both to the northeast by waves from the southwesterly quadrant, and to the west by waves from the southeasterly and northeasterly quadrants. This has resulted in the growth of a symmetrical set of flanking barriers, Caminada Spit and Grand Isle to the northeast, and the Timbalier Islands to the west. Similarly, the transgressive barrier island arc configuration of the Isles Dernieres results in bidirectional longshore transport, west toward Raccoon Point and east toward Wine Island Pass. In contrast, the north-south orientation of the Chandeleur Island arc results in an asymmetrical net transport pattern towards the north in response to the

METEOROLOGICAL EVENT	STORM SURGE (m)		OVERWASH ELEVATION (m)	
Minor Front	0.30 - 0.61		1.42 - 1.73	
Major Front	0.61 -0.90		1.73 - 2.02	
	East Delta	West Delta	East Delta	West Delta
Force 1 Hurricane Western Track	0.60 - 1.30	1.50	1.72 - 2.42	2.62
Force 3 Hurricane Western Track	0.70 - 2.40	2.35	2.76 - 4.46	4.41
Force 5 Hurricane Western Track	1.20 - 3.50	3.3	4.20 - 6.50	6.30
Force 1 Hurricane Eastern Track	1.50 - 1.80	0.60 - 0.80	2.62 - 2.92	1.72 - 1.92
Force 3 Hurricane Eastern Track	2.40 - 2.90	0 60 1.00	4.46 - 4.96	2.66 - 3.06
Force 5 Hurricane Eastern Track	3.40 - 4.00	0.90 - 1.30	6.40 - 7.00	3.90 - 4.30

Figure 6. Potential overwash conditions associated with extratropical and tropical cylcones for the Louisiana coast. East delta refers to the St. Bernard delta region, whereas west delta refers to the Lafourche delta region. Hurricane landfall at the Lafourche delta is the western track and the eastern track corresponds to landfall in the St. Bernard delta. Overwash elevations are measured in meters above mean sea level.

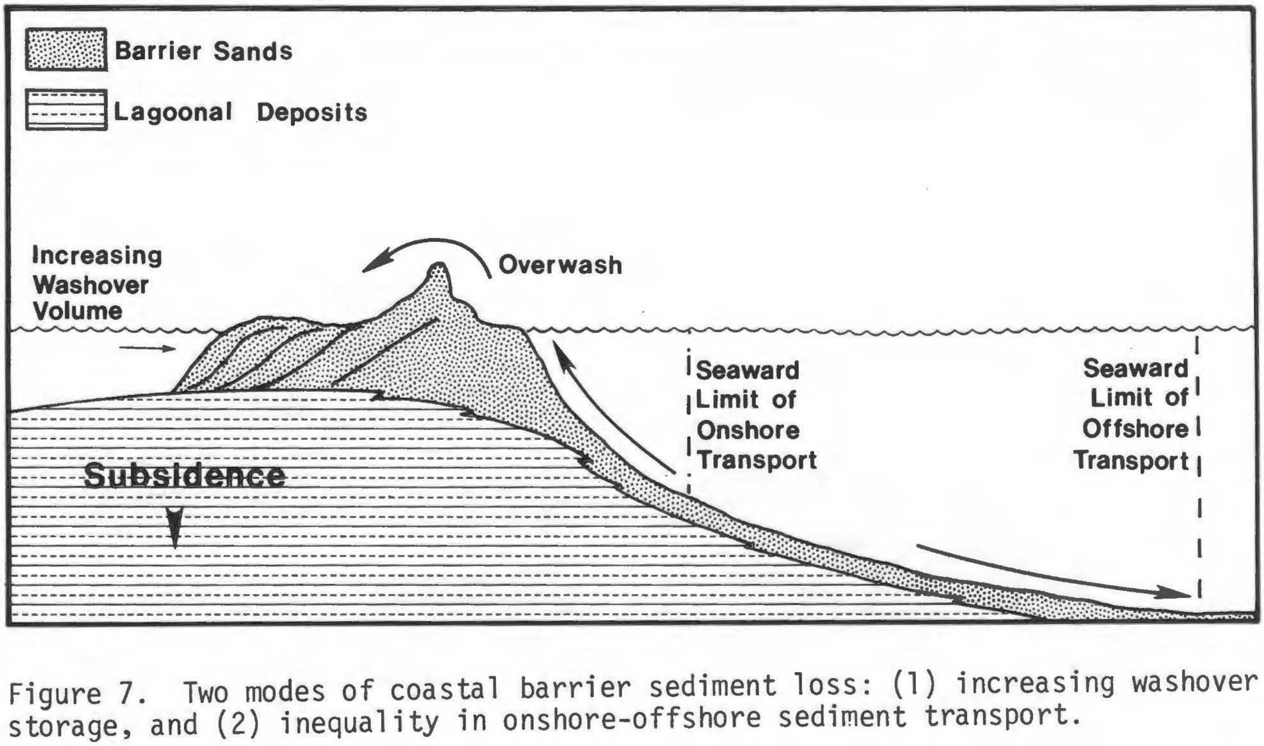


Figure 7. Two modes of coastal barrier sediment loss: (1) increasing washover storage, and (2) inequality in onshore-offshore sediment transport.

predominant wave approach from the southeast and east. Calculations from wave-refraction analysis of longshore sediment transport along the Chandeleur Islands indicate potential representative rates of 4 x 10^5 m^3/yr to the north, under 3 m high, 10-second period, azimuth 135° wave conditions, and 3 x 10^4 m^3/yr, also to the north, under 0.5 m and 5-second period, azimuth 135° wave conditions.

Active longshore transport processes on Louisiana barriers provide two further mechanisms for permanent loss of barrier sediments: (1) spit progradation, and (2) tidal inlet migration. As marginal spits prograde away from the shallow delta platforms by downdrift spit accretion into deeper interdeltaic marginal basins such as Timbalier Bay, increasing volume of sediment is required to maintain the subaerial integrity of the system. In some instances, spits prograde into even deeper tidal inlets, and require considerably larger sediment volumes. Examples of spit progradation into marginal deltaic basins are found on the north end of the Chandeleur Islands, Breton Island, and at Raccoon Point in the Isles Dernieres. Examples of progradation into tidal inlets occur at Barataria Pass, Caminada Pass, Little Pass Timbalier, Cat Island Pass, and Wine Island Pass. A prominent example of sediment loss into spit and tidal inlet complexes is provided by the westward migration of the Timbalier Islands. Between 1887 and 1978,

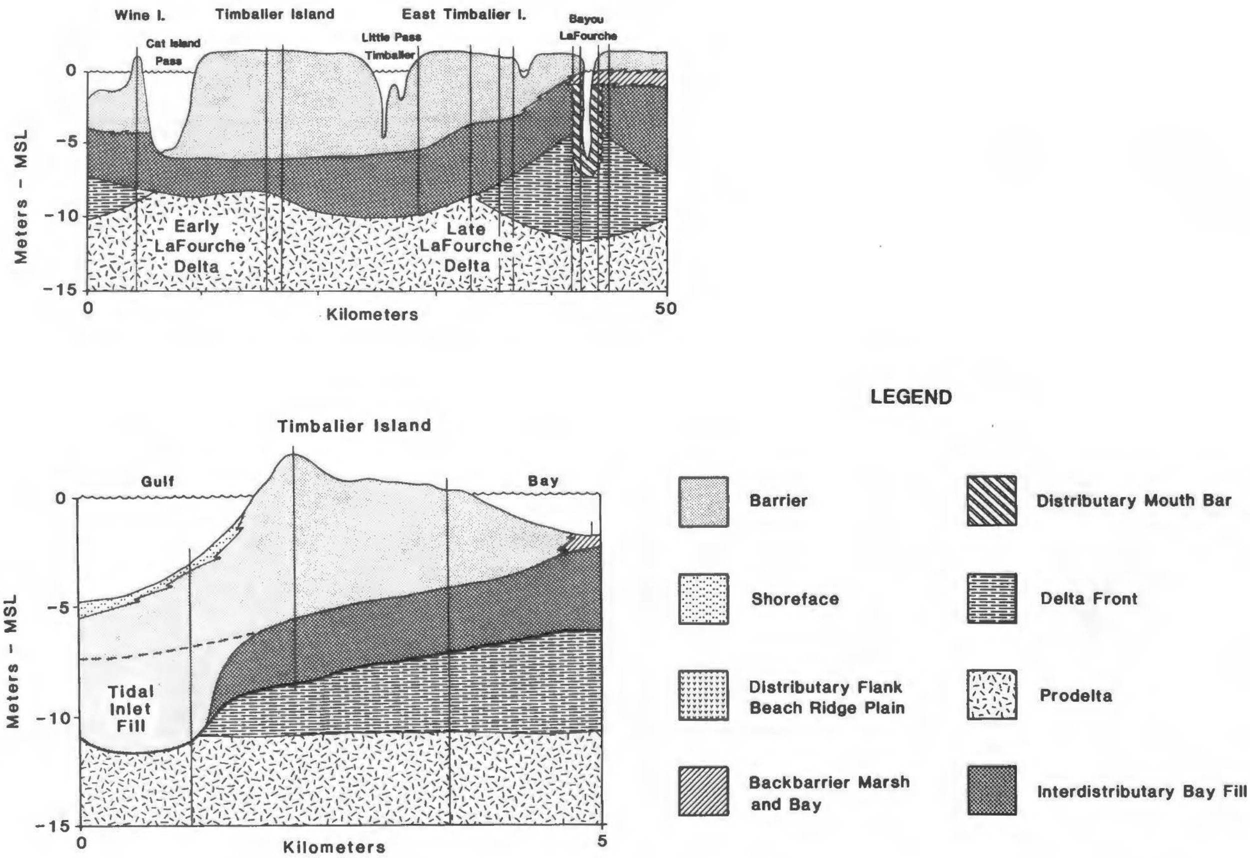


Figure 8. A stratigraphic strike section (top) and stratigraphic dip section (bottom) of the Timbalier Islands showing facies relationships and the infilled channel of Cat Island Pass offshore.

these islands migrated 6.7 km, or 74 m/yr. The average width of these flanking barriers is approximately 900 m. Soil borings indicate an average thickness for the Timbalier Islands of around 5 m (Figure 8). Therefore, the total volume of sediments below the subaerial barrier is about 3.1×10^7 m^3. This figure represents a loss of 3.9×10^5 m^3/yr of sand from the sediment dispersal system to build the Timbalier Islands. This figure only represents the sediment stored in recurved spit deposits. A stratigraphic dip section through the central portion of Timbalier Island and extending 800 m offshore shows an additional sediment sink at the infilled tidal channel of Cat Island Pass (Figure 8). The thalweg of Cat Island Pass lies seaward of the Timbalier Island shoreline and was infilled as this inlet migrated westward. The exact volume of sediment stored in this tidal channel is unknown, but it must be emphasized that tidal inlets in Louisiana are significant sediment sinks. At Quatre Bauyoux Pass, the volume of sediment stored in the ebb-tidal delta has constantly grown, due to the tidal prism increasing in size (Howard 1982). Tidal prism enlargement is caused when land loss in the backbarrier areas increases the bay area, making a progressively greater volume of water available for exchange during each tidal cycle.

Another example of a migrating tidal inlet with significant sediment loss is located 6.4 km southeast from Monkey Bayou, offshore from the southern Chandeleur Islands. Seismic information reveals the presence of relict tidal inlets infilled by southward migrating barrier complexes (Figure 9). Individual tidal channel fills contain as much as 3.5×10^5 m^3 of sand. These relict tidal inlets represent an earlier Holocene position of the Chandeleur Island arc. The seismic sections in Figure 9 shows these sand bodies lying in 8 to 10 m of water at the base of the advancing shoreface.

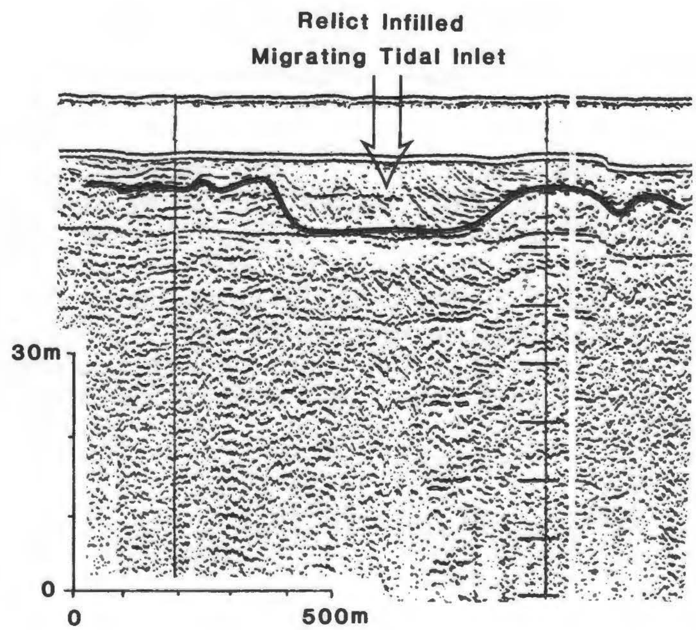


Figure 9. An offshore seismic profile showing relict infilled tidal inlet channel now bypassed by the shoreface and preserved in the inner continental shelf. The black line indicates the transgressive contact between the overlying sandy barrier unit and the underlying St. Bernard delta. The seismic line is shore parallel.

Inequality of Offshore/Onshore Transport

On most beach and barrier systems, a well-established cycle of sediment exchange exists between the beach and shoreface in response to storm and fair weather conditions. In general, sediment is eroded from the beach and nearshore bars under storm conditions and stored in bars located farther offshore or deeper on the lower shoreface. Under fair weather conditions, a variable proportion of this material may move onshore and return to the beach, resulting in accretion. This pattern of change has been well documented for southeastern Australian beaches (Short 1978). The proportion of sediment returned to the beach is dependent, among other factors, on the maximum depth from which waves can transport sediment landward under constructive fair weather conditions, compared to the maximum depth which sediments are transported seaward under erosive storm conditions (Figure 7).

To estimate the effectiveness of sediment return from offshore, the threshold depth for the initiation of sediment motion was calculated for wave conditions of 4-second period, 30 cm high; 5-second period, 50 cm high; 7-second period, 200 cm high; 10-second period, 300 cm; and 15-second period, 400 cm high. The first two of these conditions represent typical constructive conditions on the Louisiana coast. The last three conditions are typical of winter frontal storms and force 1-to-3 hurricanes. For the first two cases, 4-second and 5-second waves, the critical threshold depth offshore from the Chandeleur Islands was 5 m and 6 m, respectively. For the 7-second, 10-second and 15-second waves, critical depths offshore from the Chandeleur Islands were around 40, 60, and 150 m, respectively. Murray (1970, 1972) measured near-bottom currents off the Florida Panhandle in 3.6 m of water during the passage of Hurricane Camille and off the southern Chandeleur Islands in depths of 20 m during winter frontal storm passage. In both cases, the near-bottom current field velocity vectors were directed shore-parallel and offshore during a frontal passage associated with strong, onshore winds and high wave energy.

These data indicate the presence of a strong inequality in offshore-onshore transport related to the storm-dominated characteristics of the wide, shallow Louisiana continental shelf. Sediments transported offshore during these storm events under wave- and wind-induced nearshore circulation encounter offshore- and longshore-directed near-bottom currents. Only that sediment deposited above the 5 to 6 m depths on the shoreface will be available for subsequent return to the barrier system. This mechanism represents another means of permanent sediment loss from the Louisiana barrier system, and may explain the extensive offshore sand sheets seaward from the Chandeleur Islands reported by Frazier (1974).

THE LATE LAFOURCHE COASTAL BARRIER SYSTEM

Barrier Development

The Late Lafourche delta barrier system consists of the Bayou Lafourche erosional headland, the Caminada-Moreau coast, and two nearly symmetrical sets of flanking barriers, Caminada Pass spit and Grand Isle to the east, and the Timbalier Islands to the west (Figure 10). The barriers have developed as the shoreface retreated, actively reworking distributary sand bodies of Bayou Lafourche and the beach ridges of Cheniere Caminada (Harper 1977). The sediment dispersal pattern consists of the longshore

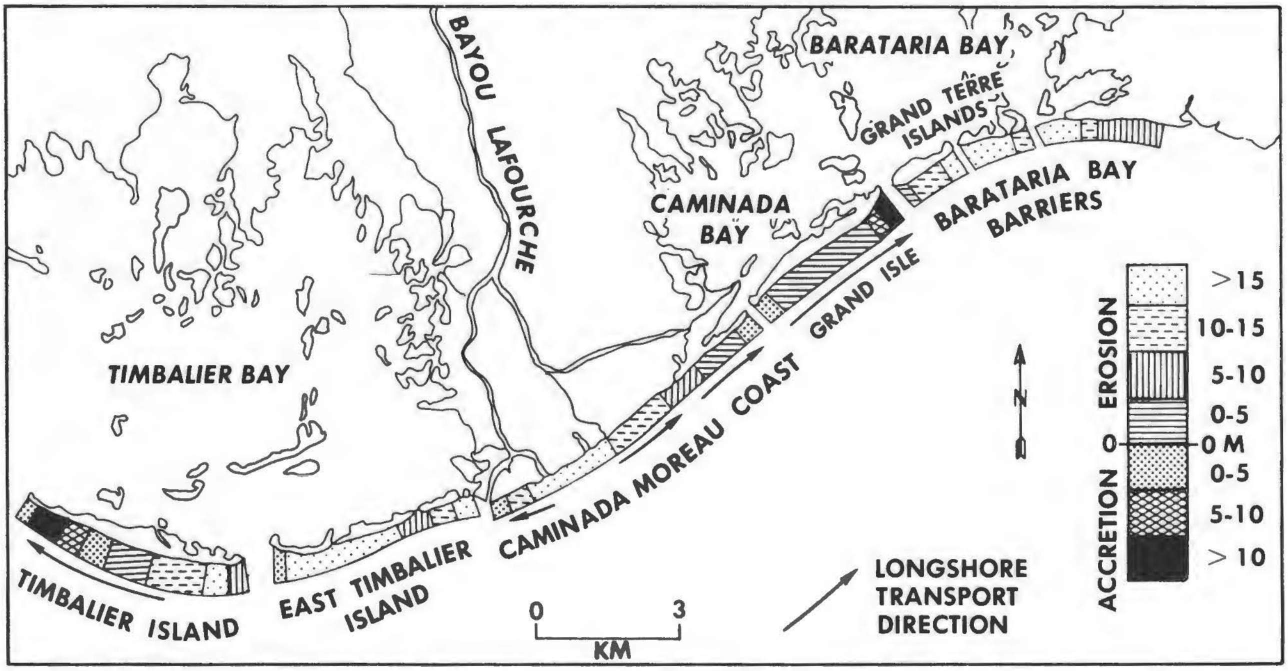


Figure 10. Location diagram showing the configuration of the Late Lafourche coastal barrier system and average rates of shoreline erosion and accretion.

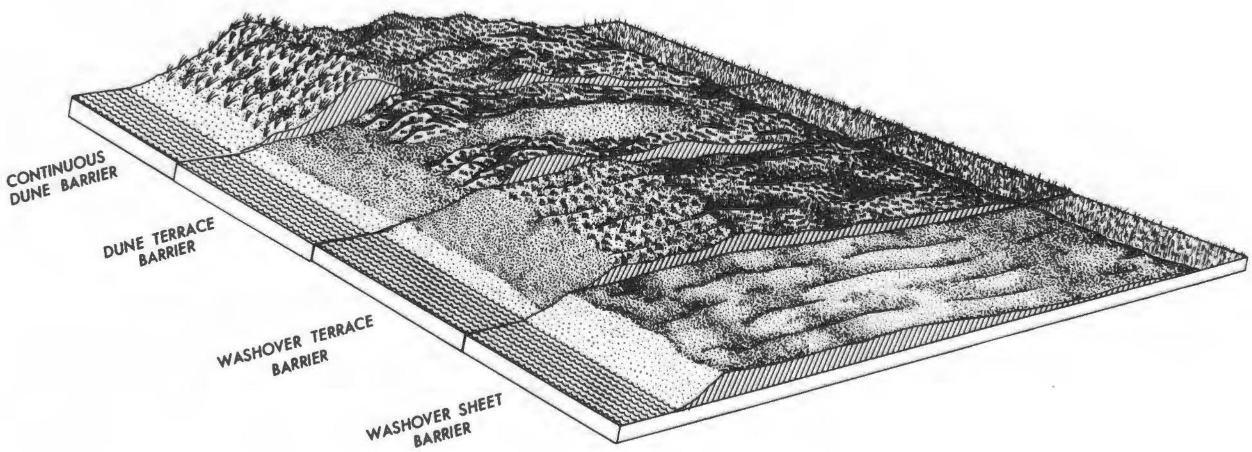


Figure 11. A three-dimensional landform diagram showing barrier types found in the Late Lafourche barrier system. Sediment availability for terrace and dune development decreases left to right, as does shoreline stability.

transport divergence from the central erosional headland and sediment accumulation downdrift of flanking barrier islands and tidal inlets both east and west of the erosional headland. The Caminada-Moreau coast is a low barrier beach, approximately 1 m above msl. This beach is a thin, continuous washover sheet with Holocene marsh outcropping on the lower beach face, reflecting a negative sediment budget and rapid coastal erosion. Increasing downdrift sediment abundance leads to the development of small channels, washover fans, and low, hummocky dune fields which eventually coalesce further downdrift to form a higher, more continuous offshore terrace, and eventually, a foredune ridge (Figure 11). Downdrift flanking barrier islands migrate laterally, in the direction of longshore sediment transport, by erosion at the updrift ends and accretion downdrift. Washover sheets and multiple shallow breaches are common on the updrift or erosional ends of these islands. Downdrift, longshore bars become more prominently developed in the nearshore zone, and toward the eastern end of the system bars become attached. In these downdrift zones, active beach ridge progradation is taking place. Recurved spit morphology formed during the growth of Timbalier Island and Grande Isle indicates the importance of an updrift sand source in the Caminada-Moreau erosional headland (Figure 12).

Shoreline Changes

In the erosional headland/flanking barrier stage, the greatest shoreline erosion problems are within the erosional headland itself and on the updrift ends of the flanking barrier islands (Figure 10). Along the Caminada-Moreau coast, erosion rates are 10 to 20 m/yr. Figure 13 shows the pattern of shoreline change from the Late Lafourche barrier system between 1887 and 1978. Note the rapid shoreline retreat of the Caminada-Moreau coast. Shoreline erosion and coastal spit progradation have smoothed the earlier irregular shoreline of 1887 and closed all of the distributaries except Belle Pass. The severest erosion is in the vicinity of Bays Marchand and Champagne. The Orthogonal Grid Mapping System (OGMS) data from 1934-78 shows that this erosion pattern is continuing. At Bay Champagne, the greatest rate of shoreline retreat measured for the 44-year period was 22.3 m/yr, with erosion decreasing eastward to 9.6 m/yr at Bayou Moreau. Field measurements along the Caminada-Moreau coast made in 1979 by the Louisiana Barrier Island Project show that tropical cyclones accounted for over 70% of the total annual erosion in that year (Figure 14).

In the Belle Pass area, erosion rates average 18.6 m/yr prior to 1954; after 1954, the OGMS data show shoreline erosion slowing, switching to accretion sometime after 1969. The sedimentation pattern changed in response to jetty construction at Belle Pass. Jetties 152 m long and 61 m wide were constructed at Belle Pass in 1934 to improve the navigation channel at Bayou Lafourche. In 1968, the jetties were expanded to 218 m long and 140 m wide, and the Bayou Lafourche navigation channel was dredged to a depth of 6 m, width of 90 m, and extended 2 km offshore (Dantin et al. 1978). These improvements created a formidable barrier to longshore sand transport and sediment bypassing to the west around Belle Pass to the Timbalier Islands. The first jetty system appears to have had little effect on the local sediment-dispersal pattern. The shoreline continued to erode at rates averaging 18 m/yr, with no significant sand accumulation updrift of the jetty system. In fact, the jetty system had to be extended landward several times to keep pace with the retreating shoreline. It was after the 1968 improvements that the sedimentation began taking place along the eastern side of Belle Pass. Accretion rates there have averaged 5.5 m/yr since 1969, representing a sink for material that would otherwise be transported further west to the Timbalier Islands.

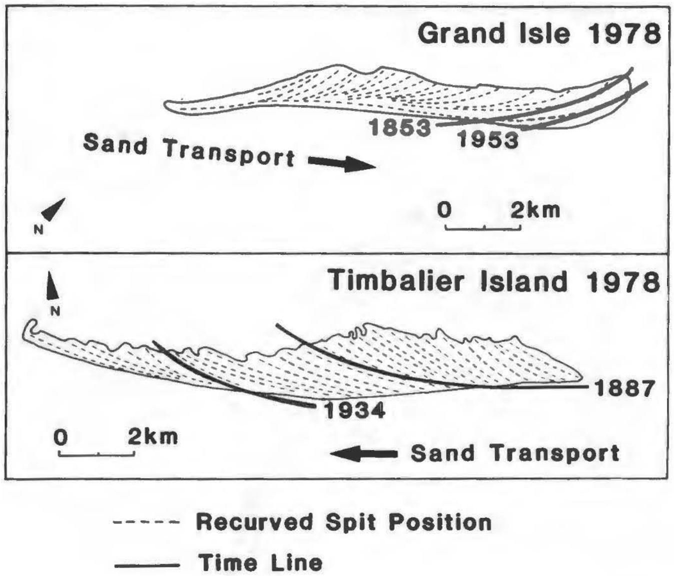


Figure 12. Recurved spit morphology of Timbalier Island and Grand Isle indicate the importance of the updrift sediment source in the Caminada-Moreau coast (see Figure 10).

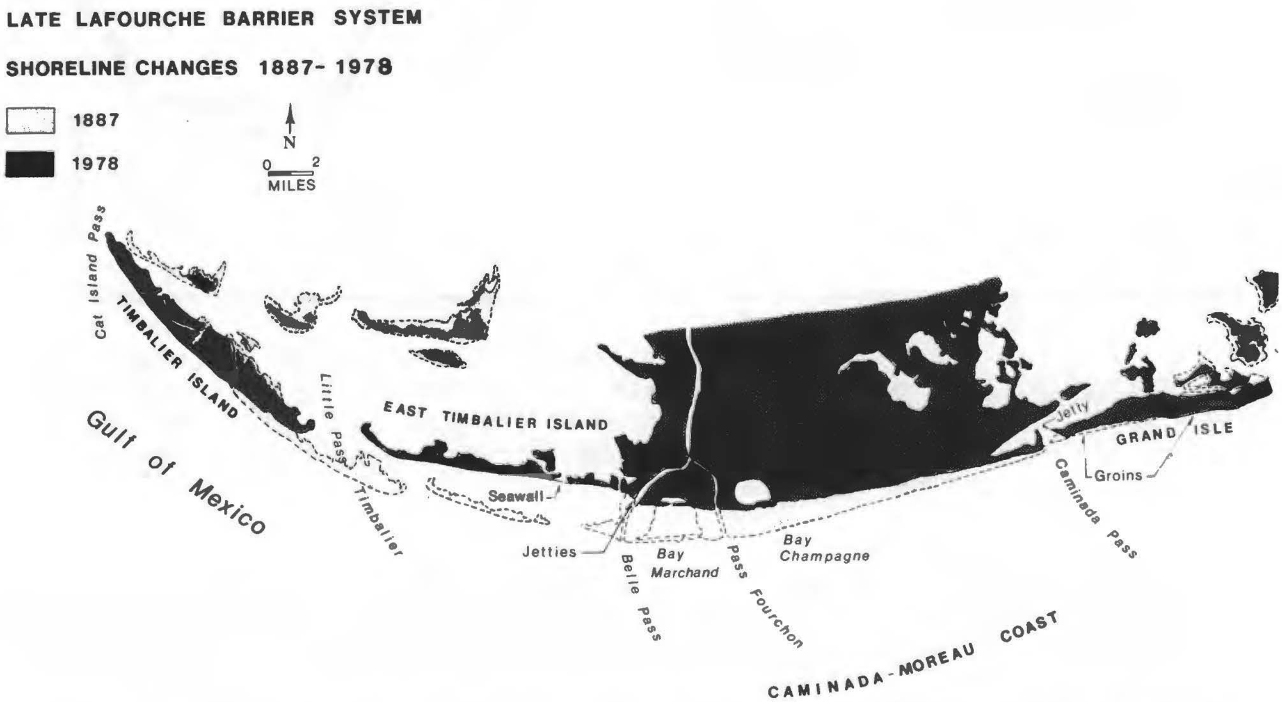


Figure 13. A historical map comparison between 1887 and 1978 showing rapid shoreline retreat along the Caminada-Moreau coast and lateral migration of the flanking barriers of Grand Isle and Timbalier Island.

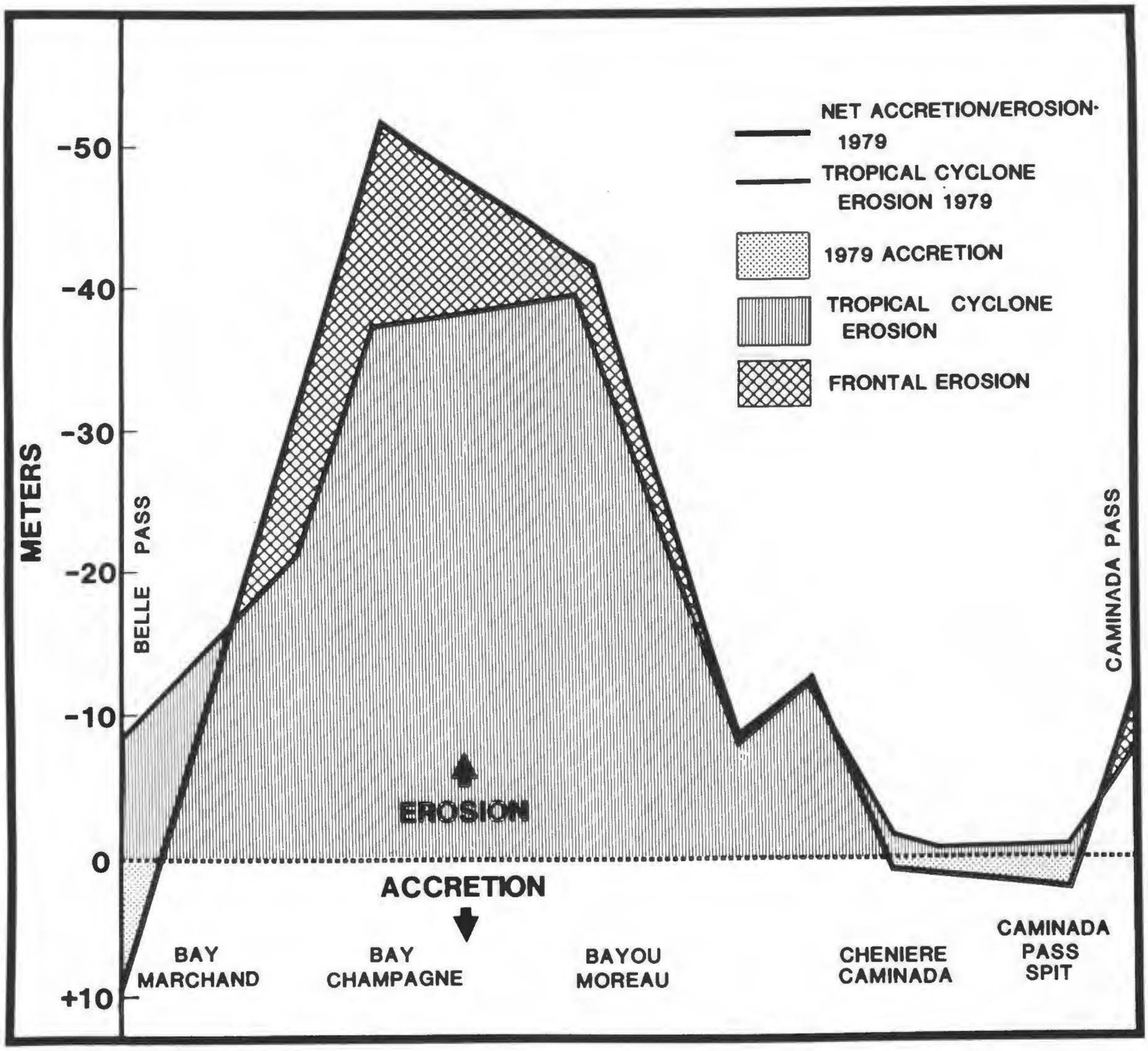


Figure 14. Shoreline erosion-accretion graph illustrating the contributions of extratropical and tropical cyclones to coastal changes along the Caminada-Moreau coast. Tropical cyclones accounted for over 70 percent of the erosion experienced in 1979. Extratropical cyclones (frontal erosion) accounted for approximately 30 percent of the annual erosion.

Timbalier Islands. Timbalier Island and East Timbalier Island are the western flanking barriers of the Bayou Lafourche headland. These barriers are composed of sand that was transported west from the erosional headland source and that bypassed Belle Pass (Figure 8). East Timbalier Island is a marginal recurved spit similar to the Caminada Pass spit, and has repeatedly been detached from the erosional headland while eroding at rates that exceed 15 m/yr. Flanking barrier islands are formed when a marginal spit detaches from the headland. This occurrence is generally associated with tropical cyclone landfall and barrier breaching. The updrift shoreline controls the orientation of the newly detached island. Updrift erosion and downdrift accretion cause rapid lateral migration and determine the stability of the island (Figure 13). Timbalier Island, an example of a detached flanking barrier, eroded on the updrift end at an

average of 18.6 m/yr. Downdrift, the erosion decreases and switches to accretion at the western end, averaging 17.4 m/yr.

Changes in the area of the Timbalier Island group reflect the impact of the navigation structures at Belle Pass. Between 1887 and 1935, 19 tropical cyclones, 7 of which were at least force-2 on the Saffir-Simpson scale (Saffir 1977), made landfall in the vicinity of these islands, resulting in only a slight decrease in total area (Figure 15). Between 1935 and 1956, both island areas increased, reflecting the low frequency of tropical cyclone landfall, with just one force-2 storm occurring. Following 1956, the area of both islands started decreasing rapidly. Hurricane frequency had increased slightly, with five tropical cyclones impacting the coast, two of at least force-2 strength. The reduction in the island area is most likely attributed to the construction of jetties at Belle Pass and the seawall groin system westward along East Timbalier Island, and not to tropical cyclone impact. All of these structures have interrupted sediment transport from the source areas within the Bayou Lafourche headland. A major factor in reduction of longshore sediment transport appears to be the 1968 extension of the Belle Pass jetties, as reflected by the dramatic changes in island areas during this time. Flanking barrier islands connected to an active sediment source are dynamic and tend to build. This appears to be the case prior to 1950 at the Timbalier Islands, when periods of frequent hurricane impact produced little reduction in island area. These flanking barriers, as long as they are receiving sediment input from the erosional headland, exist in a state of dynamic equilibrium even under the conditions of rapid subsidence. The recent land loss observed at the Timbalier Islands is directly linked to the introduction of coastal structures in the sediment dispersal system.

Caminada Pass Spit-Grand Isle. East of the Bayou Lafourche headland lie the downdrift barriers of Caminada Pass spit and Grand Isle. Along the Caminada Pass spit,

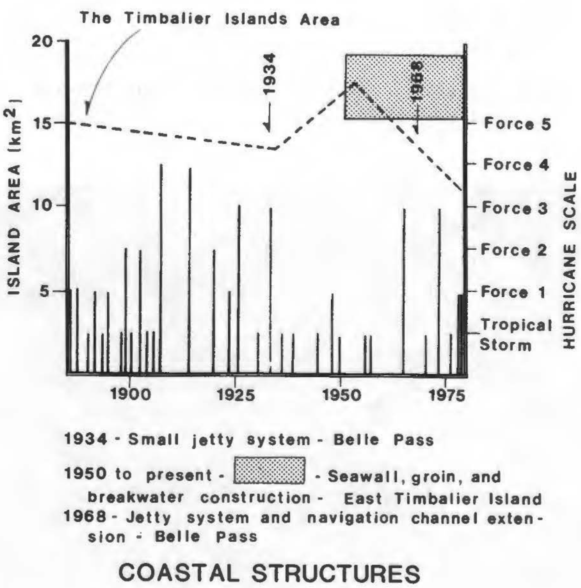


Figure 15. Changes in the area of the Timbalier Islands in relation to the effects of tropical cyclones and coastal structures. Note the rapid decrease in island area following construction of coastal structures updrift.

the rates of shoreline change vary west to east from 5 m of erosion, where the spit attaches to the erosional headland, to near stability with accretional and erosional fluctuations, adjacent to Caminada Pass (Figure 10). This pattern of shoreline change reflects the increasing sediment abundance in the nearshore zone, downdrift toward Grande Isle. The Caminada Pass spit has been breached several times in this century by hurricane landfall; the major breaches were associated with Flossie in 1956 (Figure 16) and Betsy in 1965. These breaches were unstable, infilling rapidly because of the sediment supply from the Bayou Lafourche headland. Farther downdrift at Grand Isle, the characteristic flanking barrier pattern of updrift erosion/downdrift accretion occurs, as observed at Timbalier Island. Prior to 1972, Grand Isle had historically eroded on its western end at Caminada Pass, and had accreted downdrift on its eastern end at Barataria Pass. With construction of the jetty system on the western shore of Caminada Pass, the western-end erosion stopped and minor accretion began, averaging approximately 5 m/yr. Along the central shoreline of Grand Isle, erosion rates of less than 5 m/yr are common. Farther downdrift, toward Barataria Pass, this erosional trend again turns to accretion of 5 to 10 m/yr. Prior to jetty construction at Barataria Pass in 1958, the eastern end of Grand Isle accreted 3 to 6 m/yr, which is considered usual for the downdrift end of a flanking barrier island. After 1958, sedimentation in this region accelerated, producing accretion rates in excess of 10 m/yr. The U.S. Army Corps of Engineers (1972) estimated that this jetty system traps approximately 230,000 m^3 of sand per year.

A time series of the total area of Grand Isle again indicates the importance of the impact of coastal structures compared to the impact of hurricane landfall on flanking barriers and the strategic importance of the location of the shoreline structure within the sediment dispersal system (Figure 17). Following the placement of coastal structures and the initiation of beach nourishment after 1950, Grand Isle increased in area from 7.8 km^2 in 1956 to 8.8 km^2 in 1979. This pattern is analagous to that observed in the Timbalier Islands and indicates a marked sensitivity to coastal structures and the active sediment dispersal system of the erosional headland and its flanking barriers. Placement of the structures updrift of flanking barriers results in severe erosion of marginal spits and reduction in flanking barrier island area. Placement on the downdrift ends of flanking barriers leads to localized accretion.

Figure 16. The ebb surge of Hurricane Flossy breached the Caminada Pass spit in 1956. Note the scour features along the shoreline formed by gulfward flow across the spit undergoing a hydraulic jump.

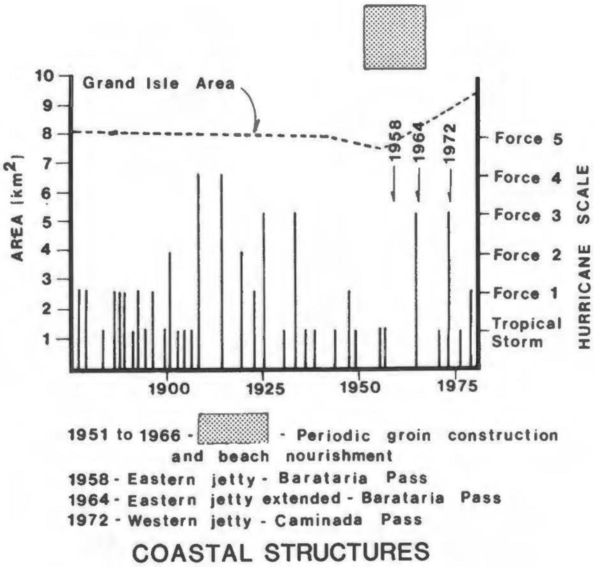


Figure 17. Changes in the area of Grand Isle in relation to the effects of tropical cyclones and coastal structures. Note the rapid increase in island area following construction of coastal structures downdrift.

THE EARLY LAFOURCHE COASTAL BARRIER SYSTEM

Barrier Evolution

The Isles Dernieres is the transgressive coastal barrier system associated with the Early Lafourche Delta (Morgan 1974) abandoned 600 to 800 years ago. This barrier island arc represents an advanced stage in evolution, resulting from extensive submergence and reworking of the Caillou erosional headland (Figure 3). The historical map series of the Isles Dernieres illustrates the transition from an erosional headland stage to a detached barrier island arc stage (Figure 18). In 1853, Pelto and Big Pelto Bay separated this barrier system from the mainland marsh by a narrow tidal channel less than 500 m wide. By 1978, these bays had increased in size threefold and merged into Lake Pelto, and the Isles Dernieres were located 7 km offshore. During this time period, the Isles Dernieres shoreline retreated more than 1 km landward, and the original island of 1953 segmented into four small islets.

The geological strike section running through the Isles Dernieres (west to east) shown in Figure 19 indicates at least two distributaries and a flanking beach-ridge plain were the principal sand sources for barrier island development. In the central portion of the island arc a thin (1 m) washover and aeolian sand unit is seen transgressing across the backbarrier marsh. Downdrift, east and west of the island arc, sand thickness increases at Wine Island and Racoon Point, respectively. In these spit complexes, the barrier sand body reaches a thickness of 5 to 6 m. With subsidence of these sand bodies, the Isles Dernieres are receiving a diminishing sediment supply. This situation is the underlying cause for the landward retreat and segmentation of the Isles Dernieres.

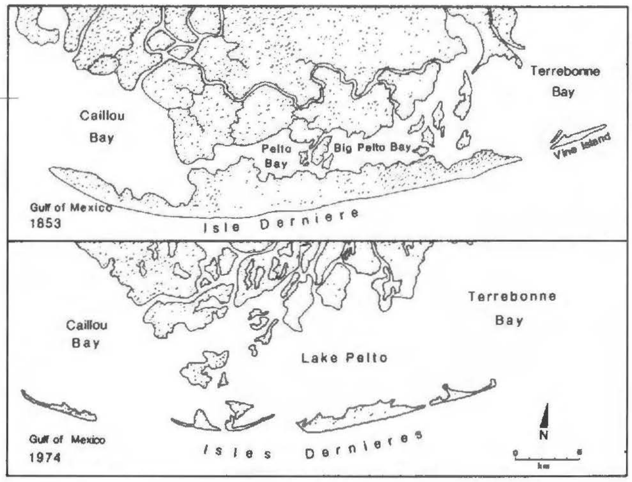


Figure 18. Historical map comparison of the Isles Dernieres showing the transition from a Stage 1 to a Stage 2 barrier system by mainland detachment.

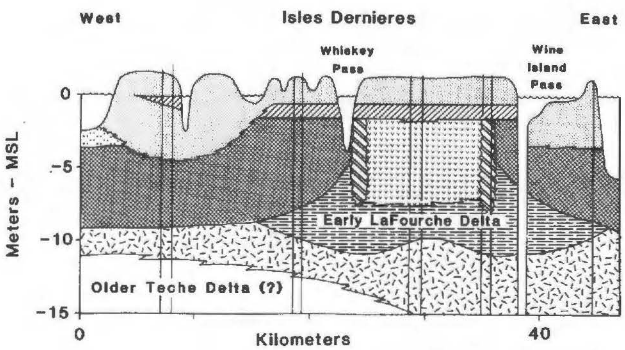


Figure 19. A stratigraphic strike section through the Isles Dernieres showing facies relationships. See Figure 8 for legend.

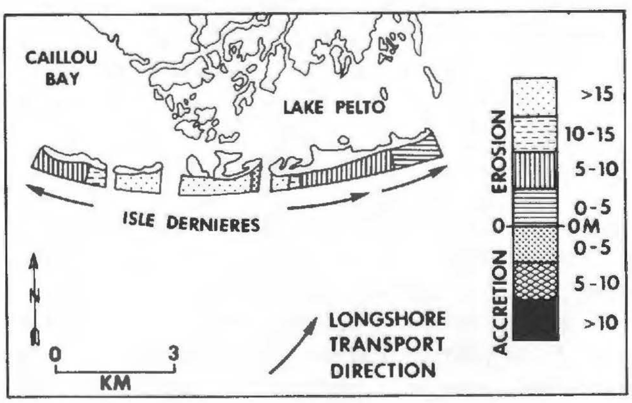


Figure 20. Average annual erosion-accretion rates along the Isles Dernieres.

Patterns of Shoreline Change

Shoreline erosion derived from the OGMS data indicate that the highest erosion rates within the Isles Dernieres occur along the central portion of the island arc (Figure 20). Here erosion rates in excess of 15 m/yr are common. Downdrift, both east and west of the central island arc, erosion rates decrease to approximately 5 m/yr. This erosion pattern reflects the influence of barrier orientation to the dominant wave approach. Throughout their evolution, the Isles Dernieres have faced directly into the dominant southerly wave approach, creating a sediment transport diversion zone in the central island arc. With sediment transported both east and west from this area, a spreading effect results, dispersing sediments over a wider area than a more asymmetrical wave approach, as at the Chandeleur Islands would.

Coastal structures have not been built in the Isles Dernieres barrier system; therefore, its sediment dispersal system is undisturbed. A plot of island area versus hurricane landfall indicates that island area has been decreasing steadily. The area of the Isle Dernieres diminished from 34.8 km^2 in 1887 to 10.2 km^2 in 1979 (Figure 21). Island land loss is very rapid, indicating the possible destruction of the Isles Dernieres within 50 years. High erosion rates must be related to rapid subsidence in the area and the lack of a substantial coarse-grained sediment imput to help maintain these barriers in this sinking coastal environment.

ST. BERNARD BARRIER SYSTEM

Barrier Development

The Chandeleur Island system occupies the eastern margin of the St. Bernard delta, abandoned approximately 1,800 years ago (Frazier 1967). This system represents an advanced stage in the evolution of a transgressive barrier island arc system. The Chandeleur Islands represent a merged system of earlier erosional headlands and flanking barriers associated with major unidentified St. Bernard delta distributaries. Seismic and vibracore data collected by the Louisiana Barrier Island Project indicate that shoreface retreat can no longer penetrate through to the sand bodies associated with the St. Bernard delta and supply coarse sediments to the island arc. These islands are presently transgressing across fine-grained lagoonal facies of Chandeleur Islands (Figure 22). Since

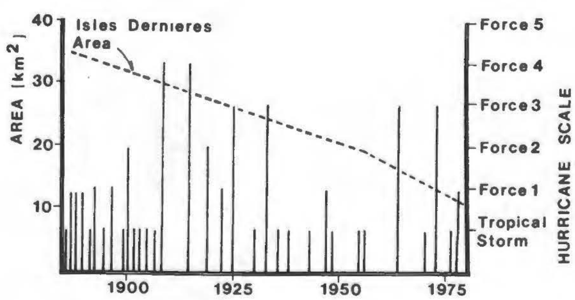


Figure 21. Changes in the area of the Isles Dernieres in relation to the effects of tropical cyclones. Note rapid land loss indicating the potential destruction of the Isles Dernieres within 50 years.

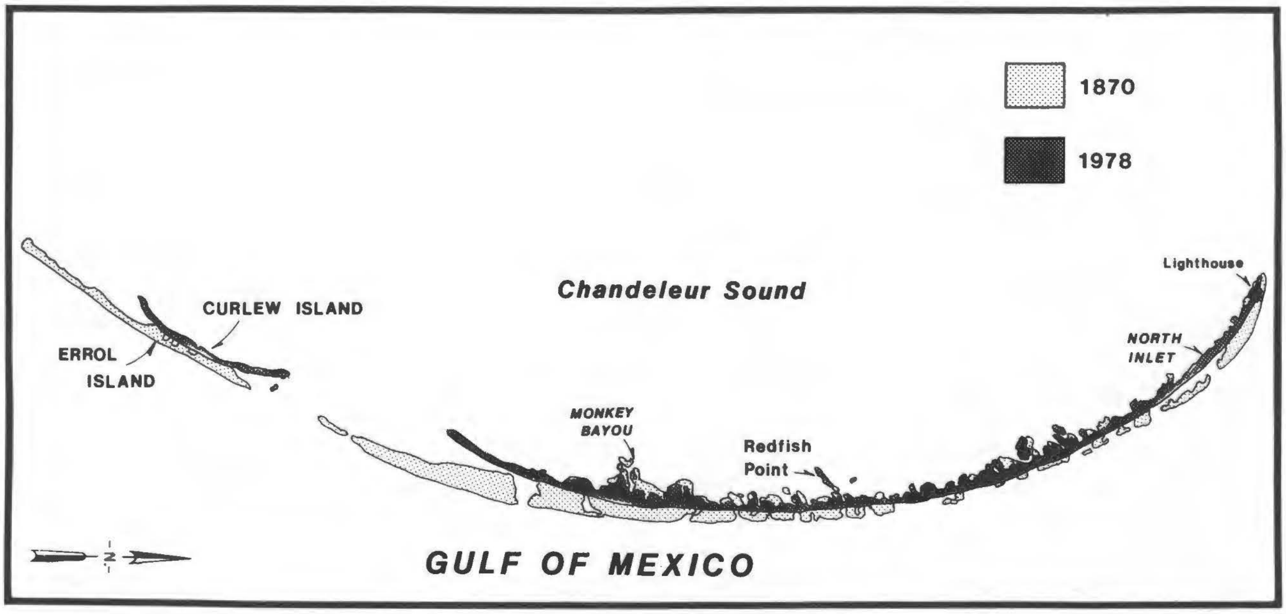


Figure 22. Historical map comparison of the Chandeleur Island arc showing its landward transgression into Chandeleur Sound.

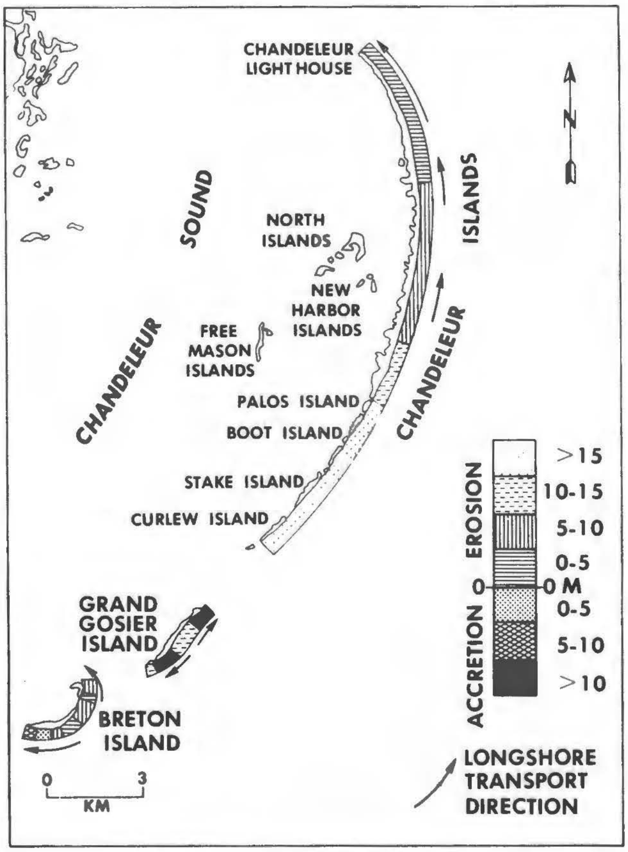


Figure 23. Average annual erosion-accretion along the Chandeleur Islands.

there is no present-day sediment source to the Chandeleur Islands, they are diminishing in size. The sediment dispersal system is recycling barrier sands within the island complex. Storm waves transport sediment seaward into a broad inner-shelf sand sheet and landward into backbarrier washover fans.

Patterns of Shoreline Change

The pattern of shoreline changes in the Chandeleur Islands is different from that in the Isles Dernieres, due to differences in shoreline orientation to the dominant wave approach. The Chandeleur Islands are oriented oblique to the dominant wave approach, whereas the Isles Dernieres face directly into the dominant wave approach. The southern end of the Chandeleur Islands receives the brunt of the wave attack; wave-refraction attenuation along the shallow inner shelf increases towards the north, and is reflected in decreasing shoreline erosion rates (Figure 23). Along the southern part of the Chandeleur Islands, erosion exceeds 15 m/yr and is characterized by periodic hurricane destruction followed by partial island re-emergence and rebuilding. Northward along the islands, erosion rates decrease from 15 m/yr to around 5 m/yr at the northern end. A plot of the area of the Chandeleur Islands versus hurricane landfalls shows the importance of periods of high hurricane frequency to total island area (Figure 24). Between 1869 and 1924, nine tropical cyclones made landfall in the Chandeleur Islands region, of which only two were above force-2 strength, resulting in a slight decrease in island area. Between 1925 and 1950, five tropical cyclones made landfall; however, only one was of hurricane force; and the remainder were tropical storm strength. For this time interval, the Chandeleur Islands only slightly decreased in area. Between 1950 and 1969, rapid decrease in the total island area of the Chandeleur Islands was related to a period of frequent hurricane landfall. Five major storms impacted the island, one of which was hurricane Camille, of force-5 strength and had deep-water wave heights measuring in excess of 20 m. As a result of these high-intensity storms, the total island area of the Chandeleur Islands decreased from 29.7 km^2 in 1950 to 21 km^2 in 1967. Sediment dispersal in this system reflects the hurricane impact on barrier islands with the finite internal sediment supply that is continually being recycled. Hurricane responses are offshore sediment transport and barrier breaching, leading to sediment losses to the offshore and tidal delta sinks. Sediment dispersal patterns are determined by barrier orientation to the prevailing regional wave climate. Barrier rebuilding in the Chandeleur Island reflects the presence of a southerly updrift sediment source supplying progradational episodes farther north.

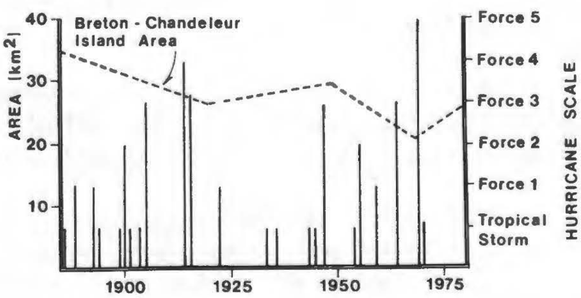


Figure 24. Changes in the area of the Chandeleur Islands in relation to the effects of tropical cyclones.

CONCLUSIONS

1. Louisiana suffers from the most severe coastal barrier erosion and land loss problem in the United States.

2. Patterns of natural shoreline change and erosion problems associated with coastal structures are interpreted using the model for deltaic barrier evolution presented here. With increasing age, coarse-grained sediments of abandoned Mississippi River deltas first form an erosional headland and flanking barriers, Stage 1, then transgressive barrier island arc, Stage 2, and finally a subaqueous inner shelf shoal, Stage 3.

3. Central erosional headlands and updrift ends of flanking barrier islands naturally retreat rapidly, while downdrift, the ends of the flanking barriers accrete. The sediment-dispersal system of an erosional headland and its flanking barriers is easily disrupted by coastal structures. Placement of structures updrift from flanking barriers causes severe erosion of the marginal spits and reduction of barrier island area. Placement on the downdrift end of flanking barrier islands leads to island accretion and downdrift erosion farther downdrift.

4. Shoreline orientation to the dominant southerly wave approach determines patterns of shoreline change in transgressive barrier island arcs. The Chandeleur Islands, oriented to the north/south, have progressively decreasing rates of erosion northward in the direction of predominant sediment transport. The Isles Dernieres are oriented east/west and are characterized by frontal retreat and island segmentation and deterioration.

5. Tropical cyclones and extratropical cyclones are the dominant factors influencing shoreline change in the central erosional headlands and transgressive barrier island arcs. The placement of coastal structures predominantly influences patterns of shoreline change in the flanking barrier systems.

RECOMMENDATIONS

1. Develop a comprehensive barrier island management plan that incorporates annual beach nourishment in strategic locations, along with a vegetative maintenance/research program.

2. Avoid the band-aid approach to coastal zone management. Shoreline protection plans that address site-specific problems typically fail because their scope is too small, not taking into account the natural working of the whole coastal system.

3. Restrict pipeline landfalls and transmission routes to environmentally sound corridors that can be monitored and managed to reduce habitat damage. Backfill and revegetate all existing pipeline right-of-ways in each barrier system to reduce the breaching potential at these weak spots.

4. Avoid using coastal structures such as groin systems and rip-rap seawalls; these protection measures have proved ineffective at critical erosion areas in Louisiana.

5. Where jetty systems and navigation channels are required, develop sediment bypassing and recycling schemes into the design requirement. At Belle Pass and Barataria Pass, a sediment bypassing scheme would alleviate downdrift erosion problems. At the Houma Ship Channel, a sediment recycling scheme of the dredge spoil could provide a source of sediment for nourishing the Isles Dernieres and the Timbalier Islands.

6. Conduct a sand resource inventory of the entire Louisiana continental shelf. Location, quantity, and quality of potential sediment borrows must be known before any beach nourishment projects can be designed. Conducting small site-specific sand resource inventories is not cost effective.

ACKNOWLEDGMENTS

Scientific results presented in this paper were sponsored by the Louisiana Office of Coastal Zone Management through a grant to the Laboratory for Wetland Soil and Sediments in the Center for Wetland Resources at Louisiana State University, Drs. W.H. Patrick, Jr., and I.A. Mendelssohn, Principal Investigators. Logistical support was provided by the Sea Grant Auxilliary. This research was conducted when Shea Penland was with the Laboratory of Wetland Soils and Sediments and Ron Boyd was with the Louisiana Geological Survey. Mary Penland edited the manuscript.

LITERATURE CITED

Boyd, R., and S. Penland. 1981. Washover of deltaic barriers on the Louisiana coast. Trans. Gulf Coast Assoc. Geol. Soc. 31:243-249.

Coleman, J.M., and W.G. Smith. 1964. Late Recent rise of sea level. Geol. Soc. Am. Bull. 75:833-840.

Curry, J.R. 1964. Transgressions and regressions. Pages 175-203 in R.L. Miller, ed. Papers in marine geology. Macmillan, New York.

Dantin, E.J., C.A. Whitehurst, and W.T. Durbin. 1978. Littoral drift and erosion at Belle Pass, Louisiana. Waterway, Port Coastal and Ocean Div., American Society Civil Engineers 104(WW4):375-390.

Dolan, R., B. Hayden, and J. Heywood. 1978. A new photogrammetric method for determining shoreline erosion. Coastal Eng. 2:21-39.

Fisk, H.N. 1944. Geological investigation of the alluvial valley of the Lower Mississippi River. Mississippi River Commission, U.S. Army Corps of Engineers, Vicksburg, Miss. 78 pp.

Frazier, D.E. 1967. Recent deltaic deposits of the Mississippi River. Trans. Gulf Coast Assoc. Geol. Soc. 17:287-315.

Frazier, D.E. 1974. Depositional episodes: their relationship to the Quaternary stratigraphic framework in the northwestern portion of the Gulf basin. Univ. of Texas at Austin, Bureau of Economic Geology Geol. Circ. 74-1. 28 pp.

Harper, J.R. 1977. Sediment dispersal trends of the Caminada-Moreau beach ridge system. Trans. Gulf Coast Assoc. Geol. Soc. 27:283-289.

Howard, P. 1982. Tidal deposits of Quatre Bayou Pass, LA. Pages 92-103 in Deltaic sedimentation on the Louisiana coast, Gulf Coast Section, Society of Economic Petrologists and Mineralogists, Tulsa, Oklahoma.

Kolb, C., and J. Van Lopik. 1958. Geology of the Mississippi River deltaic plain, southeastern Louisiana. U.S. Army Engineers Waterways Experiment Station, Vicksburg, Miss. Tech. Rep. 2. 483 pp.

Morgan, J.P. 1974. Recent geological history of the Timbalier Bay area and adjacent continental shelf. Louisiana State Univ., Museum of Geoscience, Baton Rouge, La. Melanges 9, 17 p.

Murray, S.P. 1970. Bottom currents near the coast during hurricane Camille. J. Geophys. Res. 74:4579-4582.

Murray, S.P. 1972. Observations on wind, tidal and density-driven currents in the vicinity of the Mississippi River Delta. Pages 127-142 in D.J.P. Stanley, D.D.B. Swift, and W.H. Pilkey, eds. Shelf sediment transport - process and pattern. Dowden, Hutchinson and Ross, Stroudsburg, Pa.

Penland, S., and R. Boyd. 1981. Shoreline changes on the Louisiana barrier coast. Pages 209-219 in Oceans. Marine Technology Society and ICCC (Oceanography Section).

Penland, S., and R. Boyd. 1982. Mississippi delta coastal sand barriers: an overview. Pages 71-91 in Deltaic sedimentation on the Louisiana coast. Gulf Coast Section, Society of Economic Petrologists and Mineralogists, Tulsa, Oklahoma.

Penland, S., R. Boyd, D. Nummedal, and H.H. Roberts. 1981. Deltaic barrier development on the Louisiana coast. Trans. Gulf Coast Assoc. Geol. Soc. 31:342-346.

Ritchie, W., and S. Penland. 1982. The interrelationship between overwash and aeolian processes along the barrier coastline of south Louisiana. Pages 358-362 in First International Conference on Meterology and Air/Sea Interaction of the Coastal Zone, The Hague, Netherlands, American Meterological Society.

Saffir, H.S. 1977. Design and construction requirements for hurricane resistant construction. American Society Civil Engineers., N. Y. No. 2830, 20 pp.

Short, A.D. 1978. Wave power and beach stages: a global model. Pages 1145-1162 in Proceedings 16th Coastal Engineering Conference, American Society Civil Engineers.

Swanson, R.L., and E.I. Thurlow. 1973. Recent subsidence rates along the Texas and Louisiana coast as determined from tide meausrements. J. Geophys. Res. 78:2665-2671.

U.S. Army Corps of Engineers. 1972. Grande Isle and vicinity, Louisiana: beach erosion and hurricane protection. New Orleans District.

MUDFLAT AND MARSH PROGRADATION ALONG LOUISIANA'S CHENIER PLAIN: A NATURAL REVERSAL IN COASTAL EROSION

John T. Wells
G. Paul Kemp

Coastal Studies Institute
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

The chenier plain coast of southwestern Louisiana has been receiving sediment intermittently from the Mississippi River for the last 5,000 years. A new influx of fine-grained sediment, the first such sediment pulse in perhaps 500 to 1000 years, is leading to localized coastal progradation along what has historically been one of the most rapidly retreating shorelines in the United States. Carried as suspended sediment by the "Atchafalaya mud stream," silts and clays from the Atchafalaya River are now accumulating as mudflats along a segment of coast from Freshwater Bayou Canal to Rollover Bayou. These transitory mudflats provide a buffer to incoming storm waves and serve as a temporary storehouse for littoral sediments.

Process-oriented field studies initiated in 1980, together with satellite imagery, color infrared photography, and aerial overflights since 1974, are providing insight as to present and future trends in sedimentation. Growth of the chenier plain appears initially to be by a series of transitory mudflats, a few of which become welded to the shoreline. Since 1969 the pattern of mudflat sedimentation has been increasing and shifting to the west, consistent with the direction of coastal and wave-induced currents. Accelerated growth of the chenier plain is expected when the subaerial Atchafalaya Delta outgrows Atchafalaya Bay, thus allowing an even greater volume of sediments to enter the dynamic shelf region seaward of the bay and to become entrained in the mud stream. The time scale for widespread reversal in present coastal erosion is 50 to 100 years.

INTRODUCTION

Modern man has acquired a very unstable inheritance in the coastal plain of south Louisiana, a landscape that expands and contracts in area at rates almost unequaled anywhere else in the world. The potentials for land building via rapid sediment deposition and for land loss through compaction and wind/wave erosion are both large. The degree to which these land building/land loss potentials are individually realized at any one time, as well as the degree to which they offset each other, determine the coastline's position on a cyclic curve of alternating progradation and retreat (Kolb and Van Lopik 1958). The works of Morgan and Larimore (1957), Gagliano and van Beek (1970), and Adams et al. (1978) as well as many papers in this volume, establish that the shoreline of Louisiana, taken as a whole, is currently retreating. These authors also point out, however, that this retreat shows a high degree of spatial variability. For

example, in the case of the modern Mississippi delta front, retreat is virtually nonexistent and in the case of the Atchafalaya Delta complex, it is significantly reversed. We can then draw a picture of a modern shoreline that is undergoing erosion and transgression, but that is dynamically stable at the Mississippi River delta front and is locally progradational near the Atchafalaya River mouth.

The 200-km section of shoreline extending west from Marsh Island to the Texas border is distinct in plan view from the rest of the Louisiana coast (Figure 1). The complex indentations and barrier/lagoon systems that characterize the shorelines flanking the modern Mississippi River course are not found west of Vermilion Bay. The smooth and relatively straight form of the western half of the coast reflects a depositional history different from that of the rest of Louisiana's coastal plain. Early workers hypothesized that this section evolved during the Holocene as a marginal deltaic sequence of prograding mudflats that were intermittently partially reworked into sand/shell ridges called "cheniers" (Russell and Howe 1935; Price 1955). More recently, Gould and McFarlan (1959) reconstructed the development of the "chenier plain" and adjacent shelf from cores using radiocarbon dating techniques. Their interpretation indicates that, as sea level rose from -5 m to its present level, a transgressive sequence of marine sediments was deposited over the dissected Pleistocene Prairie Formation, first filling estuaries, then later spreading across shallow bay and marsh environments.

During the final asymptotic stage of post-glacial rise in sea level some 5,000 years ago, the chenier plain began to prograde rapidly, and eventually a wedge of recent sediments 6 to 8 m thick was deposited to a width of 24 km, thus placing the shoreline roughly where we see it today (Figure 1). Pulses of sediment from the Mississippi River, transported by coast-parallel currents, were responsible for the various stages of progradation. At times when the Mississippi River introduced sediment in the vicinity of the present chenier plain, the shoreline shifted seaward; during periods when its course took the discharge farther east, sediment influx to the chenier plain was low and wave attack was able to slow or halt the advance (Gould and McFarlan 1959). Cheniers formed during these latter periods and now stand as "islands" in the marsh.

A new pulse of sediment, the first in some 500 to 1000 years, began adding soft muds to the eastern margin of the chenier plain in the late 1940's, coincident with the subaqueous development of a new delta in Atchafalaya Bay (Morgan et al. 1953). Although the delivery of sediments from the Mississippi River down the Atchafalaya River had been in progress since the mid-1500's (Fisk 1952), it was not until the mid-1900's that sedimentation in the bay and areas offshore became noticeable. This large-scale introduction of silts and clays to the coast began when the inland Atchafalaya Basin to the north became essentially sediment filled and sediment began bypassing these basin-lakes for areas to the south. In the early 1950's Morgan et al. (1953) documented the occurrence of mud deposition along approximately 50 km of coast from Marsh Island to Rollover Bayou which, in places, formed broad mudflats up to 2 m thick.

Nearly 30 years have passed since Morgan et al. (1953) first described these coastal mudflats and tied their origin to the Atchafalaya River, to the east. Whereas our understanding of the basic processes for delivering sediments to the eastern margin of the chenier plain (Figure 1) has remained the same, our ability to monitor these processes has improved significantly. Ready access to satellite imagery, color infrared photography, and digital current-meter data now allow us to monitor remotely shoreline changes and the processes that govern their behavior. In the following paragraphs we report our initial findings with respect to these questions: (1) What is the present status

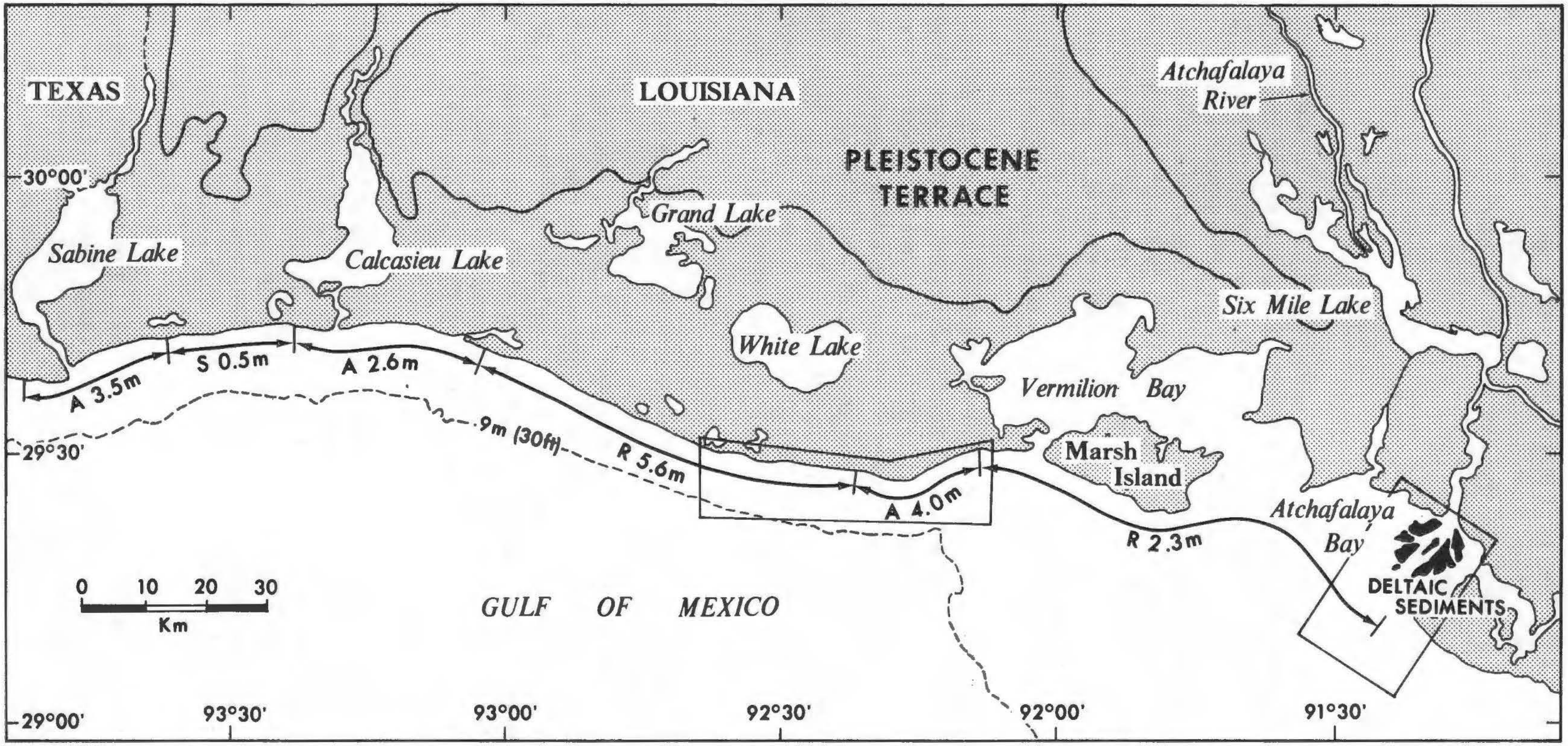


Figure 1. Coast of central and western Louisiana showing average annual rates of shoreline change from 1812 to 1954 (from Morgan and Larimore 1957). A = accretion, S = stable, R = retreat. Enclosed region of Atchafalaya Bay shows source of fine-grained sediments; enclosed segment of chenier plain is present-day downdrift recipient of these sediments.

of the chenier plain relative to the cycle of land building and land loss? (2) What connection exists between the developing Atchafalaya River delta and chenier plain sedimentaion? and, (3) What is the future for the land building in Louisiana's western coastal parishes?

PRESENT STATUS

Development of the chenier plain according to the broad brush model presented above might be expected to produce a modern shoreline either uniform in character or at least gradational from east to west. In fact, the coastline from Marsh Island to the Texas border shows as much variability as any in Louisiana. Kaczorowski and Gernant (1980) have recognized three distinct types of modern shorelines to which we add a fourth. The Type I shoreline is one of perched beaches with exhumed marsh cropping out in the surf zone (Figure 2A). Beaches consist of shell hash and sand in variable proportions, typically fronted by a storm berm less than 0.75 m in elevation and backed by washover deposits extending not more than 100 m into a brackish marsh back-barrier environment. This type of shoreline fronts more than one-half of the chenier plain coast.

The Type II shoreline is one of unvegetated mudflats and can be divided into two subcategories on the basis of sand content and origin. The first contains less than 5% sand and shell and is composed of a fluid mud derived from an offshore source (Figure 2B). These mudflats are not permanent features and today appear to be localized in a 20-km stretch of coast extending from the mouth of Freshwater Bayou Canal west to Rollover Bayou. The second type of "mudflat" may contain greater than 30% sand and shell and is found updrift (east) of the jetties at Calcasieu and Sabine passes. These essentially artificial accumulations reflect an interception of locally derived and reworked sediments.

The Type III shoreline is a sand/shell beach which differs from the Type I in that it represents a reactivated relict deposit (Figure 2C). Such deposits are found at intervals along the modern coast wherever the present surf zone truncates or parallels a chenier ridge. These beaches are most common in the western part of the chenier plain where the spacing between ridges is closer. Coarse material eroded from deposits up to 3,000 years old is entrained in the modern longshore drift system and nourishes Type I beaches to the west. Type III beaches exhibit a large range in morphology, show up to 4 m of relief, and may contain relict dune fields such as that at Chenier au Tigre on the eastern margin of the Chenier Plain.

The Type IV shoreline is one in which no continous beach exists. Brackish marsh headlands extend into the gulf at intervals of 20 to 50 m and shelter crescentic pocket beaches which contain minor accumulations of shell hash and organic debris (Figure 2D). With the exception of the Type II mudflats, all of these shorelines are erosional and have historically retreated between 3 and 10 m/yr (Adams et al. 1978). Relatively stable sections are located at Chenier au Tigre in the east and between Calcasieu and Sabine passes in the west.

Areas of Type II mudflat accumulation along the coast of the eastern chenier plain were determined from color infrared photographs taken in October 1974 and October 1978 (NASA Missions 74-293 and 78-148, respectively), from 1974 orthophotoquads, and from aerial and ground reconnaissance in 1974, 1979, and 1981. Results of these photo and ground comparisons, together with assessments by Adams et al. (1978) for 1954-69 are shown in Figure 3.

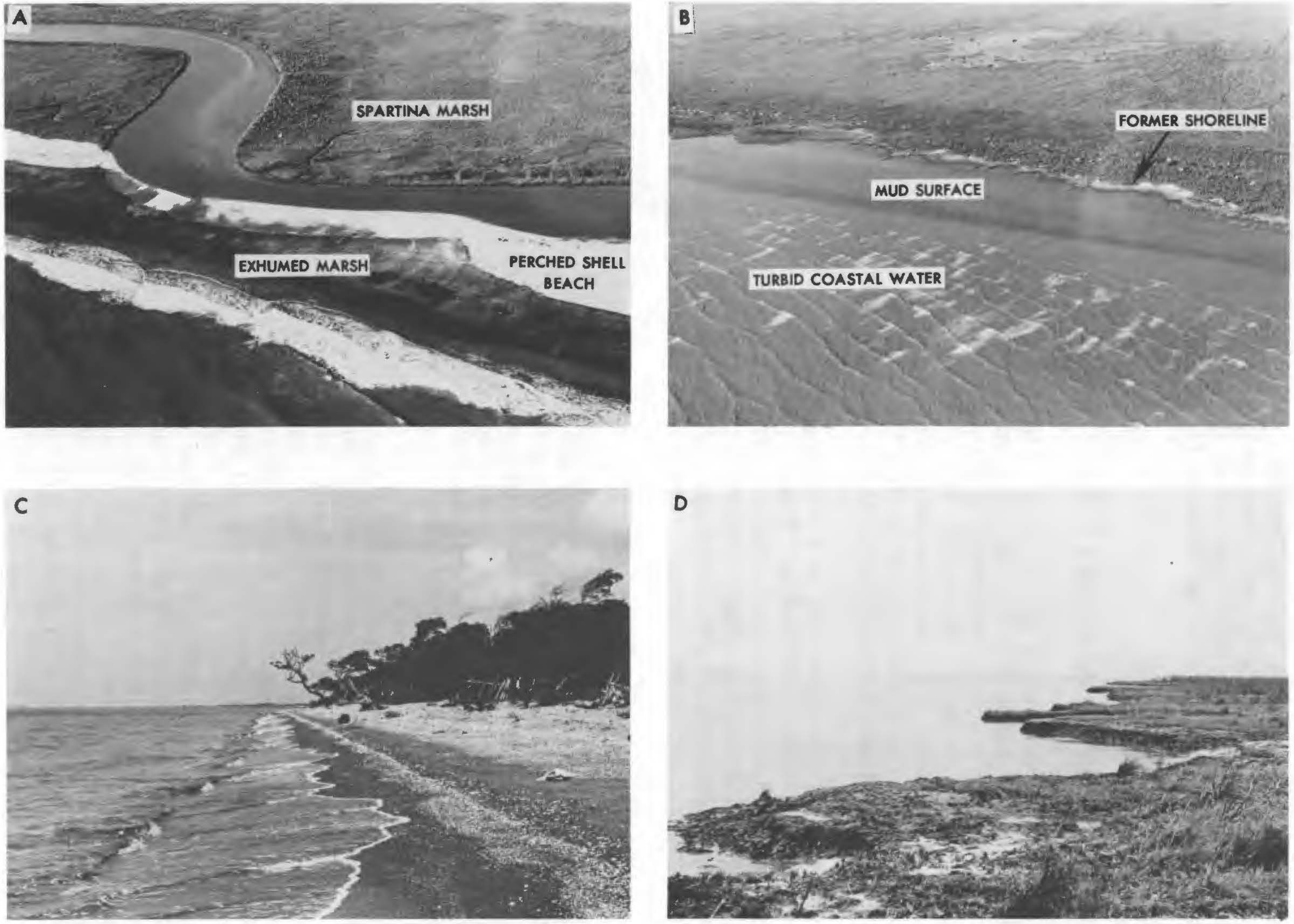


Figure 2. Type I shoreline with perched beach fronted by exhumed marsh, west of Rollover Bayou (A); Type II shoreline showing intertidal mudflat fronting active marsh, east of Rollover Bayou (B); Type III shoreline with reactivated chenier beach face, Chenier au Tigre (C); and Type IV shoreline showing marsh headlands.

Three patterns have been recognized during the 12-year period from 1969-81: (1) simultaneous erosion and accretion at the shoreline, (2) increasing length of shoreline fronted by mudflats, and (3) shift in the locus of sedimentation to the west. No attempt has been made to plot previous shorelines, and our contention is simply that the presence of mudflats indicates an instantaneously prograding shoreline. The segments of coast between mudflats are typically those that are eroding most rapidly. The processes of erosion and accretion are cyclical in both time and space, as becomes evident from close examination of Figure 3.

ATCHAFALAYA/CHENIER PLAIN CONNECTION

Turbid water that enters the Gulf of Mexico from the Atchafalaya River and flows along shore as a muddy plume is herein described as the Atchafalaya mud stream. This sediment-laden water is visible from aircraft and shows up well in LANDSAT imagery as partially saturated returns in band 5. Mud stream dimensions vary and are controlled by river discharge, tide stage, wind speed and direction, and residual currents. The plume persists, however, throughout the year and trails off to the west in approximately 75% of the images (unpublished data compiled by R. H. W. Cunningham, USACOE, New Orleans).

The well-defined seaward extent of the sediment plume on 9 February 1979 during rising river stage is evident in Figure 4. This image is typical of many in that turbid water is found not only in Atchafalaya Bay and offshore, but also in bays to the west. The inset to Figure 4 shows suspended sediment concentrations taken on the day of the satellite overpass along a transect that runs down the navigation channel and ends at the seaward edge of the sediment plume. Suspensate concentrations, determined by millipore filtration, are reported for surface waters only, and thus represent a conservative estimate of sediment throughout the water column.

Within Atchafalaya Bay concentrations range from 250 to 400 mg/l (0 to 20 km, Figure 4, inset), but increase to more than 800 mg/l seaward of the shell reef barrier (25 to 35 km). The sudden increase in concentration is perhaps a result of wave resuspension of soft sediments that are deposited rapidly as prodelta clays seaward of the bay mouth. Beyond this extremely turbid zone, concentrations decrease across the shelf to the plume edge (50 to 63 km). Outside the sediment plume, concentrations are 1 mg/l or less.

Composition of sediment in the mud stream is the same as that in the lower Atchafalaya River, primarily silt- and clay-sized particles with median diameters of 2 to 6 microns. Clay mineralogy is montmorillonite, illite, and kaolinite in the ratio 3:1:1. Data reported by Roberts et al. (1980) indicate that 63% of the sediment that enters Atchafalaya Bay is silt and clay sized. Using a mass-to-volume conversion of 425 kg/m^3, Wells and Roberts (1981) determined that this silt and clay load is 146 X 10^6 m^3 per year.

Evidence that sediments which enter the Gulf of Mexico from Atchafalaya Bay are transported to the west, as indicated by satellite imagery, is also provided by current meter moorings. Beginning in the spring of 1980, current meter data were taken at numerous stations in and seaward of Atchafalaya Bay. Typical records of speed and direction at three of these stations are shown in Figure 5. Data are from mid-depth current meter moorings made with Endeco 174 ducted-impeller, magnetic recording

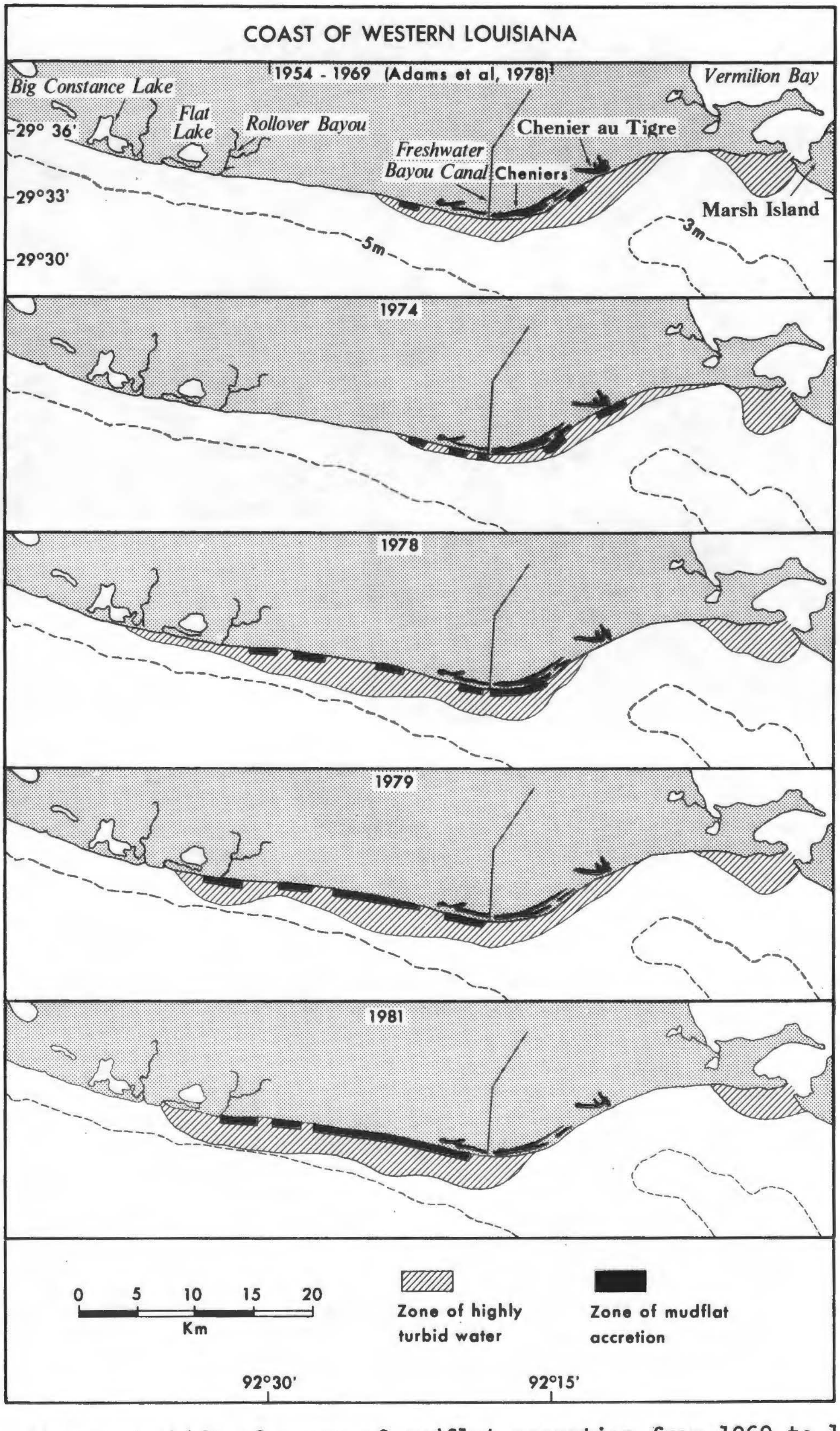


Figure 3. Westward shift of areas of mudflat accretion from 1969 to 1981.

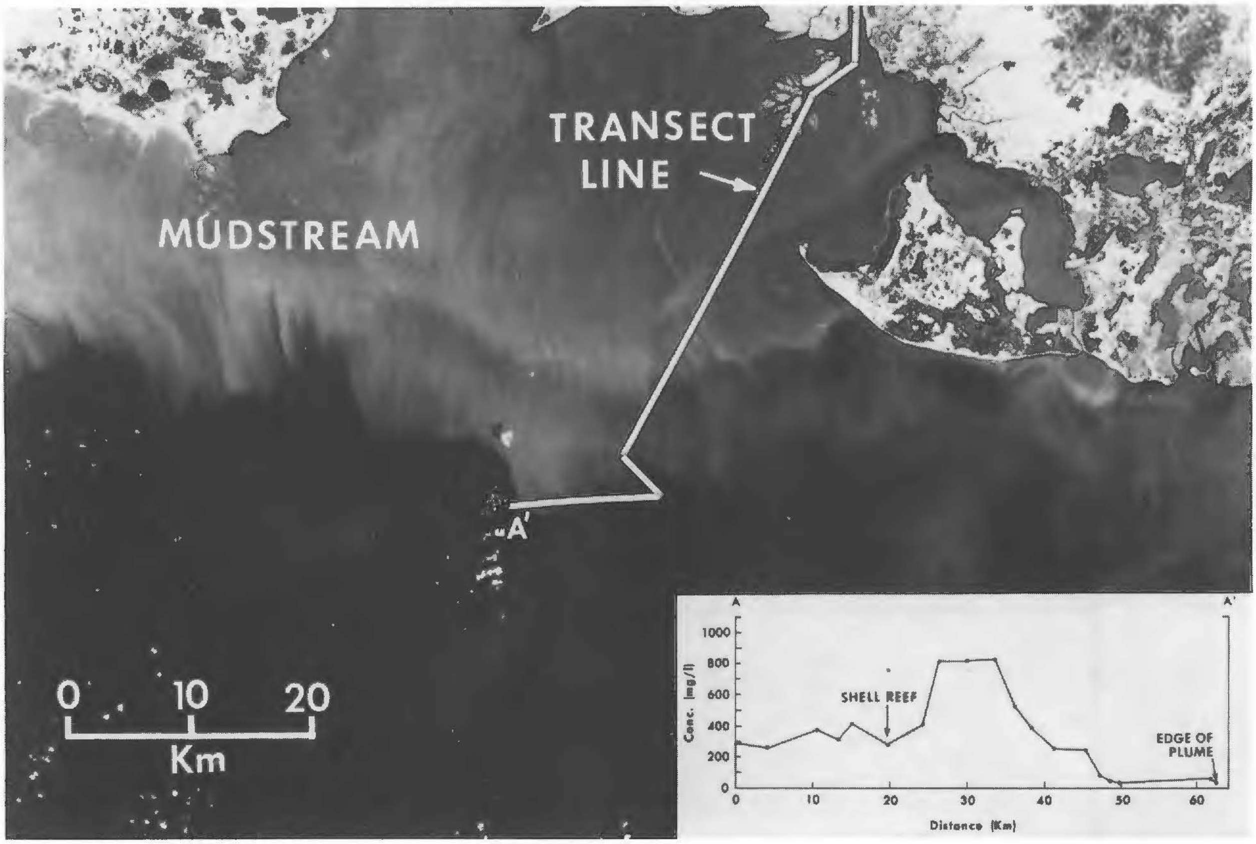


Figure 4. LANDSAT band 5 image of central Louisiana coast taken on 9 February 1979. Light tones indicate high turbidity. Inset shows suspended-sediment concentrations along transect line A-A' from lower Atchafalaya River outlet to seaward edge of sediment plume (data courtesy R. H. W. Cunningham, USACOE, New Orleans).

current meters at the locations given in Figure 6. Thirty-five days of data were obtained at station 1, five days at station 2, and over a year of continous readings have been obtained at station 3.

Current speeds on the inner shelf at station 1 are typically 10 to 30 cm/sec; direction of flow, although setting to the northwest, is influenced strongly in this February data set by the passage of cold fronts every 5 to 7 days, which sequentially produce winds first from the southwest, then from the northwest. Current speeds at station 2, just outside the bay, are 10 to 50 cm/sec and occur as well-defined pulses related to stage of the tide. Direction, however does not fully reverse as a result of tidal effects, but instead is dominated by river flow to the south from Atchafalaya Bay and flow to the west from the westerly drift component of coastal waters. In Atchafalaya Bay current speeds are substantially higher, reaching values of 40 to 80 cm/sec. Rise and fall in current speed is coincident with tidal period in the bay. Direction of flow is oriented down the navigation channel and does not change with stage of the tide.

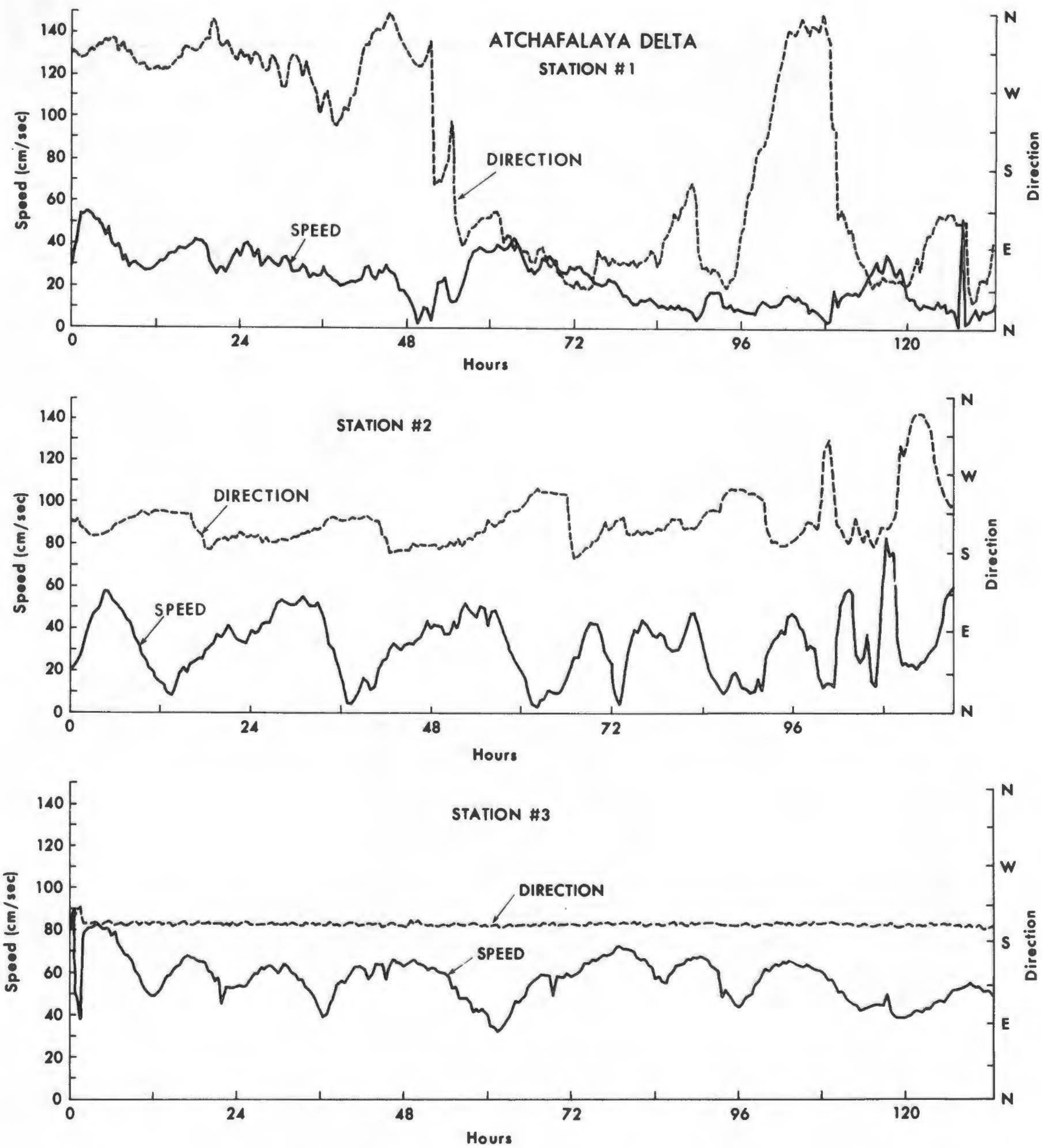


Figure 5. Time series of current speed and direction taken in and seaward of Atchafalaya Bay in Spring 1980. Station locations given in Figure 6.

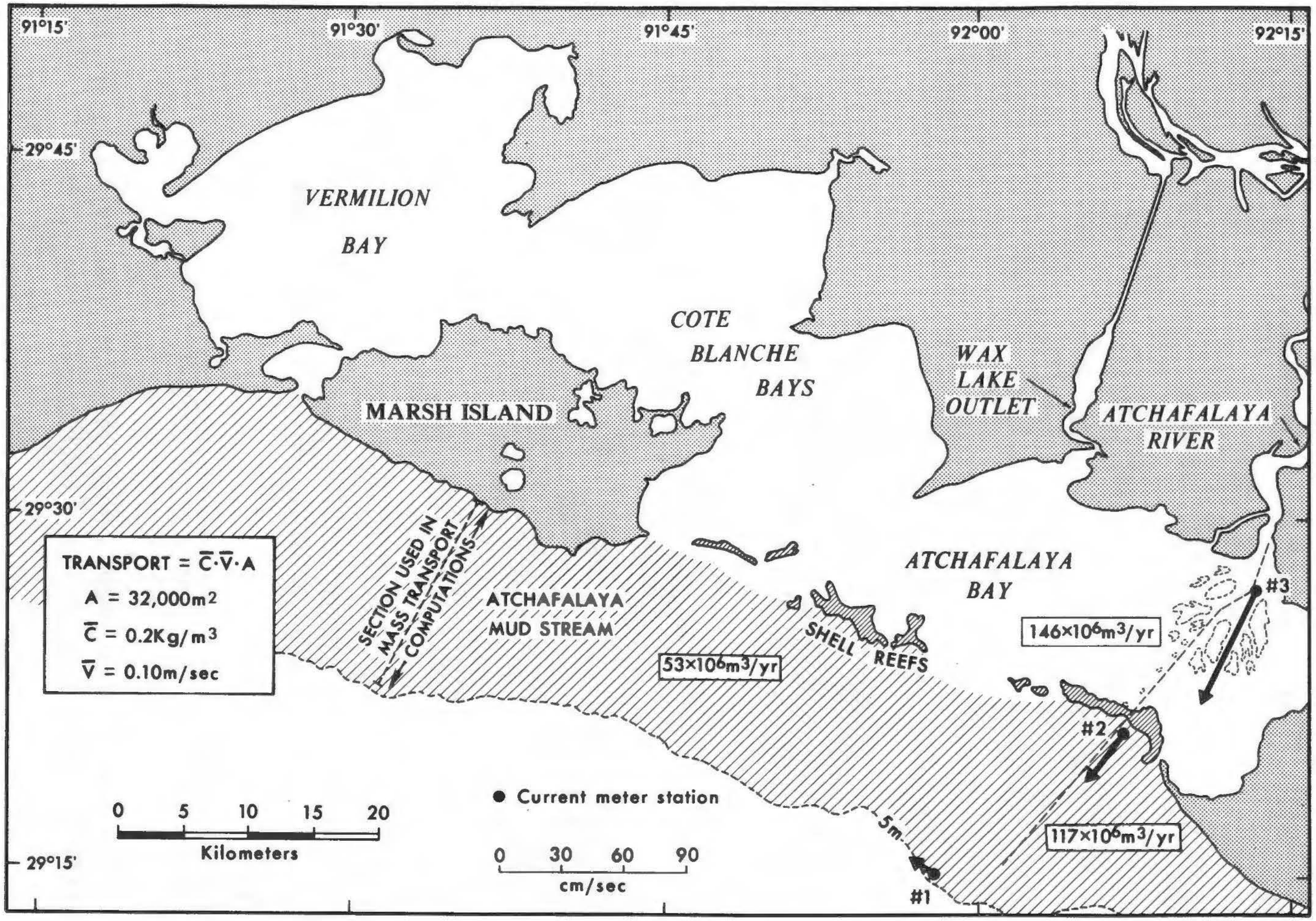


Figure 6. Central Louisiana Coast showing Atchafalaya mud stream and volume flux of sediment into and through the Atchafalaya system. Greater than 50 x 10^6 m^3/ yr of silt and clay is transported to the eastern margin of the chenier plain. Current meter stations and residual current vectors are numbered.

Residual currents computed from these records are shown in Figure 6. The overall pattern is that of strong flow down the axis of the navigation channel, spreading and reducing in speed on reaching the Gulf of Mexico, then deflection to the west on the inner shelf. Analysis of current data taken on the shelf farther to the west (longitude 90^{o} 30') also indicates residual flows to the west (Crout and Hamiter 1981).

First-order approximations of the sediment mass transported in the Atchafalaya mud stream have been made by taking the product of average suspensate concentration, cross-sectional area of the mud stream, and average drift speed of currents (Figure 6). Conversion to volume transport is made using a density of 375 kg/m^3 (Wells and Roberts 1981). When converted to transport per year, the volume of sediment moving in the Atchafalaya mud stream is 53 X 10^6 m^3, almost half of the volume of sediment that leaves Atchafalaya Bay. Evidence for an intimate connection between Atchafalaya delta development and chenier plain sedimentation can be found in the good time correlation between subaqueous deltaic sedimentation in the bay and the first appearance of mudflats near Chenier au Tigre. Abnormally high river discharge in 1973-75 correlated well with a renewal of mudflat development after a period of erosion in the 1960's.

FUTURE FOR LAND BUILDING ALONG THE CHENIER PLAIN COAST

We have established that the chenier plain coast is a downdrift recipient of renewed deltaic sedimentation, but that the rate of growth today is insufficient to stop the historic trend of shoreline retreat. There is localized instantaneous progradation in the form of ephemeral and unvegetated mudflats. Because the major effect of subtidal muds is to attenuate incoming wave energy, conditions are being created that are favorable for further sedimentation (Wells and Coleman 1981; Wells and Roberts 1981). Formation of mudflats, then, is the first stage in the feedback loop between coastal energy and shoreline response, which eventually leads to stabilization and progradation. Volume calculations show that more sediment reaches the chenier plain via the Atchafalaya mud stream than appears as new mudflats. For example, if a typical mudflat has a volume of 1 x $10^6 m^3$ to 2 x 10^6 m^3, then 25 to 50 such mudflats could form each year. Since new mudflats have not been observed to form at this rate, much of the sediment may be spread across the inner shelf as a thin veneer over a longshore distance of perhaps 100 km or more.

The ephemeral nature of these mudflats suggests that the localized process of shoreline progradation has just begun to accelerate (Wells and Kemp 1981). As a result, we hypothesize that the initial stage of coastal progradation from a new sediment pulse is one of transitory mudflats only. As sedimentation continues, new mudflats will appear and merge with existing mudflats. At its peak of development, the shoreline will become "choked" with fine-grained sediment, mudflats will stabilize and grow seaward, and new marsh vegetation will become estabished. The potential for land building by this method should not be underestimated. The entire chenier plain region itself represents a net coastal progradation of 25 km from the Pleistocene surface contact to the present Gulf of Mexico shoreline. This land building took place in not more than 5,000 years during which the many stranded beach ridges tell us that accretion alternated with erosion. Thus, a conservative estimate of the land-building potential afforded by mudflat accretion is on the order of 5 m/yr or close to the rate at which retreat is now occurring. Accelerated growth of the chenier plain is expected when the subaerial Atchafalaya delta outgrows Atchafalaya Bay, allowing a greater volume of sediments to

enter the dynamic shelf region and become entrained in the mud stream (Wells et al. in press). The time scale for widespread reversal in present coastal erosion along Louisiana's chenier plain is 50 to 100 years, provided that the Atchafalaya River discharge remains relatively constant and no sediment is artifically diverted away from the mud stream.

CONCLUSIONS

1. The chenier plain of southwestern Louisiana is presently receiving a major new influx of fine-grained sediment from the Atchafalaya River to the east, the first such sediment pulse in recorded history. Sediment is delivered by the Atchafalaya mud stream, a westerly flowing band of turbid water that may extend 20 km offshore.

2. Growth of the chenier plain appears initially to be by a series of transitory mudflats, a few of which become welded to the shoreline. The pattern of mudflat sedimentation is increasing and shifting to the west, consistent with the direction of coastal and wave-induced currents.

3. The Atchafalaya mud stream transports more sediment, by an order of magnitude, to the chenier plain than can be accounted for in yearly mudflat accretion. Much of the sediment may be spread as a thin veneer across the inner continental shelf.

4. Future development of the chenier plain will be tied intimately to the fate of Atchafalaya Bay. Accelerated growth of the chenier plain is expected when Atchafalaya Bay becomes sediment-filled, thus allowing an even greater volume of sediments to enter the dynamic shelf region seaward of the bay.

5. Widespread reversal in the present erosional trend is expected in 50 to 100 years.

ACKNOWLEDGMENTS

Support for this project was provided by the Louisiana Sea Grant University Program, a part of the National Sea Grant University Program, maintained by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce. Mrs. Gerry Dunn drafted the figures.

LITERATURE CITED

Adams, R.D., P.J. Banas, R.H. Baumann, J.H. Blackmon, and W.G. McIntire. 1978. Shoreline erosion in coastal Louisiana: Inventory and assessment. Final Report to Louisiana Department of Transportation and Development. 139 pp.

Crout, R.L., and R.D. Hamiter. 1981. Response of bottom waters on the west Louisiana shelf to transient wind events and resulting sediment transport. Trans. Gulf Coast Assoc. Geol. Soc. 31:273-278.

Fisk, H.N. 1952. Geological investigations of the Atchafalaya Basin and the problem of Mississippi River diversion. U.S. Army Corps of Engineers, Mississippi River Commission, Vicksburg, Miss., Vol. I. 145 pp.

Gagliano, S.M., and J.L. van Beek. 1970. Geologic and geomorphic aspects of deltaic processes, Mississippi delta system. Louisiana State Univ., Center for Wetland Resources, Baton Rouge. Hydrological and Geological Studies of Coastal Louisiana Rep. 1. 140 pp.

Gould, H.R., and E. McFarlan, Jr. 1959. Geologic history of the chenier plain, southwest Louisiana. Trans. Gulf Coast Assoc. Geol. Soc. 9:1-10.

Kaczorowski, R.T., and R.E. Gernant. 1980. Stratigraphy and coastal processes of the Louisiana chenier plain. Field Guide, 30th Annu. Convention, Gulf Coast Assoc. Geol. Soc. 72 pp.

Kolb, C.R., and J.R. Van Lopik. 1958. Geology of the Mississippi River deltaic plain. U.S. Army Engineer, Waterways Experiment Station, Vicksburg, Miss.,Tech. Rept. 3-483.120 pp.

Morgan, J.P., and P.B. Larimore. 1957. Changes in the Louisiana shoreline. Trans. Gulf Coast Assoc. Geol. Soc. 7:303-310.

Morgan, J.P., J.R. Van Lopik, and L.G. Nichols. 1953. Occurrence and development of mudflats along the western Louisiana coast. Louisiana State Univ., Coastal Studies Inst. Tech. Rep. 34 pp.

Price, W.A. 1955. Environment and formation of the chenier plain. Quaternaria 2:75-86.

Roberts, H.H., R.D. Adams, and R.H. W. Cunningham. 1980. Evolution of sand-dominant subaerial phase, Atchafalaya Delta, Louisiana. Am. Assoc. Petrol. Geol. Bull. 64:264-279.

Russell, R.J., and H.V. Howe. 1935. Cheniers of south-western Louisiana. Geogr. Rev. 25:449-461.

Wells, J.T. and J.M. Coleman. 1981. Physical processes and fine-grained sediment dynamics, coast of Surinam, South America. J. Sediment. Petrol. 51:1053-1068.

Wells, J.T., and G.P. Kemp. 1981. Atchafalaya mud stream and recent mudflat progradation: Louisiana Chenier Plain. Trans. Gulf Coast Assoc. Geol. Soc. 31:409-416.

Wells, J.T., and H.H. Roberts. 1981. Fluid mud dynamics and shoreline stabilization: Louisiana chenier plain. Pages 1382-1401 in Proceedings 17th Conference Coastal Engineering, Sydney, Australia.

Wells, J.T., S.J. Chinburg, and J.M. Coleman. In press. Development of Atchafalaya River delta: generic analysis. Louisiana State Univ., Coastal Studies Inst. Tech. Rep.

PANEL DISCUSSION

CAUSES: CHANGES IN DISPERSAL OF FRESH WATER AND SEDIMENTS

Gerald G. Bordelon, Moderator

Johannes van Beek, Richard Hatton, Ron Boyd, John Wells, Clark Lozes, and **Raphael Kazmann**, Panelists

Gerald Bordelon: The presentations ranged from a doomsday to a new birth, starting out with a snorkel and little worry to some good hope.

David Soileau: There has been concern about the potential adverse impacts of the proposed Avoca Island levee extention on the marshes to the east, but the Corps of Engineers has pointed out the potential beneficial impact on the tupelo-cypress and bottomland hardwood areas to the north of the marshes. Dr. van Beek, what is your opinion on this from a hydrological viewpoint?

Johannes van Beek: The hydrological issue is whether the Avoca Island levee extension will reduce water levels in the areas north of Morgan City and in the Verret Basin. The answer is yes it will, initially, in so far as those water levels are controlled by the stage of the Atchafalaya River as felt at the Amelia Channel. This will only be a temporary effect, however, because of the effects of other processes, namely subsidence and increase in stages in the Atchafalaya River due to channel development and delta progradation. Flooding in the basin east of the Atchafalaya Basin is not due to backwater flooding alone, but due to backwater flooding superimposed on tides, increased water levels due to onshore winds and large rainfalls in the basin accelerated by channelization for the purpose of agricultural drainage.

Joel Lindsey: Ring levees around developed areas have been proposed as an alternative to the Avoca Island levee extension. Which would be the most cost-effective means of flood protection?

Johannes van Beek: That is difficult to answer because of the term "cost-effective." While we do not yet have all the answers, we have learned quite a lot about deltaic processes and have documented changes. We have at least the nominal understanding necessary to suggest future directions. This involves planning for land use on a statewide basis and a commitment to those plans. It means if we have to relocate people, we will do it. Eventually we will be forced to that anyway, because we cannot stop what is happening along the Louisiana coast. We can buy time, but we cannot stop delta cycles. We can initiate new ones, but this too requires human adjustment.

David Mekasski: What would be the effect of opening the Bonnet Carre spillway on a regular basis to marsh and shoreline accretion in western Lake Pontchartrain?

Johannes van Beek: In 1973, there was significant accretion along southern Lake Pontchartrain and reductions of salinity lasting at least a year. In view of the warning that the Tangipahoa swamps are giving us, I think it is necessary to consider a major diversion into the Lake Pontchartrain system. Ideally, there would be many smaller diversions across the Mississippi River levee through the swamps into Lake Maurepas, but there are the major obstacles of Airline Highway and the ground level segments of Interstate 10. Those larger diversions to the southern lake are the only ones feasible, although Bonnet Carre may not be the only place.

John Uhl: What do you mean by small or large diversions? What types of structures are involved?

Johannes van Beek: Small structures can convey 250 to 2,000 cfs, similar to the Bayou Lamoque structure, and include siphons and box culverts. Large structures can convey about 15,000 cfs and include gates and large box culvert structures.

Raphael Kazmann: We are dealing with some substantial problems in regulating the Mississippi River flow. For one thing, the sediment available in the Mississippi River has declined by a factor of two since the 1950's. Even if we could keep the available load from being transported off the continental shelf, there would be a deficiency in restoring any equilibrum that might have existed. This deficiency may also cause some poorly understood changes in sediment transport. With less sediment transported, there is what could be called "hungry water" with more transport energy available than there is sediment to transport. This results in bank erosion. The nutrient flow to the Gulf of Mexico may have also decreasd as a result of unnecessary secondary treatment of wastes.

There is much discussion of the management of the Atchafalaya River. The Atchafalaya provides a shorter path to the gulf. This means that in the upstream reaches of the Atchafalaya, the water level is going to degrade, that is, the high water is going to be lower with time, thus providing land owners with the possibility of draining the swamp. At Simmesport, for a flow of about 200,000 cfs the water level has dropped 7 feet since the 1940's. At the lower end of the Atchafalaya there is sedimentation which is building natural levees and the water is also transporting more sediment into the Atchafalaya Bay. This deposition will require great expense to maintain navigation channels.

If the Old River control structure fails, most of the sediment and freshwater will travel down the Atchafalaya. New Orleans will be on a navigable estuary (the present Mississippi course) and all of the lower river diversion structures will simply transmit salt water. We should adapt and accept what is happening, backoff, and enjoy the present conditions while they exist. In this new land and new swamp that the Atchafalaya is building, protect the new habitat. Don't consider the present Atchafalaya Basin as a wildlife refuge; it is a wildlife death trap. Following a large flood of 1.5 million cfs or more, there will be no deer, squirrels, etc. remaining.

There is much discussion of who is going to manage the present Atchafalaya Basin, but you can't "manage" the area of the greatest geomorphological change in the country. All you can do is adapt. Government policy should not encourage people to move into the area: one such policy that is dangerous is government-subsidized flood insurance. Further, don't build new levees at public expense or raise existing ones. If people want to live there, let them build their own levees at their

own expense. As far as New Orleans goes, if people want to remain in New Orleans, they had better find a new water supply because the Mississippi will eventually abandon its course past the city, maybe in the lifetime of many in the audience.

The sediment which I indicated is no longer coming down the river is stored in reservoirs in the Arkansas, Missouri, and Ohio rivers and their tributaries. If these reservoirs are reasonably full at the beginning of a flood season, the entire flow of the river will be speeded up. Where formerly the peak in flood stage would slowly rise and persist, now the peak will rise dramatically and to higher levels. The land accretion and erosion in the delta is just the tail end of a tremendous process in the whole river basin which is going on now, and we do not know what the outcome will be.

Unidentified speaker: If there is a shortage of sediments coming into marshes to offset subsidence, has the nutrient supply also been reduced? Will freshwater diversion increase the needed nutrient supply to allow the marshes to grow?

Richard Hatton: Many nutrients are associated with particulate sediments, but I feel freshwater inputs would decrease saltwater intrusion which causes marsh destruction.

Clarke Lozes: Some freshwater diversions could also serve as flood control structures to relieve flood pressure from New Orleans by shortening the flow of river water into Lake Pontchartrain and the Barataria Basin.

Unidentified speaker: Will these freshwater diversions carry water only during high water periods or year-round?

Raphael Kazmann: High water stages carry more sediment for wetlands accretion. Also, diversions during low stages can worsen saltwater intrusion up the river and affect drinking water supplies. Therefore, substantial freshwater diversion must be confined to relatively high flow periods.

Unidentified speaker: Wouldn't that present a problem in preventing saltwater intrusion during late summer and early fall when the salinity encroachment tends to be greatest?

Johannes van Beek: Low flow periods pose a major problem. Also salts may accumulate in soils during episodes of high salinity flooding behind levees. Release of fresh water, when it is available, will help leach the salts from the soils.

Walter Sikora: Long-term records in Lake Ponchartrain show highest salinity in the fall, but do not show any long-term increase in the western lake. How then could deterioration of freshwater swamps be attributable to saltwater intrusion?

Johannes van Beek: The break up of cypress swamps seems to be due primarily to increased inundation rather than to increased salinity, but there may be some critical low salinity which affects tolerance to inundation. Therefore, freshwater diversion could increase tolerance to inundation. Also, introduction of more sediments is required to offset the effects of subsidence on increased inundation.

Dag Nummedal: There are three major natural processes which will affect long-term changes in south Louisiana that we cannot manage. One is the eventual diversion to the Atchafalaya. The second is hurricanes. Thirdly, there is a tremendous amount of evidence from tidal gauge records and climatic models that dramatic sea-level rises have just begun. We have no means or structures to deal with these problems. We should, thus, start discouraging development in the lowlands of Louisiana. We can not afford to lose New Orleans, but we don't want to create other potential traps like it.

Gary Blaize: Is there anything that can be done to protect the barrier islands? These are very important with regard to avoiding the loss of State lands and oil and gas resources to the Federal Government.

Ron Boyd: Instead of protecting the coastline for the purpose of saving State revenues, Louisiana should establish an agreement with the Federal Government regarding a fixed boundary. There are, nonetheless, a range of options for barrier island protection, most significantly, sediment bypassing at inlets and nourishment of the islands from the available sand sources such as in tidal deltas and nearshore zone. This sand can be placed back on shore and stabilized by vegetation, resulting in significantly slowing down the rate of erosion. Experience has shown that purely structural approaches such as placement of rock walls are generally not effective.

Johannes van Beek: Although there are processes we cannot stop, barrier island erosion is artifically accelerated by man's actions. If man can accelerate erosion rates, he should be able to decelerate back to rates attributable to natural processes. We must learn how best to do that in order not to be surprised by natural disasters.

Clarke Lozes: Since 1950 Plaquemines Parish has taken upon itself to initiate freshwater diversions and presently there are three structures operating and a fourth proposed. We are trying to improve their design and management, while at the same time, we are taking other steps to decrease the number of new oil and gas canals in wetlands. These may be short term approaches, effective within 100 years, but people are living in Plaquemines Parish today. It is necessary now to take definite action on some projects and these might hopefully lead us to a longer term management plan.

John Uhl: What approaches can economically be taken to return the system more to equilibrium and dominance by natural processes?

Raphael Kazmann: The only thing we can do is build diversion structures which operate automatically during high flows and do not cut off sediment in the Atchafalaya by building spoil banks which keep the sediment from spreading out. But this comes into conflict with flood protection and navigation interests.

Sherwood Gagliano: Dr. Kazmann assumes that the amount of water coming down the Mississippi will remain the same. What are the prospects that states to the north will divert water to other drainage basins?

Raphael Kazmann: The principal advocate of this has been Texas. If it were pure water, it would have to be pumped 4,000 ft to use it for irrigation. Actually the sediment loads would defeat this approach. Diverting water from Arkansas River reservoirs is more feasible, but this river does not contribute much water to the Mississippi.

Potential diversion of 200,000 to 500,000 acre/ft/yr of water from the Missouri River for a coal slurry pipeline is also rather negligible. Larger diversions for irrigation in the upper Midwest may be more significant but are probably uneconomical unless funded by the Federal Government.

Rodney Adams: If one colored on a map the areas where the projects discussed may provide some benefits, there would be a large void between the Houma Navigation Canal and the Barataria Waterway and in certain areas in St. Bernard Parish. We need some more critical permitting procedures in these areas where such mitigative approaches are infeasible.

Martha Landry: Where have the sediments which used to come down the Mississippi River been diverted?

Raphael Kazmann: Although in the upper Missouri and Arkansas Rivers there are reservoirs which can contain about twice the normal annual flow of the river, 25 percent of the reservoir capacity is to be used for storage of sediment. Missouri River water used to have a tremendously high suspended sediment load which has now been greatly reduced. They have not yet designed reservoirs which will allow sediments to effectively bypass containment, although about 10 years ago the Bureau of Reclaimation was optimistic about designing such devices.

Dag Nummedal: If by design or default the Mississippi was fully diverted to the Atchafalaya, what would be the effect on chenier plain progradation?

John Wells: With 30 percent of the Mississippi River water and sediment flow there is substantial progradation which should accelerate once the Atchafalaya Bay fills. If this increased to 60 percent or more, there would be very rapid effects in about 10 years.

Walter Sikora: The sedimentation phenomena described for the lower Barataria Bay results from reworked sediments in a saline or brackish medium. This may result in more rapid sedimentation from water flowing into the marsh than in the case of freshwater diversions into a marsh. The suspended sediments in the fresher water may settle much more slowly.

Richard Hatton: When the water flows into the marsh the sheet flow rates are very slow, such that the sediments are deposited after travelling only short distances.

John Wells: It now appears that the effect of salt flocculation has been overemphasized and that sedimentation by organic binding of fine particles is important both in marine and fresh waters.

Bob Gerdes: If enough small diversion structures were built along the lower river, would that reduce the pressure on the Old River control structure during floods?

Raphael Kazmann: They would have no effect because they are too far away, up to 200 river miles. Relief spillways must be close. Even the opening of the Morganza spillway, 10 to 12 miles away, during the 1973 flood had less of an effect than expected at the Old River control structure.

Chris Neill: It appears that chenier plain progradation is one of the most effective means of gaining new land. What are the pros and cons of letting more flow down the Atchafalaya to accelerate this process?

John Wells: Certainly the building of new land and new marsh in the Atchafalaya Bay and downdrift to the west would be a plus.

Raphael Kazmann: The negative aspects present very tough, political situations in which compromises cannot be reached. Increasing diversion to the Atchafalaya presents serious problems to the New Orleans water supply during low flow. Too little diversion causes problems at Morgan City. The question becomes "Who is going to drink salt water?"

Donald Boesch: One consequence not often discussed is the effect of river diversions on adjacent continental shelf water, particularly increased stratification and resulting low oxygen conditions, sedimentation, and nutrient enrichment. This should also be considered in evaluating diversions which affect coastal and shelf waters.

Ron Boyd: Even though there may be such effects, they would not be unusual ones in the history of the river and the adjacent continental shelf environment, because fresh water was often discharged from more than one major distributary at a time.

John Wells: It is important to realize that land loss is only a subaerial loss; the subaerial land that reverts to shallow water bottom also has a natural resource value. We need to ask how much more valuable is an acre of marsh than an acre of water bottom, as a nursery ground for shrimp or other species.

Johannes van Beek: Marshes and water bottoms are linked together. Without the input from the marsh that acre of water bottom will not be of much good. Your question should be modified to "What is the right combination of water and marsh?"

CAUSES: PHENOMENA DIRECTLY RELATED TO HUMAN ACTIVITIES

WETLAND LOSS DIRECTLY ASSOCIATED WITH CANAL DREDGING IN THE LOUISIANA COASTAL ZONE

W. B. Johnson
J. G. Gosselink

Center for Wetland Resources
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

This study addresses wetland losses directly resulting from canals, including initial construction practices and subsequent canal bank erosion. The average actual width of the newly dredged canals studied exceeded the width specified in the dredging permit by 13.4 m. The total width affected, including berm and spoil deposits, exceeded the permitted canal width by an average of 81.7 m.

As canals age, they widen through erosion. The history of three old canal systems in coastal Louisiana was examined. All these canals continue to increase in width and differences in their patterns of widening can be explained by boat traffic, length of time since construction, and substrate differences. The widening rate in the Leeville oilfield is directly related to the proximity of the canal to boat traffic. Canals in areas of greatest boat activity widened at a rate of 2.58 m/yr, while those in areas of minimal boat activity widened at a rate of 0.95 m/yr.

INTRODUCTION

Louisiana has 30% of the Nation's coastal wetlands (Turner and Gosselink 1975), but they are being lost at an alarming rate. Numerous investigators (Gagliano and van Beek 1970; Adams et al. 1976, 1978, 1980; Craig et al. 1979, 1980; Gagliano et al. 1981; Baumann and Adams in press) have examined Louisiana's land loss problems. These investigations have generally relied on large-scale mapping procedures for data extraction, concentrating on the entire coastal zone, shoreline sections, or hydrologic basins.

Manmade canals are a dominant feature of the Louisiana coast, and there is considerable evidence (Craig et al. 1979, 1980; Scaife et al. in press) that this canal network contributes significantly to wetland loss, both directly and indirectly. Direct effects are the immediate conversion of wetland to canals and spoil banks during canal construction (Darnell 1976), and the subsequent widening of canals as their banks erode through time. Indirect effects (Morton 1977) are marsh deterioration from saltwater intrusion and changes in waterflow patterns that result when deep straight canals are dredged through wetlands. In this report we document the direct wetland loss associated with dredging and historical erosion. Indirect effects are documented by Scaife et al. (in press).

We first examine the relationship between proposed canal widths specified in dredging permit applications (permitted width) and the actual wetland affected--that is, dredged or covered with spoil material. Secondly, we document the widening of canals that occurs through time as their banks erode, through case studies of three old canal systems. Finally, we show that boat traffic has a significant effect on the widening rate.

METHODS

Permit files of the U.S. Army Corps of Engineers, New Orleans District, (USACE-NOD), provided a source of canal dimensions authorized in dredging permits. Oil and gas well-access canals in Terrebonne and Cameron parishes, Louisiana, and the Louisiana Offshore Oil Port (LOOP) pipeline system from the Southwest Louisiana Canal near Leeville north to the Clovelly saltdome were evaluated. Criteria used for choosing particular canals were accessibility, recent construction (within two years), and the vegetation traversed. Table I summarizes canal locations, habitats, and approximate construction dates.

Site visits were made to LOOP on 25 July 1979 and from 6 to 8 August 1979; to Terrebonne Parish from 31 August 1979 to 3 September 1979; and to Cameron Parish from 24 to 26 September 1979. Canal widths and elevations were measured with a Lietz self-leveling level equipped with top and bottom stadia hairs, and a 3.7 m stadia rod with 0.1 cm graduations. Measurement locations on the LOOP pipeline were randomly selected. At each well-access channel, two transects were sighted perpendicularly near the well head and in the access channel.

The widths of spoil, berm, and canal were estimated. From these measurements the total width modified by the construction and the actual canal width were calculated. Canal depth and, where possible, canal length were measured.

Simple linear regressions were used to relate permitted canal width to the corresponding actual canal width and to the total impact width (width of both spoil banks and the canal). In addition, paired t-tests were used to determine if permitted berm widths, berm depths, canal widths, canal lengths, and well head slip lengths were significantly different from the actual dimensions measured in the field.

Evalutations were made of the widening rates of three canal systems: old oil field navigation canals on the Rockefeller Wildlife Refuge at Grand Cheniere, Louisiana; the Southwestern Louisiana Canal which connects Caminada Bay and Little Lake in southern Lafourche Parish, Louisiana; and the Leeville oil field canals surrounding Leeville, Louisiana.

Using data from Nichols (1961) on selected sites in the Rockefeller Wildlife Refuge, we ascertained the initial canal widths at the time of construction. Nicholls also provided the canal widths as measured in May 1958 and again in March 1961. On 26 September 1979 we remeasured the canals at the same locations.

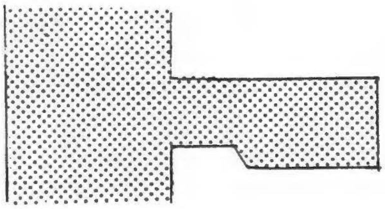
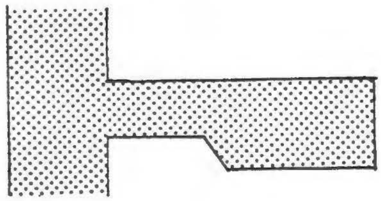
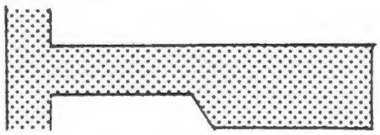
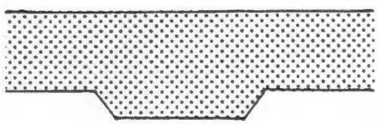
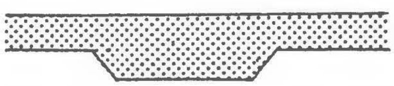
An historical evaluation of the width of the Southwestern Louisiana Canal was made by Doiron and Whitehurst (1974), using the original construction date and width, aerial imagery made, and field measurements made in 1979. We updated these measurements from Environmental Protection Agency (EPA) infared photographs made in October 1978, scaled to 1:24,000 with a Bausch and Lomb Zoom Transfer Scope.

Table 1. Location, construction completion date, and associated marsh type for canals measured in study.

Area	Parish	Location		Completion date	Marsh type
		Latitude	Longitude		
Turtle Bayou	Terrebonne	29°32'17"	91°03'42"	October 1978	Fresh
Point Au Fer Island	Terrebonne	29°15'31"	91°16'05"	December 1978	Saline-brackish
Mosquito Point, Four League Bay	Terrebonne	29°18'40"	91°10'39"	August 1979	Brackish
Lake Gero, Dulac	Terrebonne	29°22'54"	90°41'46"	December 1978	Brackish
Deep Lake, Rockefeller Refuge	Cameron	29°38'40"	92°44'32"	August 1978	Brackish
Pecan Island, White Lake	Cameron	29°44'12"	92°39'47"	March 1978	Intermediate-fresh
Little Chenier	Cameron	29°51'54"	92°59'32"	June 1979	Fresh
Mermentau River	Cameron	29°44'58"	93°04'11"	July 1977	Saline-brackish
Bayou Laforuche (LOOP, Inc. pipeline)	Lafourche			June-July 1979	Brackish-saline

The Leeville oil field was mapped from 15-minute quadrangle maps made in 1957 by the U.S. Geological Survey, and from an October 1978 EPA infrared aerial photograph scaled to 1:24,000 with a Bausch and Lomb Zoom Transfer Scope. Because of distortion, it was necessary to scale small areas of the oil field independently. Canals were placed into one of five categories, depending on their morphology and exposure to boat activity (Table 2), and their widths were measured on both maps. Widening rates exceeded the smallest change discernible using measurements of 0.5 mm on 1:24,000 imagery (Tanner 1978). Analysis of variance was used to test for widening rate differences among canal types.

Table 2. Canal types in the Leeville, Louisiana oil field

Morphology	Type	Description
	Major navigation canals (MNW)	Well-access canals extending directly off major navigation water ways (Bayou Lafourche and Southwestern Louisiana Canal)
	Oil field navigation canals (OFNC)	Well-access canals extending directly off oil field navigation canals
	Nonmajor canals (NMC)	Well-access canals well removed from regular boat wake exposure
	Side extensions on oil field navigation canals (SMNC)	Well-access areas that are widenings of existing navigation canals
	Side extensions on minor canals (SNMC)	Well-access areas that are widenings of existing canals infrequently exposed to boat wakes

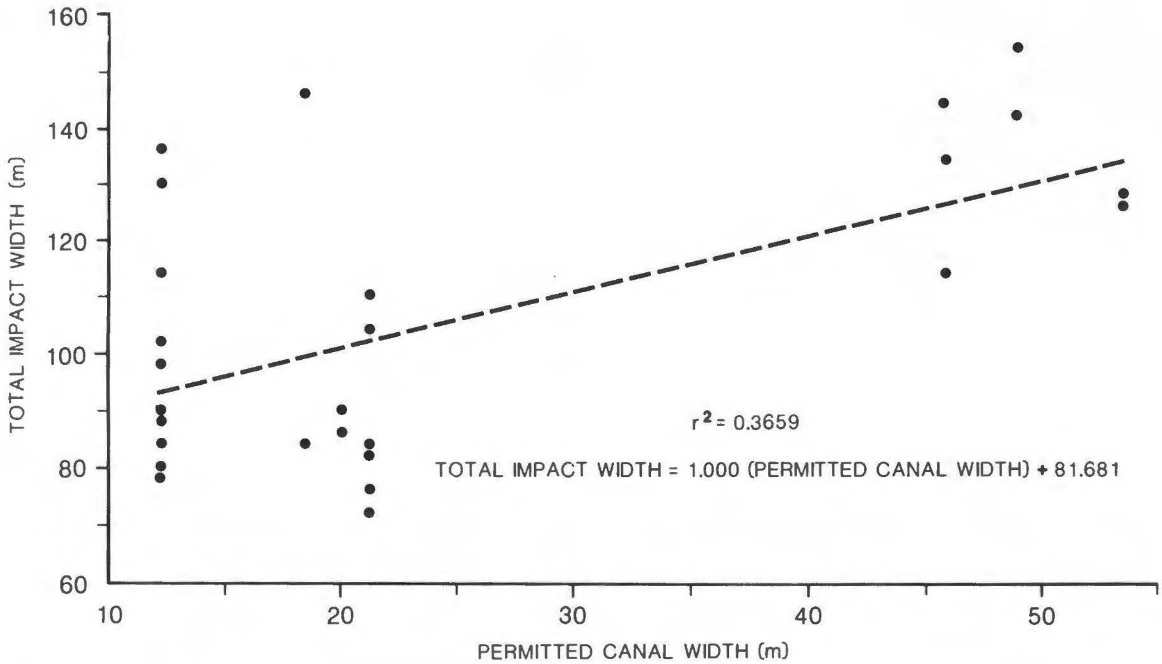


Figure 1. Relationship between proposed permitted canal widths and the total width of the wetland corridor actually modified by construction. See Table 1 for data sources.

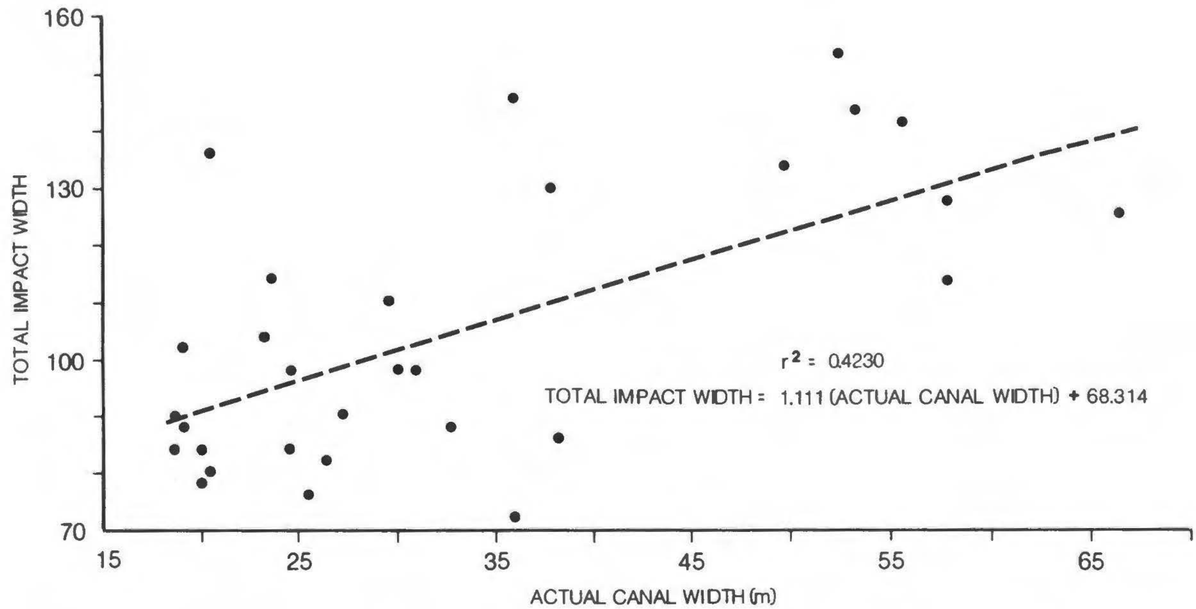


Figure 2. Relationship between actual dredged canal widths and the total width of the wetland corridor actually modified by construction. See Table 1 for data sources.

RESULTS

The relationship between canal widths as proposed in permit applications and the total width of the wetland corridor actually modified by construction is presented in Figure 1. Only 36.6 percent of the variation in the total width affected is explained by differences in the permitted dimensions. Other probable sources of variability are substrate characteristics (e.g., organic content, cohesiveness) and the care taken by dredge operators and surveyors to adhere to permitted dimensions.

The regression relation shows that total affected width, that is the width of the canal, berm, and both dredge material deposits, increased linearly as permitted canal width increased; and that the actual width affected exceeded the permitted width by 81.7 m.

As might be expected the total width affected was slightly more closely related to the actual dredged dimensions (Figures 1 and 2; r^2 =0.423). Again, the regression slope is nearly one. In cross section, berm and spoil deposits occupy about 68.3 m, and actual dredged canal widths exceeded permitted widths by about 13.4 m (81.7 m compared to 68.3 m).

Analysis of the means of permitted to actual canal dimensions (as contrasted to measurements predicted from the regression equations), showed that actual canal widths statistically exceeded permitted canal widths by 10.9 m (Table 3). Actual berm widths were 3 m less than permitted widths. Depth, total canal length, and slip length were not significantly different from permitted specifications (Table 3).

Table 3. Comparisons of permitted versus actual canal dimensions, using paired t-tests.

Dimension	Actual mean measurement (m)	Permitted mean measurement (m)	t Statistic	$P > \|t\|$
Depth	2.9	2.5	1.53	0.1511
Berm width	4.6	7.6	-4.43	0.0003
Canal width	34.4	23.5	6.30	0.0001
Total canal length	574.9	573.9	0.05	0.9643
Slip length	112.2	106.1	1.22	0.3471

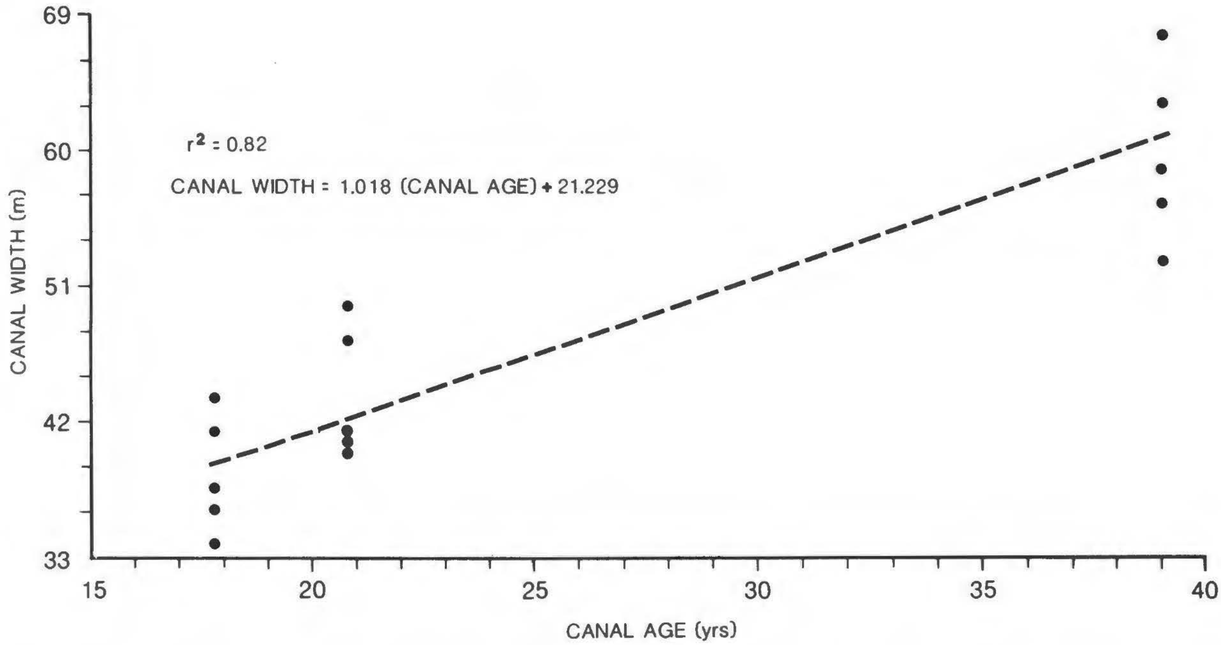


Figure 3. Relationship between canal width and age in the Humble canal system, Rockefeller Refuge, La. Locations are described in Nichols (1961).

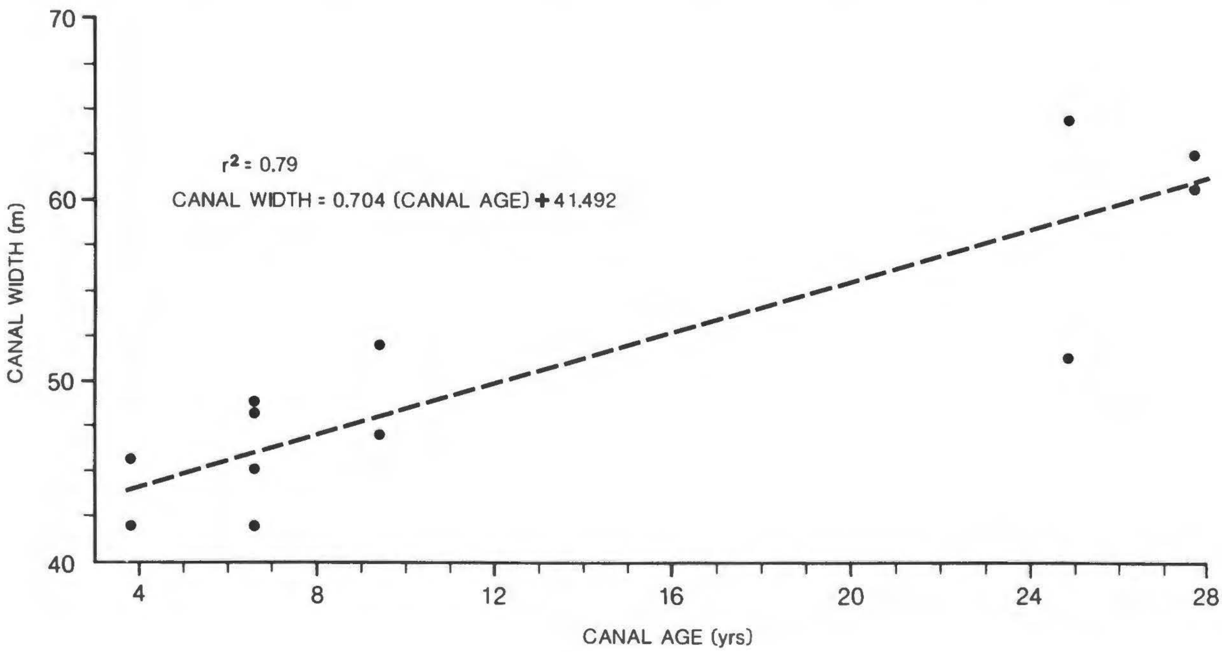


Figure 4. Relationship between canal width and age in the Deep Lake-Constance Bayou canal system, Rockefeller Refuge, La.

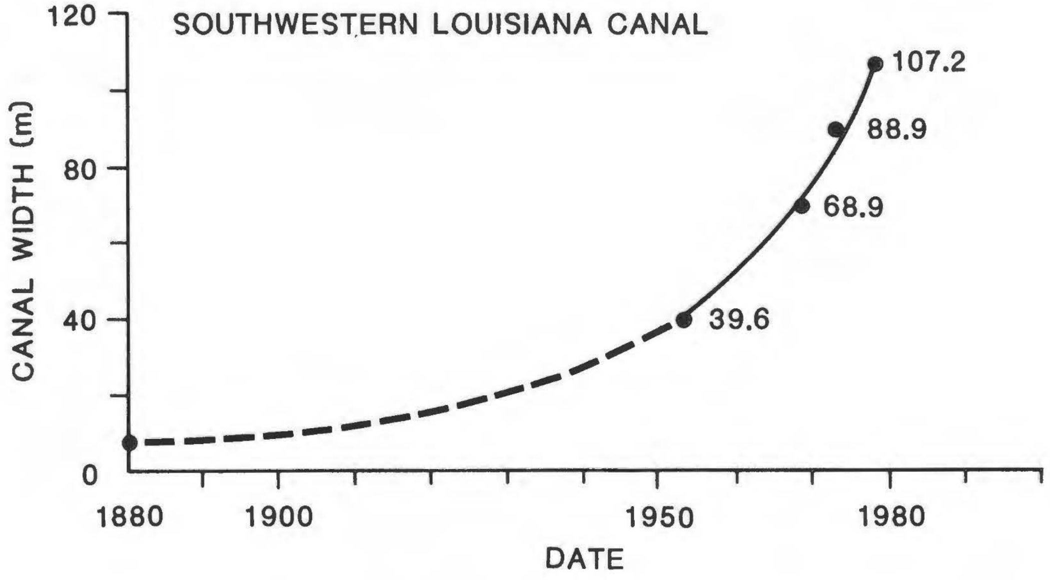


Figure 5. Relationship between canal width and age in the Southwestern Louisiana Canal, Lafourche Parish, La. See Table 5 for raw data.

Analysis of the Rockefeller Refuge canals showed that although canals widened linearly, the rate of increase and the zero age-intercept in the Humble canals were different ($P < 0.05$) from those in the Deep Lake-Constance Bayou canals (Figures 3 and 4). In the Humble canal system, canals widened at 1.018 m/yr and 82.4% of the variation in canal width was explained by canal age, while in the Deep Lake-Constance Bayou system the canal widening rate was 0.704 m/yr and 78.5% of canal width variation was explained by canal age. Widening rates for the Southwestern Louisiana Canal (Table 5 and Figure 5) were much higher than those for the Rockefeller Refuge canals (15 m/yr), and are increasing through time.

The amount of boat traffic greatly influenced the erosion rate in the Leeville oil field. Well-access canals (Table 2) widened faster when connected to major navigation waterways (2.25 m/yr) than when connected to less traveled oil field navigation canals (1.12 m/yr) or to nonmajor canals well removed from boat wake exposure (0.95 m/yr) (Table 4). When canals were widened for well access (Table 2) the width of the widened recess was not influenced by boat traffic density (Table 4, SMNC vs. SNMC).

DISCUSSION

The newly dredged canals examined in this study were an average of 13 m wider than the widths specified on permit applications. In no case were they narrower. This was expected, since the width indicated in the permit request is the minimum width at the bottom of the canal. Canal side slopes are typically about 3:1, depending on the solidity of the substrate, so that the surface width is greater than the permitted width. Berms are encouraged because, although they expand the total impact width, they also prevent spoil from backwashing and shoaling the canal, which would then require

Table 4. Numbers of observations, mean widening rate from 1957 to 1978, and standard error for different canal types in the Leeville oil field (A) and analysis of variance indicating differences in canal widening rates for the period from 1957 to 1978 (B) (See Table 1 for canal types).

A.

Canal type	Number of observations	Mean (m/yr)	Standard error
MNW	13	2.58	0.85
NMC	20	0.95	0.13
OFNC	34	1.12	0.11
SMNC	25	1.20	0.15
SNMC	12	1.16	0.15

B.

Source	df	SS	MS	F
Canal type	4	23.48	5.87	4.44**[a]
MNW vs. OFNC	1	18.75	18.75	14.19**[a]
MNW vs. NMC	1	19.76	19.76	14.95**[a]
SMNC vs. SNMC	1	0.01	0.01	0.01NS[b]
Error	98	129.52	1.32	
Total	102	153.00		

a **Highly significant ($p \leq 0.01$)

b NS Not significant ($p > 0.05$)

Table 5. Historical widening of the Southwestern Louisiana Canal measured at regular intervals by Doiron and Whitehurst (1974) and this study.

Station	1880 Original Construction width (m)	1953 Imagery measurement		1969 Imagery measurement		1973 Field measurement		1978 Imagery measurement	
		Width (m)	Increase[a] (m/yr)	Width (m)	Increase (m/yr)	Width (m)	Increase (m/yr)	Width (m)	Increase (m/yr)
0	9.1	39.6	0.4	61.0	1.3	73.2	3.1	94.5	4.3
3000	9.1	36.9	0.4	56.4	1.2	73.2	4.2	88.4	3.0
6000	9.1	36.9	0.4	61.0	1.3	73.2	3.1	109.7	7.3
9000	9.1	39.6	0.4	82.3	2.7	97.5	3.8	125.0	5.5
12000	9.1	39.6	0.4	91.4	3.2	106.7	3.8	140.2	6.7
13100	9.1	33.5	0.3	61.0	1.7	85.3	6.1	--	--
15000	9.1	42.7	0.5	47.2	0.3	57.9	2.7	91.4	6.7
18000	9.1	44.2	0.5	67.1	1.4	97.5	7.6	125.0	5.5
21000	9.1	36.6	0.4	45.7	0.6	61.0	3.8	--	--
24000	9.1	42.7	0.5	73.2	1.9	94.5	5.3	100.6	1.2
27000	9.1	36.6	0.4	64.0	1.7	82.3	4.6	109.7	5.5
30000	9.1	33.5	0.3	65.5	2.0	91.4	6.5	91.4	0
33000	9.1	36.6	0.4	76.2	2.5	97.5	5.3	115.8	3.7
36000	9.1	39.6	0.4	76.2	2.3	100.6	6.1	112.8	2.4
39000	9.1	38.1	0.4	70.1	2.0	97.5	6.9	100.6	0.6
42000	9.1	42.7	0.5	76.2	2.1	91.4	3.8	91.4	0
45000	9.1	45.7	0.5	82.3	2.3	109.7	6.9	109.7	0
47500	9.1	45.7	0.5	82.3	2.3	109.7	6.9	109.7	0
MEAN	9.1	39.6	0.4	68.9	1.8	88.9	5.0	107.2	3.7
VARIANCE	0	13.2	0.004	145.3	0.495	233.0	2.305	200.2	6.934

[a]Since previous measurement.

premature maintenance dredging. Placement of the spoil material is constrained by the length of the arm on the dredge. To some extent berm width is indirectly controlled by this. Our regression analyses showed that berm and spoil bank together generally added 68 m to the width of the wetland corridor destroyed in canal construction. When the extra unauthorized canal width was included, the total corridor width was 81.7 m wider than the permitted canal. For a well-access canal permitted at about 21 m (65 feet) the total impacted width was typically about 103 m or five times the permitted canal width. Apparently, there has been almost no policing of canal construction, nor is there a record showing whether permitted canals are ever dredged. Since habitat loss from canals is much greater than permit records indicate, closer adherence to permit dimensions should be enforced. In addition, we observe that sufficient numbers of spoil bank openings to allow the flow of water across the marsh were seldom maintained, but sheet flow over the marsh was severely impeded by all spoil banks visited.

Boat traffic greatly influences canal widening rates as demonstrated in the analysis of dead-end canals in the Leeville oil field. Dead-end canals off Bayou Lafourche and the Southwestern Louisiana Canal, the two major nearby navigation routes, widened 1.46 m/yr faster than dead-end canals off oil field navigation canals and 1.63 m/yr faster than dead-end canals some distance from boat traffic.

The re-examination of the Rockefeller Refuge and Southwestern Louisiana canals, and information gathered in other parts of the study, provide insights into the factors that influence the widening of dredged canals in wetlands. The specific controlling factors that have been identified are boat traffic, geologic environment, and width of the spoil bank. The Humble canal system has more boat traffic than the Deep Lake-Constance Bayou system and widened about 0.3 m/yr faster. The Southwestern Louisiana Canal, with even more exposure to boat wakes, widened at a mean rate of almost 3 m/yr. These trends support the findings from the Leeville oil field, but part of the dramatic difference between the widening rates of the Rockefeller Refuge and the Southwestern Louisiana canals may be the generally firmer substrates at the Rockefeller Refuge (Gosselink et al. 1979).

In the Southwestern Louisiana Canal, the initial period of slow widening followed by more rapid widening may be explained by slow erosion through the consolidated spoil banks, followed by an increased erosion rate once the canal edge reached open marsh beyond the spoil. As shown in Table 6, a hypothetical canal permitted at 21.3 m in width would have a berm and spoil bank 34.2 m wide on each side[=(100.6 - 32.3)/2]. At the initial slow widening rate of the Southwestern Louisiana Canal it would take 72 years for the canal edge to erode through the spoil bank (compared with only 27 years at the present rapid rate). The slower rate corresponds to the time between construction and the dramatic increase in erosion rate of the Southwestern Louisiana Canal. Thus, we hypothesize that once spoil banks are eroded away, one can then expect a dramatic increase in canal widening rates. The Rockefeller Refuge canals are still eroding through the spoils banks, as are most of Louisiana's oil field canals. Therefore, their widening rates are relatively low and linear (Figures 3 and 4). We predict that when these canals become 30 to 70 years old their associated land loss rates will begin to accelerate rapidly.

Table 6. A projected history of a canal widening and width impacted from a canal permitted to be 21.3 m wide in a saline Louisiana marsh. Construction dimensions were estimated using the regressions and t-tests of actual construction versus permitted widths. The rates of widening were estimated using the highest and lowest rates in the Leeville oilfield.

	Width (m)
Permitted	
Canal	21.3
Construction	
Canal	32.3
Canal and Impact	100.6

Age	Width (m)	
	LOW ($0.95\ m \cdot yr^{-1}$)	HIGH ($2.58\ m \cdot yr^{-1}$)
1 yr	33.2	34.8
5 yr	37.0	45.1
10 yr	41.7	58.0
50 yr	79.7	161.2
100 yr	127.2	290.2

ACKNOWLEDGMENTS

Contribution No. LSU-CEL-81-40 of the Coastal Ecology Laboratory, LSU Center for Wetland Resources, Baton Rouge, La. Thanks to B. Allen for a helpful review.

LITERATURE CITED

Adams, R.D., B.B. Barrett, J.H. Blackmon, B.W. Gane, and W.G. McIntire. 1976. Barataria Basin: geologic processes and framework. Louisiana State Univ. Center for Wetland Resources, Baton Rouge. Sea Grant Publ. LSU-T-76-006. 117 pp.

Adams, R.D., P.J. Banas, R.H. Baumann, J.H. Blackmon, and W.G. McIntire. 1978. Shoreline erosion in coastal Louisiana: inventory and assessment. Louisiana Department of Transportation and Development, Baton Rouge, 139 pp.

Baumann, R.H., and R.D. Adams. In press. The creation and restoration of wetlands by natural processes in the Lower Atchafalaya River System: possible conflicts with

navigation and flood control objectives. Proceedings of the 8th Conference on Wetlands Restoration and Creation, Tampa, Florida.

Craig, N.J., R.E. Turner, and J.W. Day, Jr. 1979. Land loss in coastal Louisiana (U.S.A.). Environ. Manage. 3:133-144.

Craig, N.J., R.E. Turner, and J.W. Day, Jr. 1980. Wetland losses and their consequences in coastal Louisiana. Z. Geomorph. N.F. 34:225-241.

Darnell, R.M. 1976. Impacts of construction activities in wetlands of the United States. U.S. Environmental Protection Agency, Corvallis, Oreg. EPA-600/3-76-045. 392 pp.

Doiron, L.N., and C.A. Whitehurst. 1974. Geomorphic processes active in the Southwestern Louisiana Canal, Lafourche Parish, Louisiana. Louisiana State Univ., Division of Engineering Research -RMS, Baton Rouge. Research Monographs. 39 pp.

Gagliano, S.M., and J.L. van Beek. 1970. Geologic and geomorphic aspects of deltaic processes, Mississippi Delta system. Louisiana State Univ., Center for Wetland Resources, Baton Rouge. Hydrologic and Geologic Studies of Coastal Louisiana. Rep. 1. 140 pp.

Gagliano, S.M., K.J. Meyer-Arendt, and K.M. Wicker. 1981. Land loss in the Mississippi River Deltaic Plain. Trans. Gulf Coast Assoc. Geol. Soc. 31:295-300.

Gosselink, J.G., C.L. Cordes, and J.H. Parsons. 1979. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas, Vol. 1. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-78/9. 302 pp.

Morton, J.W. 1977. Ecological effects of dredging and dredge spoil disposal: a literature review. U.S. Fish Wildl. Serv. Tech. Pap. 94. 33 pp.

Nichols, L.G. 1961. Erosion of canal banks on the Rockefeller Wildlife Refuge. Louisiana Wildlife and Fisheries Commission, Refuge Div., New Orleans. (unpublished report).

Scaife, W., R. E. Turner, and R. Costanza. In press. Indirect impact of canals on recent coastal land loss rates in Louisiana. Environ. Manage.

Tanner, W.F. 1978. Standards for measuring shoreline changes: a study of the precision obtainable, and needed, in making measurements of changes (erosion and accretion). Coastal Research. Florida State Univ., Tallahassee. 87pp.

Turner, R.E., and J.G. Gosselink, 1975. A note on standing crops of *Spartina alterniflora* in Texas and Florida. Contrib. Mar. Sci. 19:113-118.

CANALS AND WETLAND EROSION RATES IN COASTAL LOUISIANA

R. Eugene Turner
R. Costanza
W. Scaife

Center for Wetland Resources
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

Canals have increased in area from practically zero at the beginning of the century to about 2.4% of the Louisiana coastal surface area in 1978. The annual increase in canal area is continuing to climb in 1981 as a result of new canal dredging and the widening of existing canals. Land loss rates across the coastal zone since the 1890's, among hydrologic units, and within areas of similar substrates and equal distances to the coast, are all positively related to estimates of canal density. Further, estimates of land loss at zero canal density (from regression equations) are similar to the 7,000 year coast-wide rate of gain in land. Within 7 1/2' quadrangle maps, the new "holes" or ponds in the marsh have appeared close to canals, not near natural channels. Coastwide, canal surface is about 10% of the total land loss. Based on our analysis we conclude that coastal erosion rates in Louisiana are largely an indirect result of canal dredging activities or use. The mechanism for the effect probably involved an alteration in wetland hydrology, but a complete understanding is presently lacking. Thus corrective measures cannot be identified and implemented with confidence until more is known about the mechanisms of canal and spoil bank effects on wetland hydrology.

INTRODUCTION

Canals are conspicuous features of the south Louisiana wetlands. At surface level, in a boat, their great length, density, and diversity can go unnoticed. A few hundred feet above the ground, however, they stand out as dominant geomorphic features. Most still have some remnants of their original levees formed from the dredge spoil put aside during construction. A few, notably gas pipeline canals, were filled in almost as soon as the pipe was laid and are no longer evident; the plants there have regained their former position in the reworked soil. Many canals are still in commercial and recreational use; others are blocked at one or both ends. They lie straight in contrast to the twisting, anastomotic natural channels which the canals often intersect. Water within canals rises and falls with the tide, contains fish, and is not noticeably different from bayou water in many respects. The linear structure of canals and the resulting effects on water and sediment movement constitute the major difference between canals and natural drainage systems.

These canals were largely absent at the turn of the century. Almost all were constructed to help in the recovery of mineral deposits located thousands of meters

below ground. Canals abound in every parish, in every wetland plant community and soil type, and have increased gradually, not suddenly, in density. In effect, a giant experiment is being conducted and we have only to recognize it as such to evaluate the results. The random surface distribution of canals and their differences in density over a wide geographical area and in different geological surface substrates provides a laboratory for the examinaton of their effects on a variety of wetland processes. This study represents some preliminary assessments of the relationship between land loss and canals, based on recently acquired, detailed area measurements.

The Louisiana coastal zone has grown seaward for 7,000 years at a new steady gain of 500 to 600 ha annually. Since 1900, however, there has been a net annual loss of land. The annual land loss rates have increased as the number of canals has increased. The prevalent explanation for the cause of the acceleration in land loss rates usually relies heavily on two arguments: first, that the disruptive influence of the Mississippi River levees reduces natural overbank flooding and shunts sediments offshore, and second, that there is a natural decay of deltas. Canals are generally considered ancillary factors in this explanation (e.g., Gagliano et al. 1981). There is a qualitative attractiveness to this argument, with which one of us has grappled before (Craig et al. 1980), but the data for a quantitative evaluation were limited then. Now, however, we have new data (Wicker 1980) to support the examination of an alternative hypothesis: that canal density is directly correlated with increased land loss rates at the local and regional levels and through time, and that impact of canals varies with changes in soil conditions and proximity to sediment sources. It is worth mentioning at the outset that the point of this exercise is not to place blame on one factor or another but, instead, to help understand what is happening and, thus, help provide for the enlightened and effective management of these valuable renewable resources.

CANAL DENSITY

Major inventories of canals and land loss in the Louisiana coastal zone have been conducted by Barrett (1970), Gagliano et al. (1971, 1981), Chabreck (1972), Gosselink et al. (1979), and Wicker (1980). These are the sources we will use in the figures that follow. The different surveys have various geographic boundaries that may not coincide. The most extensive data set available is for the deltaic plain, which extends from the Mississippi-Louisiana border to just west of the emerging Atchafalaya delta. We have normalized inconsistencies in geographic boundaries by expressing the area of canals as a percentage of annual loss based on the change from the initial to the later conditions.

The average canal density for the whole deltaic plain has increased steadily since 1890, when we presume there were very few canals (Figure 1). The canal area has climbed geometrically with time. From 1955 to 1978, it increased from 1% to 2.4%, or at a doubling rate of around 20 years. Including spoil banks, the total land area affected approached 10% by 1978, a magnitude equal to the surface area one would expect the natural drainage features to occupy in an unaltered marsh. The relationship between natural channel density and canal surface area is an inverse one (Craig et al. 1980). Natural channel density decreased logarithmically, while canal density increased linearly in the vicinity of the Leeville oilfield. The natural hydrology is obviously altered by the reduction in lateral flooding as a result of the spoil bank levees, by obstructing natural channels, and by the linear and uniform conduit created by the canals.

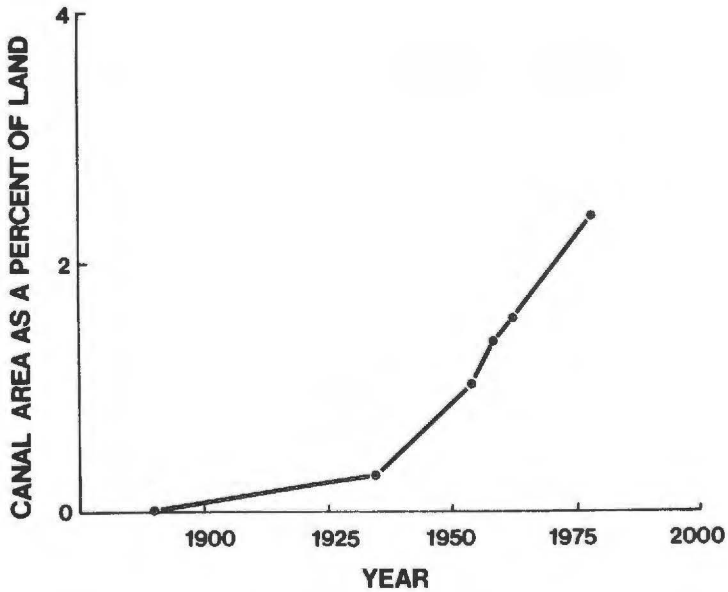


Figure 1. Canal density in the deltaic plain as determined from various surveys (data from Chabreck 1972; Gagliano 1973; and Wicker 1980).

CANAL DENSITY AND LAND LOSS RATES

The whole coast is not uniform with respect to canal density and land loss rates. Land loss rates for 1955 to 1978 were as low a -2% annually (a net gain of land) in the active Mississippi River delta and in the Atchafalaya delta. Canal densities vary among the hydrologic units as well (Table 1). Some are above 3% and others are below 1%. Canal densities have increased in the last 25 years in every hydrologic unit. There is a general relationship between canal density and land loss rates in each hydrologic unit (Figure 2). The point at which canal density is zero is also where land loss rates are slightly below zero (a net gain). Further, if one looks at the historical changes in land loss rates for the whole region, the same pattern emerges (Figure 3). Land loss is high when canal densities are high. Both were low at the turn of the century and have increased coincidentally since. The first estimates of land loss, for 1891 to the 1930s, are perhaps too high, since the early maps did not delineate marsh ponds and drainage channels. The present land loss rates are considerably more accurate and average about 0.8% annually from 1955 to 1978. Now (1982), land loss rates are near 1% annually. This translates to a regional "half-life" of 50 years. There is no indication that trends in either canal density or land loss rates are changing in Louisiana.

These latter relatonships were sufficiently interesting to justify comparing land loss rates with canal densities in individual quadrangle sheets of the coastal zone for 1955-78 (Scaife et al. in press). Subsidence rates and the substrate in each delta lobe differ (Morgan 1963; Adams et al. 1976). One net effect of delta building is the progradation of younger sediments over older sediments. The latter are more consolidated and therefore more resistant to erosion. Also, wave attack and

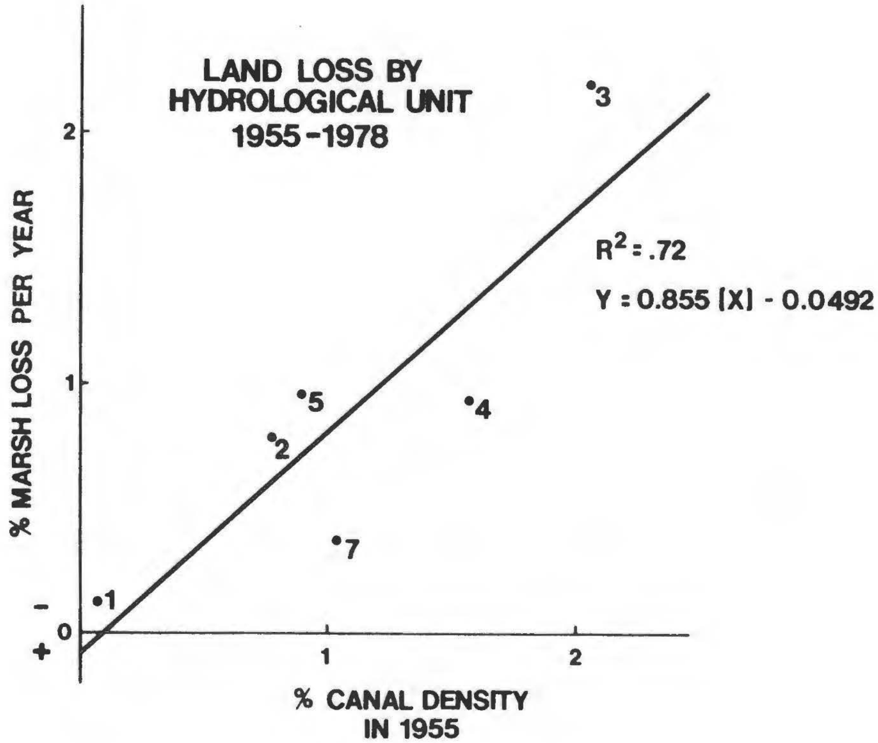


Figure 2. The percent annual wetland loss as related to the average canal density for the six hydrological units of the deltaic plain (from Wicker 1980).

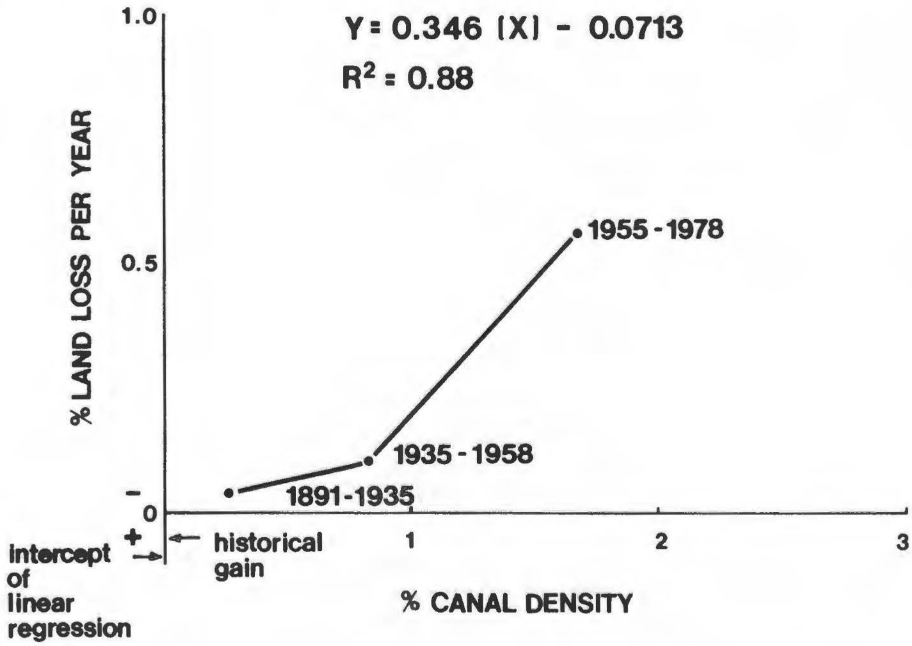


Figure 3. Land loss for three intervals between 1891 to 1978 in relation to the average canal density for those intervals. The intercept of a simple linear regression based on these three points is compared with the historical net gain for the last 7000 years (Gagliano 1973; Wicker 1980; Gagliano et al. 1981).

Table 1. Canal area expressed as a percentage of land area in the deltaic plain in 1955 and 1978 for each of seven hydrological units. Data from Wicker (1980).

UNIT	REGION	1955 %	1978 %
1	Lake Pontchartrain	0.08	0.33
2	Breton Sound	0.79	1.82
3	Mississippi River Delta	2.05	3.70
4	Barataria Bay	1.58	3.45
5	Timbalier and Terrebonne Bays	0.90	2.59
6	Atchafalaya Delta	1.18	3.66
7	Vermilion Bay	1.06	2.24

redistribution of sediments is greatest near the coast, particularly for the fine-grained sediments of the delta tip (Coleman 1976).

We therefore assigned a delta age based on Frazier's (1967) maps and a distance to the coast for each mapping unit. Land loss was higher nearer the coast in younger delta substrates. But within groups of similar soils, the same pattern emerged: (1) land loss rate was directly related to canal density, and (2) land loss rate was very near zero when canal density was zero. An example of the analysis is shown in Figure 4. The only exception was the Atchafalaya delta where land building is occuring. The direct relationship otherwise holds for land areas both near and far from major sediment sources. Proportionally, more land is lost per canal in younger rather than older deltas, and in areas nearer the coast. New "holes" or ponds in the marsh also appear in association with canals and away from natural channels (Figure 5).

A summary of our present linear regression analyses of canal density vs. land loss rates is in Table 2. There is a consistent pattern within similar substrate types, among hydrological units, and across the coast for the three survey intervals since 1890. Further, the estimate of the land loss that would occur at zero canal density ranges from 10% of the present total land loss rate to a net gain. The average "intercept estimate" of the three methods, (A, B, and C in Table 2) is almost exactly the same as the historical average land increase we might expect, judging from the 7,000-year history of land building in the coastal zone.

Put another way, the indication is that canal densities, since 1890, are high where land loss is high and near zero where land loss is zero (except for the Atchafalaya delta region) for areas with a variety of substrates and of varying distances from the coast. The slopes of the regression lines vary with delta age and distance to the coast. One

Table 2. Estimates of the residual rates of land loss excluding that explained by canal density in linear regressions [land loss = a + b (canal density)] compared with present total land losses and the historical average gain. (a = y-intercept or residual rate; n = number of observations; R^2 = coefficient of determination for the regression equation).

Interval	Region	n	R^2	a (% loss/yr)	Source
I. Analytical Determinations of Non-Canal Influences					
A. 1891-1978 in 3 intervals	Deltaic Plain	3	0.88	-0.07 (gain)	Figure 3
B. 1955-1978	Hydrological Units, excluding Atchafalaya Delta	6	0.72	-0.05 (gain)	Figure 2
C. 1955-1978	7 1/2' quadrangles:				
	1) Teche Delta, inland	7	0.61	-0.02	Scaife et al. (in press)
	2) Lafourche Delta, inland	5	0.97	+0.10	
	3) St. Bernard Delta, inland	12	0.67	+0.12	
	4) St. Bernard Delta, inland	9	0.48	-0.10	
	5) Pleistocene	5	0.92	+0.04	
	6) Lafourche, coastal	12	0.69	+0.30	
	mean ± 1 std. dev.			+0.07 ± 0.14 (loss)	
Average of A, B, and C				-0.02 (gain)	Gagliano et al.
II. Total land loss, 1955-1978	Deltaic Plain			+0.85 (loss)	Gagliano et al. 1981; Wicker 1980; USFWS data
III. Historical net gain, 7000 yr BP to present	Deltaic Plain			-0.05 (gain)	527 ha/yr (1302 ac/yr) accretion

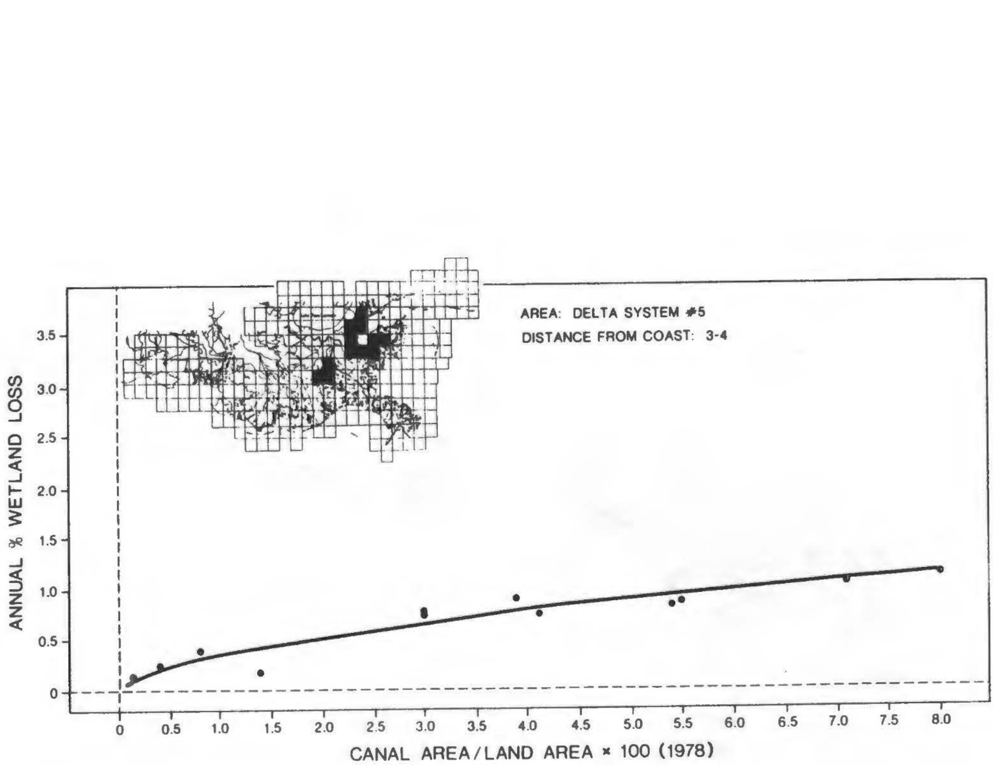


Figure 4. Land loss per 7 1/2'quandrangle for the delta system outlined in the map. Canal area is expressed as a percent of the total land area in 1978. This analysis and other examples are provided in detail in Scaife et al. (in press).

explanation might be that this relationship is the result of only the direct removal of land by the canal dredging operations, that is, the direct loss. But this is not supported by an analysis of the available data (Figure 6). Canal surface area accounts for less than 10% of the total land loss from 1955 to 1978, though from the 1930's to 1958 it amounted to 39%. Rather, the relationship must be explained on the basis of indirect impacts. It is probably associated with a combination of the canal, the dredging activity, subsequent use of the canal, and coincidental engineering (such as levees).

Given these relationships, it is worth examining the present trend in canal area added each year (Figure 7). The Louisiana Department of Natural Resources has records of the canal area it has permitted for the first 105 days of 1981. We prorated that amount for 365 days. Since the actual area of a canal is 1.46 times the permitted area (Johnson and Gosselink 1982), the amount of new canal area added each year is still accelerating. Further, many, but not all, canals widen with age (Craig et al. 1980; Johnson and Gosselink 1982). If the amount of canal area added each year approaches anywhere near a 1% annual widening rate, an area equal to the permitted area should also be added to the 1981 estimate of new canal area. The geometric increase in canal density is thus still occurring.

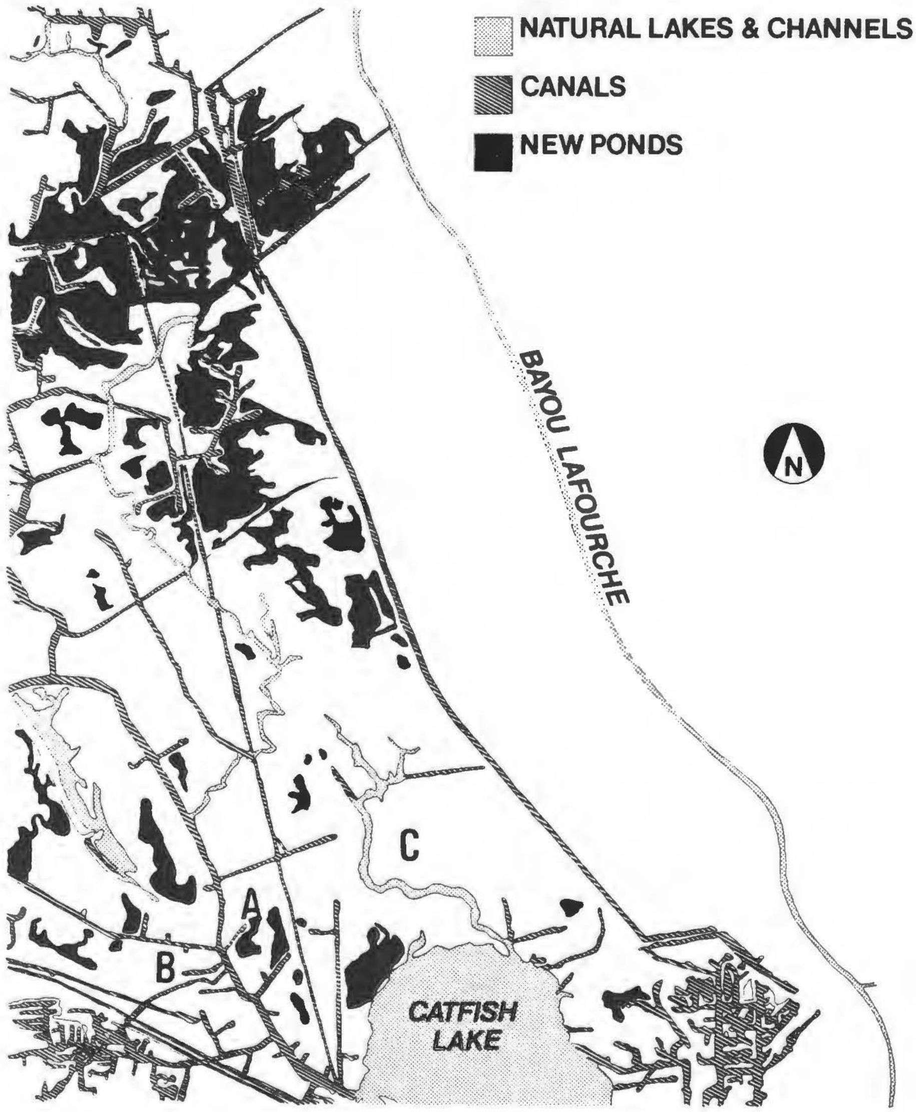


Figure 5. "New ponds" that formed in the vicinity of Golden Meadow, in southern coastal Louisiana from 1969 to 1978. Ponds that coalesce together, eroding lake edges, and eroding ponds are not shown. Ponds are black, canals are cross-hatched and the natural drainage lakes and channels are stippled. Note that all the new ponds are in the vicinity of canals and not near the one natural channel drainage basin draining into the north side of Catfish Lake.

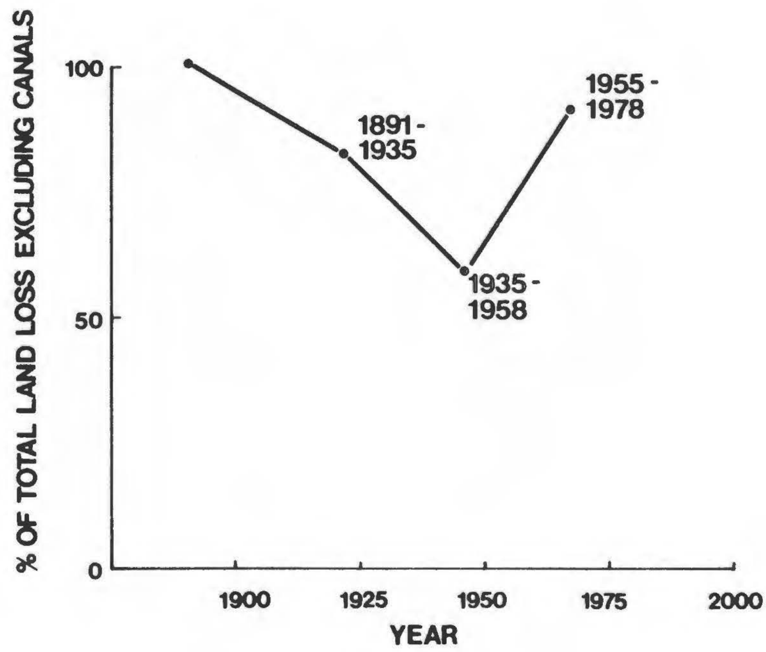


Figure 6. Land loss not directly attributable to an increase in canal density from 1890 to 1978 for three different intervals (Gagliano 1973; Wicker 1980).

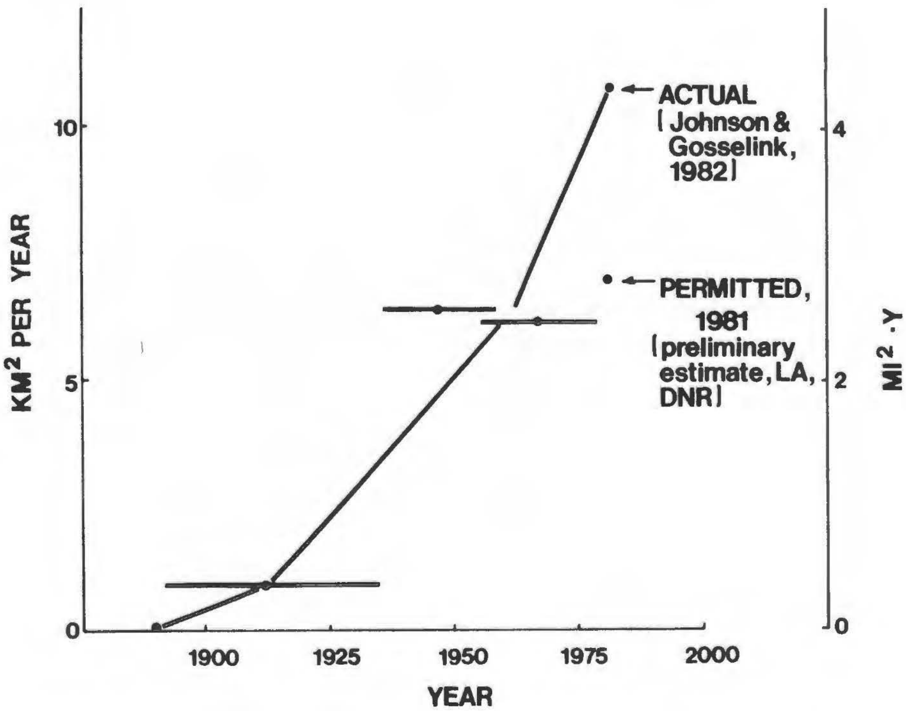


Figure 7. The area of canals added annually in the deltaic plain from 1891 based on analyses for three intervals (Gagliano 1973; Wicker 1980) extrapolated to an estimate for 1981 based on Louisiana Department of Natural Resources permits for the first 105 days (assuming 75 % in the deltaic plain) adjusted by an actual area to permit area ratio of 1.46 computed by Johnson and Gosselink 1982).

CONCLUSION

There is strong indication that canal development is directly and indirectly related to land loss rates. Causal mechanisms are still poorly understood, however. Canal densities are not only increasing through time, but accelerating. As a result, land loss rates are expected to increase as well. Since new canal dredging must now be permitted by regulatory bodies, one might argue that regulatory action could influence further canal density, and land loss rates. Perhaps fewer than a half-dozen of the first 2,000 dredging permits issued in 1981 by the Department of Natural Resources were denied (although many are modified during review), and even these were subsequently approved by the Secretary. Another solution might be to mitigate or minimize the damages of existing and new canals. We have little data on the usefulness (or damage) of the various mitigating techniques which have been suggested, such as weirs, backfilling, or spoil bank design, for regional land loss reduction. River diversion schemes and current land building in the Atchafalaya are locally important, but on a regional scale these could, at best, reduce present total land loss rates by only 5% to 10% (Day and Craig 1982).

State Senator Nunez asked at this conference, "Would there be a land loss problem if we had no canals?" Although natural and artificial deterioration of older delta lobes due to wave attack and the deficit of sediment accretion compared to subsidence and sea level rise results in localized land loss, our analyses indicate that the direct and indirect effects of canal development have greatly exacerbated the rate and geographic extent of land loss in Louisiana. Furthermore, existing canals, through indirect mechanisms, will continue to encourage significant wetland loss, compounding the effects of new canals. With canals, the historic inevitability of local delta erosion and statewide gain is altered; local erosion has expanded statewide, and there is a net land loss of enormous magnitude.

We have inherited a truly major problem, but are doing little to solve it. Any management plan that is to successfully combat coastal erosion on a meaningful level must therefore address canal impacts and management. For example, increases in barrier island erosion rates may be more symptomatic of the problem, than, as some have argued, causal. As the area of wetlands behind the islands erodes, more water is flushed in and out with each tide and storm. This enlarged tidal prism carries more salt water, has greater system-wide currents, and alters sediment and water balances for plants that bind the soil and barrier island dunes. The system-wide perturbation, caused by canals, of estuarine salt balance, hydrology, sediment supply, and plants requires an integrated study by a variety of experts. One grand experiment has been conducted for 90 years and we can now see the results. Perhaps we can learn from it and proceed in a less damaging manner in the future. The present attitude of the State of Louisiana seems to be that the effect of canals is ancillary or, at lease, not major. We estimate that canals are the causal agents for at lease a majority (perhaps as much as 90%) of the present land loss, yet the Joint Commitees of Natural Resources of the Louisiana Legislature (1981) included no major programs for mitigation of canal effects among the $38 million in projects recommended for the first phase of implementation of the Coastal Environmental Protection Trust Fund Act.

ACKNOWLEDGMENTS

We thank E. Swenson for his comments, K. Westphal and C. Harrod for drafting the figures, and Jo Paula Lantier for typing the manuscript.

LITERATURE CITED

Adams, R.D., B.B. Barrett, J.H. Blackmon, B.W. Gane, and W.G. McIntire. 1976. Barataria Basin: geologic processes and framework. Louisiana State Univ., Center for Wetland Resources, Baton Rouge. Sea Grant Publ. LSU-T-76-006.

Barrett, B.B. 1970. Water measurements of coastal Louisiana. Louisiana Wildlife and Fisheries Commission, U.S. Department of the Interior Fish and Wildlife Serv., Bureau of Commercial Fisheries Project. 2-22-T, P.L. 88-309.

Chabreck, R. 1972. Vegetation, water, and soil characteristics of the Louisiana coastal region. Louisiana Agricultural Experiment Station, Baton Rouge. AEA Inf. Ser. 25.

Coleman, J.M. 1976. Deltas: Processes of deposition and models for exploration. Continuing Education Publishing Co., Inc. Champaign, Ill.

Craig, N.J., R.E. Turner, and J.W. Day, Jr. 1980. Wetlands losses and their consequences in coastal Louisiana. Z. Geomorph. Suppl. 34:225-241.

Day, J.W., Jr., and N.J. Craig. 1982. Comparison of effectiveness of management options for wetland loss in the Louisiana coastal zone. Pages 231-237 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, Biological Services Program, Washington, D.C. FWS/OBS-82/59.

Frazier, D.E. 1967. Recent deltaic deposits of the Mississippi River: their development and chronology. Trans. Gulf Coast Assoc. Geol. Soc. 17:287-315.

Gagliano, S.M. 1973. Canals, dredging, and land reclamation in the Louisiana coastal zone. Louisiana State Univ. Center for Wetland Resources, Baton Rouge. Hydrologic and Geologic Studies of Coastal Louisiana. Rep. 14.

Gagliano, S.M., P. Light, and R.E. Becker. 1971. Controlled diversions in the Mississippi delta system: an approach to environmental management. Louisiana State Univ., Center for Wetland Resources, Baton Rouge. Hydrologic and Geologic Studies of Coastal Louisiana. Rep. 8.

Gagliano, S.M., K.J. Meyer-Arendt, and K.M. Wicker. 1981. Land loss in the Mississippi River deltaic plain. Trans. Gulf. Coast Assoc. Geol. Soc. 31:295-300.

Gosselink, J.G., C.L. Cordes, and J.W. Parsons. 1979. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas. Vol. I. U.S. Fish and Wildlife Service, Office of BiologicalServices FWS/OBS-78/9. 302 pp.

Johnson, W.B., and J. G. Gosselink. 1982. Wetland loss directly associated with canal dredging in the Louisiana coastal zone. Pages 60-70 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, Biological Services Program, Washington, D.C. FWS/OBS-82/59.

Morgan, J.P. 1963. Louisiana's changing shoreline. Louisiana State Univ. Coastal Stud. Inst., Baton Rouge. Tech. Rep. 16, Pt. D. 13 pp.

Scaife, W., R.E. Turner, and R. Costanza. In press. Indirect impact of canals on recent coastal land loss rates in Louisiana. Environ. Manage.

Wicker, K.M. 1980. Mississippi deltaic plain region ecological characterization: a habitat mapping study. A user's guide to the habitat maps. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-79/07.

PANEL DISCUSSION

CAUSES: PHENOMENA DIRECTLY RELATED TO HUMAN ACTIVITIES

Roger Saucier, Moderator

Andre Delflache, James G. Gosselink, R. Eugene Turner, Michael Lyons, Joan Phillips, and **John Woodard**, Panelists

Joan Phillips: The environmental community has been interested in the problem of wetland loss in Louisiana for over 10 years. The environmental community coalesces on the one idea of preserving renewable resources which produce revenue, food and cultural heritage. On the other hand, non-renewable resources must also be conserved. We must not let renewable resources be destroyed in the process of extracting nonrenewable resources. Environmentalists have been expressing concern and appearing before legislators on the need to protect renewable wetland resources in the exploitation of nonrenewable resources since at least 1976. We should have been mitigating these impacts since the depth of the wetlands loss problem was recognized. We must begin the process of correcting these mistakes immediately.

We have had some progress including the adoption of a coastal zone management program and permitting of wetlands activities under this program. But is it working? Are new canals being shortened or eliminated where possible? Are we using all techniques feasible and practicable to preserve and conserve renewable resources? My concern is that we are not presently accomplishing these objectives. Out of 1,300 coastal use permits issued thus far by the Louisiana Department of Natural Resources, two were appealed, but a stay order to halt the activities could not be gained before the appeals were heard by the Coastal Commission. There is no communication on the feasibility of directional drilling to reduce the need for wetland dredging between the Coastal Management Section and the Office of Conservation, both within the Louisiana Department of Natural Resources. When is the expertise and staff necessary for thorough evaluation of permits going to be available?

The nonrenewable resources will be there in years to come if not exploited now, thus we must stop now the destruction of renewable wetland resources in this exploitation. Other states seem to be recognizing the importance of water resources. For example, Florida has enacted a law placing a 5-cent sales tax on every $100 of property sold to be used for protection of water resources. Such a continuous source of funding is needed in Louisiana to protect water resources, enable sound permitting and acquire important wetlands.

The environmental community will be there to at least assure that environmental laws are implemented. We charge the scientific community to develop the data necessary to determine what kinds of activities and in what intensity can be allowed in wetlands without jeopardizing production of renewable resources. We ask the public to join in our pursuit of wetlands preservation. We ask the Legislature to fund the acquisition of knowledge and sound management and protection of wetland resources.

John Woodard: I am involved in the management of surface resources of extensive wetlands in Terrebonne and Lafourche parishes for my company, Tenneco LaTerre. We lease surface resources for fur trapping, alligator hunting, waterfowl and game hunting. These uses require some activities including the placement of canals to utilize the resources to their fullest. Many of the canals constructed for this purpose are now wide waterways, bearing out what erosion has done. About 40 years ago most large land owners became involved in an extensive marsh management program mainly for hunting and trapping interests. We recognized how critical it is to maintain stable water levels as they affect the integrity and productivity of the marsh. These management programs have included construction of levee systems, mud plugs, and water control structures that allow tidal exchange and have been quite successful in reducing the impacts of later operations such as oil and gas operations. Although the deterioration from the dredging of canals has not been reduced to a minimum, enormous strides have been made because the land owners have been able to work with the oil and gas operators to suggest designs which reduce these rates of deterioration. Discussions among the land owners, oil and gas operators, and regulatory agencies generally result in further refinement to reduce the amount of detrimental activity required to drill a well or place a pipeline. Energy production is very important for the State and Nation, thus we need logical plans which allow continued energy production together with needed environmental protection.

David Mekasski: Where wetland protection through such means as directional drilling is not economically feasible, what are the benefits and limitations of mitigating these effects through restoration of wetlands in another areas?

Michael Lyons: A number of companies have on the suggestion of Federal agencies or the Coastal Management Section backfilled existing canals. We are not sure what the benefits of backfilling are, but much more backfilling is being done today and has been done within the last two years.

Unidentified speaker: We have seen aerial photographs of intense development of canals, sometimes with parallel, adjacent access canals. Do oil companies cooperate and use existing access canals where possible to reduce this effect?

Michael Lyons: In the early years of development that was more prevalent, but there is not much of that today.

Joel Lindsey: There have been some problems in one company gaining access through another's canal. There may be legal constraints. But it is very difficult now for companies to dredge parallel canals nearby because of permitting review.

Len Bahr: Is there any technical reason for leaving wellhead access canals at their original depth and width after the drilling barge is removed? Couldn't they be serviced by smaller vessels requiring smaller access channels?

John Woodard: Servicing of the well with a workover rig requires nearly the same draft as the initial drilling rig.

Johannes van Beek: Given that drilling is likely to continue, how do we determine the processes which affect the ecosystem through hydrological modification by canals and the procedures to mitigate adverse effects?

R. Eugene Turner: It hasn't been until recently that we have even had sufficient data allowing the correlations which indicate the magnitude of the canal problem. The experiences from management practices such as employed by large land owners have not been quantified with hard data. Thus, we are presently unable to describe the processes which will govern the effectiveness of mitigation and there is not much effort being presently expended to do so. Experimental approaches are required to describe the specific causes of canal-induced wetlands loss and the effectiveness of mitigative procedures.

Joan Phillips: We have to put our money where our mouth is and develop the funding sources which will allow us to do what Dr. Turner suggested. What we need is a "superfund" for wetlands. There is evidence that damage is being done, thus we should slow down development to a manageable point to allow the assessment of the effectiveness of ways to deal with these impacts. Instead of specific mitigation on each project, perhaps there can be a tax collected to fund investigations and subsequent improved accretion and nourishment of wetlands.

James Gosselink: I have a little different prespective. I think we know the major processes--subsidence accelerated with hydrological modification due to canals. Management for specific purposes changes natural relationships; one component may become more productive at the expense of another. An example is the extensive canal development in wetlands in southwestern Louisiana to manage for waterfowl and furbearers. Recent data show that land loss within these impounded areas is accelerated. Management can not do better than nature has managed to do over eons. We need a big plan that handles social displacement and maximizes natural processes such as Atchafalaya delta formation. I think we are piddling around the edges with backfilling. As important as it is in the short run, it really is not going to address the long-run problems.

Charlotte Fremaux: Are there long-term plans being developed which include the various piecemeal activities altering coastal wetlands? For example, does the Corps of Engineers have a plan encompassing their various projects such as navigation channels?

David Stuttz: To my knowledge there is no grand scheme. The Corps does not go out and invent projects but responds to identified needs. In a limited way we address broader scale planning through the permit process.

Sue Hanes: I am with the Corps of Engineers Planning Division. As we write an environmental impact statement we consider the impact of an activity on the area in the context of cumulative impacts of various activities such as oilfield canals, navigational dredging, and levee construction.

Paul Yakupzack: What effect will the deregulation of natural gas have on drilling activities in wetlands?

Michael Lyons: The effect is uncertain. The deregulation of oil did not result in a great increase in drilling activity in south Louisiana. The number of wells drilled per year has gone from 1,800 in the 1950's and 1960's to 1,100 to 1,200 presently. This downward trend will continue because the remaining undiscovered resources are generally in small pockets.

Pat Mason: What is the feasibility of directional drilling in lieu of access canals in wetlands?

Michael Lyons: Directional drilling is not generally viable because of technical and legal problems. Exploratory wells require straight vertical drilling for geological interpretation and intercepting several stratographic objectives. There is also the problem of legal disputes regarding drilling from one land owner's property to structures under that of another. A directionally drilled well is approximately 50 percent more expensive than a straight well and this frequently makes it uneconomical to drill the project.

Walter Sikora: I disagree with the doomsday approach expressed by Jim Gosselink. Human activities are an important cause of land loss and good data are required in order to deal with them. It is not acceptable to our society to stop drilling in wetlands, thus we need to develop ways it can be accomplished without unacceptable environmental losses.

James Gosselink: I do not disagree. In response to the short-term outlook, we need better information but can not afford to delay action because everyone cannot be satisfied. Nature has had a long time to optimize biological-environmental relationships. Any human changes which interfere with them will be detrimental. Therefore, if we do not know the consequences of an action we should take a conservative position and try to keep as much as possible to natural landscape features and processes. I suggest, however, that we need to look more than we have toward the long term, where many of these short-term issues will be insignificant.

Len Bahr: I would argue that the cost differential between directional drilling and conventional approaches involving wetlands dredging may not be that great if the environmental costs were borne by the developer. It may be much cheaper to society in the long run to directionally drill than to dredge new canals.

Michael Halle: Why should the oil industry be exempt from the type of regulation imposed on strip-mining of coal with regard to restoring the land to contours enjoyed before mining? What does it cost to backfill canals?

Michael Lyons: Backfilling wetland canals and restored strip-mined land differ in their effectiveness. The dredged material backfilled in wetland canals will generally not restore the original landscape. I do not know the specific cost of backfilling, but it is less expensive than directionally drilling.

Donald Boesch: Would Dr. Saucier offer some direction regarding wetland restoration based on his experiences in habitat development from dredged material?

Roger Saucier: It is generally unrealistic to use fine-grained material dredged with a dragline and stored subaerially to refill a canal. The technology exists, however, and is eminently practicable, if local geography permits, to hydraulically dredge material from one canal to another canal or pond and create a wetland similar to that displaced.

Donald Moore: Even though leveling of spoil banks may not be able to totally restore wetlands displaced by a canal, it can restore the area where the spoil was placed and return it to a coastal wetland elevation.

Roger Saucier: While it may not be practical to use material which has been in spoil banks for a great amount of time for wetlands creation, spoil banks can be degraded even though the material may have experienced a 50 percent volume reduction. This reduces the effects of the spoil banks themselves, including accelerated subsidence in the immediate area, and blockage of surface drainage and overland flow.

Murray Hebert: I hear many complaints from permit applicants that requirements are overly broad and restrictive and, in many cases, counterproductive.

John Woodard: As a large land owner, my company is usually able to work out such problems. Smaller land owners and independent operators may have more problems because they lack areas in which to mitigate or the resources to accomplish mitigation. As environmental concerns increase it has become a more difficult process to obtain permits, but we have been generally successful if we modify the project to obtain the permit.

Michael Lyons: I do not think regulatory programs have been overly restrictive. Often Federal agencies suggest that the feasibility of directional drilling or backfilling should be studied but do not absolutely require either. If these would be absolutely required, it may be overly restrictive. Backfilling, for example, may be effective in some areas and not others.

CONSEQUENCES: EFFECTS ON NATURAL RESOURCES PRODUCTION

THE EFFECT OF COASTAL ALTERATION ON MARSH PLANTS

Robert H. Chabreck
School of Forestry and Wildlife Management
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

The Louisiana coastal marsh is subdivided into four vegetative types: saline, brackish, intermediate, and fresh. The types occur in bands generally paralleling the coastline and contain characteristic water salinity levels and plant communities. Activities of man coupled with natural processes, such as subsidence and erosion, have removed many natural tidewater barriers and reduced freshwater flow through the marshes. As a result, saltwater intrusion from the Gulf of Mexico has increased and the boundaries of vegetative types have been altered. The saline vegetative type has greatly increased in size and the brackish and intermediate types have shifted inland. This has caused a drastic reduction in the size of the fresh vegetative type.

INTRODUCTION

The coastal marshes of Louisiana are one of the most productive habitats for fish and wildlife in North America. The high production of fish and wildlife is directly related to the abundance and diversity of photosynthetic plants produced within the area. These plants are the basic source of energy for dependent animal populations, and conditions enhancing plant growth serve to benefit fish and wildlife. On the other hand, activities which alter environmental conditions can be detrimental to plants and drastically affect fish and wildlife populations.

Activities which have had the most damaging impact on marsh vegetation are canal construction associated with oil and gas exploration, pipelines, navigation, and flood control; permanent drainage for agriculture, industry, and urbanization; modified drainage patterns associated with levee and highway construction and spoil deposits; and dredge and fill operations. The activities of man coupled with natural processes such as subsidence and erosion have greatly altered environmental conditions and thereby changed the distributional patterns of plants. Only with a complete understanding of the distributional patterns and the environmental conditions necessary for optimum plant growth can the magnitude of coastal alteration be assessed.

THE COASTAL REGION OF LOUISIANA

Marshes of the Louisiana coastal region encompass an area of approximately 1.7 million ha and span the full coastline of the State. The marshes extend inland for distances ranging from 24 to 80 km and reach their greatest width in southeastern Louisiana.

Water levels in these marshes are greatly affected by rainfall, tides, and local drainage patterns. Water levels are typically within 30 cm of the marsh surface with exceptions occurring with storm tides or during periods of excessive rainfall or prolonged drought. The effects of tides are greater in areas nearer the Gulf of Mexico, however, tide levels in the gulf also affect water drainage from interior marshes. In addition to its effect on marsh water levels, tidal action in the gulf also provides a source of highly saline water to the marshes. The daily fluctuating action causes highly saline waters to move inland and mix with advancing fresh water to form a vast estuarine basin. The mixing of salt water from the gulf and fresh water from inland sources provides a horizontal stratifiction of water salinities. Water salinities range from highly saline (20 to 25 ppt) near the coastline and gradually decline inland until a zone of fresh water is reached along the northern perimeter of the marsh region.

Penfound and Hathaway (1939) studied the coastal marsh in southeastern Louisiana and noted that water salinity and water depth were major factors governing plant species distribution. They subdivided the marsh into types on a basis of salt concentration of free soil water, designated these types as saline, brackish, slightly brackish (intermediate), and fresh, and described the plant associations within each type. The marsh types along the entire Louisiana coast were mapped by Chabreck et al. (1968) and Chabreck and Linscombe (1978) on a basis of the plant associations described by Penfound and Hathaway (1939). Chabreck (1972) described the plant species composition and soil and water characteristics of each marsh type.

DESCRIPTION OF MARSH TYPES

Marsh vegetative types along the Louisiana coast generally occur in bands paralleling the coastline. The vegetative types are comprised of characteristic associations of plant species with similar salinity tolerances (Table 1).

Saline Vegetative Type

The saline vegetative type borders the shoreline of the Gulf of Mexico and is subject to daily tidal fluctuations. This type forms a narrow band in the chenier plain of southwestern Louisiana, but is very extensive in the deltaic plain of southeastern Louisiana. The two regions combine to form a total salt marsh area of 270,000 ha (Chabreck 1970). The saline type of the deltaic plain is dissected by numerous embayments and tidal inlets and as a result is exposed to rapid and drastic tidal action. The shoreline of the chenier plain is fringed by an almost continous beach deposit. The beach restricts intrusion of gulf waters, and delays runoff of fresh water.

Water salinities average 18.0 ppt (range: 8.1 to 29.4 ppt), and soils have a lower organic content (mean: 17.5%) than fresher types located further inland. Vegetation within this type consists of few species. The species are salt-tolerant and dominated by Spartina alterniflora, Distichlis spicata, and Juncus roemerianus (Table 1).

Brackish Vegetative Type

The brackish vegetative type is further removed from the influence of highly saline gulf waters than the saline type, but is still subject to daily tidal action. The brackish type is a major vegetative type of coastal Louisiana and comprises 520,000 ha. Normal water depths exceed that of saline marsh and soils contain higher organic content (mean:

Table 1. Plant species composition of the marsh types in the Louisiana coastal marshes (Chabreck 1970).

Scientific Name	Colloquial Name	Vegetative Type (Percentage)			
		Saline	Brackish	Intermediate	Fresh
Batis maritima	Saltwort	4.41	0	0	0
Distichlis spicata	Saltgrass	14.27	13.32	0.36	0.13
Juncus roemerianus	Black rush	10.10	3.93	0.72	0.60
Spartina alterniflora	Smooth cordgrass	62.14	4.77	0.86	0
Eleocharis parvula	Dwarf spikerush	0	2.46	0.49	0.54
Ruppia maritima	Widgeongrass	0	3.83	0.64	0
Scirpus olneyi	Olney bulrush	0	4.97	3.26	0.45
Scirpus robustus	Saltmarsh bulrush	0.66	1.78	0.68	0
Spartina patens	Marshhay cordgrass	5.99	55.22	34.01	3.74
Bacopa monnieri	Waterhyssop	0	0.92	4.75	1.44
Cyperus odoratus	Flatsedge	0	0.84	2.18	1.56
Echinochloa walteri	Walter's millet	0	0.36	2.72	0.77
Paspalum vaginatum	Seashore paspalum	0	1.38	4.46	0.35
Phragmites communis	Roseau cane	0	0.31	6.63	2.54
Alternanthera philoxeroides	Alligator weed	0	0	2.47	5.34
Elocharis sp.	Spikerush	0	0.82	3.28	10.74
Hydrocotyle umbellata	Pennywort	0	0	0	1.93
Panicum hemitomon	Maidencane	0	0	0.76	25.62
Sagittaria falcata	Bulltongue	0	0	6.47	15.15
Other species		2.43	5.09	25.26	29.10
TOTAL		100.00	100.00	100.00	100.00

31.2%). Water salinities average 8.2 ppt (range: 1.0 to 18.4 ppt). This marsh type characteristically contains numerous small bayous and lakes.

The brackish type contains greater plant diversity than the saline type but is dominated by two perennial grasses, Spartina patens and Distichlis spicata (Table 1). An important wildlife food plant of brackish marsh, Scirpus olneyi, grows best in tidal marsh free from excessive flooding, prolonged drought, and drastic salinity changes. The species is, however, often crowded out by the domiant grasses, particularly S. patens.

Intermediate Vegetative Type

The intermediate vegetative type lies inland from the brackish type and occupies an area of 280,000 ha. This type receives some influence from tides and water salinities average 3.3 ppt (range: 0.5 to 8.3 ppt). Water levels are slightly higher than in the brackish type, and soil organic content averages 33.9%. Plant species diversity is high and the area contains both halophytes and freshwater species used as food by a wide variety of herbivores. Spartina patens dominates the intermediate type as it does the brackish type, but to a lesser degree. Other common plants are Phragmites communis, Sagittaria falcata, and Bacopa monnieri (Table 1).

Fresh Vegetative Type

The fresh vegetative type occupies the zone inland from the intermediate type and south of the Prairie formation and Mississippi River alluvial plain. In many areas the fresh type is adjacent to or intermixed with forested wetlands (swamp). The fresh vegetative type encompasses an area of 530,000 ha and is equal to the brackish type in size. The type is normally free from tidal influence and water salinities average only 1.0 ppt (range: 0.1 to 3.4 ppt). Because of slow drainage, water depth and soil organic content (mean: 52.0%) are greatest in the fresh type. In some fresh marshes, soil organic matter content exceeds 80% and the substrate for plant growth is floating organic matter referred to as flotant by Russell (1942). The type also supports the greatest diversity of plants and contains many species which are preferred foods of wildlife. Dominant plants include Panicum hemitomon, Eleocharis spp., Sagittaria falcata, and Alternanthera philoxeroides.

COASTAL ALTERATIONS

Stratification of the Louisiana coastal marshes into distinct vegetative types has historically been maintained naturally by surface features and hydrological processes. The advance inland of saline gulf waters was usually restricted by natural barriers, such as beaches, cheniers, low marsh ridges, and natural levees along streams and lakes. The meandering and shallowing of coastal streams as they moved inland reduced their capacity to carry large volumes of salt water. The discharge of fresh water from inland sources through coastal streams also served to dilute and prevent the inland advancement of saline tide waters.

Activities of man including leveeing, canal dredging, and stream channelization coupled with natural processes, such as subsidence and erosion, have reduced the effectiveness of saltwater barriers and altered hydrological processes. Canals and channelized streams which connect tidal saltwater sources to inland marshes of lower salinity function in two ways to alter vegetative types. During low tides in the Gulf of

Mexico, the canals flush fresher water from interior marshes and lower water levels. Then, with high tides in the gulf, salt water is able to move farther inland. The process is gradual, and a period of several years may be necessary for the effects to become evident.

As water salinity increases in an area, plants unable to tolerate the higher salinity die and are gradually replaced by species adapted to the new salinity regimes. Greatest damage to plants takes place when fresh marsh containing high levels of soil organic matter is subjected to water of much greater salinity and strong tidal action. Plants in the area are killed by increased water salinity, and the organic substrate becomes loose and disorganized without plants roots to hold it together. As tide water moves through the area, small amounts of organic matter are picked up by the current and flushed out through tidal channels. Before new species can become established, marsh elevations may drop 10 to 20 cm over broad areas. Open ponds and lakes thus develop and productive marshland is lost. Thousands of hectares of marsh in the deltaic plain of southeastern Louisiana have been thus affected. The chances of such areas again supporting emergent plant growth is very unlikely unless corrective action is taken on a large scale.

Prior to levee construction along the Mississippi River, overbank flooding would send vast quantities of fresh water and alluvium down former channels of the river and other streams emptying into the gulf on the deltaic plain. In many areas flood water from the Mississippi River would reach the Gulf of Mexico via sheet flow over the marshes.

As a result of overbank flooding, a tremendous area of fresh marsh was developed and maintained. Also, nutrient-rich sediment was added to the marsh, thus enhancing productivity and promoting land building.

Because of several disastrous floods, the Mississippi River Commission was formed in 1879, and levee construction for flood control began in 1882. Completion of the levee system required many years, but today the levee system extends southward to the active delta (approximately 100 km south of New Orleans). Approximately one-third of the Mississippi River flow is diverted through the Atchafalaya River during flood stage. The remainder is carried through the leveed channel of the Mississippi to the Gulf of Mexico.

CHANGES IN VEGETATIVE TYPES

A comparison of studies by Penfound and Hathaway (1939), O'Neil (1949) and Chabreck (1970) disclosed that the plant species composition within vegetative types changes very little over a period of several decades. Environmental conditions or successional stages may cause certain species to become abundant locally. On a coastwide basis, however, the species composition of individual types has remained relatively stable. Changes most noticable were the decline of three-cornered grass (<u>Scirpus olneyi</u>) in the brackish type (Palmisano 1967) and sawgrass (<u>Cladium jamaicense</u>) in the intermediate and fresh types (Valentine 1977). In recent years, smooth beggartick (<u>Bidens laevis</u>) has greatly increased in the fresh vegetative type (Kinler et al. 1981).

Although little modification has taken place within vegetative types, considerable change has been noted among vegetative types during the past three decades. This change was caused by coastal alteration which resulted in increased saltwater intrusion and general shifts in the boundaries of vegetative types.

The location of vegetative types in the Louisiana coastal marsh was delineated during previous investigations by O'Neil (1949), Chabreck et al. (1968), and Chabreck and Linscombe (1978). Each investigation represented a different time period and provided a base from which temporal changes in vegetative types could be evaluated.

Changes in the location of the saline and brackish vegetative types over a period of approximately 25 years were determined by comparing the vegetative type map by O'Neil (1949) with that by Chabreck et al. (1968). The saline type in the chenier plain in southwestern Louisiana changed very little over the period and occupied a narrow zone about 0.8 km wide adjacent to the Gulf of Mexico. Comparisons of the saline types in the deltaic plain showed a different situation, however. Measurements from the earlier study may revealed that the saline vegetative type extended inland for an average of 9.3 km from the gulf shoreline, but the 1968 map placed this type 12.7 km inland, an encroachment averaging 3.4 km over the 25-year period.

The brackish vegetative type was also compared on the two maps. Measurements revealed that the brackish marsh extended inland an average of 14.5 km during the 1941-45 period (O'Neil 1949) and 15.6 km in 1968, a retreat of only 1.1 km. Considerable differences were noted, however, between the chenier plain and deltaic plain marshes. The O'Neil map shows the deltaic plain brackish type extending inland for an average of 20.0 km; but, in 1968, the northern boundary of this type was 26.1 km inland. In contrast, the brackish type of the chenier plain extended inland for a mean distance of 9.0 km during the O'Neil study, but by 1968 the northern boundary of this type had advanced seaward to a line only 5.2 km inland.

Since the saline vegetative type maintained essentially the same position over the years in the chenier plain, the seaward advancement of the northern boundary of the brackish type represents a reduction in the width of this type. In fact, O'Neil (1949) shows the chenier plain brackish type as a strip 8.2 km wide, while Chabreck et al. (1968) shows this same type 4.2 km wide, a reduction of about 47 percent. The brackish type in the deltaic plain, however, actually widened during the 25-year period. During the earlier period, this type was 10.6 km wide, but by 1968, the average width had increased to 13.4 km.

The widening of the saline and brackish vegetative types in the deltaic plain resulted from saltwater intrusion from the Gulf of Mexico into the intermediate and fresh vegetative types. Increased canal dredging and stream channelization, coupled with subsidence and erosion, were major factors in the change. The reduction in the width of the brackish type on the chenier plain reflected a reduction in water salinities in that area. Factors operating to reduce water salinities during the 25-year interval included the discharge of large amounts of fresh water by the Atchafalaya River into the area plus construction of levees and water control structures to prevent saltwater intrusion.

Changes in the size of vegetative types in the Louisiana coastal marshes were determined for a 10-year period by comparing the size of types mapped by Chabreck et al. (1968) with those mapped by Chabreck and Linscombe (1978). Chabreck and Linscombe (in press) computed the size of vegetative types and areas where types had changed to either saltier or fresher conditions. They found that vegetative types had changed on 3,730 km^2 or 21.9% of the State's coastal marshland over the 10-year period. This represented a change to saltier vegetative types on 13.7% of the area and to fresher types on 8.2% of the area with a net change to saltier conditions on 5.6% of the entire coastal marshes or 950 km^2.

In 1968 the fresh vegetative type encompassed 5,260 km^2, but by 1978 it had been reduced to 4,900 km^2 (6.8%). During the same time period, the saline vegetative type increased from 3,768 km^2 to 4,105 km^2 (8.9%). Only slight changes in size were noted in the brackish and intermediate types from 1968 to 1978; the brackish type increased 96 km^2 (1.8%) and the intermediate type decreased 73 km^2 (2.6%). The brackish and intermediate types are actually transitional zones between the saline and fresh types. As a result of coastal alteration, salt water moved further inland during the 10-year interval. This caused the saline vegetation type to expand in size and the transitional zones (brackish and intermediate types) to retreat further inland with very little modification in size. Consequently, the fresh vegetative type was reduced in size, and the inland advancement of the saline vegetative type was mostly at the expense of the fresh type.

LITERATURE CITED

Chabreck, R.H. 1970. Marsh zones and vegetative types in Louisiana coastal marshes. Ph. D. Dissertation. Louisiana State Univ., Baton Rouge. 113 pp.

Chabreck, R.H. 1972. Vegetation, water and soil characteristics of the Louisiana coastal region. La. Agric. Exp. Stn. Bull. 664. 72 pp.

Chabreck, R.H., T. Joanen, and A.W. Palmisano. 1968. Vegetative type map of the Louisiana coastal marshes. Louisiana Wildlife and Fisheries Commission, New Orleans.

Chabreck, R.H., and G. Linscombe. 1978. Vegetative type map of the Louisiana coastal marshes. Louisiana Department of Wildlife and Fisheries, New Orleans.

Chabreck, R.H. and G. Linscombe. In press. Changes in vegetative types in Louisiana coastal marshes over a 10 year period. Proc. La. Acad. Sci.

Kinler, N.W., G. Linscombe, and R.H. Chabreck. 1981. Smooth beggartick, its distribution, control and impact on nutria in coastal Louisiana. Worldwide Furbearer Conference Proceedings, Frostburg State College, Frostburg, Md. 1:142-154.

O'Neil, T. 1949. The muskrat in the Louisiana coastal marshes. Louisiana Department of Wildlife and Fisheries, New Orleans. 159 pp.

Palmisano, A.W. 1967. Ecology of Scirpus olneyi and Scirpus robustus in Louisiana coastal marshes. M.S. Thesis. Louisiana State Univ., Baton Rouge. 145 pp.

Penfound, W.T., and E.S. Hathaway. 1939. Plant communities in the marshlands of southeastern Louisiana. Ecol. Monogr. 8:1-56.

Russell, R.J. 1942. Flotant. Geogr. Rev. 32:74-98.

Valentine, J.M. 1977. Plant succession after saw-grass mortality in southwestern Louisiana. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 30:634-640.

EFFECTS OF WETLAND DETERIORATION ON THE FISH AND WILDLIFE RESOURCES OF COASTAL LOUISIANA

David W. Fruge

U.S. Fish and Wildlife Service
P.O. Box 4305
Lafayette, LA 70502

ABSTRACT

The vast wetlands of the Louisiana Coastal Region (LCR) are of national importance to fish and wildlife. These wetlands are winter habitat for one-fourth of the North American dabbling duck population, a large portion of the Mississippi Flyway's diving ducks, and over 400,000 geese. Coastal Louisiana also supports numerous other migratory birds, many of which nest in its wetlands. The LCR marshes produce the largest fur harvest in North America, and support the largest volume of estuarine-dependent fish and shellfish landings in the United States. Fish and wildlife related recreation in the LCR is also extensive, including over 5 million man-days of saltwater fishing in 1975 and 676,000 man-days of waterfowl hunting during the 1977-78 season.

Prior studies documented an annual land loss rate of over 42.7 km^2(16.5 mi^2)/yr in the LCR. More recent investigations indicate that this rate of wetland loss has more than doubled since 1956. Wetland deterioration, which is partially attributable to natural causes, has been greatly accelerated by human influences such as navigation channel excavation, agricultural drainage, and construction of mainline Mississippi River levees that have prevented freshwater and sediment overflow into adjacent subdelta marshes. Continued wetland deterioration may lead to serious declines in estuarine-dependent fish and shellfish harvest, fur catch, waterfowl habitat, and related fish and wildlife productivity.

The U.S. Fish and Wildlife Service has long advocated freshwater diversion for habitat improvement in the Mississippi deltaic plain region and is presently participating in the evaluation of several freshwater diversion sites being investigated by the U.S. Army Corps of Engineers. It is anticipated that marsh restoration measures involving freshwater diversion and other approaches will also be financed by the State of Louisiana through its Coastal Environmental Protection Trust Fund.

INTRODUCTION

Area Setting

The Louisiana Coastal Region (LCR) contains a vast expanse of valuable wetlands. Chabreck (1972) estimated that this area contained approximately 1 million ha (2.5 million acres) of fresh to saline marsh, 0.7 million ha (1.8 million acres) of ponds and

lakes, 0.9 million ha (2.2 million acres) of bays and sounds, and over 50,000 ha (125,000 acres) of bayous and rivers in 1968. The LCR has been divided into two main physiographic units (Morgan 1973): the deltaic plain of the central and eastern portions and the chenier plain of the western portion. Both of these regions have been developed over the past 5,000 years by a series of prograding and overlapping deltaic lobes composed of sediments transported by the lower Mississippi River and its distributaries. Both the deltaic plain and the chenier plain have been the subject of extensive ecological characterization efforts by the U.S. Fish and Wildlife Service's National Coastal Ecosystems Team. Approximately 74% of Louisiana's coastal marshes occur in the deltaic plain, while 26% are found in the chenier plain.

Importance to Fish and Wildlife

Fisheries. Louisiana consistently leads the United States in volume of commerical fishery landings. Nearly 3.7 billion kg (1.7 billion lb) of commercial fish and shellfish, worth approximately $190 million at dockside, were landed in Louisiana during 1978 (National Marine Fisheries Service 1979). The bulk of this catch is composed of estuarine-dependent species including menhaden, Atlantic croaker, seatrout, spot, red drum, blue crab, brown shrimp, white shrimp, and American oyster. The LCR also supports a large recreational fishery. Approximately 580,000 persons expended over 5 million saltwater angling days in the area in 1975, spending over $35 million (U.S. Fish and Wildlife Service 1977). Approximately 373,000 man-days were spent sport shrimping in the LCR in 1968 (U.S. Fish and Wildlife Service 1976), and present effort is believed to be much higher.

Wildlife. The Louisiana coastal marshes are of great importance to migratory waterfowl, providing winter habitat for more than two-thirds of the entire Mississippi Flyway waterfowl population in recent years (Bellrose 1976). Palmisano (1973) noted that one-fourth of the North American puddle duck population winters in these wetlands, with peak numbers of over 5.5 million of these birds recorded during December 1970. Coastal Louisiana's wetlands also support over one-half of the continental mottled duck population, with fall populations of 75,000 to 120,000 birds reported (Bellrose 1976). Diving ducks are also abundant in the Louisiana coastal marshes and adjacent waters during fall and winter. More than 90% of the Mississippi Flyway's 870,000 lesser scaup winter in Louisiana, primarily in its coastal zone (Bellrose 1976). In addition, nearly 38% of the canvasbacks that winter in the Mississippi Flyway occur in Louisiana, mostly in Six Mile and Wax lakes of the lower Atchafalaya basin and Atchafalaya delta (Bellrose 1976). Many ducks present in fall and spring are transients that utilize the LCR for feeding and resting enroute to or from Central and South America (Palmisano 1973). The Louisiana coastal marshes and adjacent ricefields have supported 369,000 lesser snow geese and 55,000 white-fronted geese in recent years (Art Brazda, U.S. Fish and Wildlife Service, Lafayette, Louisiana, personal communication).

The LCR wetlands provide important habitat to numerous other migratory birds. Common game species include clapper rail, king rail, sora, common snipe, purple gallinule, and common gallinule. Non-game migratory species are also abundant in the area. A total of 148 nesting colonies of seabirds, wading birds, and shorebirds representing 26 species and over 794,000 nesting adults were inventoried in the LCR during 1976 (Portnoy 1977). In addition, approximately 14 active bald eagle nests were recorded by Fish and Wildlife Service personnel in the LCR during 1980, representing the largest nesting concentration of this endangered species in the south-central United States.

Because of its extensive coastal wetlands, Louisiana has been the leading fur-producing area in North America as long as records have been kept (Lowery 1974). The Louisiana fur harvest accounted for nearly one-third of the Nation's fur take in the 1969-70 season (U.S. Fish and Wildlife Service 1971). According to the Louisiana Department of Wildlife and Fisheries (1978b), over 3.2 million pelts worth more than $24 million were taken in Louisiana during the 1976-77 season. Muskrat and nutria, primarily coastal species, accounted for nearly 90% of the pelts harvested during that period.

In recent years, alligator numbers in the LCR have exceeded 500,000, thus permitting controlled hunting in much of the area. In 1979, 16,300 alligators worth approximately $1.7 million were harvested in the LCR (Louisiana Department of Wildlife and Fisheries 1980).

The LCR supports extensive sport hunting and other wildlife-oriented recreation. For example, an estimated 676,000 man-days were spent waterfowl hunting in the LCR during the 1977-78 season (Louisiana Department of Wildlife and Fisheries 1978a), and the 1980 demand for nonconsumptive wildlife-oriented recreation in the LCR was projected at 1.14 million man-days (U.S Fish and Wildlife Service 1976).

MAGNITUDE OF WETLAND DETERIORATION IN COASTAL LOUISIANA

Early studies by Gagliano and van Beek (1970) documented a net annual land loss rate of 42.7 km^2 (16.5 mi^2) in the LCR. This estimate was based on a comparison of maps covering the periods 1931-42 and 1948-67.Recent studies of wetland loss have been conducted in the chenier plain ecosystem of southwest Louisiana and southeast Texas (Gosselink et al. 1979). Based on these studies, it was estimated that approximately 1,800 ha (4,400 acres)/yr of marsh were converted to open water, spoil deposits, or agricultural or urban uses between 1952 and 1974 in the Louisiana portion of the chenier plain. A recent study (Wicker 1980) of the Mississippi Deltaic Plain Region (MDPR) conducted for the Fish and Wildlife Service's National Coastal Ecosystems Team and the U.S. Bureau of Land Management produced dramatic results. Data obtained from planimetering habitat maps prepared for this study revealed that approximately 188,000 ha (465,500 acres) of coastal marsh were lost in the Louisiana portion of the MDPR between 1955-56 and 1978, for an annual loss rate of about 8,300 ha (20,600 acres) or 32.3 mi^2/yr. Combining this estimate with the estimated marsh loss rate of 1,800 ha (4,400 acres)/yr in the chenier plain, it is estimated that the marshes of the entire LCR are being lost at an approximate rate of 10,000 ha (25,000 acres)/yr or 100 km^2 (39 mi^2)/yr. This is more than twice the rate of 42.7 km^2 (16.5 mi^2)/yr reported by Gagliano and van Beek (1970).

CAUSES OF WETLAND DETERIORATION

Wetland deterioration in the LCR is attributed to land loss and salt water intrusion. According to Craig et al. (1979) land loss in the LCR results from an interaction of natural and man-induced impacts. Natural land loss occurs through subsidence, compaction, and erosion of the substrate following cessation of active deltaic deposition (Morgan 1973). Barrier islands and tidal inlets buffer coastal marshes from storm energy and regulate salinities. The erosion of barrier islands and widening of tidal inlets have also been identified as causes of land loss (Craig et al. 1979). Numerous man-induced alterations have accelerated natural wetland loss. Federally financed

navigation channels, mainline Mississippi River levees, and upstream diversions and flood control reservoirs have virtually eliminated overbank flooding along the lower Mississippi River. Consequently, most of the riverborne sediments are being transported past formerly active deltas and into the deeper Gulf of Mexico (Gagliano and van Beek 1970). This loss of sediment input has, except in Atchafalaya Bay, prevented large-scale delta building, and has accelerated subsidence and erosion of existing marshes. Other human causes of wetland loss include canal dredging and associated spoil disposal and drainage of wetlands for agricultural purposes (Gagliano 1973). Gagliano (1973) attributed approximately 25% of the total land loss in coastal Louisiana during the previous 30 years to oil and gas industry dredging.

Saltwater intrusion, another major cause of wetland deterioration, is occurring in many areas of the LCR. Saltwater intrusion has wide-ranging adverse effects, such as allowing encroachment of the predaceous southern oyster drill (Thais haemastoma) onto productive oyster reefs and conversion of fresher marshes to more saline types or to open water.

FISH AND WILDLIFE IMPLICATIONS OF WETLAND DETERIORATION

Fisheries

The marshes of the LCR are extremely important to the maintenance of its estuarine-dependent sport and commerical fisheries. These wetlands produce vast amounts of organic detritus, an important trophic component of estuarine fish and shellfish productivity. The marshes and associated shallow waters of the LCR are also important as nursery habitat for many estuarine-dependent species. This importance has been documented by numerous authors, such as Herke (1971), White and Boudreaux (1977), Rogers (1979), and Chambers (1980). There is growing evidence that the amount of marsh is the most important factor influencing estuarine-dependent fishery production. Turner (1979) reported that Louisiana's commercial inshore shrimp catch is directly proportional to the area of intertidal vegetation, and that the area of estuarine water does not seem to be directly associated with shrimp yields. He further noted that the loss of wetlands in Louisiana has a direct negative effect on fisheries. Although the effects are masked by large annual variations in yield, wetland losses in the LCR reported by Craig et al. (1979) are equivalent to 2.86 million km^2 (6.31 million lb) of shrimp harvest "lost" over the past 20 years (Turner 1979). Lindall et al. (1972) presented evidence that shrimp and menhaden are being harvested at or near maximum substainable yield. These species accounted for nearly 99 percent of the total volume of Louisiana's commerical fish and shellfish landings in 1976. Further evidence that this is occurring was presented by Harris (1973), who noted that any substantial decreases in marsh habitat will result in decreased estuarine-dependent fishery production. An analysis of the dependence of menhaden catch on wetlands in the LCR was conducted by Cavit (1979). The findings of this analysis suggest that menhaden yields are greatest in those LCR estuarine basins having the highest ratio of marsh to open water. Based on the evidence cited above, continued wetland loss in the LCR could lead to serious declines in its estuarine-dependent fishery.

Wildlife

Wildlife dependent on the LCR marshes face serious habitat declines as a result of future land loss and saltwater intrusion. Losses of fresh to intermediate marsh or

conversion of these wetlands to more saline types will adversely affect migratory puddle ducks, as relative abundance of these waterfowl in the LCR is highest in the fresher marsh types (Palmisano 1973). Based on rather conservative projections of declines in habitat quality and abundance in the LCR, it has been estimated that demand for waterfowl hunting will exceed available supply by 454,000 man-days by the year 2020 (U.S. Fish and Wildlife Service 1976). Habitat quality and quantity for other marsh birds such as rails, gallinules, American coot, and various wading birds will also be reduced by continued wetland deterioration. Nutria comprised roughly 70% of Louisiana's total fur harvest between 1970 and 1975 (O'Neil and Linscombe 1975). Nutria catch per acre is highest in fresh marsh, declining progressively in the intermediate, brackish, and saline marsh types (Palmisano 1973).

Alligator populations also reached peak levels in fresh to intermediate marshes (McNease and Joanen 1978). Accordingly, continued wetland deterioration can be expected to result in declines in fur harvest and alligator populations, especially as land loss and saltwater intrusion reduce fresher marsh acreage.

DISCUSSION OF MEASURES TO REDUCE WETLAND DETERIORATION

Except for regulation of development, the primary measures investigated to date for control of wetland deterioration in the LCR have involved diversion of Mississippi River water into adjacent marshes and estuarine areas for salinity control and creation of new subdeltas. A plan for introduction of Mississippi River water into the subdelta marshes of southeast Louisiana was submitted by the Fish and Wildlife Service to the U.S. Army Corps of Engineers in 1959 (U.S. Fish and Wildlife Service 1959). This plan included a recommendation for the construction of four water control structures, having a combined discharge capacity of 620 m^3/sec (24,000 cfs), to divert Mississippi River water for salinity control. The structures would have benefited an estimated 107,000 ha (264,500 acres) of marsh and estuarine waters. The annual benefits of this plan in increased oyster yields, furbearer harvest, and waterfowl utilization were estimated at $841,600, exceeding costs by 62%. That plan, now known as the "Mississippi Delta Region, Louisiana" project, was authorized by Public Law 89-298 on 27 October 1965. Detailed planning of one of the four authorized diversion structures was initiated in 1969, but was suspended when local interests failed to furnish economic justification for their requested change in the location of that structure (U.S. Army Corps of Engineers 1975). It should be noted that, despite the obvious need for the project to mitigate the adverse effects of the Mississippi River mainline levees, the project is classified as "enhancement", making local interests responsible for 25% of the project costs. This has been cited by local interests as one reason for their reluctance to participate in the project. Now there is renewed local interest, however, in one of the four diversion structures (Caernarvon site), and a new letter of assurance is reportedly forthcoming from the State of Louisiana to the Corps of Engineers indicating a willingness to assume 25% of the project cost. The most comprehensive treatment of measures for arresting land loss and saltwater intrusion in the LCR is contained in a report prepared by Gagliano et al. (1973b) under contract to the U.S. Army Corps of Engineers. That study was conducted in conjunction with a broad evaluation of the LCR by an ad hoc interagency group and evaluated two primary measures for addressing wetland deterioration, including:

(1) controlled introduction of Mississippi River water into adjacent estuarine marshes and bays for salinity control and nutrient input; and

(2) creation of subdeltas along the lower Mississippi River through controlled freshwater diversion into adjacent shallow bays.

A multi-use management plan for south-central Louisiana was subsequently developed (Gagliano et al. 1973a). This plan recommended certain developmental controls, management and maintenance of barrier islands, erosion control, and surface water management of existing runoff surpluses and controlled subdelta building with diverted Mississippi River water and sediments.

Despite the virtually universal recognition of the seriousness of the wetland deterioration problem in the LCR and the existence of plans to address that problem, no major federally financed measures have been implemented. Two ongoing Federal water resource studies being conducted under the leadership of the U.S. Army Corps of Engineers offer considerable promise, however, for large-scale supplemental freshwater introduction into the subdelta marshes of the LCR. These include the Louisiana Coastal Area Study and Mississippi and Louisiana Estuarine Areas Study. With regard to the latter study, preliminary estimates by the U.S. Fish and Wildlife Service indicate that between $4.4 and $5.2 million in annual benefits to fish and wildlife can be realized with a single large-scale diversion into the Lake Pontchartrain-Lake Borgne area of southeast Louisiana (Fruge and Ruelle 1980).

In 1979, the Louisiana Legislature enacted legislation directing the Secretary of the Louisiana Department of Transportation and Development to prepare a freshwater diversion plan for Louisiana. Components of that plan are being formulated and are expected to complement any freshwater introduction measures implemented by Federal agencies. More recently, Louisiana Governor Dave Treen signed legislation providing $35 million for studies and projects to address coastal erosion problems. The funding will be obtained from the newly designated Coastal Environmental Protection Trust Fund. It is anticipated that a portion of these funds will be expended on marsh restoration measures such as freshwater diversion projects.

It is clear that the important fish and wildlife resources of the LCR are threatened by rapid, continued degradation of its wetland habitat through land loss and saltwater intrusion. This problem is widely recognized by natural resource managers, scientists, and the public at large, and positive measures have been proposed to address it. Definitive action must be taken, however, to implement these measures at the earliest possible date.

LITERATURE CITED

Bellrose, F.C. 1976. Ducks, geese and swans of North America. A Wildlife Management Institute book sponsored jointly with Illinois Natural History Survey. Stackpole Books, Harrisburg, Pa.

Cavit, M.H. 1979. Dependence of menhaden catch on wetland habitats: a statistical analysis. Unpublished report submitted to U.S. Fish and Wildlife Service, Ecological Services Field Office, Lafayette, La. U.S. Fish and Wildlife Service, Office of Biological Services, National Coastal Ecosystems Team, NSTL Station, Miss. 12 pp.

Chabreck, R.H. 1972. Vegetation, water and soil characteristics of the Louisiana coastal region. La. Agric. Exp. Stn. Bull. 664 72 pp.

Chambers, D.G. 1980. An analysis of nekton communities in the Upper Barataria Basin, Louisiana. M.S. Thesis. Louisiana State Univ., Baton Rouge. 286 pp.

Craig, N.J., R.E. Turner, and J.W. Day, Jr. 1979. Land loss in coastal Louisiana. Pages 227-254 in J.W. Day, Jr., D.D. Culley, Jr., R.E. Turner, and A.J. Mumphrey, Jr., eds. Proceedings of the Third Coastal Marsh and Estuary Management Symposium. Louisiana State Univ., Div. of Continuing Education, Baton Rouge.

Fruge, D.W, and R. Ruelle. 1980. Mississippi and Louisiana estuarine areas study. A planning-aid report submitted to the U.S. Army Corps of Engineers, New Orleans District, New Orleans, Louisiana. U.S. Fish and Wildlife Service, Division of Ecological Services, Lafayette, La. 86 pp.

Gagliano, S.M. 1973. Canals, dredging, and land reclamation in the Louisiana coastal zone. Louisiana State Univ., Center for Wetland Resources, Baton Rouge. Hydrologic and Geologic Studies of Coastal Louisiana. Rep. 14. 104 pp.

Gagliano, S.M., P. Culley, D.W. Earle, Jr., P. King, C. Latiolais, P. Light, A. Rowland, R. Shlemon, and J. L. van Beek. 1973a. Environmental altas and multiuse management plan for south-central Louisiana, Vol. I. Louisiana State Univ., Center for Wetland Resources, Baton Rouge. Hydrologic and Geologic Studies of Coastal Louisiana. Rep. 18. 132 pp.

Gagliano, S.M., P. Light, and R.E. Becker. 1973b. Controlled diversions in the Mississippi delta system: an approach to environmental management. Louisiana State Univ., Center for Wetland Resources, Baton Rouge. Hydrologic and Geologic Studies of Coastal Louisiana. Rep. 8. 146 pp.

Gagliano, S.M., and J.L. van Beek. 1970. Geologic and geomorphic aspects of deltaic processes, Mississippi delta system. Louisiana State Univ., Center for Wetland Resources, Baton Rouge. Hydrolgoic and Geologic Studies of Coastal Louisiana. Rep. 1. 140 pp.

Gosselink, J.G., C.L. Cordes, and J.W. Parsons. 1979. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas. U.S. Fish and Wildlife Service, Office of Biological Services. 3 vol. FWS/OBS-78/9 through 78/11.

Harris, A.H. 1973 Louisiana estuarine dependent commercial fishery production and values (regional summary WRPA-9 and WRPA-10 analysis of production and habitat requirements). Report prepared for U.S. Department of Commerce, National Marine Fisheries Service, Water Resources Division. St. Petersburg, Florida. 36 pp.

Herke, W.H. 1971. Use of natural, and semi-impounded, Louisiana tidal marshes as nurseries for fishes and crustaceans. Ph. D. Dissertation. Louisiana State Univ., Baton Rouge. 264 pp.

Lindall, W.N., Jr., J.R. Hall, J.E. Sykes, and E.L. Arnold, Jr. 1972. Louisiana coastal zone: analysis of resources and resource development needs in connection with estuarine ecology. Section 10 and 13--fishery resources and their needs. Prepared for

U.S. Department of the Army, New Orleans district, Corps of Engineers, Contract 14-17-002-430. National Marine Fisheries Service Biological Laboratory, St. Petersburg Beach, Fla. 323 pp.

Louisiana Department of Wildlife and Fisheries. 1978a. 1977-1978 waterfowl survey. Baton Rouge. 12 pp.

Louisiana Department of Wildlife and Fisheries. 1978b. Wildlife resources of Louisiana. Wildl. Educ. Bull. 93. Baton Rouge. 34 pp.

Louisiana Department of Wildlife and Fisheries. 1980. News release 80-48. 8 August.

Lowery, G.H., Jr. 1974. Fur in Louisiana. Pages 21-45 in The mammals of Louisiana and its adjacent waters. Louisiana State Univ. Press, Baton Rouge.

McNease, L., and T. Joanen. 1978. Distribution and relative abundance of the alligator in Louisiana coastal marshes. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies. 32:182-186.

Morgan, J.P. 1973. Impact of subsidence and erosion on Louisiana coastal marshes and estuaries. Pages 217-233 in R.H. Chabreck, ed. Proceedings of the Second Coastal Marsh and Estuary Management Symposium. Louisiana State Univ., Div. of Continuing Education, Baton Rouge.

National Marine Fisheries Service. 1979. Fisheries of the United States, 1978. Curr. Fish. Stat. 7800. NOAA-S/T 79-183.

O'Neil, T., and G. Linscomb. 1975. The fur animals, the alligator, and the fur industry in Louisiana. Louisiana Wildlife and Fisheries Commission, New Orleans. Wild. Educ. Bull. 106. 66 pp.

Palmisano, A.W. 1973. Habitat preference of waterfowl and fur animals in the northern gulf coast marshes. Pages 163-190 in R.H. Chabreck, ed. Proceedings of the Second Coastal Marsh and Estuary Management Symposium. Louisiana State Univ., Div. of Continuing Education, Baton Rouge.

Portnoy, J.W. 1977. Nesting colonies of seabirds and wading birds--coastal Louisiana, Mississippi, and Alabama. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-77/07. 126 pp.

Rogers, B.D. 1979. The spatial and temporal distribution of Atlantic croaker, Micropogon undulatus, and spot, Leiostomus xanthurus, in the upper drainage basin of Barataria Bay, Louisiana. M.S. Thesis. Louisiana State Univ., Baton Rouge. 96 pp.

Turner, R.E. 1979. Louisiana's coastal fisheries and changing environmental conditions. Pages 363-370 in J.W. Day, Jr., D.D. Culley, Jr., R.E. Turner, and A.J. Mumphrey, Jr., eds. Proceedings of the Third Coastal Marsh and Estuary Management Symposium. Louisiana State Univ., Div. of Continuing Education, Baton Rouge.

U.S. Army Engineer District, Corps of Engineers, New Orleans, Louisiana. 1975. Mississippi Delta Region Salinity Control Structure, Louisiana, condition of improvement, 30 June 1975. Page 3-17A in Project maps, vol. 2: Flood control, Mississippi River and tributaries.

U.S. Fish and Wildlife Service. 1959. A plan for freshwater introduction from the Mississippi River into sub-delta marshes below New Orleans, Louisiana, as part of the Mississippi River and Tributaries Review. U.S. Fish and Wildlife Service, Division of Ecological Services, Lafayette, La. 48 pp.

U.S. Fish and Wildlife Service. 1971. Fur catch in the United States, 1970. Wild. Leafl. 499. Washington, D.C. 4 pp.

U.S. Fish and Wildlife Service. 1976. Fish and wildlife study of the Louisiana coastal area and the Atchafalaya Basin Floodway. Appendix D., part 3: sport fish and wildlife harvest. U.S. Fish and Wildlife Service, Division of Ecological Services, Lafayette, La. 61 pp. Unpublished.

U.S. Fish and Wildlife Service. 1977. 1975 National survey of hunting, fishing and wildlife associated recreation. Washington, D.C. 91 pp.

White, C.J., and C.J. Boudreaux. 1977. Development of an areal management concept for gulf penaeid shrimp. Louisiana Wildlife and Fisheries Commission, Oysters, Water Bottoms and Seafoods Division, Tech. Bull. 22. New Orleans. 77 pp.

Wicker, K.M. 1980. Mississippi Deltaic Plain Region ecological characterization: a habitat mapping study. A user's guide to the habitat maps. U.S Fish and Wildlife Service, Office of Biological Services. FWS/OBS-79/07.

SOME CONSEQUENCES OF WETLAND MODIFICATION TO LOUISIANA'S FISHERIES

Barney Barrett
Louisiana Department of Wildlife and Fisheries
Box 14526
Baton Rouge, LA 70898

ABSTRACT

Agencies of State and Federal Governments as well as local interests have long recognized that Louisiana's wetlands are undergoing adverse ecological changes. These changes are the result of both natural processes and the works of man.

The dominant ecological change taking place in the coastal area is habitat alteration--wetlands are eroded and replaced by water. Now there are many proposals to reduce erosion rates which include freshwater introduction, jetties, and additional restrictions on activities.

Freshwater introduction may be the most efficient means of reducing land loss rates. Fresh water, particularly from the Mississippi River, would reduce saltwater intrusion and contribute nutrients and sediments to the estuaries and wetlands. Changes in water regimes, however, could drastically alter animal populations as occurred in Sabine Lake. The water cycle was changed by the construction of the Toledo Bend reservoir and dam which resulted in a drastic reduction in shrimp harvest in this lake.

RECOGNITION OF THE PROBLEM

We are not just learning about land loss. There was a realization that flood control projects on the lower Mississippi River were causing adverse ecological changes prior to oil and gas activity in south Louisiana. With the leveeing of the Mississippi River along with industrial development and its accompanying channelization and dredging, the problem was intensified and the rate of habitat destruction increased.

The Louisiana Wildlife and Fisheries Commission and its predecessors, as well as the affected parishes and other local interests, have recommended repeatedly, since as early as 1900, that Mississippi River water be directed into adjacent subdelta marshes to maintain habitat.

U.S. Fish and Wildlife Service (1959) stated "Loss of fertility, formerly maintained at a high level by overflow water from the Mississippi River is reducing the value of the subdelta marshes as nursery and rearing grounds for all fish and wildlife forms". These observations made 22 years ago remain true today.

The problem of land loss is much more serious today because of the rate of loss now

taking place--10,205 ha (25,216 acres) per year according to Gagliano (1981). The actual rate of habitat loss may be greater than these calculations indicate, as these figures may not include wetlands removed from their historic use because of drain and fill activities, and it may not include vast areas surrounded by hurricane protection levees, road beds or other structures which essentially block off or disrupt drainage patterns. This separation of wetlands inhibits the flow of nutrients and aquatic life from one system to another and, therefore, that area of marsh is lost for any significant contribution to fishery production. Additionally, the land loss rates do not include areas which cannot be exploited for living resources because of pollution. For instance, the State Health Department prohibits the harvest of oysters east of the Mississippi River in areas which are exposed directly to Mississippi River waters from siphons and other water control structures.

Society is irreversibly committed to the protection of life and property by maintaining levees along the Mississippi and other rivers. Therefore, efforts to build new lands are basically limited to controlled freshwater introduction from the rivers at selected sites. The overall effects need to be carefully projected and evaluated in advance because such effects could be more damaging than beneficial. Even if the rivers were allowed to seek natural courses, the present sediment load would not be adequate to compensate for land loss rates due to the trapping of sediments by impoundments upstream. It required approximately 6,000 years to form Louisiana's coastal area by natural processes. If the present coastal area is considered to be 2,400,000 ha (6,000,000 acres) of land and shallow water bodies then the accretion rate for the past 6,000 years was 400 ha (1,000 acres) per year. We are presently losing coastal wetlands at the rate of 10,205 ha per year (Gagliano 1981). Therefore, natural accretion rates would not be adequate to maintain our coastal area. It is obviously misleading to calculate accretion rates over a 6,000-year period, but any way the numbers game is played, the task of appreciably reducing present land loss rates is monumental.

In addition to having only limited resources to build new land, we are also limited in protecting existing wetlands as many of the forces and processes which reduce the coastal land area are not presently controllable. The freeze of 1961-62 resulted in the destruction of the black mangroves, large fish kills, reduced oyster harvest, and the 1962 shrimp harvest was one of the lowest of record. The impact of this freeze, which formed ice in the lower part of Barataria Bay, was short-lived on the animal population. It took approximately 7 years for the black mangroves to come back, however. These mangroves are important to the area as they reduce erosion and aid in land building by trapping sediments in their root systems. The passage of hurricane "Betsy" in 1965 resulted in the immediate loss of entire islands and caused hundreds of feet of coastline and shoreline recession. Uncontrollable natural subsidence also is a major factor in land loss. To a limited extent, subsidence due to mineral extraction is controllable.

FISHERIES MANAGEMENT OPTIONS

Any proposed use of large amounts of river water for land building should be carefully considered. The reduction of the discharge of fresh water at the river mouth may affect biological processes in the adjacent estuaries and the nearshore Gulf of Mexico. Spawning and migration patterns may be severely impacted if the flow of the river is altered.

Fishermen should take an interest in efforts to maintain our coast as the industry

cannot long survive at the present land loss rate. Additionally, the fishing industry may be damaged by measures taken to reduce this rate.

Saltwater intrusion, as a result of reducing the discharge of fresh water, can severely affect shrimp production. Reduction of the brackish zone limits the shelter and food available to maturing shrimp. The increase in estuarine salinities as a result of land loss and concomitant saltwater intrusion may increase shrimp harvest over a short period because of enlarged nursery grounds (Barrett 1975). A point will be reached, however, when there are no longer enough marshes to nourish the historic nursery grounds; then, shrimp harvest will decline permanently.

As 75 to 85 percent of the species of fishes and macroinvertebrates inhabiting our coastal areas are estuarine dependent, changes in our estuaries, such as salinity increases and loss of detritus from marsh reduction, would damage these stocks.

A case in point is the effect of the Toledo Bend Reservoir on the marine animal communities in Sabine Lake (Whitehead and Perret 1974). Seasonal pulses of fresh water into this lake prior to flow control consisted of high discharges during early spring and low discharges during the summer. This water cycle is normal for Louisiana streams, and apparently ideal for shrimp and other marine species. Since 1967, high freshwater discharges into Sabine Lake occur throughout the summer as a result of control structure operation. The impact of this change in water cycles has been dramatic on shrimp production in this lake. Prior to 1967, annual shrimp catches in Sabine Lake were as large as 385,000 kg (850,000 lb). Since 1967, annual shrimp catches in the lake were 31,000 kg (67,000 lb) with an average annual catch of 9,000 kg (20,000 lb) between 1967 and 1977.

Oyster populations are reduced as higher salinities resulting from coastal erosion allow inhabitation by predators and pathogens. An instance which demonstrated the advantages of freshwater introduction to oyster production was reported by the Louisiana Wildlife and Fisheries Commission (1960). The Bayou Lamoque structure, which was completed in 1956 for the purpose of improving oyster habitat east of the Mississippi River, discharged 6×10^8 m^3 (500,000 acre-feet) of river water into the adjacent marshes in 1957. Following this discharge, oyster yields increased about 100% and survival of young oysters improved because of a reduction in predators and pathogens and an increase in nutrients.

Many of the uses of our marshes result in impacts which physically destroy and reduce the quality of these marshes. Users of the marshes are regulated by licenses and permits, however, the rate of land loss with its related adverse effects on animals and habitats continues to increase.

Management of an animal population is an effective tool for preserving and propagating fish and wildlife--for example, the alligator has now been taken off the endangered species list in Louisiana. Years ago the alligator was becoming endangered primarily because of overhunting. Laws were then enacted which prohibited the taking of alligators. During the period that these animals were protected, populations increased. The protection of animals can easily be accomplished by establishing seasons, bag limits and methods of kill.

The habitat of the various animals using the marshes and estuaries is not well protected; habitat maintenance is as important to the survival and well being of fish and

wildlife as hunting and fishing regulations. Sea turtles are endangered primarily because of habitat loss and predation on eggs and young. The brown pelican population was eliminated locally because of the poor quality of habitat and the accumulated presence of pesticides in its foods. The fisherman, trapper, and hunter are subjected to enforceable regulations and limits. These regulations and limits are changed frequently to accommodate changes in animal population. We do not have adequate regulations for habitat preservation. Discharges of pollutants into coastal waters are generally policed by the industry; requirements for dredging activities are difficult to enforce; and apparently many dredging permits have been approved with little modification.

There is a pressing need to begin activities which would reduce land loss rates. In our haste to reduce these rates, however, we should be very careful to not duplicate the impact which occurred in Sabine Lake as a result of changes in the water regime. Although efforts to reduce land loss rates will be expensive, the loss of 10,209 ha (25,216 acres) during the next 12 months will result in the loss of millions of dollars to the State and its citizens. A stepwise approach should include measures to stabilize or retard erosion initially in critical areas while carefully planning future development. All phases should be approached on an interdisciplinary basis to utilize the best possible expertise to achieve the desired results, both short- and long-term.

LITERATURE CITED

Barrett, B.B. 1975. Environmental conditions relative to shrimp production in coastal Louisiana. La. Dep. Wildl. Fish. Tech. Bull. 15. 22 pp.

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 Natural Resources and Jesse Guidry, Secretary Louisiana Department Wildlife and Fisheries. Coastal Environments, Inc. Baton Rouge, La. 13 pp.

Louisiana Wildlife and Fisheries Commission. 1960. Eighth biennial report Louisiana Wildlife and Fisheries Commission 1958-1959. Louisiana Wildlife and Fish. Commission, Div. of Education and Publication. New Orleans.

U.S. Fish and Wildlife Service. 1959. A plan for freshwater introduction into sub-delta marshes below New Orleans, Louisiana as part of the Mississippi River and Tributaries Review. U.S. Fish and Wildlife Service, Division of Ecological Services, Lafayette, La. 66 pp.

Whitehead, C.J., and W.S. Perret. 1974. Short term effects of the Toledo Bend project on Sabine Lake, Louisiana. Proc. Annu. Conf. Southeast Assoc. Game Fish Comm. 27:710-721.

WETLAND LOSSES AND COASTAL FISHERIES: AN ENIGMATIC AND ECONOMICALLY SIGNIFICANT DEPENDENCY

R. Eugene Turner
Center for Wetland Resources
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

Louisiana's coastal fishing industry landings are limited by the area of coastal wetlands, not open water. The relationship is not sufficiently understood, but is demonstrable through the life history patterns of all the commercially important species, organism density in the vicinity of altered and natural wetland-water edges, experiments in predation, and correlation analysis of landings data and wetland quantity and quality. The management implications are that wetland area should be conserved in order to maximize for the largest potential fisheries yields. The impact of previous wetland losses are not well documented because of lack of good landings data that accounts for both year-to-year environmental influences and a changing fishing effort. At a projected 1% wetland loss rate over the next 20 years, the commerical fishing industry will experience a potential one billion dollar loss spread throughout the industry (exclusive of the recreational value). Thus with a mere 10% reduction in the present loss rates, the annual savings would be 5 million dollars.

CORRELATION OF FISHERIES AND WETLANDS

Across the broad geographic perspective of coastal environments it seems quite clear that where wetlands and estuaries are large in area there are likely to be substantial fishing industries nearby. To be sure, many fishing operations are nowhere near wetlands, for example, the tuna and anchovy fisheries; but it is generally true that if one can find a good-sized coastal wetland-estuary on the map and a suitable harbour nearby that there is commerce in locally-caught fish and invertebrates.

This correlation is easily shown with species such as penaeid shrimp whose worldwide price is stable and high. Within an area, such as Louisiana, coastal wetland area is directly correlated with the commerical landings of shrimp caught in inshore waters (Figure 1). Since the annual inshore catch is a fairly uniform percentage of the total annual catch, the relationship is true for all landings vs. wetland area in Louisiana. Worldwide, the weight caught per area wetland does vary within the geographic limits of distribution of penaeids (Figure 2). We might show similar graphs for blue crab landings (Turner and West, unpublished) or, if we had the landings data, for many species whose life history involved a period of migration between coastal wetlands and open water. The relationship between landings and open water, in contrast, is not a statistically significant one, though it appears to be negative (Turner 1977). Furthermore, for shrimp, at least, it is also true that the species of shrimp landed is directly related to the kinds of vegetation present in the estuary. Brown shrimp in Louisiana, for example, are

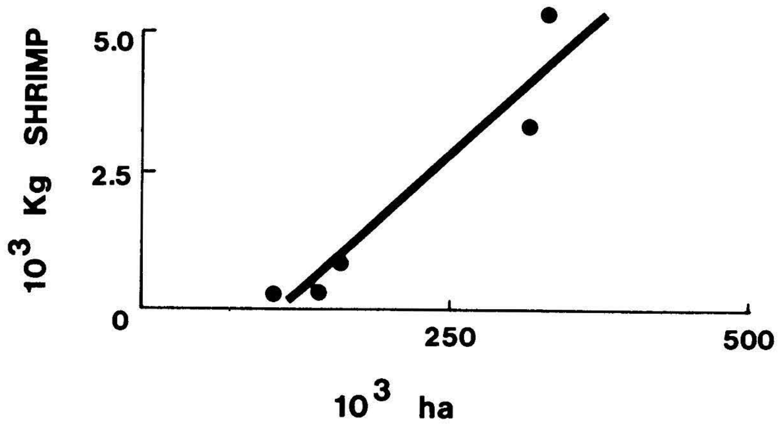


Figure 1. The relationship between the area of wetland vegetation in each hydrologic unit in south Louisiana and the commercial yields of shrimp caught therein (adapted from Turner 1977).

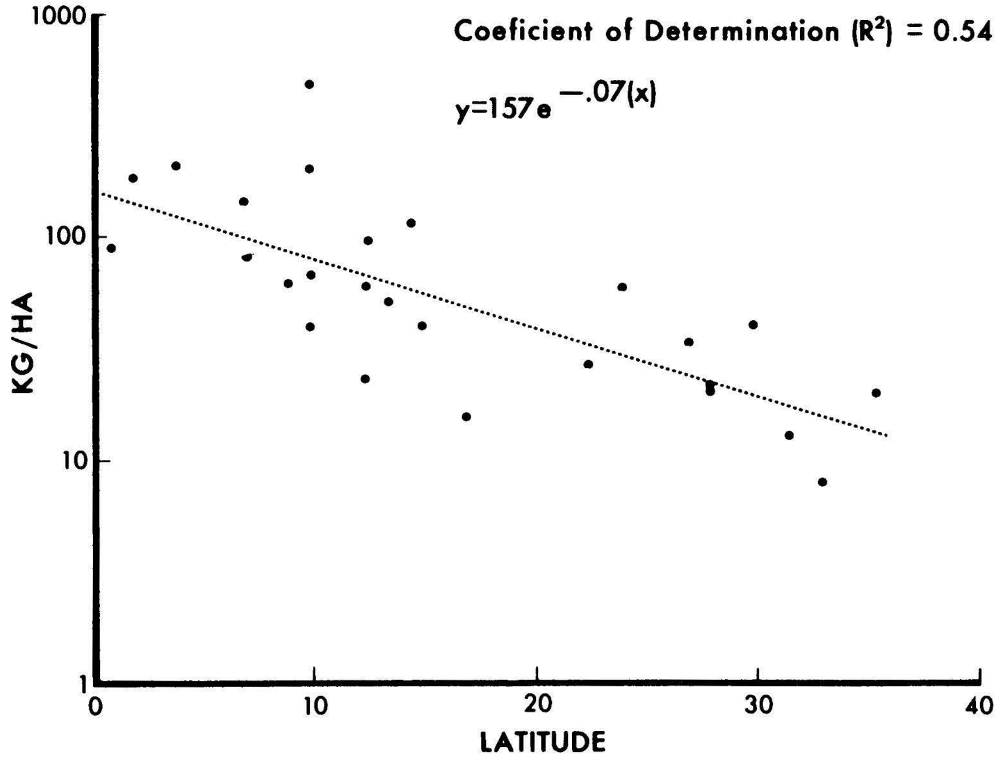


Figure 2. The relationship between the yield of penaeid shrimp per area of coastal vegetation (kg/hectare) and latitude. Only commercial quantities were evaluated; the areas are for states in the U.S. and various countries throughout the world (adapted from Turner 1977).

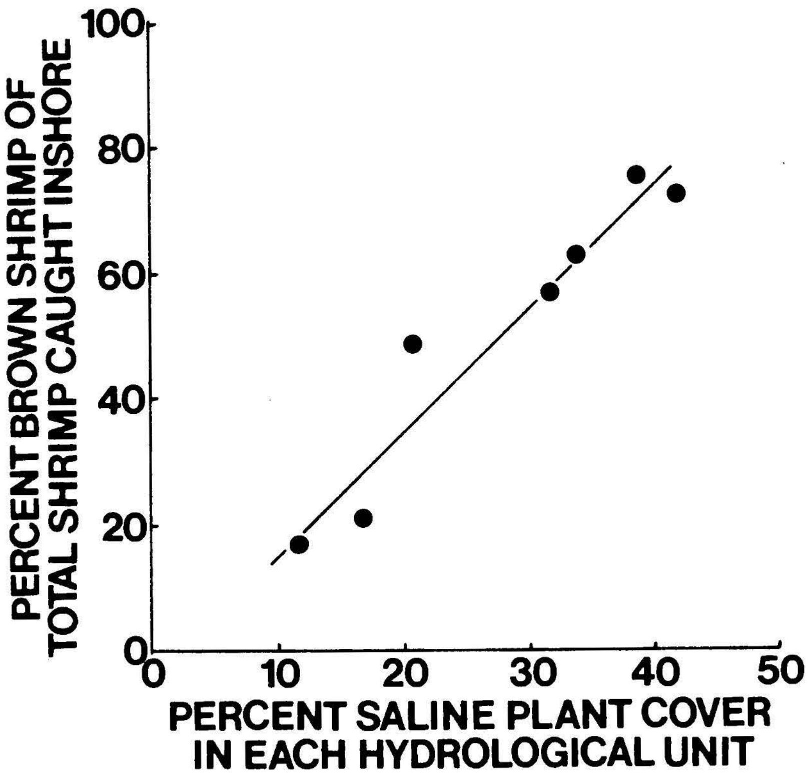


Figure 3. The relationship between the percent of brown shrimp caught in Louisiana's coastal hydrologic units and the type of vegetation in that unit (adapted from Turner 1977).

prevalent where saline wetland vegetation is proportionally high (Figure 3). In summary, then, a coastal fisheries species whose life cycle involves use of the estuary for the juveniles is considered estuarine-dependent; in Louisiana this amounts to essentially all of the landings (McHugh 1966; Chambers 1980). The area of wetlands, not that of open water, seems to be the factor limiting the local species abundance.

Coastal wetlands are very productive ecosystems as a result of abundant water, nutrient supplies, and tidal flushing. In comparing animal production in various ecosystems, where plant production is high, animal production is generally also high (Table 1). The greater grazing efficiency in aquatic ecosystems further increases animal production relative to plant production. In wetlands, the percent consumption of plant matter by animals averages 8% and is similar to that of animals in most terrestrial systems. The renewal of animal biomass is twice annually. The net result is that wetlands are excellent natural protein "factories" (Turner 1982).

Attempts to distinguish between animal production in "wet" land and that in the overlying water are problematical, since wetlands are, by definition, dependent on the hydrological regime for the maintenance of ecosystem integrity. Sediments, nutrients, and gases move from wetland to water and back again in very complex ways, which we are only now beginning to describe in detail (e.g. Pomeroy and Wiegert 1981). Our terrestrial experience in desert, forest, and grassland ecosystems has often led us to assume conveniently (and erroneously) that, in wetlands, water is also functionally

Table 1. Preliminary estimates of animal secondary production, consumption, standing stock and turnover for different ecosystems (adapted from Whittaker and Likens 1973). The ecosystems are ranked according to the level of production. Animal production in swamps and marshes is the highest of any terrestrial ecosystem ($9.0\ gC \cdot m^{-2} \cdot yr^{-1}$) even though the authors did not include the role coastal wetlands play in estuarine and coastal water fish food webs. Animal production in coastal systems is quite high (up to $18\ gC \cdot m^{-2} \cdot yr^{-1}$). The standing stock of animal carbon is generally directly related to the reproduction rate although the effect of different turnover rates is also apparent. Aquatic systems have a generally higher percent plant production consumed by animals than terrestrial systems; however, this may reflect a difference in the way organisms are classified by scientists.

Ecosystem type	$gC \cdot m^{-2}$ animal biomass	% animal consumption plant production	$gC \cdot m^{-2} \cdot yr^{-1}$ animal production	Days turnover of animal biomass
Rock, ice, and sand	0.01	2	0.0004	9125
Desert scrub	0.02	3	0.15	486
Tundra and alpine meadow	0.02	3	0.2	365
Cultivated land	0.02	1	0.3	243
Boreal forest	2.2	4	1.4	573
Woodland and shrubland	2.2	5	1.4	573
Temperate evergreen forest	4.5	4	2.4	684
Temperate deciduous forest	7	5	2.7	946
Temperate grassland	3.1	10	3.3	343
Open ocean	1.1	40	3.4	118
Tropical seasonal forest	5.4	6	4.0	493
Lake and stream	2.2	20	5.5	146
Tropical rain forest	9.0	7	6.5	505
Savanna	6.8	15	7.0	354
Continental shelf	9.0	30	7.3	450
Swamp and marsh	4.5	8	9.0	183
Upwelling zones	4.5	35	12.5	131
Estuaries	6.8	15	17.8	139
Algal bed and reef	9.0	15	18.3	180
TOTAL CONTINENTAL	3.1	7	2.5	452

distinct from land. This assumption has resulted in confusion, for example, about whether some aquatic animals are actually wetland-dependent and, therefore, should be included in estimates of wetland animal production, though they live primarily in the open water. There is little dispute on this point if the animal lives, feeds, and reproduces within wetlands. But what about the temporary resident, the migrating waterfowl arriving in south Louisiana from Canada? What about the larval fish and shrimp, which are spawned offshore and enter the estuary to live for only a tenth of their life cycle? Fish, birds, and some invertebrates make long and involved migrations between feeding ground and "nursery area". Penaeid shrimp spawn in deep oceanic zones, and may arrive simultaneously with waterfowl in coastal wetlands to grow. River prawns of southeast Asia move downstream to estuaries to spawn. In South America some fish move both upstream and downstream to wetlands during their life cycle (Welcomme 1979). A common denominator of these life history patterns is the considerable distance between the habitat where the adults feed and the wetland where they began life or spent the critical early stages of it.

This nursery value of wetlands is a result of both the food found there and the refuge value it affords prey. Wetland "edge" is an important locus for both functions. The organic content of sediment adjacent to a natural marsh and that of sediment separated from the marsh by a bulkhead, or levee are compared in Figure 4. The edge next to the marsh has a much greater organic content than the edge without a marsh, and this is typical. The same author found higher animal densities within the natural edge than in the edge altered by a levee (Figure 5).

Aquatic organisms suffer high predation when young. Wetland habitats limit the access of larger predators simply because the zone is shallow. Prey species exploit the micro-environment among the vegetation in order to avoid predators. Charnov et al. (1976) conducted a simple experiment documenting this (Figure 6). When insect larvae were placed in an aquarium together with a predator, they quickly hid in the darkened corners. Wetlands are analogous to the corners of the aquarium: they provide both hiding places and a source of food for larvae. Vince et al. (1976) documented a field example of this for a temperate salt marsh. There the saltmarsh killifish, Fundulus heteroclitus, preys upon two amphipods at the marsh/water interface. The dense, small stems provide cover for the prey and reduce successful predation. As a consequence the size distribution and abundance of the prey are directly dependent on the vegetation density.

Because of these strong relationships between wetlands and coastal fisheries species, it is possible to predict adult abundances if the environmental conditions during juvenile life stages are known. Mortality is proportionally greatest while the species is small; thus the available potential value of wetland habitat is modified by annual climatic changes, e.g., temperature, flooding, and salinity (Condrey 1979; Barrett 1975; Turner 1979). Wetlands are productive, and the fisheries couplings with wetlands are known to exist. The mechanism of the couplings are not clear, however; the animal's life history is an expression of the evolutionary adaptation to an exploitable habitat, be it edge, food or both.

CONSEQUENCES OF WETLANDS LOSS

For management purposes it is a lot to know that wetlands areas, not water surface area, limits commerical fishing yields. Based on the available information one can firmly

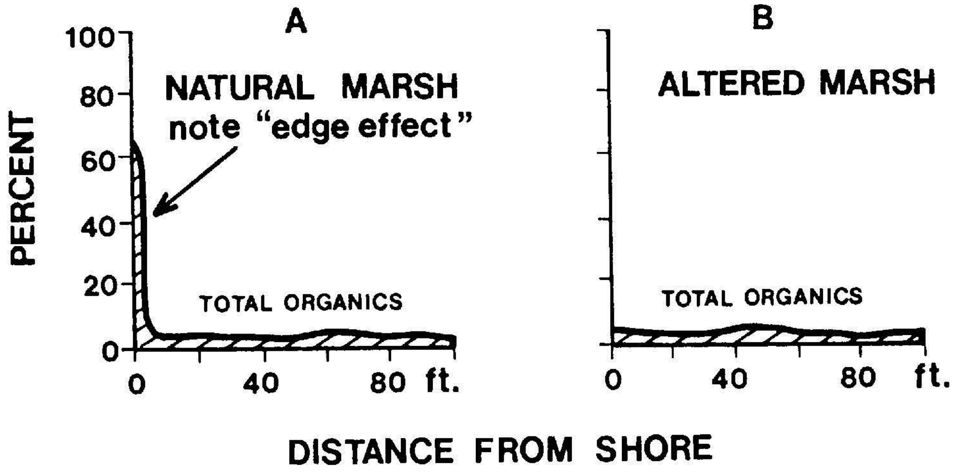


Figure 4. Example of qualitative change in the land-water interface, with and without wetlands (Mock 1967). The percent organic material in the estuarine sediments immediately adjacent to a natural marsh (A) increased peripheral to the marsh, whereas no such increase was found adjacent to an altered marsh (B) which had an artificial levee between the normal low-water line and the higher wetland.

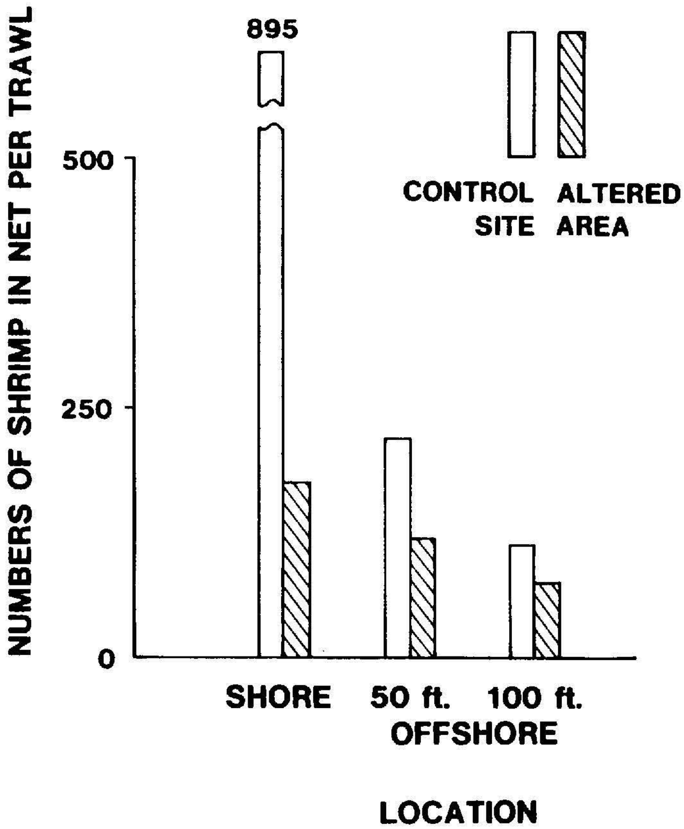


Figure 5. Mean catch of juvenile shrimp per trawl sample at various distances from a wetland with and without an artificial levee (Mock 1967)

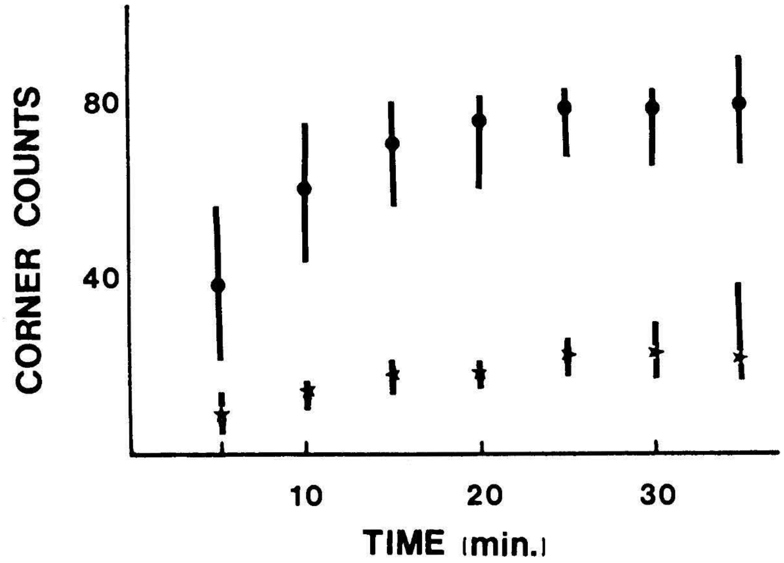


Figure 6. Predator avoidance by mayfly nymphs, indicated by their distribution in the corners of a chamber depending on whether a fish predator was present (upper line) or absent (lower line) (Charnov et al. 1976). The corners in these experiments are analagous to refuge provided by vegetation within shallow wetland zones.

conclude that the present high coastal wetland losses in Louisiana will eventually translate into a reduction in commercial and recreational fish yields. The natural potential fish yields are decreasing, not increasing. This decline is not yet apparent in the fisheries statistics of landings for at least two reasons. First, the annual variations in landings are large in relation to the wetland loss rates. For example, the commercial shrimp and blue crab fishing efforts have, at times, been steady from one year to the next. The landings one year might be twice that of the next year, however. In comparison the land loss rates, hence wetland loss rates, are about 1% annually over the last 25 years (Wicker 1980). Secondly, fishing effort in Louisiana has increased dramatically in the last 25 years. Double-rigged shrimp trawling was introduced in the mid-1950's and not completely adopted by all the fleet for several more years. Larger vessels with more horsepower have been added every year, and some industries, like the menhaden industry, have added more fishing vessels (and spotter planes) almost continuously throughout the 1960's and 1970's. The hidden, cumulative effect of land loss on Louisiana's fisheries is distributed over a long period amongst many fisherman. With the combination of increased fuel costs, inflation, and a now nearly full fishing industry, the effects of land loss rates will be felt dramatically in the coming years; this will be especially true as the loss rates continue to accelerate beyond 1% annually. Doi et al. (1973) documented an example of the effects of coastal habitat losses on fisheries in the Seto inland sea in Japan. As the area of intertidal land was lost to land reclamation, the shrimp catches declined proportionately and sharply.

If we assume that a 1% decline in the potential fishery yield is equivalent to the 1% per year wetland loss, then the cumulative loss in dockside dollar value over the next 20 years is equal to twice the present value ($190 million dollars in 1978) of the entire commercial landings, or $380 million. At least 50% of this value is a result of the high

volume and price of the commercial shrimp harvest. Recreational catches are considerable, but not included in this estimate. The actual total economic value is three times higher than the dockside value as a result of value added during processing and delivery (Jones et al. 1974). Thus over the next 20 years the present expected wetland loss rate of at least 1% annually could result in a cumulative commercial fishing economic loss of 1.1 billion dollars to Louisiana. A substantial proportion of the current wetlands loss is a direct result of new human activities (Craig et al. 1980). If wetland loss were reduced by only 10% over the next 20 years (an average 0.9% loss rate average) the general savings in fishing catch value would be worth 5 million dollars annually, or a total of 100 million dollars over the 20 years. Small percentage changes in large numbers, when accumulated over two decades become a very significant number. It is a number worth considering when the long-term benefits are weighed against the immediate costs of a quick recovery of non-renewable resources. A small investment in the future now may have potentially less painful consequences later.

ACKNOWLEDGMENT

This report is Publication CEL-SG-82-010 of the Coastal Ecology Laboratory Center for Wetland Resources, Louisiana State University.

LITERATURE CITED

Barrett, B.B. 1975. Environmental conditions relative to shrimp production in coastal Louisiana. La. Dep. Wild. Fish. Tech. Bull. 15. 22 pp.

Chambers, D.G. 1980. An analysis of nekton communities in the upper Barataria Bay Basin, Louisiana. M.S. Thesis. Louisiana State Univ., Baton Rouge. 286 pp.

Charnov, E.L., G.H. Orians, and K. Hyatt. 1976. Ecological implications of resource depression. Am. Nat. 110:247-259.

Condrey, R.E. 1979. Draft environmental impact statement and fishery management plan for the shrimp fishery of the Gulf of Mexico, United States waters. Louisiana State Univ., Center for Wetland Resources, Baton Rouge.

Craig,N.J., R.E. Turner, and J.W. Day, Jr. 1980. Wetland losses and their consequence in coastal Louisiana. Z. Geomorph. N.F. 34:255-241.

Doi, T., K. Okada, and K. Isibashi. 1973. Environmental assessment on survival of Kuruma prawn, Penaeus japonicus, in tideland. I. Environmental conditions in Saizyo tideland and selection of essential characteristics. Bull. Tokai Reg. Fish. Res. Lab. 76:37-52.

Jones, L.L., J.W. Adams, W.L. Griffin, and J.A. Allen. 1974. Impact of commercial shrimp landings on the economy of Texas and coastal regions. Tex. Agric. Exp. Stn. Publ. TAMU SG-75-204. 18pp.

McHugh, J.L. 1966. Management of estuarine fishes. Am. Fish. Soc. Spec. Publ. 3:133-154.

Mock, C.R. 1967. Natural and altered estuarine habitats of penaeid shrimp. Proc. Gulf Caribb. Fish. Inst. 19:86-98.

Pomeroy, L.R., and R.G. Wiegert (eds.) 1981. The ecology of a salt marsh. Springer, New York. 271 pp.

Turner, R.E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Am. Fish. Soc. 106:411-416.

Turner, R.E. 1979. Louisiana's fisheries and changing environmental conditions. Pages 363-370 in J.W. Day, D.D. Culley, R.E. Turner, and A.J. Mumphrey, eds. Proceedings of the Third Coastal Marsh and Estuary Management Symposium. Div.of Continuing Education, Louisiana State University, Baton Rouge, La.

Turner, R.E. 1982. Protein yields from wetlands. Pages 405-415 in B. Gopal, R.E. Turner, R.G. Wetzel and D. F. Whigham, eds. Wetland ecology and management. International Science Publishers, Jaipur, India.

Vince, S., I. Valiela, and N. Backus. 1976. Predation by the salt marsh killifish Fundulus heteroclitus (I.) in relation to prey size and habitat structure: consequences for prey distribution and abundance. J. Exp. Mar. Biol. Ecol. 23:255-266.

Welcomme, R.L. 1979. Fisheries of African floodplain rivers. Longman, New York. 318 pp.

Whittaker, R.H., and G.E. Likens. 1973. Carbon in the biota. Pages 281-300 in G.M. Woodwell and E.R. Pecan, eds. Carbon and the biosphere. USAEC Symp. Series No. 30. Washington, D.C.

Wicker, K.M. 1980. Mississippi Deltaic Plain Region ecological characterizations: a habitat mapping study. A user's guide to the habitat maps. U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-79/07.

PANEL DISCUSSION

CONSEQUENCES: EFFECTS ON NATURAL RESOURCES PRODUCTION

James G. Gosselink, Moderator

Robert H. Chabreck, David W. Fruge, Barney Barrett, R. Eugene Turner, Mike Voisin and **John Teal,** Panelists

James Gosselink: Let me ask Mr. Voisin and Dr. Teal if they have any comments before we have a general discussion.

Mike Voisin: Do we want to maintain the coastal marshes as they were in 1940, 1950, 1960, 1970 or let them to continue to degrade before taking action? Being in the oyster industry, I would hope we try to save them as they are today. We are very satisfied with the existing conditions, even though we do have some problems. Oyster fishermen were the first to feel the loss of marshes and barrier islands. Oyster supplies dwindled in terms of catch per boat while the total catch remained the same. In the 1930's and 1940's oysters were fished up to 10 to 15 miles offshore. Oysters are dependent on brackish water of 5 to 15 ppt, but with salt water intrusion oystering has moved inshore.

Oysters are good indicators of environmental quality; they don't move and they can't lie. If we manage the environment to maintain oyster production, as it is today we will also be preserving valuable coastal environments. As oyster production moved inshore, the pollution of coastal waters with human wastes has moved down toward the coast. The convergence of intruding salt water and the pollution line is reducing available habitat for oyster production and harvest. Other problems facing the oyster industry are oil company exploration, salt-dome leaching for petroleum storage and the proposed Avoca Island levee extension, which would limit the introduction of fresh water into the west Terrebonne marshes, one of the State's leading oyster grounds. Production east of the Mississippi River is declining and oyster growth rates have slowed there because of marsh deterioration. Production is shifting to Terrebonne, Lafourche, Vermilion and Iberia parishes where the Atchafalaya River supplies fresh water and nutrients. If we can save the oyster as it is today, we will save the coast as it is today.

John Teal: In the over twenty years I have been a student of salt marsh ecology in Georgia and New England, I have witnessed the evolution of research and understanding and also the development of concern about the destruction of coastal marshes. Louisiana has more marshes than any other state in the United States and most of the problems associated with marshes. I won't say you also have most of the understanding about how marshes work, but you obviously have a lot of it in Louisiana. In New England the marshes are small and we can isolate inputs and outputs and thus have advantages in some of the ways one can do research.

The general problems of wetland destruction and, in a broad sense, the consequences to fish and wildlife are understood. The consequences of actions taken

to restore or protect wetlands and estuaries must be understood, consequently the processes which support productivity must also be understood. Correlations between wetland characteristics and natural resource production provide an indication of the overall relationships, but more detailed information on actual processes is required. This requires experimental approaches to marsh ecology. Improved cooperation from fisherman and other natural resource harvesters, who are often reluctant to provide detailed information on their harvests, offers the potential of extensive and meaningful data if treated properly.

The changes in Louisiana's coastal environments provide an experiment on a very large scale, which can provide insight to the relationship of wetlands and natural resource production. If this can be combined with sufficient long-term support of scientific enterprises to describe processes in detail, sound natural resource management strategies may result.

James Gosselink: In the Calcasieu estuary where wetland loss has been rapid, inshore shrimp yields have increased. How can this be interpreted?

Barney Barrett: Erosion and saltwater intrusion may in the short run increase shrimp production by increasing the area of nursery grounds with salinity above 10 ppt. Calcasieu Lake is somewhat saltier than it was years ago, but, as marsh habitat loss proceeds, shrimp production will decline.

Eugene Turner: The inshore yield is a fairly constant proportion of the total catch (including the offshore catch) on a statewide basis. Thus the inshore catch statistics in the Calcasieu estuary are probably also representative of the contribution of the estuary to the offshore catch. In the Calcasieu estuary, freshwater has been diverted to rice fields, causing an increase in salinity, and consequently short-term increases in shrimp yield. Fishing effort has also increased.

James Gosselink: Is fossil peat, released by wetland erosion, important as a food source?

Eugene Turner: Natural channels are continuously reworked and release peat. I do not think that the accelerated wetland loss causes a great increase in peat released.

John Teal: Organic matter which accumulates in marsh sediments below the top few millimeters is quite resistent to degradation and I doubt that it is an important food source.

Donald Boesch: For particular important fishery species such as shrimp, we can relate production to a number of variables, such as the area of saline marsh, the amount of natural marsh edge, mixture of open water and marsh, and critical temperature conditions. Do we satisfactorily know what these optimum conditions are for any particular species? If not, what do we need to know?

Barney Barrett: The brackish zone of the marsh estuaries is being compressed and reduced. This may result in a series of rather salty estuaries extending to the Intracoastal Waterway and an abrupt transition to freshwater. The objective is to maintain a broad brackish habitat rather than management for a particular fishery species.

Donald Boesch: Limiting considerations to one species for the moment, couldn't the

shrimp nursey value of a system be enhanced by controlling salinity regime and water-marsh edge habitat?

Eugene Turner: The issue is more complex than one salinity zone or the length of edge. Conditions beneficial to brown shrimp may not be benefical to white shrimp, for example.

Donald Landry: Shrimp production is not a function of the area of saline marsh but of total estuarine area, which is a function of rainfall, riverflow, etc.

Barney Barrett: An area with a great amount of saline marsh and marsh edge may have higher shrimp production than one with less, but there will be considerable year-to-year fluctuatious due to rainfall, river discharge, temperature and the amount of nursery area.

Eugene Turner: The long-term average is a function of nursery ground area, which is wetlands, not open water -- for brown shrimp it is saline marsh, for white shrimp it is brackish and fresh marsh. On top of that, of course, there will be year to year variation.

Mike Voisin: Because shrimp migrate and vary so much, oysters are a better gauge of estuarine productivity.

Donald Boesch: The point of my original question is to lead to the question of how do we manage the various hydrological units of coastal Louisiana for multi-species production. In some large units (e.g. Terrebonne-Timbalier basin) we may be able to maintain a range of conditions suitable for shrimp, oysters, etc. In smaller areas or areas where freshwater input overwhelms tidal effects (e.g. Atchafalaya Bay) it may be unrealistic to expect production of all these living resources. Should we have a conscious strategy of managing these large systems with salinity gradients for multiple resources and other systems for a single resource?

David Fruge: For managing large basins we should plan on freshwater diversion managed to retard wetland loss, not necessarily change wetland types. We have also proposed diversions along the lower Mississippi River to create new subdeltas and new marsh.

Donald Boesch: Then you would manage for maximum wetland vegetation rather than for a particular harvestable resource?

David Fruge: The resources will occupy the niches that are provided for them.

Donald Boesch: You would like to manage for grass and Mike Voisin for oysters, that's my point.

David Fruge: I believe controlled freshwater diversions can do both by promoting marsh growth and protecting oysters from predators. The primary areas being considered for diversions are at Caernarvon, upper Barataria Basin and subdeltas at the river mouth. There isn't yet much opposition to these diversions. Perhaps an oyster fisherman in the immediate vicinity of a diversion would lose production due to pollution or the fresh water itself. Most management agencies, however, are supporting freshwater diversion.

Mike Voisin: That's right, the biggest problem with freshwater diversion is with the oyster industry. But the oyster industry is the best organized of the fishermen groups. Oyster growers are for freshwater diversion in some situations and against it in others. An oyster grower may have invested time and money or inherited a lease and the Corps of Engineers might destroy it by opening up the Bonnet Carre spillway or the Morganza spillway. The oyster fishermen are vocal and unified and have more political impact than other fishermen groups.

Helen Kennedy: Couldn't the oyster fisherman just move his grounds farther from the source of freshwater diversion as salinity shifts?

Mike Voisin: There are two oyster fisheries in Louisiana -- a private fishery and a public fishery. There are 800,000 acres set aside for the public fishery and 250,000 acres of oyster grounds are privately leased. The leases do not shift with the salinity.

Wendill Curole: The main problems confronting freshwater diversion are economic and social. There are relatively few areas where freshwater can be economically diverted, thus our attention should be practically focused on these areas. Secondly, there are some social effects such as the dislocation of oyster growers as has been discussed.

Ray Varnell: In the case of the Bayou Lamoque structure, the purpose for this diversion was to ameliorate some of the predation problems affecting adjacent oyster beds. Some of the beds have been silted in, but a much larger area was opened to production. On the other hand, the oyster growers are plagued by a pollution problem as a result of poor river water quality.

James Gosselink: Since the main source of fresh water is the Mississippi River, can that pollution problem be solved?

Ray Varnell: There are structural designs which will allow the introduction of water through marshes which act as a filters for pollutants.

John Teal: That mechanism depends on what the pollutants are. It is not very effective for compounds which are soluble in water.

Ray Varnell: Most of the Mississippi River pollutants are adsorbed on particulate material which settles in the marshes.

Scott Liebowitz: Aren't we fighting an uphill battle with lower river diversions, when the natural tendency of the river is to shift to the Atchafalaya River and rapidly build a delta? Might not we gain more by diverting more flow down the Atchafalaya and concentrating on building that delta cheaply and effectively?

David Fruge: I don't think lower river diversions are futile. These diversions can markedly slow the rate of marsh loss and modification. The Atchafalaya delta should be managed also and activities which interfere with the active marsh growth in that area (such as the Avoca Island levee extension) should be avoided.

Donald Landry: I represent Terrebonne Parish, an area greatly affected by the Atchafalaya River. The issues surrounding flood control, navigation, and land building are very complex. The rapid building of land at the mouth of the

Atchafalaya will have tremendous detrimental impacts which are not socially or economically acceptable at thus time. The eventual changes will require substantial changes including movement of people, and new technology must be developed to deal with it. The lower river diversions are of small magnitude which do not intefere with what is occurring at the mouth of the Atchafalaya.

Don Moore: With regard to the earlier issue of optimal conditions in wetlands for living resources, a good objective would be to maximize the area of brackish marsh. Saline marsh is a good brown shrimp nursery and intermediate marsh is good white shrimp nursery, while brackish marsh provides good nursery conditions for both.

Paul Yakupzack: Who is the savior of the marsh? Is it a State agency, Federal agency? Many agencies are involved, but none seems to be the leader or even a clearing house of information.

Darryl Clark: The Coastal Management Section of the Department of Natural Resources is not the "savior". We are often put in the position of many regulators of being attacked from all sides -- industry, fishermen, academics, environmentalists. We must balance these competing interests. This is difficult because of the lack of hard knowledge available and the dynamic nature of our coastline. We are trying a number of approaches including marsh creation. Coastal protection projects have been recommended to the Legislature and are proposed for funding.

Mike Voisin: It boils down to politics. If enough people become aware of the problem, then the politician will become the savior, because that's what he wants to be.

Murray Hebert: No one person or group can be the savior of the coast. What we are doing today is certainly a step in the right direction. Certainly, education is critical at this point -- education of the public and legislators. The Joint Committees on Natural Resources have recommended spending $38 million on projects, which in many cases are just to maintain the status quo. If the State can move forward, the Federal agencies will fall in line. For the first time, I believe we are moving in that direction.

Donald Landry: Who is going to do it? We are. The educated public. We must save ourselves through public awareness.

Linda Deegan: If fish and wildlife resources are worth about $190 million annually, how can these concerns compete with the petroleum industry, worth over $10 billion annually?

Donald Landry: You don't have to compete, because the two resources are not incompatible. They both can co-exist and be beneficial. For example, the major land companies which own 90 percent of wetlands in Terrebonne Parish and develop oil and gas resources are very interested in protecting the marshes. Renewable and nonrenewable resource interests must work together.

CONSEQUENCES: SOCIAL AND ECONOMIC

LEGAL IMPLICATIONS OF COASTAL EROSION IN LOUISIANA

Paul Hribernick
Michael Wascom

Sea Grant Legal Program
Law Center
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

Erosion in the coastal zone of Louisiana has serious legal consequences for all property owners -- private, State and Federal. When a private property owner and the State are placed in an adversarial position, the general rule of Louisiana law dictates that erosion works against the private property owner's interest and works in favor of the State's interest. When the State and the Federal Government are placed in an adversarial position, the general rule of law dictates that erosion works against the State's interest and works in favor of the Federal Government's interest. Following these general rules, if the forces of nature work to erode a private property owner's land, he may lose title of that land which erodes, and its valuable mineral resources, to the State. Similarly, if the forces of nature work to erode the coastline of Louisiana, the State may lose to the Federal Government, title to land in the Outer Continental Shelf in an amount corresponding to the number of acres of coastline that has eroded. At stake are invaluable mineral resources which pass with the ownership of the land.

THE LEGAL IMPLICATIONS OF COASTAL EROSION IN LOUISIANA

The weathering effects of natural forces in the coastal zone contribute to endless alteration of the landscape. The physical causes of this erosion and its ramifications are currently objects of intense scientific inquiry. Science is not the only discipline studying, and reacting to, the severe changes worked by erosive forces in the coastal environment of Louisiana, for in addition to habitat loss, hydrological modification, adverse effects on fisheries, and myriad other physical manifestations, erosion presents significant legal consequences for landholders in the coastal zone. This paper will examine the legal implications of erosion to coastal property owners in Louisiana. First, how erosion changes the relationship between an individual private property owner and the State will be explored. Later, the relationship between the State Government and the Federal Government as property owners will be examined to illustrate potential changes in legal ownership directly attributable to coastal erosion.

EROSION, STATE WATER BOTTOM OWNERSHIP, AND THE PRIVATE PROPERTY OWNER

Ownership of property is an ancient and fundamental legal right in western civilization.[1] In addition to exclusive rights to the surface, private property owners may possess preeminent rights in subsurface minerals[2] and even the airspace above the land[3]. The measure of the property owner's rights is tied to the surface area of his holdings [4] and boundaries established on the surface serve as a convenient method delineating the rights of adjoining proerty holders.

Just as any person may own property in his individual capacity, the State may own property and exercise all normal proprietary functions over its domain.[5] In the celebrated 1845 case, Pollard's Lessee v. Hagan,[6] the U.S. Supreme Court determined that each state owned the lands underneath navigable waters within the state. The Court reasoned that because the original 13 states owned the land under their navigable waters, all states subsequently entering the union should take ownership of equivalent water bottoms because the Constitution promised them "equal footing" at statehood. [7] Because Pollard's Lessee v. Hagan involved only the tidewaters of Mobile Bay, and was further complicated by a deed of cession from the State of Georgia to the United States, the case did not make clear whether the equal footing doctrine gave the states title to the beds of inland navigable waters not affected by the tide. Subsequent Supreme Court decisions, however, held that the states did own the bottom of inland navigable waters, (such as the upper Mississippi)[8]. Still later, the Supreme Court decided that state law--rather than Federal common law--controlled the disposition of navigable water bottoms, including what general rules of law would apply when such lands eroded.[9] Therefore, in Louisiana's coastal wetlands, Louisiana property law dictates the consequences when a private landowner's property erodes under the forces of nature.

Since the State of Louisiana owns the beds of navigable bodies of water, a key inquiry that must be made before the legal consequences of erosion can be determined is whether or not the body of water abutting the private landowner's property is "navigable." Louisiana courts have essentially adopted the Federal admiralty definition of navigability.[10] The Daniel Ball,[11] a U.S. Supreme Court case, defines navigable rivers in the following manner:

> "Those rivers must be regarded as public navigable rivers in law which are navigable in fact. And they are navigable in fact when they are used, or are susceptible of being used, in their ordinary condition, as highways for commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on waters."[12]

Using this definition, Louisiana courts have determined that historical commercial use [13] or actual present commerical use [14] may adequately demonstrate navigability for property law purposes.

Once navigability has been determined, the legal consequences which result from erosion depend on where the erosion is occurring. Louisiana property law recognizes three distinct types of shoreline: lakeshore; banks of rivers, bayous and streams; and seashore. Similar types of erosion in each of these areas can have widely differing legal consequences for the private property owner.

Lakeshore Erosion[15]

Article 500 of the Civil Code prevents the riparian[16] landowner from taking any property rights in land exposed by the gradual receding of a lake (dereliction) or in the gradual buildup of sediment on the lakeshore (alluvion). At the same time, Articles 450 and 452 hold that the bottoms of navigable water bodies are public things and incapable of private ownership. Because the courts have ruled that the State owns the bottom of a navigable lake up to the high watermark,[17] Louisiana law, in effect places the private property owner abutting a navigable lake, in a "no win" situation. If the lake shrinks due to imperceptible natural causes, his property is separated from the water by a strip of state-owned land. If his shoreline is eroding or his land is subsiding, the State takes title to any land that is inundated by the expanding lake waters.[18]

It has already been noted that the equal footing doctrine requires that the state be given title to all land under navigable waters when it enters the union. When Louisiana was admitted to the Union in 1812, it was given ownership to all land beneath navigable waters up to the high water mark. Because Article 500 prevents the State from losing any land to the private riparian landowner, the threshold question of navigability assumes critical importance when assessing the property law implicatons of shoreline erosion in a coastal lake. If the water body was navigable in 1812, Article 500 dictates that the limit of such navigable waters in 1812 is an immutable line in favor of the State.[19] That is, irrespective of the waterway's present navigability, the State will always own as much as was navigable in 1812. Furthermore, erosion on lake shorelines serves to increase state land ownership in direct proportion to the decrease in private property ownership.

The Louisiana Supreme Court in Miami Corp. v State,[20] summarized the rule:

> "It apppears to be the rule that where the forces of nature--subsidence and erosion--have operated on the banks of a navigable body of water, regardess of whether it is a body of fresh water or the sea, or an arm of the sea, the submerged area becomes a portion of the bed and is insusceptible of private ownership."[21]

Furthermore,

> "The mere fact that a portion of the bed of a navigable body of water may have been formed by the action of natural forces does not change the situation, for the rule is, that when submersion occurs, the submerged portion becomes a part of the bed or bottom of the navigable body of water in fact, and therefore the property of the State, by virtue of its inherent sovereignty, as a matter of law."[22]

Under this rule, the determination that a body of water was navigable in 1812 will dictate the legal consequences of erosion in a lake 170 years later.

If the water body was not navigable in 1812 a different set of legal consequences occurs. In such a case, the lake bottom is a private thing[23] and may be held by the private property owner. Therefore, if subsidence creates a lake on private property after 1812 or enlarges (or shrinks) an existing but non-navigable lake, the owner does not lose title to the land. If the lake that was non-navigable in 1812, becomes navigable due to natural forces, the Civil Code and the jurisprudence of Louisiana provide no definite

answer as to the ownership of the lake. A literal reading of Article 450 would require that ownership of the bed must go to the State, but this view has been criticized.[24]

Bank Erosion of Rivers, Bayous, and Streams

Deltaic river systems are much more dynamic than lakes and different laws govern the ownership effects of erosion on private property adjacent to rivers, bayous, and streams. Navigability is still important, but the "immutable line" concept of lakeshore erosion does not apply in the riverbank erosion situation. Rather, the courts adhere to the concept implicit in the Code that navigability and its relationship to property law must reflect the nature of Louisiana's rivers.[25] Generally, the courts apply the same navigability tests for rivers as for lakes and if a river is deemed navigable, the equal footing doctrine grants title of the bed to the State. But unlike lakes, portions of rivers can rapidly become navigable, while other segments may become non-navigable. Because of this, the concept of navigability as applied to rivers must more accurately reflect the changing nature of Louisiana's rivers.

If a river is determined to be navigable, State law limits the state-owned bed to such lands covered by mean low water as measured on both banks.[26] If the river is found to be non-navigable, the bed may be held in private ownership.[27]

The critical question that governs the Louisiana courts' inquiry into the legal consequences of riverbank erosion is not navigability, but rather the nature of change brought about by erosive forces. If the change is gradual and imperceptible, erosion creates one set of legal consequences, but if erosion is sudden and avulsive, another set of consequences arise.

There are four imperceptible changes on navigable rivers that are specifically recognized under Louisiana law: erosion, accretion (or alluvion), dereliction and the creation of islands and sandbars. As a general rule, the riparian landowner loses to the State any land that is eroded by a navigable river, but gains from the State any alluvion that is deposited on his bank which causes his property to accrete.[28] This rule is best summed up by the Louisiana Supreme Court in <u>Succession of Delachaise v. Maginnis</u>:[29]

> "In . . . [a] . . . sense it may be said that rivers give or take away, like change or fortune. If it takes away the owner must bear the loss; if it gives, justice affords him the gain."[30]

The Louisiana courts have determined that since the Civil Code dictates that the beds of navigable rivers are insusceptible to private ownership, erosion creating new riverbed must work in favor of the State because "once a body of water is found to be navigable, it follows that the bed or bottom must be held to be the property of the State."[31]

The Civil Code specifically sets out the rules for accretion or alluvion.[32] Article 499 simply states that "the alluvion belongs to the owner of the bank . . ." It must be noted, however, that although the banks of navigable streams may be held in private ownership, Article 499 reserves to the public the right to occupy such banks for necessary purposes (e.g., wharfs, boat landing, drying of nets).

Dereliction, the imperceptible drying up or retreat of a navigable river, is treated similarly to accretion. Ownership of newly exposed land belongs to the riparian,[33]

subject to the Code provision which reserves some uses of the exposed bank to the public.[34]

Ownership of newly formed islands and sandbars is controlled by Article 505. If an island or sandbar arises in the channel of a navigable river, ownership goes to the State. If a sandbar does not arise independently in the channel, but rather grows out from the shore, it is treated as an accretion and ownership goes to the riparian.[35] Litigation over the ownership of sandbars invariably turns on which side can prove how the sandbar was created.[36]

If erosive forces cause a sudden, or avulsive change, the legal implications are quite different from those of imperceptible changes. The general rule with avulsive changes, as directed by the Civil Code, is that the State will exchange ownership of the old bed for ownership of the new bed.[37] If a river suddenly changes course, abandoning its original bed and inundating the land of a former riparian, the State takes ownership of the new bed and the landowner (who now has a river running across his former riparian estate) takes the original bed. In <u>Fitzsimmons v. Cassity</u>,[38] the Louisiana Court of Appeal expressed the rule this way:

> " When a river changes its course and for this purpose appropriates private property for its new bed, the lawmaker, out of a spirit of justice and fairness, has wisely ordained, in effect, that the owner of the appropriated land shall be compensated for his loss by becoming owner of the abandoned bed."[39]

The court makes it clear that even though the old channel may still be navigable, the bed nonetheless goes into private ownership.[40] The Code provides, however, that if the river ever resumes its original channel, all parties shall retake their former lands.[41]

If an avulsive action of a river cuts off riparian land and creates an island, the Civil Code provides that the ownership of the island does not change.[42] This provision works in conjunction with Article 504 which provides for the exchange of bed ownership when a river changes course to insure predictable legal consequences in the wake of an avulsive change.

<u>Seashore Erosion</u>

The legal effects of erosion along the seashore are similar to those of erosion along a lakeshore except that navigability is of little importance. The Submerged Lands Act [43] granted Louisiana paramount rights to the seabed from the mean ordinary low tide line seaward to the three-mile territorial limit. Civil Code Article 450, in addition to recognizing ownership of the territorial seabed, grants the State ownership of the seashore.

Seashore is defined in the Code as "the space of land over which the waters of the sea spread in the highest tide during the winter season."[44] This definition has been interpreted to require more than mere tidal influence to demonstrate that waters are actually part of the sea. In this way, the courts have limited "seashore" to the actual coast and "arms of the sea".[45] Working with this definition and the guidance of the Code, Louisiana courts have held that ownership of any seashore that erodes to become sea bottom is transferred to the State.[46] Moreover, any accretions along the seashore are property of the State.[47] The littoral[48] landowner is placed in a "no win" situation

similar to that of the lakeshore landowner: if his land is eroding, he loses ownership to the State; if his land is accreting, he becomes separated from the ocean by a strip of state-owned land.

Reclamation Process

The potentially immense value of oil beneath a landowner's property is generally calculated on the basis of surface land ownership. Erosion, and subsequent transfer of ownership to the state, may mean significant losses in future royalty revenue[49] to a property owner whose land is eroding. In an effort to address this problem, the State Legislature acted in 1978 to create a process by which a property owner can reclaim lands lost to the state by erosion.[50] The Louisiana Consitiution provides that:

> "The legislature shall neither alienate nor authorize the alienation for the bed of a navigable water body, **except for purposes of reclamation by the owner to recover land lost through erosion.**"[51] (emphasis added).

The legislature exercised the option granted to them in the Constitution and provided a mechanism whereby a property owner can earn back land he lost to erosion and thereby protect potential oil revenue.[52] The landowner must apply to the Department of Natural Resources (DNR) and provide them with a professional survey showing the exact extent of the land claimed to be lost by erosion. DNR will review the application and seek the input of the Attorney General, the Department of Transportation and Development, the Department of Wildlife and Fisheries, and any other State agency or local government who may have an interest in the reclaimed area. If all parties consent to the application,[53] the landowner will be give a two-year permit to reclaim the land. The gravity of the coastal erosion problem is highlighted by the fact that the statute specifically encourages coastal landowners to reclaim lands out to the baseline decreed by the U.S. Supreme Court in the 1975 Tidelands decision.

STATE WATER BOTTOM OWNERSHIP AND THE FEDERAL GOVERNMENT

Although the State generally inherits a superior legal positon in relation to the private landowner when erosion destroys private lands, when State lands are being eroded, the state's legal position ultimately proves to be inferior to the Federal Government's paramount rights.[54]

Relying on Pollard's Lessee v. Hagan,[55] the states always assumed that the equal footing doctrine applied to lands beneath the three-mile territorial sea. With the advent of commercially practical offshore drilling technology in the late 1940's and the subsequent discovery of huge oil reserves on the Outer Continental Shelf, the states looked forward to lucrative oil revenue from production in the territorial sea. This scenario was shattered in 1947 by the U.S. Supreme Court in United States v. California.[56] That decision held that the United States maintained paramount rights in the land seaward of the low water mark. The outcry from coastal states convinced Congress that remedial action was necessary. A political solution was forged in 1953 with the passage of the Submerged Land Act.[57] This act effectively reversed the Supreme Court's United States v. California decision by deeding title to the seabed, for the width of the territorial sea, to the adjacent coastal State.

In an effort to maximize its territorial ownership, Louisiana became embroiled in a cumbersome series [58] of Supreme Court cases against the United States.[59] This litigation culminated in 1969 with United States v. Louisiana,[60] where the Court decided two questions of critical importance for understanding the legal implications of coastal erosion. First, the Court decided that international law must be applied to determine Louisiana's coastline. The net effect of this decision was to minimize Louisiana's offshore claims.[61] Second, and more important, the Court declared Louisiana's coastline to be **ambulatory.** This means Louisiana's baseline (from which the territorial sea is measured) can move landward as the coast erodes, depriving Louisiana of substantial offshore oil revenue. This fact is made clear in the June 1981 decree [62] where the Supreme Court implies that if the coastline recedes due to erosive forces, the United States would have the right to seek a more favorable boundary with the state in court.[63]

CONCLUSIONS

When a Louisiana private property owner's lands are subjected to erosion, he is placed in an adversarial position with the State. If the private property abuts a navigable river, the riparian loses to the State any property which erodes, but gains ownership of any alluvion that builds up along his river bank. If the private property abuts a navigable lake or the coastline, the littoral owner is placed in a "no win" situation. Any portion of his land which erodes is lost to the State and ownership of any new land created between his property line and the water vests in the State, cutting the littoral owner off from the water by a strip of state-owned land. However, State law generally allows the private land-owner to reclaim any land lost to erosion.

When the State's coastline is subjected to erosion, the State is placed in an adversarial position with the Federal Government. As erosion forces the coastline landward, the State's territorial sea theoretically moves a corresponding distance landward. Unlike the private landowner, the Federal Government does not give the State a chance to reclaim lands lost to erosion. As a result, Louisiana may untimately lose valuable offshore mineral rights to the Federal Government if the courts are ever asked to recompute the State's coastline which is the baseline for measurement of the territorial sea.

ACKNOWLEDGMENTS

This publication is a result of research sponsored by the Louisiana Sea Grant Program, part of the National Sea Grant Program maintained by the National Oceanic and Atmospheric Administration, United States Department of Commerce. The Federal Government is authorized to produce and distribute for government purposes notwithstanding any copyright notation that may appear hereon.

FOOTNOTES

1. The right of an individual to hold private property is of such significance that it is a specifically protected right in U.S. Constitution. See, U.S. CONST. amend. V

2. See generally, Mineral Code, La. Rev. Stat. Ann. Section 31:4 et seq.

3. See e.g., Herrin v. Sutherland, 74 Mont. 587 (1925), City of Newark v. Eastern Airlines, 159 F. Supp. 750 (1958)

4. As a general proposition, established oil field rights can be conceptualized as being in direct proportion to surface area owned in a declared field. See generally, La. Rev. State. Ann. Sections 31:9-11

5. AUBRY AND RAU, CIVIL LAW TRANSLATIONS, Vol. II Sections 169, 170 (7th ed. 1961)

6. 44 U.S. (3 How.) 212 (1845)

7. The Court's reasoning in Pollard's Lessee v. Hagan was that because the lands under navigable waters were not specifically granted to the United States by the Constitution, they were thereby reserved to the original 13 States. The Court then concluded that Article IV, Section 3 of the Constitution (which controls the formation of new states) and Article I, Section 8, clause 16, (which was interpreted by the Court at that time to prevent Federal control over lands other than the District of Columbia and military reservations) read together, demanded that newly created states be admitted on the same terms ("equal footing") as the original 13 States. Therefore all states own the land under their navigable waters. See also, La. Civ. Code Ann. art. 450

8. See, Shively v. Bowlby, 152 U.S. 1, (1893); Eldridge v. Trezevant, 160 U.S. 452 (1895)

9. See, United States v. Chandler-Dunbar, 229 U.S. 53, (1913); Oregon ex rel State Land Board v. Corvallis Sand and Gravel Co., 429 U.S. 363 (1977)

10. See generally, YIANNOPOULAS, LOUISIANA CIVIL LAW TREATISE, 42 (2d ed. 1980)

11. 77 U.S. (10 Wall.) 557 (1870)

12. Id., at 563

13. See, State v. Aucoin, 206 La. 787, 20 So 2d 136, (1944). See Also, Id. at 158, (Fournet, J., dissenting); Amite Gravel Sand Co. v. Roseland Gravel Co., 148 La. 704, 87 So. 718 (1921); State v. Jefferson Island Salt Mining Co., 183 La. 304, 163 So. 145 (1935)

14. State ex rel Atchafalaya Basin Levee District v. Capdeville, 146 La. 89, 83 So. 421 (1919); State v. Jefferson Island Salt Mining Co., supra, note 13

15. The threshold question of whether or not a body of water is a lake or a river is generally dictated by the physical characteristics of that water body, which the courts will examine on a case by case basis. Some factors the court looks to are the size of the water body, source of its water (is it primarily drainage or river flow?), presence or absence of current, flow within well-defined banks, amount of sediment load carried by the water. See, Slattery v. Arkansas Natural Gas, 138 La. 783, 70 So. 806 (1916); Amerda Petroleum Corp. v. State Mineral Board, 203 La. 473, 14 So. 2d 61 (1943); State v. Placid Oil Co., 200 So. 2d 154 (La. 1974)

16. Riparian refers to those things related to, or located on, the bank of a natural watercourse.

17. State v. Placid Oil Co., 300 So. 2d 154 (La. 1975), cert. denied, 419 E.S. 1110 (1975)

18. Miami Corp. v. State, 186 La. 784, 173 So. 315 (1937), overruling State v. Erwin, 173 La. 507, 138 So. 84 (1931)

19. See, YIANNOPOULAS, supra, note 10. As can be imagined, the proof problems in establishing what was navigable in 1812 are enormous. Most, if not all water bottoms were unsurveyed at that time. Although the burden of proving navigability rests with the state, it is not a task of such insurmountable magnitude as to nullify State claims to newly inundated lands.

20. Supra, note 18

21. Id., at 322

22. Id., at 323

23. La. Civ. Code Ann. art. 453

24. See, La. Civ. Code Ann. art. 506. See also, La. Civ. Code Ann. arts, 499-505 See, YIANNOPOULAS, supra, note 10. This criticism is lent indirect support by the Supreme Court's recent decision in Kaiser Aetna v. United States, 444 U.S. 164 (1979). In that case, the Court held that a non-navigable pond that was artificially connected to the sea could not be ruled open to public navigation without paying its private owners compensation under the Eminent Domain Clause of the Fifth Amendment to the U.S. Constitution. The courts in Louisiana may be willing to extend this rule and require the State to compensate a private landowner if the State takes title to the bed of a formerly non-navigable lake on the landowner's property.

25. See, La. Civ. Code Ann. art. 506. See also, La. Civ. Code Ann. arts. 499-505

26. See, Smith v. Dixie Oil Co., 156 La. 691, 101 So. 24 (1924)

27. La. Civ. Code Ann. art. 506. See State v. Aucoin, supra, note 13; Bank of Coushatta v. Yarborough, 139 La. 510, 71 S. 784 (1916)

28. See, Esso Std. Oil v. Jones, 233 La. 915, 98 So. 2d 236 (1957), State v. Capdeville, supra, note 14. It should be noted in this situation that land loss experienced by one land owner will be accompanied by a deposition of alluvion and a corresponding gain to some other landowner, usually on the opposite bank. Therefore, although the State stands to gain greatly from erosion of private property, the laws of nature dictate that the State's water bottom holdings remain relatively constant. This is not accurate, however, when both banks of a navigable river are eroding. In that case, the State's gain is absolute.

29. 44 La. Ann. 1043, 11 So. 715 (1892)

30. Id., at 716

31. State v. Capedeville, supra, note 14 at 425. See also, Miami Corp. v. State, supra, note 18

32. La. Civ. Code Ann. arts. 499-501

33. Esso Standard Oil v. Jones, supra, note 25

34. La. Civ. Code Ann. art. 499

35. Id.

36. See, Butler v. State, 244 So. 2d 888 (La. App. 1971), writ denied 246 So. 2d 680. Before accurate survey records were kept, the burden of proving how a sandbar evolved was immense. With modern scientific mapping and satellite observation technique, proof problems will be minimized in the future.

37. La. Civ. Code Ann. art. 504

38. 172 So. 824 (La. App. 1937)

39. Id., at 829

40. Louisiana Courts are apparently disposed to grant all the former bed--including sandbars attached to land--to the landowner whose property is now inundated by the river, See, Stephens v. Drake, 134 So. 2d 674 (1961). The court apparently decides that Article 504 overrules Article 499 when the two come into conflict.

41. La. Civ. Code Ann. art 504

42. La. Civ. Code Ann. art 503

43. 43 U.S.C.A. Sections 1301 et seq. See text accompanying notes 54 to 63, infra

44. La. Civ. Code Ann. art 451

45. An "arm of the sea" is generally considered any body of water immediately adjacent to, or directly connected with the sea. See, Buras v. Salinovich, 154 La. 495, 97 So. 748 (1923) citing Morgan v. Negodich, 40 La. Ann. 246, 3 So. 636 (1887) with approval. Lake Pontchartrain has always been held to be an arm of the sea.

46. New Orleans Land Co. v. Board of Levee Comm'rs., 171 La. 718, 132 So. 121 (1931)

47. Ruch v. New Orleans, 43 La. Ann. 275, 9 So. 473 (1891)

48. Littoral refers to those things related to, or located near, the coastline.

49. If the eroded lands are presently subject to a lease, the State will take ownership of those lands subject to any existing leases. The legislature has provided that the landowner will not lose any presently valid lease. See, La. Rev. Stat. Ann. Section 9:1151. This limits the landowner's loss to royalty revenue derived from a discovery

of minerals subsequent to his loss of the land due to erosion.

50. 1978 La. Acts, 645

51. La. CONST. art 9, Section 7

52. La. Rev. Stat. Ann. Section 41:1702. This statute specifically gives the landowner the right to recover all oil, gas and mineral rights in addition to the actual land surface.

53. Although the statute is not precisely clear, Sections (D) and (H) of La. Rev. Stat. Ann. Section 41:1703 would appear to give each one of these agencies and local governments veto power over the proposed reclamation.

54. The state loses relative to the Federal Government both when state land and any private landowner's property is eroded. The reason is that the baseline, or coastline, from which the three-mile territorial sea (the bottom of which belongs to the state) is computed, is measured from the points of land that extend farthest into the Gulf of Mexico, be they privately owned or state owned. If state lands erode, the baseline (and therefore territorial sea) moves landward. Similarly, when private lands erode, even through the state gains onwership of the new bottom, the baseline moves landward and the states gain from the private landowner is offset by its loss to the Federal Government.

55. supra, note 6

56. 332 U.S. 19 (1947)

57. supra, note 43

58. United States v. Louisiana, 339 U.S. 699 (1950) (applies U.S. v. California rule to Louisiana); 354 U.S. 516 (1957) (Louisiana attempts to litigate its territorial sea, but Supreme Court rules that Alabama, Florida, Mississippi, and Texas are necessary parties and must be joined); United States v. Louisiana, et. al, 363 U.S. 1 (May 1960) (Supreme Court rejects Louisiana's claim to a nine-mile territorial sea and grants only three miles); United States v. Louisiana, et. al, 364 U.S. 502 (Dec. 1960) (Final decree defining coastline at ordinary low water); United States v. Louisiana, 382 U.S. 288 (1965) (Court rejects Texas' attempt to use artificial jetties to enlarge its territorial sea); United States v. Louisiana, 394 U.S. 11 (1969), See text accompanying notes 54-56; United States v. Louisiana, 420 U.S. 529 (1975) (Court overrules Louisiana's objections to special master's report); United States v. Louisiana, et al., 422 U.S. 13 (1975) (Court supercedes 1965 baseline it had established and orders an accounting of oil revenue); United States v. Louisiana, ______ U.S. ______ 49 U.S. L.W. 4825 (1981) (Final decree setting ambulatory coastline and territorial sea; Court orders a final accounting due 1 December 1981).

59. The Constitution vests original jurisdiction in the Supreme Court when a state sues the United States directly. In such cases, the Supreme Court is the trial court of first instance. Because of the time-consuming nature of such cases, the Court will generally appoint a special master to hear the case and make recommendations to it. Of course, the Court is free to disregard the findings of the special master.

60. 394 U.S. 11 (1969)

61. For example, Louisiana had claimed that Breton and Chandeleur islands delineated the baseline of Louisiana and that the territorial sea must be measured out three miles from their shore. International law disapproves such a claim, granting a coastal state only a three mile ring around islands that are greater than three miles offshore. See, Guste and Ellis, Louisiana Tidelands Past and Future, 21 Loy. L. Rev. 817, at 326

62. United States v. Louisiana, _____ U.S. _____, U.S.L.W. 4825 (1981)

63. Id., at 4825

ECONOMIC AND CULTURAL CONSEQUENCES OF LAND LOSS IN LOUISIANA

Donald W. Davis

Earth Science Department
Nicholls State University
Thibodaux, LA 70310

ABSTRACT

Louisiana's coastal lowlands are facing a serious dilemma. The problem is related directly to man's interference with the Mississippi River's flow regime and the effects of erosion induced by natural processes--winds, waves, currents, and tides. As a result, the wetlands are out of balance. Progradation has been superseded by erosion with land disappearing at an alarming rate. Approximately 103.6 km^2/yr (40 mi^2/yr) are being destroyed--changing from barrier island and protected marshes to open water.

The next 200 years are critical, since a large portion of Louisiana's coastal zone will be eroded away. In the process an important nursery ground and habitat for migratory waterfowl, fur and hide-bearing animals and fisheries will be lost. "High" land, already scarce, will be at a premium and the cumulative economic effect will be measured in the billions of dollars.

New Orleans will lose its natural defense against a hurricane-induced storm surge. With parts of the "Crescent City" 6.1 m (20 ft) below sea level, it cannot afford to be at the mercy of an unimpeded tropical cyclone. Without the surrounding marshes, the first line of defense will have vanished.

Trappers will lose the habitat preferred by muskrat and nutria. The Nation's preeminent fur-producing region, producing from $2 million to $24 million in annual pelt sales, will be gone. Additional renewable resources, such as shrimp, oysters, crab, and menhaden, worth hundreds of millions of dollars annually, will no longer have a habitat that supports more than 25% of the country's commercial fisheries. Concomitant with the decline in these industries will be the partial demise of the nearly $200 million recreational industry.

Probably the most important single loss to the State will be Louisiana's land/water boundary. As this line retreats, the limit of Louisiana's offshore zone moves shoreward. The end result is the forfeiture of millions of dollars in oil royalties--at least $20 million for each mile of coastal retreat. Further, the multibillion dollar infrastructure associated with the petroleum industry also faces the loss of valuable "high" ground; thus a number of favorable advantages of living and working in Louisiana are changed.

Unique lifestyles will also be altered or lost. Centuries-old traditions will die. The cultural heritage of the region will be diluted and the economic resources responsible for

billions will be gone. The final question is: "Can we afford the loss of Louisiana's wetlands?"

INTRODUCTION

South Louisiana's 6.5 million acres of coastal wetlands account for 40% of the Nation's marsh ecosystems (Gosselink 1980). The region is defined by elevation and the absence of trees. Where the land is at least 0.5 m (18 inches) above sea level, a swamp forest will be evident. The marsh, on the other hand, is a conspicuous lowland--literally a sea of grass.

The physical and biological complexities of this unique physiographic province are the subject of numerous technical reports, papers, and monographs. The initial work of a multitude of wetland scientists established the guidelines for subsequent research. These individuals contributed significantly to the systematic examination of alluvial environments. Their interdisciplinary studies provided insight into the surface and subsurface elements that comprise the various marsh habitats. From this foundation, interest in the coastal lowlands proliferated.

Early investigators discovered the vast expanse of marsh is larger than Connecticut and Delaware combined and a product of the wandering distributaries and alluvial processes of the Mississippi River. With each channel change river-borne sediments were diverted into new areas. The Mississippi River, therefore, created this large extensive band of coastal property. Prior to the late 1800's, south Louisiana experienced at least 6,000 years of deltaic progradation.

Unfortunately, Louisiana's coastal zone is presently out of balance--a great natural catastrophe is occurring. Land is disappearing. For the entire Louisiana coast, marsh losses in 1980 exceeded 10,000 ha (25,000 acres)/yr--a rate that is increasing geometrically and not arithmetically. With 1 million ha (2.5 million acres) of fresh to saline marsh, 700,000 hectares (1.8 million acres) of ponds and lakes, and 900,000 hectares (2.2 million acres) of bays and estuaries, there is now more water than land (Fruge 1981). Land building in the deltaic plain has been replaced by a projected rate of loss of approximately 100 km^2 (40 mi^2)/yr (Gagliano, et al. 1981), coupled with a rise in sea level estimated to be 30 cm (1 ft) per century, the wetlands are in serious danger. By comparison, on the national level approximately 400,000 ha (1 million acres) of coastal marshes have been lost since 1954 at a rate of 15,000 ha (38,000 acres)/yr (Gosselink 1980). In Louisiana, at least 300,000 ha (800,000 acres) have been lost in the last 80 years with more than half of this occurring since 1950 (Gagliano 1981).

These land loss figures are staggering, since Louisiana's wetlands provide a habitat for more than two-thirds of the Mississippi Flyway's wintering waterfowl, the largest fur and alligator harvests in North America, and more than 25% of the country's commercial fisheries. Few states can compete with Louisiana in the production of renewable and nonrenewable resources; yet due to land loss, they are threatened and may vanish.

The land that is eroding at a record rate is a result of sediment deposition associated with the Mississippi River. For centuries, sediment laden water has fanned out along the coast, creating two distinct zones: the deltaic and chenier plains, east and west, respectively, of Vermilion Bay.

THE DELTAIC PLAIN

The deltaic plain is the site of a series of seven deltaic lobes extending seaward at different times during the last 6,000 to 7,000 years. Except for the modern "bird's foot" delta, each lobe advanced into the shallow waters of the continental shelf and was distinguished by numerous distributaries. These channels continued to bifurcate, thus aiding the distribution of the river sediments and progradation of the coast. Through time, the recurring channel changes created the intricate "horse's tail" pattern of levee fingers extending into the wetlands. Fluvial-marine materials deposited in the prodelta, interdistributary and intradelta environments built up an estimated 75% of the deltaic plain (Kolb and Van Lopik 1958; Frazier 1967). Most of this land is an abandoned subdelta composed of alluvial ridges, beaches, marsh and water surface, where accretion has been replaced by subsidence and erosion.

In the paludal environments, the organic bulltongue (Sagittaria) and other grass-derived materials develop in place. They are not altered by alluvial deposits. In these tracts organic material continually decays and accumulates as peats, in effect, building the marsh "down" rather than "up." Decomposition maintains an organic layer that thickens with subsidence to a depth of 3 to 6 m (10 to 20 ft) (Russell 1942; Kolb and Van Lopik 1958).

On a regional basis, some southeastern Louisiana surfaces may sink as much as 5 m (17 ft) per century (Kolb and Van Lopik 1958). In many areas aggradation simply cannot keep pace with subsidence. Small ponds often develop that expand rapidly as wind-driven waves attack the poorly consolidated sediments that make up the shore (Gagliano and van Beek 1970).

Further, the construction of flood levees and the dredging of drainage, navigation, petroleum, and logging canals upset the sedimentation balance, influenced salt water intrusion, and disrupted the natural flow regimes. Consequently, the Mississippi's natural processes were altered and erosion began to overshadow deposition. Sediments are now channeled off the continental shelf. This waste of sediments deprives the coast of the "material" that sustained the balance and prevents the building of new marshes. There is nothing available that can offset the rapid rate of wetland loss (Fruge 1981). Salt water moves inland and kills the root mat that "holds" the marsh together. In the 1900's this reversal in the natural cycle has accelerated from a loss of 17.3 km^2/yr (6.7 mi^2/yr) in 1913 to nearly 104 km^2/yr (40 mi^2/yr) in 1980 (Gagliano 1981).

THE CHENIER PLAIN

On southwestern Louisiana's near-sea-level grasslands the surface is broken by a series of long, narrow sand ridges, locally called cheniers (Howe et al. 1935). Referred to as the chenier plain, the area was formed by wave action pushing sand up onto shore (Russell and Howe 1953; Price 1955). Each chenier marks the position of a once active shoreline (Schou 1967). When the Mississippi occupied one of its western courses, clays, muds, and sands were carried westward by littoral currents advancing the chenier plain as a mud coast. Interruptions in the progradation process allowed coarser particles to accumulate as a ridge. An increase in sedimentation caused the shoreline to advance leaving the conspicuous, oak-covered chenier as the region's most impressive and continuous topographic feature (Howe et al. 1935).

"Prairie marshes" associated with the 3,000 km^2 (1,200 mi^2) of chenier plain have an old and firmer foundation (Coleman 1966). Subsidence is not as important in the ecology of these marshes as it is in the newer formation to the east (O'Neil 1949). The region is subjected to uninterrupted wave attack that rapidly erodes the shoreline. Like the deltaic plain, it is also facing a serious land loss problem.

ECONOMICS OF ENDANGERED MARSH: LOSS OF MORE THAN JUST LAND

Built by the Mississippi and eroded by natural processes often accelerated by man, Louisiana's marshes nevertheless nurture and support a vast natural resource that is threatened by the cumulative effects of marsh deterioration.

Since the late 1930's the wetlands complex has experienced rapid economic growth and development. Much of this growth is a result of the hydrocarbons extracted onshore and, more recently, offshore. Oil and gas account for a multibillion dollar industry. Agriculture, seafood, trapping, and recreation are multimillion dollar industries. In addition, Louisiana's largest city and the Nation's leading seaport, New Orleans, is directly or indirectly tied to the economics of the marsh. Land loss affects each industry differently, but in the long term, it is not in the State's best interest, since it will have a cumulative effect on Louisiana's economy.

To understand the complexities of the land loss problem as it relates to the cultural/economic intricacies of the wetlands, six topics will be discussed: New Orleans, trapping, fisheries,recreation, hydrocarbons and land use.

New Orleans: The Sea Level City

When people think of Louisiana, they think of New Orleans. The city is synonymous with the State. It is Louisiana's largest city and has recently become the country's largest seaport. Like the rest of south Louisiana, New Orleans is a product of the Mississippi. From early cotton packets, to modern petrochemical industries that flank its course from Baton Rouge to New Orleans, the Mississippi provided the principal impetus for regional growth.

To make New Orleans the city that it is required extensive drainage and reclamation programs. When the area was surveyed in 1720, each block was circled with canals. These channels established New Orleans' dependence on a drainage network. Levee construction began as early as 1718. Ten years later, a manmade embankment 1.6 km (1 mile) long protected the "Vieux Carre." By 1735, it totaled 64 km (40 mi) (Davis and Detro 1980). In 1743, an ordinance required property owners to complete their levees or forfeit their lands (Schneider 1952). It was apparent that this settlement would always face drainage problems, a battle yet to be won (Samuel 1959).

To insure that settlers confronted the drainage problem, Governor O'Reilly, in 1770, issued regulations: "To every family coming to settle in the province, a tract was to be granted... on condition that the grantee should within three years, construct a levee...finish a highway..., with parallel ditches towards the levee,..." (Martin 1882). These regulations guaranteed Louisiana's lowlands would be adequately drained. As a result, drainage and reclamation has become an integral part of New Orleans' growth. In the process, the "Crescent City" is the only North American city that has, for more than two and a half centuries, fought a continuous battle with flooding.

With parts of the city more than 6 m (20 ft) below sea level, New Orleans depends on levees and drains to protect the populace. A single pump failure, or levee crevasse can be disastrous. The city has learned to cope with these problems(Schneider 1952); yet it was not added to the Orleans Parish Levee District until 1950. With city funds, levees were built on the river.

After the disastrous flood of 1927, the need for flood control became apparent. To save New Orleans, the levee was blown up creating an artificial crevasse (Simprich 1927). The Army Corps of Engineers began to construct the Mississippi's "guide levees." In modern Louisiana these manmade embankments protect cities, towns, villages, farmland, and industrial complexes. In retrospect, they have allowed New Orleans to reclaim commercial, industrial, and residential property. With much of this "new" land below sea level, rain runoff and groundwater seepage is pumped uphill.

Levee systems are essential to keep flood waters out. Pumps operate continually to remove the excess. With continued urban/industrial expansion into the wetlands, there is a constant problem with subsidence. When drained, the peat land shrinks and subsides by as much as 75%. Developments, therefore, must withstand 3.5 m (12 ft) of subsidence during the first 50 years after drainage and the levees must provide protection from high tides, rains, and hurricanes (Wagner and Durabb 1976).

As the marsh deteriorates the buffer zone between the Gulf of Mexico and New Orleans narrows. This "cushion" is the city's first line of defense. It serves many useful purposes. As a site for the urbanite to engage in outdoor recreation, it is without parallel. For the people in New Orleans, however, it buffers against a hurricane's storm surge. When this barrier has eroded away, the city is in a most precarious situation, since it has no manmade defenses that can compare to the marsh. With parts of New Orleans more than 6 m (20 ft) below sea level, flooding is a constant problem. Even though the area is drained, the natural system is superceded by an artificial one that, at times, cannot accommodate the torrential rainstorms of the summer months. With its "foreland" eroding, the city is in a dubious position. Since two of the city's immediate marsh neighbors, Plaquemine and St. Bernard parishes, have projected land loss rates in 1980 of 3,574 ha/yr (8,831 acres/yr) and 685 ha/yr (1,695 acres/yr), respectively, their marsh's life expectancy are 52 and 152 years (Gagliano 1981). Consequently, the "cushion" is disappearing at an astonishing rate. The data clearly suggest Louisiana's largest urban agglomeration will require substantial new flood protection measures within the next 50 to 100 years, particularly as the area becomes more exposed to open water.

The Settlers and Their Occupations

Louisiana's coastal zone has been the site of continuous human occupancy for at least 12,000 years. From prehistoric Indians, to modern communities of French-speaking "Cajuns," the alluvial wetlands have supported a range of cultures and settlements. Numerous ethnic groups colonized the aquatic lowlands, locating their homes and villages on protected and well-drained land, near navigable waterways, and not too far from their fishing, hunting, trapping, and agricultural areas (Detro and Davis 1974). They established also the region's dependency on wetland resources.

Unlike New Orleans, the settlers within the wetlands were French farmers, trappers, and fishermen. They regarded the semiaqueous terrain as an attractive location for their new "marsh villages." In addition to the French, a group of Yugoslavian

oyster fishermen settled along the bayous, bays, and lakes southeast of New Orleans. In time they were joined by other Balkan immigrants (Evans 1963). Germans, Irish, Italians, Spanish, Lebanese, Filipinos, and Chinese settled within the coastal wetlands. These "folk" became farmers, laborers, oystermen, shrimpers, trappers, and truck farmers. As a result, the regional economy was established by the diverse ethnic mosaic that typifies the coastal zone. The mixing of nationalities resulted in a milieu that is absolutely unique in the United States (Evans 1963) and a subsistence lifestyle based on the folk occupations established by these original settlers--trapping, fishing (both for sport and profit) and farming.

Trapping: A Multimillion Dollar Industry

Few people recognize that North America's most productive fur-producing region is Louisiana's alluvial wetlands. The fur business dates to the 1700's, but the State did not become a significant fur producer until the twentieth century. At its height, the trapping industry provided employment for at least 20,000 people. Now less than a third of that number are licensed trappers. Severance tax records reveal these individuals account for nearly half of the Nation's fur harvest. In less than 50 years, the marsh dweller transformed Louisiana's alluvial lowlands into the country's pre-eminent fur-producing region, with an annual yield often greater than that of the remainder of North America. This extensive near-sea-level habitat has been responsible for as much as 65% of the country's yearly fur harvest (Davis 1978).

In the early 1800's, alligator (Alligator mississippiensis), mink (Mustela vison), and raccoon (Procyon lotor) were valuable hide and furbearing animals. These species, although important, did not account for the state's spectacular growth. Two small mammals are the industry's principal furbearers--the muskrat (Ondatra zibethicus) and nutria (Myocastor coypus). For more than 50 years, the muskrat was the largest fur producer; in a good season, more than 5 million animals would be trapped. Unlike the indigenous muskrat, the nutria was accidentally introduced into the wetlands; it is an exotic. This Argentinian rodent is a prolific animal that diffused throughout the State. In less than 30 years, it supplanted the muskrat and became Louisiana's most important furbearer.

Trappers harvest approximately 1.5 to 2.5 million nutria annually; since the early 1940's, more than 100 million have been removed from the marsh. Originally considered worthless, the animals' presence has resulted in a multimillion dollar industry. With yearly pelt sales that vary from $2 million to $24 million. The fur industry generates inconsistent income since between two successive seasons, pelt sales can differ by as much as $12 million. Although muskrat and nutria are the backbone of the industry, trappers also add to their income by harvesting raccoon, mink, otter and, since reclassification, the alligator. Each of these animals contributes to the economic survival of the remaining trappers within the coastal zone. Consequently, trapping is an important "folk" industry that continues to be a significant source of income.

The fur business is tied to the marsh, which Penfound and Hathaway (1938) conveniently divided into four vegetative types: saline, brackish, intermediate, and fresh. Various maps (O'Neil 1949; Kolb and Van Lopik 1958; Chabreck et al. 1968) document the elongate patterns of these vegetation assemblages. In general, the bands parallel the coast in an east-west direction. The areal limits are not stationary, but change with various edaphic factors, disrupting the vegetation and contributing to a decline in the furbearing population.

As the coast retreats, the saline marsh will expand reducing the range of the brackish and intermediate marsh's three-cornered grass (Scirpus olneyi) that provides 90% of the muskrat's food supply (O'Neil 1949) and accounts for "the most productive fur habitat along the northern gulf coast" (Palmisano 1972). Continued land loss will eventually influence the canouch (Panicum hemitomon) and alligator grass (Alternanthera philoxeroides) that are a nutria favorite. Ultimately, this renewable resource will be lost. As a result, an industry that has been an important part of the marsh dweller's winter subsistence activity will be lost. A part of the region's cultural heritage will die and a unique lifestyle will be lost.

Fishing: By Weight or Value, the Wetlands Are a Seafood Factory

Each year Louisiana fishermen catch more than 680 million kg (1.5 billion lb) of estuarine-dependent fish and shellfish, primarily menhaden, oysters, shrimp, and the nearly ubiquitous blue crab, representing more than one-quarter of the country's total catch (National Oceanic and Atmospheric Administration 1975). The region's biological wealth has provided a means of subsistence for its human inhabitants since prehistoric times. Fishing is an important part of the region's cultural heritage. In the seasonally oriented economy of the wetlands, the trapper finishes the fur harvest in February and by May he has prepared his boat for opening day of the shrimp season. Though wetland inhabitants long considered the marsh low in monetary value, they always profited from an abundant seafood harvest. With time and increased demand, Louisiana's seafood catch has escalated in value to more than $190 million annually; thus, the State is number one by weight and second in value (Ringold and Clark 1980; Aquanotes 1981).

This harvest is directly related to Louisiana's coastal wetlands. The State's economicaly important fish species spawn or migrate into the coastal estuaries to take advantage of the rich food supply, protective habitat, annual changes in meteorological conditions and other favorable factors. Flooding and salt stress are particularly important, since they determine the length of the growing season and the marsh's productivity. This influences the fisheries resource, in as much as they are dependent on the wetland's abundant food supply (Gosselink 1980). The reduction of this productive habitat through land loss affects the commercial fisheries. This is particularly true in the shrimp industry, where the yields are directly associated with the wetland area.

The commercial seafood industry developed with the exploitation of shrimp and oysters, harvested commercially since the late 1800's. These two species account for nearly half of the State's annual fisheries income, with shrimp landings representing from 20%-30% of the total shrimp harvest in the United States.

Shrimp. Two species of shrimp are harvested: brown (Penaeus aztecus) in the spring and white (P. setiferus) in the fall. These penaeid shrimp spawn and hatch offshore, but grow to a marketable size in the region's estuarine environments. Louisiana's extensive area of intertidal vegetation provides the necessary environmental factors to insure the shrimp's survival. The estuarine-dependent shrimp need the marshes, not open water to mature into a marketable size. Current changes from marsh to open water will affect the resource by reducing the harvestable shrimp considerably. Originally harvested by cast nets and haul seines, commercial fishermen now use a Lafitte skiff outfitted with an otter trawl or poupier (butterfly net). With the introduction of the otter trawl in 1915, the shrimping industry was revolutionized completely. A larger area could now be harvested with fewer men, thus yielding a greater production per man because of the increased efficiency of the gear (Padgett

1960). By 1920, Louisiana's total shrimp catch was 14.5 million kg (32 million pounds) -- nearly twice as great as the preceding year (Viosca 1920; Padgett 1960).

Prior to the availability of ice and modern freezing techniques, shrimp caught in southeast Louisiana's fishing grounds were taken to one of the numerous drying platforms to be dried, packaged, and sold. Although plagued by frequent hurricanes and a declining market, Barataria, Timbalier, Terrebonne, Caillou, and Atchafalaya bays, as late as 1962, supported 23 shrimp drying platforms (Pillsbury 1964). Three years later, a mere 16 remained. Less than 5 now survive and operate only intermittently (Davis 1976).

With more sophisticated boats and equipment, the shrimp harvest has grown rapidly. Expansion of the industry resulted in the shrimp becoming the most valuable seafood in Louisiana. The catch is second only to menhaden in quantity, but first in dollar value. Since 1880, Louisiana has led the gulf states in shrimp catch 69% of the time (Barrett and Gillespie 1973). This catch is worth from \$100 to \$140 million annually (Larson et al. 1980).

Despite a fairly stable commercial shrimp harvest, the yearly catch per fisherman has declined. Recent data suggests that the catch is directly related to the available marsh vegetation. Loss of this vegetation has a direct negative impact on this fishery. In short, loss of marsh reduces shrimp production and with time the industry appears to be in danger (Fruge 1981). One of the country's richest nursery grounds may be lost and a centuries old fishing tradition will disappear.

Oysters. The oyster industry relies almost totally on one species, the American oyster (*Crassostrea virginica* Gmelin). Other species do not contribute significant amounts to the catch. Since 1939, when Louisiana's oysterman harvested more than 5.8 million kg (13 million pounds) (Lyles 1967), the catch statistics have fluctuated dramatically, with a general decline in production (Van Sickle et al. 1976; Dugas 1977). Louisiana currently leads the gulf states in production, with an average yield of about 4 million kg (9 million pounds) of meat yearly. This figure has remained constant over the last 20 years with only severe environmental catastrophies influencing the harvest. Although environmental problems occasionally affect production, such as diverting the sediment-laden waters of the Mississippi through the Bonne Carre Spillway into Lake Pontchartrain. Louisiana generally ranks second nationally (after Maryland) in yields. Dockside value of Louisiana's oyster harvest is between \$3 million and \$4 million annually (Lyles 1967; U.S. Department of Commerce 1968-1975).

As oystermen are "farmers of the sea", they must contend with a number of forces that can destroy the crop (Gunter 1955). The oyster has a number of enemies. The oyster drill, or boring snail (*Thais haemostoma* and *T. floridana*) locally known as a "conch" and the saltwater drum (*Pogonias cromis*) are at the top of the "unwanted list" (McConnell and Kavanagh 1941; Waldo 1957; Van Sickle et al. 1976; Dugas 1977). The deadly drill occurs over a wide area in Louisiana's oyster bedding waters, but it must have high salinities to survive (Burkenroad 1931; Galtsoff 1964). The saltwater drum is another unwanted predator that congregates in large schools whose collective appetite can destroy a bedding ground in a single night (Van Sickle et al. 1976). Both predator problems are saltwater dependent.

Although oyster culture is plagued by a number of problems, the oyster fisherman continues to be the backbone of this commercial fishing industry. Along the bayous of south Louisiana oyster luggers are part of the waterfront landscape. They represent a commitment to harvesting the oyster in much the same way as the Lafitte skiff relates

to the shrimp fishermen. Through time, the oystermen has learned to live with all his problems. In 1913, there were at least 1,700 people involved in Louisiana's oyster industry (Hart 1913). Today, there are more than 2,000 liscensed oystermen, each of whom pays a small lease fee to stake out an oyster bed. In 1912, there were almost 7,000 ha (17,000 acres) leased to oystermen (Hart 1913). Currently, there are more than 80,000 ha (200,000 acres) involved in the fishery (Dugas 1977).

The industry is thriving, but its future will depend, in part, on the environmental changes taking place along the coast. The distribution of the oyster depends on the salinity content within the estuarine and nearshore areas. Salinity in many of the interdistributary basins is increasing as a result of the coastal deterioration that has accompanied land subsidence and canalization (Chapman 1968; Barrett 1970; Morgan 1972; Davis 1973). With increases in salinity, and if more firm substrata are available, oyster populations could actually increase. If the land that encloses the estuarine environments is lost, however, and the area becomes open water, then the industry will decline and another renewable resource will be gone.

Menhaden . The third valuable commercial marine resource is the menhaden (*Brevoortia patronus*), or "pogie." The first landings of menhaden were reported in the region around 1940, although commercial exploitation of the species can be traced back to the early 1800's along the Atlantic coast (Lyles 1967; Christmas and Etzold 1977; Frye 1978). Since then, menhaden has become the principal industrial fish taken in Louisiana. The reason for its apparent late development is that the oily flesh of the species is not suitable for human consumption, but when processed it is a valuable source of oil and animal feed.

Catch statistics reveal that the first landings were in West Florida. In 1880, less than 450 kg (1,000 lb) were harvested. Since this small beginning, the industry has expanded considerably. Although variability exists in the catch record,landings have increased steadily since the 1950's (Christmas and Etzold 1977). The production curve reached its peak in 1971 when Gulf of Mexico ports processed 700 million kg (1.6 billion lb). Since this record year, landings have exceeded 450 million kg (1 billion lb) annually (Christmas and Etzold 1977).

Louisiana's "pogie" fleet annually harvests from 270 to more than 450 million kg (600 million to 1 billion lb) of this industrial fish. With the area located in and around the Mississippi delta as particularly productive, combined with improvements in fishing gear, menhaden fishermen harvest a catch worth, in most years, in excess of $10 million (Perrett 1968; St. Amant et al. 1973; Wheeland and Thompson 1975).

Although "shrimp is king" in Louisiana, by weight the menhaden industry is the State's most important fishery. Consequently, the menhaden catch has made the ports of Cameron, Empire-Venice, and Dulac-Chauvin among the top five fishing ports in the United States. Combined, these ports account for a fisheries harvest greater than 390 million kg (850 million lb), which represents more than $80 million in annual fisheries income. With continued emphsis on providing protein meal to the underdeveloped countries, the future of the menhaden industry looks favorable. It is, however, necessary to maintain the estuarine environments used by the young fish in the early stages of their development (Rientjes 1970; Dunham 1972). If this habitat is lost, then the menhaden could be seriously impacted.

The habitat changes that would result from land loss would mean that Louisiana's position as the Nation's number one "seafood factory" would vanish. In addition, the jobs directly and indirectly associated with these renewable resources would also disappear.

Recreation: The Favorite Pastime of Coastal Sportsmen.

With one out of every two Americans involved in outdoor recreation, and with water serving as the largest single attraction, the water bodies and biologic resources of coastal Louisiana attract both resident recreationalists and out-of-state tourists in rapidly increasing numbers. The income generated by the recreation/tourist trade plays an important role in the region's economic structure.

Grimes and Pinhey (1976) noted that by the year 2000, Louisiana wetlands will be needed to meet the recreational demand of the State's expanding population. With two-thirds of Louisiana's inhabitants located within 2 hours driving time of the marshlands, the coastal zone and associated offshore waters are already available to a large population for day or overnight use.

In 1970, Louisiana's deltaic wetlands supported an estimated 10 million man-days of recreational activity annually (Martin 1972). If this figure increases to 25 million user days by 1985, as expected, Louisiana's deltaic wetlands will be worth in excess of $55 million/acre/yr (assuming a user-day value of $15/day). The onshore and offshore recreational areas are utilized at a relatively intense rate due to their accessibility and because they are free of high user fees and other use-inhibiting factors. With 90% of the land lost in freshwater marshes, however, the preferred winter habitat of puddle ducks is being reduced. By the year 2000, the "recreational ledger" will show a deficit of more than 360,000 user-days. There will not be enough marsh to meet the hunter demand (Fruge 1981).

Nevertheless, the coastal marshes provide outdoor enthusiasts with year-round recreational opportunities. In fall and winter, hunters, trappers, and fishermen harvest ducks, muskrat, nutria, alligator, and numerous fresh- and saltwater fish. In contrast, spring is the season to shrimp, crab, crawfish and fish for spotted seatrout (*Cynoscion nebulosus*), largemouth bass (*Micropterus salmoides*), and red snapper (*Lutjanus campechanus*). From the beginning of spring until the first cold front moves through the area, fishing and boating are the principal elements in the use-cycle. By late September, the gallinule (*Gallinula choropus*) season is open, followed by quail, dove, rail, snipe, duck, and geese (Chabreck and Joanen 1966).

Hunting and fishing: the principal recreational activities. Louisiana is a wintering area for between 6 million to 8 million waterfowl per year; approximately 75% to 80% concentrate in the coastal marsh (Burts and Carpenter 1975). The 36 waterfowl species that winter in Louisiana make hunting an extremely important and popular recreational activity (St. Amant 1959).

Sportsmen take advantage of the birds migratory cycle and have utilized the chenier and deltaic plains as a major waterfowl hunting locale, bagging 2.8 million water fowl in the 1977-78 season. In that same season, the coastal parishes contributed 63% of the total State waterfowl harvest (Gauthier 1978).

Wetland hunting is a traditional winter sport activity. As a renewable resource, the migratory populations are maintained by properly managing the wetlands. This is

accomplished by closely regulating hunting activity during breeding, migration, and wintering activities (Duffy and Hoffpaeur 1966; Herring 1974). In short, habitat preservation is the key to maintenance of the waterfowl resource and an annual recurring income that in most years exceeds $80 million (Larson et al. 1980).

Species diversity of fresh- and saltwater fish and shellfish in the coastal lowlands results in fishing generating the highest participation rates of all the recreational activities. As a year-round leisure-time activity that varies with the breeding cycle of the various fish species, water levels, fishing pressure, and habitat productivity (Lambou 1963), fishing-related expenditures exceed $40 million annually (International Marine Expositions 1978). More than 11,000 km (7,000 mi) of wetland shoreline provide more than 390,000 resident fishermen with extensive recreational opportunities. Since 1950, the number of resident licenses in the coastal marshes has increased by more than 100,000. This indicates that sport fishing is a popular recreational pastime and one that will continue to grow in popularity. Consequently, Louisiana will need more fishing areas, not less.

Along Louisiana's coast there are 60 species of fish that are associated with the estuarine or marine environments (McIntire et al. 1975). Freshwater fisherman seek a diversity of fish species, especially largemouth bass (considered the top gamefish), catfish, "sac-a-lait" or crappie, and bluegill or bream. The black bass (largemouth bass) is considered the state's most sought-after game fish. Whereas, saltwater fisherman primarily catch spotted seatrout, Atlantic croaker (Micropogon undulatus), one of the most abundant commerical fish along the gulf coast (Rogillio 1975), redfish (Sciaenops ocellata), sometimes referred to as "bull" or "rat" reds, and black drum (Pogonias cromis). The spotted seatrout is the main species caught, representing 40% of the daily saltwater fish catch (Louisiana Wild Life and Fisheries Commission 1970).

In addition, offshore there are more than 2,500 oil and gas platforms that serve as artificial reefs for fish communities. The fishing activity near the "rigs" is often excellent. To take advantage of this clustering, 40 to 50 charter boats ferry saltwater anglers to these sites.

It is apparent that the recreational sportsman benefits greatly from Louisiana's wetlands. The area is a recreational resource of inestimable value. It has been utilized throughout this century to meet the leisure-time needs of the State's inhabitants and others. Those who take advantage of this unique environment recognize its value, since they provide millions of recreational efforts per year. Unfortunately, as the area is lost, the habitats perferred by the game birds and fish will dwindle, thus affecting an industry that contributes an estimated $200 million to Louisiana's economy. Loss of this revenue will result in the collapse of the infrastructure that is supported by the industry. Also affected will be the number of unhappty individuals who can no longer profit from a marsh that provides the water-oriented sportsman with unexcelled recreational opportunities.

FROM AGRICULTURE TO OIL: THE CHANGE IN LAND USE PATTERNS

Throughout Louisiana's history, agricultural activities have occupied an important position in the wetland's social and economic environment. The wealth gained from hydrocarbons, commercial fishing and trapping, industrial development and tourism do not overshadow the value of agricultural products. The favorable climate and fertile

alluvial soils allow almost every crop indigenous to the western hemisphere to be raised. Arable land, however, is limited in this region because of poor drainage and the availability of land suitable for agriculture. For more than 200 years the Nation's marshlands were thought to be of no economic value; they were considered worthless. Nevertheless, in New England and the Middle-Atlantic states many wetland grasses were harvested for livestock. Lamson-Scribner (1896) reported hay production of up to 1 ton per acre, with hay stacks dotting the coastal lowlands. For more than half of the twentieth century the marsh was not developed for its intrinsic value. It was reclaimed to satisfy the needs of an expanding population (Allen and Anderson 1955). The agricultural lessons learned on the eastern seaboard were apparently forgotten or ignored.

Today, the alluvial wetlands are recognized as a valuable and highly productive environment, whose productivity can easily outstrip the best cultivated land. It is a renewable resource; one that operates with minimum capital expenditures and is epitomized in Louisiana.

Those who originally entered coastal Louisiana were explorers, hunters, trappers, and fishermen. Travel records and archaeological investigations reveal that these "folks" depended on the land for their subsistence. English, French, Acadian, and Creole farmers followed and created scattered communities along the natural levees of the region's bayous.

By 1822, the coastal zone's population was scattered along the main cheniers, coteaux, hummocks, islands, and natural levees. This "high ground" supplied farmer-trapper-fisher "folk" with the essential requirements for their economic existence and became the focal point of human occupancy. In a sense, these communities are considered a homogenous unit, since people consider a bayou settlement, regardless of length, as a single entity with varying degrees of continuity.

Farming was practiced throughout the region. Many areas that were farmed are now underwater or so small and isolated that they can no longer be used for row-crop agriculture. Most of these tracts are composed of mineral and organic soils firm enough to support cattle, but not suitable for farming by traditional methods. Consequently, marsh dwellers for more than 100 years have been grazing cattle within the marsh. They have learned to live with a serious problem and yet maintain a way of life that serves as a link to the past and is an important part of the region's cultural heritage. Since approximately 20% of Louisiana's cattle graze the wetlands, it is a unique industry. Proper and often inventive management techniques allow the herds to survive. The marshes are a recognized cattle producing region, that will continue only if careful management of the region continues.

Traditionally, arable natural levee land has been used to produce sugar cane. With mills closing and price uncertainties, the future of the business is in question,however. Farmers are selling their land. The form and intensity of land use competition with sugar cane are perhaps most visible. Since the region has become more populous, more prosperous, more urbanized, and more industrialized since World War II, land is at a premium.

The dynamic nature of the growth trend is derived essentially from the long-term development of the area's vast hydrocarbon resources. Extensive service base expansion at the expense of agricultural production, commercial fishing, and trapping activities,

the relatively low average cost of living, a favorable tax structure, an attractive climate and the unique cultural/recreational amenities also contribute to the region's growth. A recent source of land use competition is associated with hydrocarbon development: oil and natural gas wells, pipeline pumping stations, and natural gas processing plants. Individually, these uses occupy relatively small plots of land. Together, although precise estimates are not available, the total area involved is substantial. Few farmers refuse to sacrifice a portion of their cropland to gain the potential income from an oil or gas well or the proceeds from a long-term oil lease.

Suburban expansion is apparent also throughout the sugar region and the population of the entire coastal zone is growing at an annual rate of approximately 5% (University of New Orleans 1977). Competitive land uses associated with urbanization are often directly linked to the petroleum industry.

Sailors exploring the coast of Louisiana and Texas in the 1600's recorded seeing a black slick floating on the sea. This seepage provided a small clue to the vast storehouse of hydrocarbons trapped in a geosyncline stretching from Mississippi, through Louisiana and into the coastal provinces of Texas. The resource was not drilled until 1901 when a wildcatter completed the first producing well in south Louisiana (Postgate 1949). In developing this resource more than 28,000 wells have been drilled in the coastal zone.

In 1947 the search for recoverable hydrocarbons moved offshore and a new chapter was added to the history of the petroleum industry (Londonburg 1972). Since the successful completion of Kerr-McGee's, Phillips Petroleum's and Stanolind Oil's first offshore well on the continental shelf, the oil industry has drilled more than 20,000 wells in the open waters of the Gulf of Mexico. Currently, more than 2,500 platforms are pinned to the Gulf's floor. With the ever-increasing demand for hydrocarbons, oilmen are drilling in areas previously considered economically unfavorable. Working in the coastal marsh and then farther and farther offshore, drilling crews are now drilling on leases more than 241 kilometers (150 miles) from logistic support bases in water greater than 304 meters (1,000 ft) deep.

Largely as a result of this activity, Louisiana produces at least 35% of the Nation's natural gas and 25% of its oil. As production has increased, so have support industries such as storage yards, pipe suppliers, and pipeline contractors. The needs of the oil industry have spurred growth in ship-building and all kinds of marine supply businesses that vend everything from diving equipment to fast-food, shore-to-ship, catering services.

The dynamic growth of oil and gas exploration during the last three decades has placed an entirely different demand on the relatively few "chunks" of high-and-dry real estate in the coastal zone; the demands for solid ground now include much more than having a firm place to anchor a drilling platform. The need for onshore support bases, platform fabricators, pipe supply yards, ship yards, and service facilities have increased exponentially. Today, virtually every community that borders the bayous of south Louisiana serves as headquarters for one or more support services needed by the oil and gas industry. Because land is at such a high premium, some firms have built extremely compact facilities to handle the large and complex operations needed to build ships, offshore platforms, and other complicated pieces of machinery. Refiners and petrochemical manufacturers compete for the few large plots so they can install plants as close as possible to the source of their required hydrocarbons. As a result, population clustering has created a heterogeneous mixture of residential, commercial, industrial,

and transportation properties. Settlements are agglomerated into strips because of the reciprocal relationship between each and the natural environmental restraints placed on urban and built-up land. The strips are limited by a finite quantity of arable property, reflected in land use patterns and threatened by continued land loss.

As the petroleum business is a multibillion dollar industry, land loss will have a dramatic effect on the region's oil- and gas-related economy. Logistic support sites will be lost, thus complicating the movement of men and equipment to production sites. More importantly, as the land erodes, so does the State's land/water boundary; consequently, the outer limit of Louisiana's offshore zone moves shoreward. The end result is Louisiana's oil royalties decrease by at least $20 million per mile of coastal retreat and a highly significant source of revenue is changed. This is probably the single most important immediate result of land loss and one that can change a number of favorable advantages of living and working in Louisiana.

CONCLUSIONS

By nature coastal regions are the most continually changing zones on earth; they represent one of the most viable and complex regions on the globe. Within this environment there is a never ending interplay between the great forces and processes of nature that are constantly resculpting the region's topography. Man has had relatively little effect on these agents; he has no control over the natural processes that have for centuries influenced the coast. He has, however, promoted directly and indirectly some coastal modifications. The manmade elements that have altered flow regimes, sediment patterns and vegetative assemblages have created a problem. The problem is related directly to man's interference with the Mississippi's flow regime. As a result, the wetlands are out of balance. Land loss forces now supersede constructive forces thus threatening the jobs, industries, and lifestyles of the people whose lives are tied directly or indirectly to the coast. The final question is: "Can we afford the loss?"

LITERATURE CITED

Allen, P. F., and W. L. Anderson. 1955. More wildlife from our marshes and wetlands. Pages 589-596 in Water. Yearbook of Agriculture, U. S. Department of Agriculture, Washington, D. C.

Aquanotes. 1981. Land loss: coastal zone crisis. Aquanotes 10:1-5

Barrett, B. B. 1970. Water measurements of coastal Louisiana. Louisiana Wild Life and Fisheries Commission, New Orleans.

Barrett, B. B., and M. C. Gillespie. 1973. Primary factors which influence commercial shrimp production in coastal Louisiana. Louisiana Wild Life and Fisheries Commission. Tech. Bull. 9.

Burkenroad, M. D. 1931. Notes on the Louisiana conch, Thais haemostoma Linn, in its relation to the oyster Ostrea virginica. Ecology 12:656-664.

Burts, H. M., and C. W. Carpenter. 1975. A guide to hunting in Louisiana, the hunter's paradise. Louisiana Wild Life and Fisheries Commission, New Orleans.

Chabreck, R. H., and T. Joanen. 1966. Seasonal marsh scenes. La. Conserv. 18:16-17.

Chabreck, R. H., T. Joanen, and A. W. Palmisano. 1968. Vegetative type map of the Louisiana coastal marshes. Louisiana Wild Life and Fisheries Commission, New Orleans.

Chapman, C. 1968. Channelizaton and spoiling in Gulf coast south Atlantic estuaries. Pages 93-106 in J. D. Newsom ed. Proceedings of the Coastal Marsh and Estuary Management Symposium. T. J. Moran's Sons, Inc., Baton Rouge, La.

Christmas, J. Y., and D. J. Etzold. 1977. The menhaden fishery of the Gulf of Mexico, United States: a regional management plan. Gulf Coast Research Laboratory, Ocean Springs, Miss.

Coleman, J. M. 1966. Recent coastal sedimentation: central Louisiana coast. Louisiana State Univ., Coastal Studies Inst. Ser. 17.

Davis, D. W. 1973. Louisiana canals and their influence on wetland development. Ph. D. Thesis. Louisiana State Univ., Baton Rouge.

Davis, D. W. 1976. Shrimp drying, ancient art. Aquanotes 5:1,2,6.

Davis, D. W. 1978 Wetlands trapping in Louisiana. Pages 81-92 in S. B. Hilliard, ed. Man and environment in the lower Mississippi Valley. Louisiana State Univ., School of Geoscience, Baton Rouge.

Davis, D. W., and R. A. Detro. 1980. New Orleans drainage and reclamation--a 200-year problem. Z. Geomorph. 34:87-96.

Detro, R. A., and D. W. Davis. 1974. Louisiana marsh settlement succession: a preliminary report. Paper read before Associaton of American Geographers, Seattle. Unpubl. m.s.

Duffy, M., and C. Hoffpaeuer. 1966. History of waterfowl management. La. Conserv. 18:6-11.

Dugas, R. J. 1977. Oyster distribution and density on the productive portion of state seed grounds in southeastern Louisiana. Louisiana Wild Life and Fisheries Commission Tech. Bull. 23.

Dunham, F. O. 1972. A study of commercially important estuarine dependent industrial fishes. Louisiana Wild Life and Fisheries Commission Tech. Bull. 4.

Evans, O. 1963. Melting pot in the bayous. Am. Heritage 15:30-51.

Frazier, D.E. 1967. Recent deltaic deposits of the Mississippi River, their development and chronology. Trans. Gulf Coast Assoc. Geol. Soc. 17:287-315.

Fruge, D. 1981. Crisis in the coastal marsh. La. Conserv. 33:4-7.

Frye, J. 1978. The men all singing, the story of menhaden fishing. Donning Company, Norfolk, Virginia.

Gagliano, S. M. 1981. Special report on marsh deterioration and land loss in the deltaic plain of coastal Louisiana. Coastal Environments, Inc., Baton Rouge, La.

Gagliano, S. M. and J. L. van Beek. 1970. Geologic and geomorphic aspects of deltaic processes, Mississippi delta system. Louisiana State Univ., Coastal Studies Institute, Baton Rouge. Hydrologic and Geologic Studies of Coastal Louisiana. Part I, Vol. I.

Gagliano, S. M., K. J. Meyer-Arendt, and K. M. Wicker. 1981. Land loss in the Mississippi River deltaic plain. Trans. Gulf Coast Assoc. Geol. Soc. 31:295-300.

Galtsoff, P. S. 1964. The American oyster Crassostrea virginica (Gmelin). U.S. Fish Wildl. Serv. Fish. Bull. 64.

Gauthier, H. 1978. 1977-1978 waterfowl survey. Louisiana Wild Life and Fisheries Commission, Baton Rouge. Unpubl. m.s.

Gosselink, J. 1980. Tidal marshes, the boundary betwen land and ocean. U. S. Fish and Wildlife Service, Office of Biological Services, Washington, D. C. FWS/OBS-80/15.

Grimes, M. D., and T. K. Pinhey. 1976. Recreation potential of private lands in Louisiana's coastal zone. Louisiana State Univ., Center for Wetland Resources, Baton Rouge.

Gunter, G. E. 1955. Mortality of oysters and abundance of certain associates as related to salinity. Ecology 36:601-619.

Hart, W. O. 1913. The oyster and fish industry of Louisiana. Trans. Am. Fish. Soc. 42:151-156.

Herring, J. L. 1974. Sound reasons for hunting seasons. La. Conserv. 26:4-8.

Howe, H. V., R. J. Russell, B. C. McGuirt, and B. C. Craft. 1935. Reports on the geology of Cameron and Vermilion Parishes. Louisiana Department of Conservaton, Geol. Surv. Bull. 6.

International Marine Expositions, Incorporated, Market Research Department. 1978. Marine expositions annual market research notebook: the marine market. Internatonal Marine Expositions Incorporated, Chicago, Ill.

Kolb, C. R., and J. R. Van Lopik. 1958. Geology of the Mississippi River deltaic plain, southeastern Louisiana, vol. I. U. S. Army Engineers Waterways Experiment Station, Vicksburg, Miss. Tech Rep. 3-403.

Lambou, V. W. 1963. Fishing in Louisiana today and tomorrow. La. Conserv. 15:16-20.

Lamson-Scribner, F. 1896. Grasses of salt marshes. Pages 325-332 in Yearbook. U. S. Department of Agriculture, Washington, D. C.

Larson, D. K., D. Davis, R. Detro, P. Dumond, E. Liebow, R. Motschall, D. Sorensen, and W. Guidroz. 1980. Mississippi deltaic plain region ecological characterization: a socioeconomic study. Vol. 1., Synthesis papers. U. S. Fish and Wildlife Service, Office of Biological Services, Washington, D. C. FWS/OBS-79/05.

Louisiana Wildlife and Fisheries Commission. 1970. Monetary value of fishes. Louisiana Wildlife and Fisheries Commission, New Orleans. Unpubl. m.s.

Lyles, C. H. 1967. Fishery statistics of the United States. 1965. U.S. Bur. Commer. Fish. Stat. Dig. 59.

Martin, F. 1882. The history of Louisiana from the earliest period. J. A. Gresham, New Orleans.

Martin, W. O. 1972. Louisiana's marsh is world's estuary area. Nicholls Worth, Thibodaux, Louisiana. 18 (29 September):3.

McConnell, J. N., and L. D. Kavanagh. 1941. The Louisiana oyster. Louisiana Department of Conservation Bull. 1.

McIntire, W. G., M. J. Hershman, R. D. Adams, K. D. Midboe, and B. B. Barrett. 1975. A rationale for determining Louisiana's coastal zone. Louisiana State Univ., Center for Wetland Resources, Coastal Zone Management Ser. 1.

Morgan, J. P. 1972. Impact of subsidence and erosion on Louisiana coastal marshes and estuaries. Pages 217-233 in R. H. Chabreck, ed. Proceedings of the Second Coastal Marsh and Estuary Management Symposium. Louisiana State Univ., Div. of Continuing Education, Baton Rouge.

National Oceanic and Atmospheric Administration, National Marine Fisheries Service. 1975. Fishery statistics of the United States annual. U. S. Natl. Mar. Fish. Serv. Stat. Dig. 69.

O'Neil, T. 1949. The muskrat in the Louisiana coastal marshes. Louisiana Wild Life and Fisheries Commission, New Orleans.

Palmisano, A. W. 1972. Habitat preference of waterfowl and fur animals in the northern gulf coast marshes. Pages 163-190 in R. H. Chabreck, ed. Proceedings of the Second Coastal Marsh and Estuary Management Symposium. Louisiana State Univ., Div. of Continuing Education, Baton Rouge.

Padgett, H. R. 1960. The marine shellfisheries of Louisiana. Ph. D. Thesis. Louisiana State Univ. Baton Rouge.

Penfound, W. T., and E. S. Hathaway. 1938. Plant communities in the marshland of southeastern Louisiana. Ecol. Monogr. 8:1-56.

Perret, W. S. 1968. Menhaden or pogies. Louisiana's most valuable commercial fish. La. Conserv. 20:14-15.

Pillsbury, R. 1964. The production of sun-dried shrimp in Louisiana. J. Geogr. 63:254-258.

Postgate, J. C. 1949. History and development of swamp and marsh drilling operations. Oil Gas J. 47:87.

Price, W. A. 1955. Environment and formation of the chenier plain. Quaternaria 2:75-86.

Rientjes, J. W. 1970. The gulf menhaden and our changing estuaries. Pages 87-90 in Gulf and Caribbean Fisheries Institute, Proceedings. 22nd annu. session.

Ringold, P. L., and J. Clark. 1980. The coastal almanac. W. H. Freeman and Company, San Francisco, Calif.

Rogillo, H. E. 1975. An estuarine sportsfish study in southeastern Louisiana. Louisiana Wild Life and Fisheries Commission, Fish. Bull. 14.

Russell, R. J. 1942. Flotant. Geogr. Rev. 32:74-98.

Russell, R. J., and H. V. Howe. 1953. Cheniers of southwestern Louisiana. Geogr. Rev. 25:449-461.

St. Amant, L. S. 1959. Louisiana wildlife inventory and management plan. Louisiana Wild Life and Fisheries Commission, New Orleans.

St. Amant, L. S., L. K. Benson, D. M. Bradburn, A. H. Harris, and C. Janvier. 1973. Louisiana wetlands prospectus. Louisiana State Planning Office, Baton Rouge.

Samuel, R. 1959. ...to a point called Chef Menteur...: the story of the property known as New Orleans East, Inc. New Orleans East, Inc., New Orleans.

Schneider, G. 1952. The history and future of flood control. American Society of Civil Engineers, Waterways Div., Chicago, Ill.

Schou, A. 1967. Pecan Island, a chenier ridge in the Mississippi delta plain. Geografiska Ann. 49A:321-326.

Simpich, F. 1927. The great Mississippi flood of 1927. Natl. Geogr. Mag. 52:243-289.

U.S. Department of Commerce, Natonal Oceanic and Atmospheric Administration, National Marine Fisheries Service, 1968-1975. Fishery statistics of the United States annual. U.S. Natl. Mar. Fish. Serv. Stat. Dig. 56-69.

University of New Orleans, Division of Business and Economic Research. 1977. Statistical abstract of Louisiana. 6th ed. New Orleans.

Van Sickle, V. R., B. B. Barrett, L. J. Gulick and T. B. Ford. 1976. Barataria basin: salinity changes and oyster distribution. Louisiana State Univ., Center for Wetland Resources, Baton Rouge.

Viosca, P. 1920. Louisiana, greatest in the production of shrimp, Penaeus setiferus. Pages 106-130 in Louisiana Department of Conservation. Fourth Biennial Report.

Wagner, F., and E. Durabb. 1976. The sinking city. Environment 18:32-39.

Waldo, E. 1957. The Louisiana oyster story. Louisiana Wild Life and Fisheries Commission, Wild Life Educ. Bull. 32.

Wheeland, H. A., and B. G. Thompson 1975. Fisheries of the United States, 1974. U.S. Natl. Mar. Fish. Serv. Curr Fish. Stat. 6700.

PANEL DISCUSSION

CONSEQUENCES: SOCIAL AND ECONOMIC

Edward W. Stagg, Moderator

Paul Hribernick, Michael Osborne, Donald W. Davis and **Charles Broussard**, Panelists

Charles Broussard: I can best illustrate how regulations can interfere with environmental use or management by relating a case study. One of the earliest attempts to acquire a permit for deterring saltwater intrusion was in Vermilion Parish. Hurricane Edith in 1971 caused six openings allowing tidal transport of brackish water into the Mermentau Basin. The maintenance of the Mermentau Basin as a freshwater area for rice farming, fish and wildlife habitat, and navigation was mandated by Federal law. The act, however, did not allow the Corps of Engineers to expend Federal funds except for control structures. The State Office of Public Works, therefore, funded a project to close these breaches and bids were advertised in October 1972. Section 404 of the Clean Water Act became effective in 1972 and I thought it would be a great assistance in protecting our coastal environment. It has had the opposite effect in this case, however. Letters of concurrence were sought and obtained from a large number of State and Federal agencies, including the U.S. Fish and Wildlife Service, for this project. The National Marine Fisheries Service, however, objected to the closure of the breaches saying this is a saltwater estuarine area. To this day, there has still been no permit issued and there are now 167 attachments to the original application.

The intent of the laws related to coastal zone management is not being realized. Rice farming has been driven out of the area. Waterfowl populations declined because of a reduction in millet, or wild rice, from 80,000 acres to a few thousand acres. Duck populations declined from more than a million to less than 200,000. Hardness of ground water in the region has increased due to saltwater intrusion from negligible amounts of 12 grains/gallon in deep wells in 1930 to 70 to 90 grains/gallon, which is not fit for rice farming or human consumption.

Donald Landry: The Houma Navigation Canal was built with Terrebonne Parish funds but is maintained by the Corps of Engineers. It has now widened beyond the 700 ft right-of-way. What is the legal responsibility of the assuring local agency to the property owners?

Paul Hribernick: Similar problems exist with the Houma Navigation Canal and the Mississippi River Gulf Outlet. The law is unclear with regard to bodies of water made navigable. If the bottom is found to be in State ownership, normal erosion rules would apply, and land owners may be able to reclaim land damages for which they haven't received compensation from the government. The law does not say who pays for restoration, however. The land owner may be able to sue in a tort for compensation in which case the liability of the government would be limited to fair market value of the lost property.

Michael Osborne: The legal liability may depend on the stated responsibility in the assuring agreement.

John Uhl: This question has been recently raised with the Corps of Engineers in regard to the Harvey Canal.

Clarke Lozes: Assurances require that the Federal Government be held harmless and safe from damages and require State and local government maintenance.

Rod Emmer: In preparation of an environmental impact statement for the Almonaster-Michoud Industrial District in New Orleans, we identified, as an impact, accelerated erosion of the Mississippi River Gulf Outlet and recommended implementation of structural measures to offset this erosion. The responsibility for protecting the shoreline may be identified beforehand in this case.

Michael Osborne: It seems to me that the parish could make a strong legal argument that, in the case of navigation canals designed or constructed by the Corps of Engineers, that if the canal widened beyond the right of way, the Corps inadequately designed the project for its 50-year life.

John Uhl: What can be done to streamline the permit process?

Charles Broussard: There should be limits to the time allowed for response to permit applications. There should be clarification of the role of State agencies in the review process. For example, in the Mermentau Basin case, the National Marine Fisheries Service would not accept the Louisiana Department of Wildlife and Fisheries report. Also, there should be limits to the time for interagency conflict without resolution.

John Uhl: We tried to include in the Jefferson Parish coastal zone management program time limits for reasonable responses and discussion of 6 months to one year. This was met with some consternation.

Charles Broussard: The Secretary of the Army has the right to make a decision even when a conflict is not resolved, but such decisions are politically difficult.

Michael Osborne: There is some confusion of these past procedures and problems under Corps of Engineers administration of Sections 10 and 404 with the present State adminstered coastal use permit system begun in October 1980. Often the blame for these environmental conflicts belongs with the people who engineered the project for not anticipating these problems of conflicts in water resource uses.

Charles Broussard: In the Mermentau Basin case, a broad view of multiple resources was held from the beginning and was the reason for developing the project. Replacement of the Vermilion Locks has begun at a cost to the Federal Government of $36.8 million. This project is being developed to maintain the integrity of the Mermentau Basin, yet within a stone's throw we are not allowed to close the breaches in order to prevent saltwater intrusion.

Paul Hribernick: Section 404 is an attempt to effect multdisciplinary decisionmaking but, in the political compromises needed to pass the act, effective veto power was

given to agencies which serve different constituencies. For example, the National Marine Fisheries Service represents commercial fishing interests, the Corps of Engineers represents navigation interests, and the Fish and Wildlife Service represents wildlife and recreation interests. We need better administrative solutions to resolve the conflicts which develop among the constituencies. The State coastal zone management program is set up to assist in the resolution of these conflicts. The Coastal Management Section must make permit decisions within 42 days from receipt of application unless inadequate information is included in application. In the short existence of the coastal use permit program, 800 decisions were issued in an average of 56 days including delays because of inadequate information. The possibility of general use permits is also being considered to further streamline the process. The State program also includes coordination meetings with Federal and State agencies during which individual projects are reviewed.

Unidentified speaker: A recent memorandum of understanding between the Corps of Engineers and Environmental Protection Agency sets up a process for special treatment of hardwood bottomlands. Can anyone explain this process?

Michael Osborne: The Avoyelles Sportsman's League case led to an argument regarding which agency has the right to decide what is a wetland. The agreement to which you refer is an attempt to establish this responsibility.

George Robichaux: The Department of Health and Human Resources is engaged in an on-going flood plain management program and one consideration is specific prohibition of habitation within flood plains. Beyond immediate intransigence, what will be the long-term social and cultural impacts of that type of prohibition?

Donald Davis: There would definitely be cultural impacts because many residents have occupied these areas for many generations. It is difficult to tell someone that they can not live where their grandfather did and most people will refuse to move. If it is a question of no longer offering them subsidized flood insurance, I think that most people would still resist moving.

Donald Landry: The Federal flood insurance program is being reviewed and the total elimination of subsidized flood protection in coastal areas is being considered.

Charles Broussard: If we are not allowed to protect our barrier islands, land loss will accelerate to unbelievable rates throughout south Louisiana.

Donald Landry: Does land accreted on a barrier island go to the property owner?

Paul Hribernick: Land accreted on a barrier island goes to the State. Receding shoreline can be reclaimed by private land owners at their own expense.

OPTIONS: BARRIER ISLAND AND SHORELINE PROTECTION

FUTURE SEA LEVEL CHANGES ALONG THE LOUISANA COAST

Dag Nummedal

Department of Geology
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

The relative elevation of sea and land has been changing throughout time in response to two fundamentally different groups of factors. Global factors include changes in the volume of the ocean basins due to tectonic processes and changes in the total amount of ocean water due to glaciation. Local factors include subsidence of continental margins and the compaction of recent sediments. During this century, global sea level (eustatic) appears to have been rising at a rate of 1.2 mm/yr. Along the south-central Louisiana coast the land surface appears to be sinking at a rate of about 8 mm/yr.

Recent global climatic modelling strongly suggests that we are about to enter a period of rapid warming due to increased amounts of carbon dioxide (CO_2) in the atmosphere. As a consequence, eustatic sea-level rise is predicted to accelerate both because of steric expansion of the ocean water and continued melting of polar ice caps. For the next 40 years the eustatic sea-level rise may average 10 mm/yr. The local relative sea level in coastal Louisiana would therefore rise at about twice its present rate over this time period. At this rate local sea level will, in the year 2020, stand some 70 to 75 cm higher than now.

INTRODUCTION

Sea level, that universal elevation datum, is neither level nor constant. Spatial and temporal fluctuations in sea level occur at all scales and frequencies.

Global sea-level variations on the geologic time scale of tens of millions of years occur in response to tectonically controlled changes in the volume of the ocean basins (Hays and Pitman 1973). The actual change in location of the shoreline on a continental margin becomes a function of the rate of global (eustatic) sea-level change relative to the rate of margin subsidence, sedimentation (or erosion), and a number of local factors. On passive continental margins (as the U.S. Atlantic and Gulf of Mexico coasts) the rates of tectonically controlled changes in the relative elevation of sea and land are quite slow, typically a few mm per 1,000 years (Pitman 1978, 1979). Furthermore, the slow yet persistent subsidence of a continental margin geosyncline is generally compensated by landward mantle flow and uplift of the coastal plain. Evidence for this is seen in progressively older, uplifted strata in a landward successsion away from the

present Atlantic and Gulf of Mexico shorelines (Oaks and DuBar 1974).

Superimposed on these essentially tectonic sea-level changes are higher-frequency fluctuations of a multitude of origins. Periodic formation of continental ice sheets and attendant deglaciations have, at least since the Pliocene and possibly throughout the Cenozoic (Matthews and Pore 1980), been responsible for major sea-level changes on a typical time scale of 10,000's of years. Present sea level appears to be at an elevation comparable to that reached during earlier major interglacials. The latest low stand of sea level occurred at the peak of the late Pleistocene Wisconsin glaciation some 18,000 years ago. Early sea level curves (Curray 1965; Milliman and Emery 1968) indicated that this low stand was as much as 130 m below present sea level. Recent work by Dillon and Oldale (1978) and Blackwelder (1980), however, strongly suggests that sea level may have risen much less than 100 m since the late Wisconsin low (Figure 1).

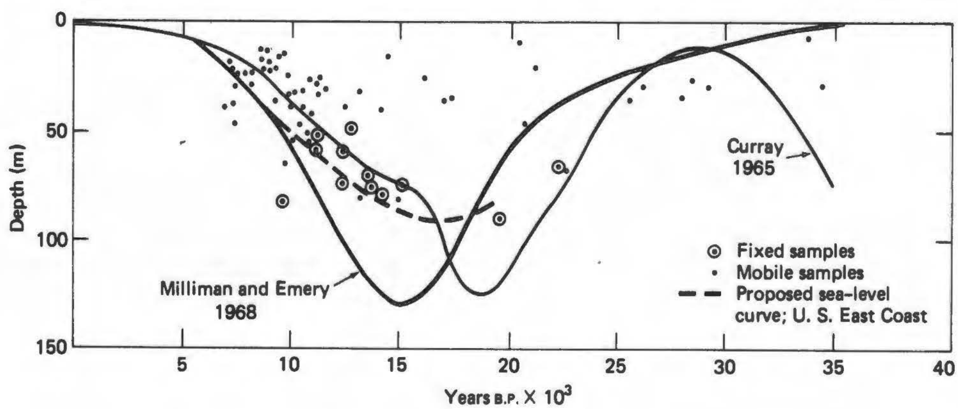


Figure 1. Sea-level curves for the late Quaternary inferred from radiocarbon-dated samples along the east coast of the U. S. (Dillon and Oldale (1978). The most recent curve (dashed) suggests a late Wisconsin low stand of less than 100 m below present sea level.

Regardless of the absolute magnitude of sea-level rise over the last 18,000 years, this "Holocene transgression" is responsible for the existence of a multitude of coastal sedimentary sequences (deltas, fluvial channel fills, marsh deposits, tidal channel fills) on the present shelf floor (Curray 1965; Swift 1976; Field et al. 1979; Pilkey et al. 1981). At the time of maximum ice retreat, global sea level rose at a rate of about 1 m/century, a rate which is about four orders of magnitude faster than the long-term tectonically induced global sea-level changes.

Because the relative abundance of stable oxygen isotopes in deep-sea sediments is a measure of global oceanic temperatures, one can reconstruct a paleo-temperature time series from analysis of deep-sea cores (Figure 2). This curve suggests the existence of numerous glaciations on a time scale of about one every 100,000 years throughout the Pleistocene (Shackleton and Cita 1979).

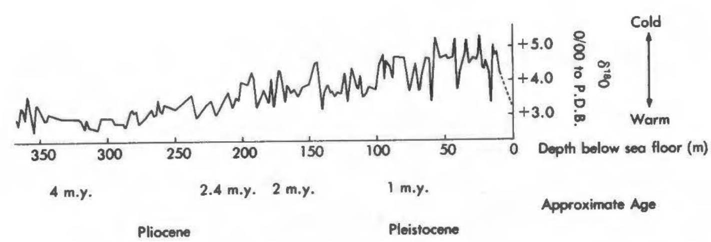


Figure 2. Oxygen isotopic record for the Pliocene and Pleistocene in Deep Sea Drilling Project Site no. 397 in the Atlantic Ocean off northwest Africa (modified from Shackleton and Cita 1979). High $\delta^{18}O$ values indicate periods of global cooling and formation of continental ice sheets.

RECENT GLOBAL SEA LEVEL CHANGES

Sea-level fluctuations on the time scales discussed have controlled the time-stratigraphic evolution of continental margin sedimentary sequences. They also provide some hints of what factors should be considered in trying to explain present short-term sea level fluctuations (10's of years) and they may guide our modelling efforts in attempts to predict the future. In the following discussion of present and near-future sea-level changes, a clear distinction has been made between eustatic factors (i.e., factors which affect the global sea level) and local factors (which include subsidence and local oceanographic effects).

Recent data increasingly support the view that sea level did not rise in a smooth and continuous fashion during the Holocene transgression. The rise appears to have been characterized by a series of oscillations with an amplitude of a few meters on a typical time scale of 100's of years. Data supporting this view are mostly archaeological (Figure 3A, Brooks et al. 1979), yet historical data in Europe suggest that there has been a one-meter sea-level fluctuation within the last millenium (Figure 3B, Rhode 1978). The most recent sea-level minimum coincides with the peak of the "little ice age" at the end of medieval time.

Over the last century an increasing number of tide gauges have been installed in harbors around the world. Records from such gauges yield information about the local relative change in level of the sea and the land upon which the gauge is placed. All such records demonstrate large fluctuations in mean annual sea level; generally, however, these fluctuations are superimposed on a secular trend. The annual fluctuations derive from long-term meteorological tides (atmospheric pressure variations), continental run-off and winds (Fairbridge and Krebs 1962). The longer term (decades) trend is more controversial yet of paramount significance to human efforts at developing the coastal zone.

Attempts to derive the rate of global sea-level rise from such tide gauge records have generally been based on various trend analysis techniques applied to the "average" of records from a number of stations. Records from stations known to be subject to rapid sinking (Galveston, Texas; Louisiana coast) or rising due to glacioisostatic rebound (Scandinavia, parts of Canada) or underthrusting of an oceanic plate (Oregon,

Washington, Alaska, and Japan) are customarily excluded in such trend analysis. Yet little is really known about continental subsidence rates at the remaining tide gauge stations.

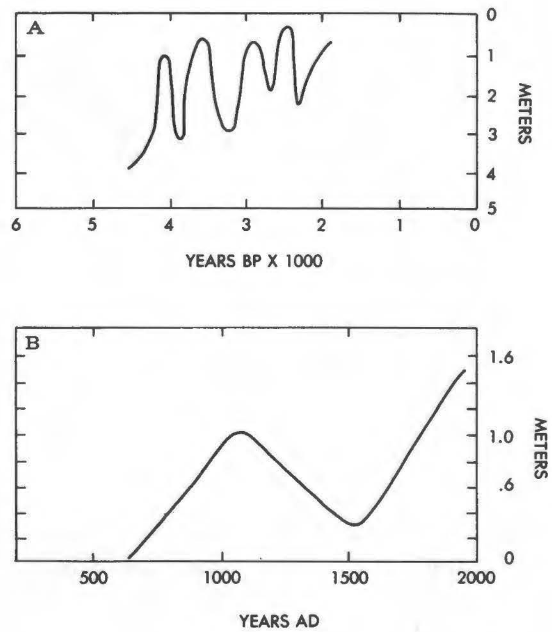
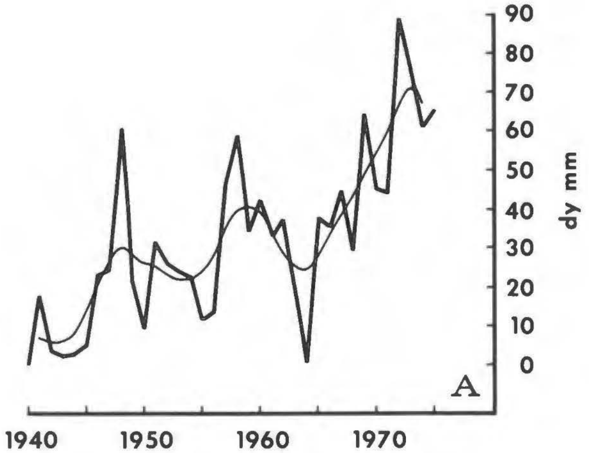


Figure 3. A. Sea-level fluctuations on the central South Carolina coast over the last 4000 years (modified from Brooks et al. 1979). Curve is based on radiocarbon dated archaeological samples and basal peats. B. Sea-level fluctuations on the North Sea coast of Germany since 650 A.D. (modified from Rhode 1978). The curve is based on historical data.

In view of these complications it is remarkable that five independent analyses of sea-level rise have arrived at nearly identical global rates. Gutenberg (1941) appears to have been the first to identify a world-wide rise in sea-level since the mid-1800's at a rate of about 1 mm/yr. Analysis of a larger number of stations by Fairbridge and Krebs (1962) yielded a rate of rise of 1.2 mm/yr between 1900 and 1950. A comprehensive analysis of all reliable U.S. tide gauge data by Hicks (1978) gave a relative rise (with respect to North America as a whole) of 1.5 mm/yr (Figure 4A) for a 36-year period from 1940 through 1975. Emery (1980) found that the sea levels at 247 tide gauge stations of the world did exhibit a rise of about 3 mm/yr since 1940. The most recent study (Gornitz et al. 1982) which is based on more than 700 tide gauge stations. All geographic regions of the world experienced a sea-level rise (after correcting for uplift or subsidence of the land when known), and the global rate of rise is 1.2 mm/yr (Figure 4B)(Gornitz et al. 1982). This study (Gornitz et al. 1982) may come the closest yet to actually having identified global eustatic sea-level change.



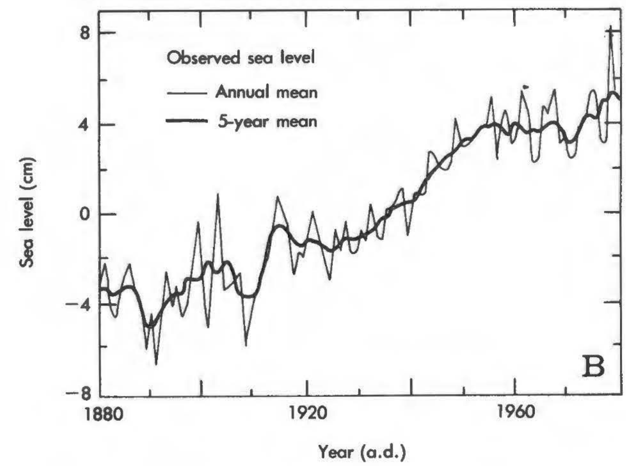


Figure 4. A. Average sea-level time series for all U. S. tide gauge stations with the exception of Alaska and Hawaii (Hicks 1978). B. Global mean sea-level trend from tide gauge data (modified from Gornitz et al. 1982).

Mean sea-level fluctuates seasonally (Pattullo 1966; Nummedal and Humphries 1978). Along the U. S. gulf coast the annual amplitude is about 25 cm (Marmer 1952). Sea level is maximum in early fall due to the steric effect (thermal expansion of seawater above the thermocline). Other factors affecting seasonal sea level include freshwater runoff from the continent (Meade and Emery 1971) and persistent winds (Behrens et al. 1977).

To test whether the thermal expansion of water also could have a long-term effect on rising sea level, Gornitz et al.(1982) correlated the global mean sea-level trend for the last century and the global mean temperature curve for the same time period derived by Hansen et al. (1981). Using 5-year running means of both parameters they obtained a correlation coefficient of 0.8. Best regression fit was obtained for a time lag of 18 years between the temperature and sea-level rise curves. This lag time is of the same order as the thermal relaxation time of the upper layer of the ocean. The findings suggest that at least part of the observed global sea-level rise is attributable to the thermal seawater expansion. A simple one-dimensional model of the heat flux into the ocean and the attendant thermal expansion suggests that only about half of the observed rate of global sea-level rise can be attributed to steric expansion; the balance may reflect a slow, but steady, melting of polar ice sheets as well as lowering of global groundwater levels.

PREDICTION OF FUTURE CHANGES IN GLOBAL SEA LEVEL

Sea-level studies have traditionally been historical and empirical. The derived sea-level curves have been so variable (Bloom 1977) as to make trend extraction and future predictions all but impossible. Yet scientifically based estimates of future sea levels should be a key component in decisions regarding the use and protection of low-lying coastal lands. The findings reviewed above now permit such a prediction.

From the analysis presented in this paper, temperature emerges as the key control on sea level. It directly controls steric water expansion and the mass balance of the polar ice sheets. It indirectly controls global surface- and groundwater budgets. The global mean temperature record over the last century can best be explained in terms of the combined effects of natural climatic cycles and a warming trend from addition of CO_2 to the atmosphere ("greenhouse effect") due to the burning of fossil fuels (Broecker 1975).

An extension of Broecker's analysis has been made in Figure 5 with temperature data updated through 1980 and the model of Hansen et al. (1981) used as a basis for the predicted CO_2-related warming trend. The figure demonstrates that observed temperatures essentially fall within the range predicted from the two component trends for most of the century. Global temperatures over the last few years, however, have risen significantly above the predicted trend.

The natural temperature cycles used in this analysis are based on analysis of stable isotopes (^{18}O) in ice cores from Camp Century in Greenland (Dansgaard et al. 1971). Whatever the origin of the climatic cycles observed in the Greenland ice cores, the pattern has been essentially stable during the last 1,000 years. Two cycles appear to be inherent in the Camp Century temperature record, one of 80-year and another of 180-year duration. The curve in Figure 5 is the composite of these two cycles. Because of the regular harmonic pattern this natural temperature curve can easily be extended and thus provide one element in the predicton of future global temperature trends.

It is well documented that the CO_2 content of the terrestrial atmosphere has been steadily increasing in this century (Siegenthaler and Oeschger 1978). Numerical modelling of the atmospheric response to an increase in its CO_2 contents by Manabe and Wetherald (1975) and Hansen et al. (1981) suggested that a doubling of the CO_2 content in the atmosphere from "pre-industrial" levels of about 300 ppm to 600 ppm would increase global temperatures by 2.4°C to 3.5°C. A major unknown, is the rate of rise of atmospheric CO_2 content because this is largely controlled by industrial patterns throughout the world.

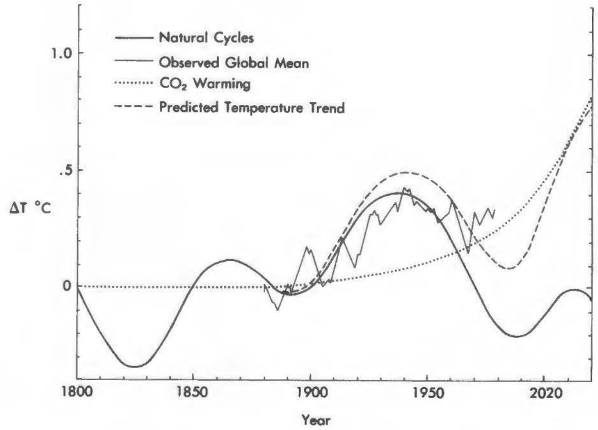


Figure 5. Global temperature variations. The predicted temperature trend is the composite of that due to CO2-induced warming and natural temperature cycles. Observed global temperatures and predicted CO_2 warming from Hansen et al. (1981). Figure design modeled after Broecker (1975).

According to the model of Hansen et al. (1981) for slow energy growth (1.5% annual growth in energy consumption) one would expect an increase in global temperature of about 1.5°C at the end of the next century. Using the thermal expansion model (Gornitz et al. 1982) for sea water, the steric effect alone would cause a corresponding increase in global sea level (eustatic) of about 30 cm. If the steric effect has been responsible for half of the observed sea-level rise over the last century and this same ratio should continue under a regime of further global warming, then total eustatic sea-level increase for the next century would be 60 cm. Eustatic sea-level rise over the last century was only about 12 cm. This predicted five-fold increase in the rate of eustatic sea-level rise should be attributed both to the increased atmospheric CO_2 and the fact that for the next 40 years the earth will experience the warming phase of the natural (Camp Century) temperature cycles (Figure 5). Because of cyclicity of the natural temperature variations, sea level is likely to increase in a step-wise rather than linear fashion over the next century. The next 40 years (1980-2020) will probably be the period of the most rapid rate of sea-level rise. The eustatic rate of rise could conceivably be as high as 1 cm/yr during that time. That rate corresponds to the most rapid post-glacial rise some 11,000 to 12,000 years ago.

Without intending to be alarmist, another consequence of the predicted global warming must be mentioned for the sake of completeness. This concerns the West Antarctic ice sheet. This ice sheet is grounded below sea level making it vulnerable to rapid disintegration and melting in case of a general warming (Hughes 1973; Mercer 1978). Since the present summer temperature in its vicinity is about -5°C a global warming of 2.5°C might seem insignificant. All global atmospheric models stress, however, that the magnitude of polar temperature fluctuations exceed those of the global mean because of albedo-related positive feedback. A global warming will reduce high-latitude snow cover, reduce the surface albedo, and thus heat that region more rapidly than low-latitude zones (Manabe and Stouffer 1980). A 2°C global warming may cause a temperature rise of about 5°C in Antarctica and thus induce melting of the West Antarctic ice sheet. The response to that event would be an increase in global sea level of between 5 and 6 m (Mercer 1978). This rise would not be uniform across the globe, however, because of changes in the gravitational attraction exerted by the ice sheet on the surrounding ocean, the Earth's immediate elastic response to the unloading, and the long-term response due to viscous flow within the mantle (Clark and Lingle 1977). Furthermore, the time scale of ice sheet disintegration is presently unknown.

SEA-LEVEL CHANGES IN LOUISIANA

Local relative sea-level rise includes eustatic and local components. Prediction of future sea-level changes along the Louisiana coast, therefore, requires knowledge about land subsidence. In view of a "eustatic" sea-level rise of 1.2 mm/yr, it is clear that most of the local sea-level rise observed on the Louisiana coast is due to subsidence (Swanson and Thurlow 1973).

Figure 6 presents three tide gauge records from the central Louisiana coast as well as a longer time series from Galveston, Texas, all of which document a history of rapid local relative sea-level rise. The longer Galveston record documents well the temporal changes in observed rates of sea-level rise. For example, if the entire Galveston record is averaged one finds a rate of rise of 5.5 mm/yr. If one only considers the 20-yr time span from 1950 to 1970, the rate then was 2.5 mm/yr. The rapid local change in sea-level at Galveston between 1940 and 1945 (Figure 6) might be due to man's activities in

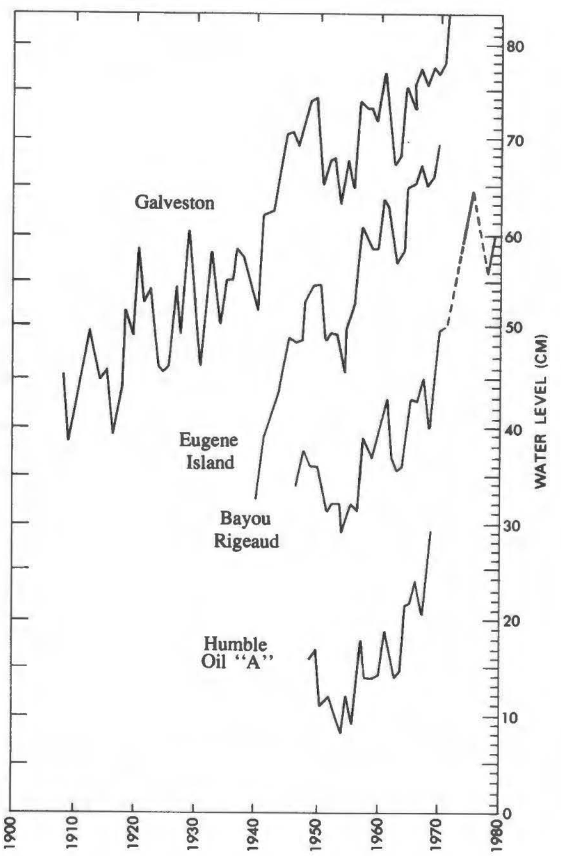


Figure 6. Yearly mean sea-level series for four stations along the north-central gulf coast. Data from tide gauges at Galveston, Eugene Island (at the entrance to Atchafalaya Bay), Bayou Rigaud (Grand Isle), and Humble Oil Platform "A" (13 km off Grand Isle). Data from Hicks and Crosby (1974) and Baumann (1980).

the area, although sea-level curves from as far away as Pensacola show a rapid increase during the same period. In view of these rapid temporal changes, the predicted subsidence rates in the following paragraph should be considered very tentative.

From Humble Oil "A" and the Bayou Rigaud tide gauge records (Figure 6), one finds a rate of local sea level rise of between 1.0 and 1.1 cm/yr for the period of duration of the two records. By subtracting a rate of 1.2 mm/yr for eustatic rise, one arrives at a subsidence rate of about 9 mm/yr for the south-central Louisiana coast. Farther west, at Eugene Island, at the entrance to Atchafalaya Bay, one finds a subsidence rate of 7.3 mm/yr. A longer-term average subsidence rate can be derived from a ^{14}C-based local relative sea-level curve determined for the Caminada-Moreau beach ridge plain in southern Lafourche Parish (Gerdes 1982). Gerdes' data suggest that local relative sea level in that region has risen a total of 2.75 m during the last 1,000 years (Figure 7). This corresponds to an average rate of 2.75 mm/yr. If one compensates for a eustatic rise of 1.2 mm/yr (assuming this rate to be valid for the last 1,000 years), then one finds a local long-term subsidence rate of 1.55 mm/yr. This is a much lower rate than that derived

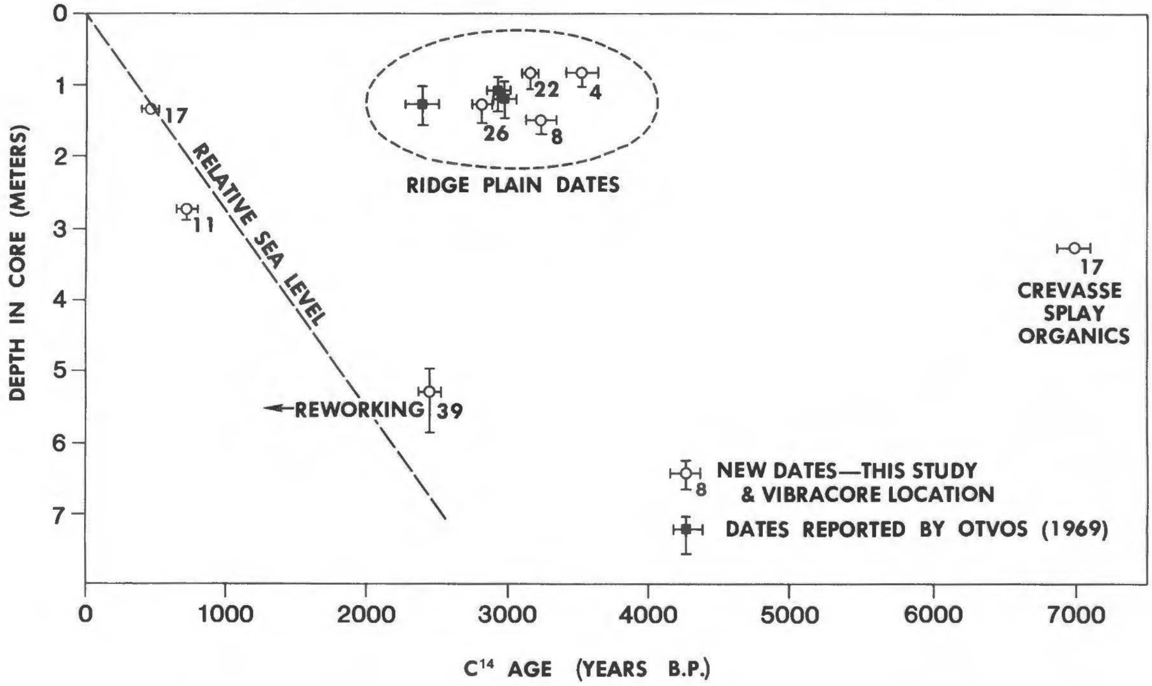


Figure 7. Inferred relative sea-level rise at the Caminada coast of Lafourche Parish (Gerdes 1982). The curve is based on radiocarbon-dated basal peats and in situ, articulated shells of Crassostrea virginica.

from local tide gauges, an observation which has two alternative interpretations: (a) natural processes of subsidence in coastal Louisiana are highly time dependent, or (b) the rapid subsidence over the last few decades is largely man-induced. Whichever cause is the dominant, however, neither is likely to alter the current subsidence rate dramatically over the next 40 years. A linear extrapolation of current subsidence rates would predict a cumulative subsidence over the next 40 years of 36 cm for the Grand Isle area and 29 cm at Eugene Island. The numbers are high; however, both are less than the predicted eustatic rise (40 cm) for the same period. Table I summarizes the predicted amounts of eustatic rise, subsidence, and local relative sea-level rise for the Louisiana coast over the next 40 and 100 years.

Table I. Predicted future changes in sea level on the Louisiana coast based on data from Bayou Rigaud (Grand Isle) and Eugene Island (Atchafalaya Bay).

Year	Eustatic rise (cm)	Subsidence (cm)	Local relative sea-level rise (cm)
2020	40	29-36	69-76
2080	60	73-90	133-150

CONCLUSIONS

It has often been assumed in past writings that changes in sea level are too slow and imperceptible to play a significant role in shoreline changes on time scales of concern to human development. This paper has demonstrated that, contrary to this belief, sea level is likely to rise at a fast and accelerating pace in the very near future.

Now, local relative sea-level changes along the Louisiana coast appear to be dominated by subsidence. The rate of subsidence is more than five times as high as the average rate of eustatic sea-level rise for the last century. Eustatic sea level is directly controlled by global mean temperature through changes in the specific volume of near-surface water and melting of polar ice sheets. The global mean temperature, in turn, is affected by periodic natural climatic cycles and a CO_2-induced "greenhouse effect". Using conservative estimates for the rate of CO_2 release, one finds that the global warming over the next decades may cause a eustatic sea level rise of about 1 cm/yr between the years 1980 and 2020. This rate exceeds the local subsidence rate of coastal Louisiana implying that global eustatic sea-level changes will be our greatest concern in the next few decades.

The estimated eustatic rise plus subsidence may amount to about a 75-cm local relative sea-level rise over the next 40 years along the Louisiana coast. With that rate of rise, it is imperative that plans for development and protection of the Louisiana coast take sea-level changes into account.

LITERATURE CITED

Baumann, R. H. 1980. Mechanisms of maintaining marsh elevation in a subsiding environment. M.S. Thesis. Louisiana State Univ., Baton Rouge.

Behrens, E.W., R. L. Watson, and C. Mason. 1977. Hydraulics and dynamics of New Corpus Christi Pass, Texas: a case history, 1972-73. U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, Va. GITI Rep. 8.

Blackwelder, B. W. 1980. Late Wisconsin and Holocene tectonic stability of the United States mid-Atlantic coastal region. Geology 8:534-537.

Blackwelder, B. W., O. H. Pilkey, and J. D. Howard. 1979. Late Wisconsin sea levels on the southeast U.S. Atlantic shelf based on in-place shoreline indicators. Science 204:618-620.

Bloom, A. L. 1977. Atlas of sea-level curves. Department of Geological Sciences, Cornell Univ., Ithaca, N. Y.

Broecker, W. S. 1975. Climatic change: are we on the brink of a pronounced global warming? Science 189: 460-463.

Brooks, M. N., D.J. Colquhoun, R. R. Pardi, W. Newman, and W. J. Abbott. 1979. Preliminary archaeological and geological evidence for Holocene sea-level fluctuations in the lower Cooper River Valley, S. C. Fla. Anthropol. 32: 85-103.

Clark, J. A., and C. S. Lingle. 1977. Future sea-level changes due to West Antarctic ice sheet fluctuations. Nature 269: 206-209.

Curray, J.R. 1965. Late Quaternary history, continental shelves of the United States. Pages 723-735 in H. E. Wright and D. G. Frey, eds. The Quaternary of the United States. Princeton Univ. Press, Princeton, N. J.

Dansgaard, W., S. J. Johnson, J.B. Clausen, and C. C. Langway, Jr. 1971. Climatic record revealed by Camp Century ice core. Pages 37-56 in K.K. Turekian, ed. Late Cenozoic glacial ages. Yale Univ. Press, New Haven, Conn.

Dillon, W. D., and R. N. Oldale. 1978. Late Quaternary sea-level curve: reinterpretation based on glacio-eustatic influence. Geology 6: 56-60.

Emery, K. O. 1980. Relative sea-levels from tide-gauge records. Proc. Natl. Acad. Sci. U.S.A. 77: 6968-6972.

Fairbridge, R. W., and O. A. Krebs, Jr. 1962. Sea-level and the southern oscillation. Geophys. J. 6: 532-545.

Field, M. E., E. P. Meisburger, E. A. Stanley, and S. J. Williams. 1979. Upper Quaternary peat deposits on the Atlantic inner shelf of the United States. Geol. Soc. Am. Bull. 90:618-628.

Gerdes, R. G. 1982. Stratigraphy and history of development of the Caminada-Moreau beach ridge plain, southeast Louisiana. M.S. Thesis. Louisiana State Univ., Baton Rouge.

Gornitz, V., S. Lebedeff, and J. Hansen. 1982. Global sea-level trend in the past century. Science 215: 1611-1614.

Gutenberg, B. 1941. Changes in sea-level, postglacial uplift, and mobility of the earth's interior. Geol. Soc. Am. Bull. 52: 721-772.

Hansen, J., D. Johnson, A. Lacias, S. Lebedeff, P. Lee, D. Rind, and G. Russell. 1981. Climate impact of increasing atmospheric carbon dioxide. Science 213:957-966.

Hays, J. D., and W. C. Pitman. 1973. Lithospheric plate motions, sea-level changes and climatic and ecological consequences. Nature 246: 13-22.

Hicks, S. D. 1978. An average geopotential sea-level series for the United States. J. Geophys. Res. 83: 1377-1379.

Hicks, S. D. and J. E. Crosby. 1974. Trends and variability of yearly mean sea-level, 1893-1972. National Oceanic and Atmospheric Administration, Tech. Memo. NOS 13.

Hughes, T. 1973. Is the West Antarctic ice sheet disintegrating? J. Geophys. Res. 78:7884-7910.

Manabe, S., and R. J. Stouffer. 1980. Sensitivity of a global climate model to an increase of CO_2 concentration in the atmosphere. J. Geophys. Res. 85:5529-5554.

Manabe, S., and R. T. Wetherald. 1975. The effects of doubling the CO_2 concentration on the climate of a general circulation model. J. Atmos. Sci. 32: 3-15.

Marmer, H. A. 1952. Changes in sea-level determined from tide observations. Pages 62-67 in Proceedings. 2nd Coastal Engineering Conference.

Matthews, R. K., and R. Z. Pore. 1980. Tertiary ^{18}O record and glacio-eustatic sea-level fluctuations. Geology 8: 501-504.

Meade, R. H., and K. O. Emery. 1971. Sea-level as affected by rivèr runoff, eastern United States. Science 173:425-427.

Mercer, J. H. 1978. West Antarctic ice sheet and CO_2 greenhouse effect: a threat of disaster. Nature 271:321-325.

Milliman, J. D., and K. O. Emery. 1968. Sea-levels during the past 35,000 years. Science 162:1121-1123.

Nummedal, D., and S. M. Humphries. 1978. Hydraulics and dynamics of North Inlet, South Carolina, 1975-76. U.S. Army Coastal Engineering Research Center, Ft. Belvoir, Va. GITI Rep. 16.

Oaks, R. Q, and J. R. DuBar (eds.). 1974. Post-Miocene stratigraphy, central and southern Atlantic coastal plain. Utah State Univ. Press, Logan.

Otvos, E. G., Jr. 1969. A subrecent beach ridge complex in southeastern Louisiana. Geol. Soc. Am. Bull. 80: 2353-2358.

Pattullo, J. G. 1966. Seasonal changes in sea-level. Pages 485-496 in M. N. Hill, ed. The sea, vol. I. Interscience.

Pilkey, O. H., B. W. Blackwelder, H. J. Knebel and M. W. Ayers. 1981. The Georgia Embayment Continental Shelf: stratigraphy of a submergence. Geol. Soc. Am. Bull. 92: 52-63.

Pitman, W. C. 1978. The relationship between eustacy and stratigraphic sequences of passive margins. Geol. Soc. Am. Bull. 89:1389-1403.

Pitman, W. C. 1979. The effect of eustatic sea-level changes on stratigraphic sequences at Atlantic margins. Pages 453-460 in J. S. Watkins, L. Montadert, and P. W. Dickerson, eds. Geological and geophysical investigations of continental margins. Am. Assoc. Petrol. Geol. Mem. 29, Tulsa, Okla.

Rhode, H. 1978. The history of the German coastal area. Die Kuste 32: 7-29.

Shackleton, N. J., and M. B. Cita. 1979. Oxygen and carbon isotope stratigraphy of benthic foraminifera at Site 397: detailed history of climatic change during the Late Neocene. Pages 433-445 in U. von Rad, W. B. F. Ryan et. al., eds. Initial reports of the Deep Sea Drilling Project, vol. 47. U. S. Government Printing Office, Washington, D. C.

Siegenthaler, U., and H. Oeschger. 1978. Predicting future atmospheric carbon dioxide levels. Science 199:388-395.

Swanson, R. L., and C. I. Thurlow. 1973. Recent subsidence rates along the Texas and Louisiana coasts as determined from tide measurements. J. Geophys. Res. 78: 2665-2671.

Swift, D. J. P. 1976. Continental Shelf sedimentation. Pages 311-350 in D. J. Stanley and D.J.P. Swift, eds. Marine sediment transport and environmental management. Wiley, New York.

EFFECTS OF COASTAL STRUCTURES ON SHORELINE STABILIZATION AND LAND LOSS - THE TEXAS EXPERIENCE

Robert A. Morton

Bureau of Economic Geology
The University of Texas
Austin, TX 78712

ABSTRACT

Recent studies indicate that Texas is losing about 120 ha (300 acres) of wetlands and 40 ha (100 acres) of gulf-front property annually. Although total land losses in Texas are considerably less than those in Louisiana, they are still substantial and the reason many shoreline protection structures have been erected. The structures have not always produced the desired effects, however. Instead, some have accelerated erosion of nearby beaches. Groins have generally been ineffective because sand supply is inadequate where beaches are eroding. With one exception, seawalls built on Gulf of Mexico beaches have failed or have been severely damaged during storms. Most bulkheads and seawalls have protected the adjacent property, but at the expense of publicly-owned recreational beaches that are eroded by the reflected wave energy. Because of similarities in geologic setting and physical processes along the gulf coast, the effects of these structures can be evaluated and the results applied to Louisiana where shoreline stabilization is being considered to mitigate land loss.

INTRODUCTION

Public and private property worth millions of dollars is lost annually from coastal environments around the world including areas of south Louisiana and Texas that border the Gulf of Mexico (Figure 1). Some of these land losses are natural products of shoreline erosion and submergence of the land surface; other losses commonly result from surface modifications such as dredging, river control, and building coastal defense structures.

The coastlands of Louisiana are dominated by extensive deltaic plain marshes and bays bordered by minor barrier islands in the east and a broad chenier plain in the west, all associated with construction and abandonment of the Mississippi River delta (Figure 1). In contrast, the Texas coast is characterized by much smaller oceanic deltas (Rio Grande, Brazos-Colorado) and intervening barrier-strandplain features, bays, and minor marshes (Figure 1). Despite these proportional differences in coastal environments, the similarities in physical processes, geologic setting, and human activities between the areas make the shoreline responses to coastal structures in Texas applicable to similar settings in Louisiana. In both states, coastal structures are being used to mitigate land loss along migrating barriers that are remarkably similar in origin and geologic setting. For example, the gulf beach and barriers (East Timbalier Island and Grand Isle), that front the Lafourche subdelta are comparable in many respects to the gulf beach and barriers (East Matagorda Peninsula, Follets Island, Galveston Island) that front the Brazos-Colorado delta (Figure 1).

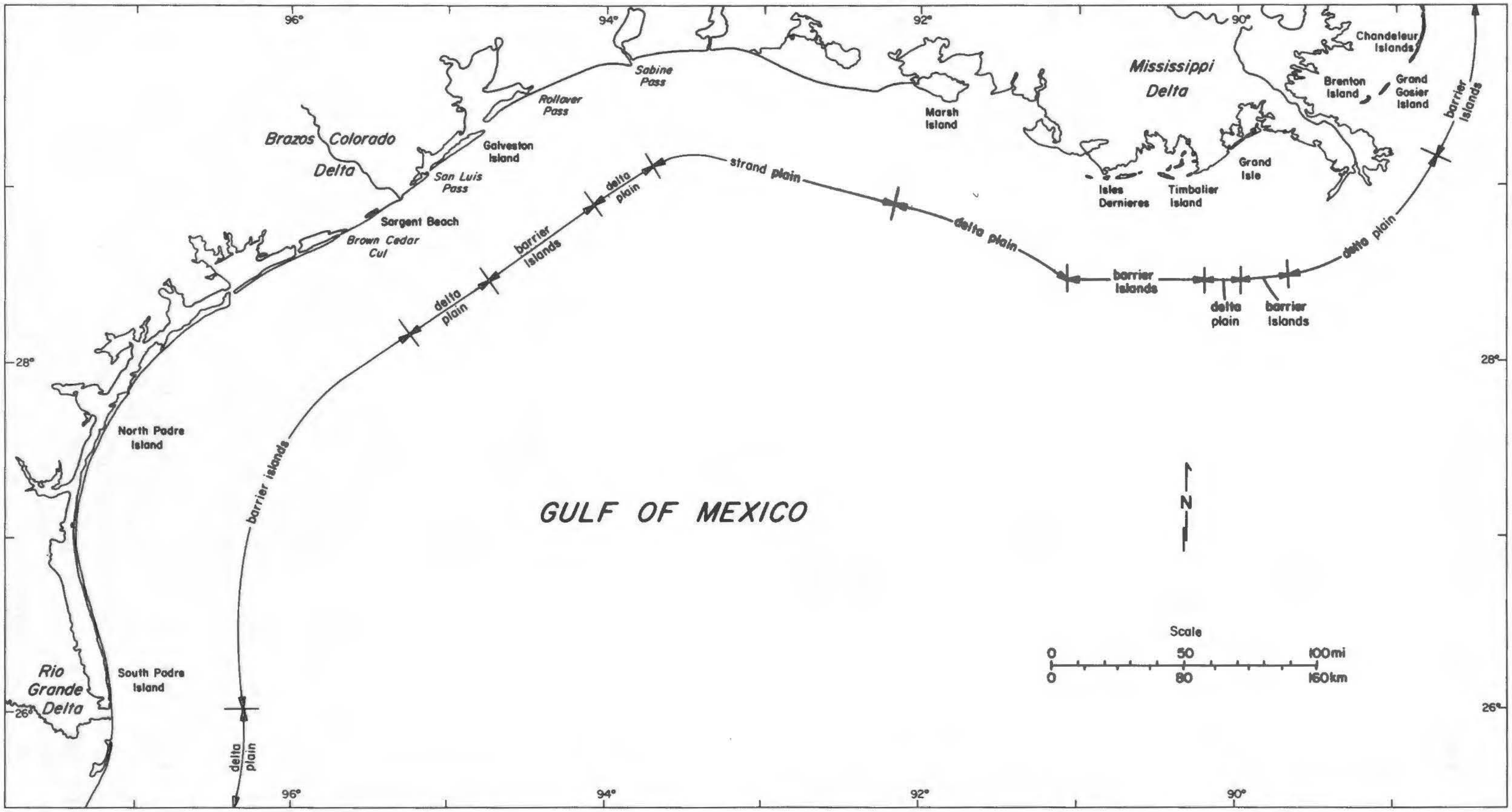


Figure 1. Geomorphic subdivision of coastal Texas and Louisiana. Land loss in Texas is limited primarily to erosion of the gulf and bay shorelines whereas substantial land loss in Louisiana results from wetlands submergence and excavation, as well as erosion.

SUMMARY OF LAND LOSSES IN TEXAS

In this century alone land losses along the Texas gulf shoreline have amounted to more than 4,000 ha (10,000 acres) and average rates of loss have increased from about 14 ha (35 acres)/yr near the turn of the century to nearly 160 ha (400 acres)/yr over the past decade (Morton 1977). Accelerating land losses of substantially greater magnitude (10,000 ha/yr) have also been reported for the Louisiana coast (Gagliano et al. 1981). The magnitude of land loss in Texas is illustrated in Figure 2 which shows nearly 320 m of beach retreat with erosion rates averaging between 7 and 8 m/yr. Although land losses in the bays and lagoons have not been quantified in detail, they probably represent additional losses of about 120 ha (300 acres)/yr. These high rates of land loss have led to the emplacement of numerous breakwaters, jetties, groins, bulkheads, and seawalls in an attempt to hold back the sea or at least delay the retreat of the shoreline. Unfortunately these structures have not always accomplished their intended purposes and in some instances they have actually caused increased beach erosion.

Bays and Lagoons

Shorelines bordering the bays and lagoons are typically low clay bluffs, wetland marshes, or sand and shell beaches. Each shoreline type formed under different geological conditions and each responds differently to present-day processes.

The clay bluffs are composed principally of Pleistocene fluvial-deltaic sediments that form the upland areas of the adjacent Coastal Plain. Of the three shoreline types, clay bluffs exhibit the greatest disequilibrium with extant coastal processes and, therefore, are the most vulnerable to wave attack and undercutting. As a result, essentially all clay bluffs are retreating at rates up to 7 m/yr.

Coastal marshes that fringe the bays of the upper Texas coast are decreasing in area not only because of shoreline erosion, but also because of sediment compaction and attendant submergence. These wetland losses caused by sediment compaction are fewer in Texas when compared to Louisiana owing to the smaller area of delta-plain and bay-margin marshes where this process occurs. The loss of wetlands in Texas is primarily a function of shoreline retreat which averages 3 to 5 m/yr in many areas. By comparison, sand and shell beaches are relatively stable although their rate of retreat is commonly on the order of 0 to 2 m/yr.

Gulf Shoreline

In contrast to historical changes in the bay shorelines that are complex (McGowen and Brewton 1975; White et al. 1978), changes in the Texas gulf shoreline are fairly systematic and beach erosion is most severe in three areas (Figure 1): between Sabine Pass and Rollover Pass, between San Luis Pass and Brown Cedar Cut (vicinity of the Brazos River delta, Figure 2), and on South Padre Island (vicinity of the Rio Grande delta). Each of these areas is characterized by thin sand beaches that are retreating over marsh and delta-plain muds at average rates of 3 to 5 m/yr regardless of storm frequency and intensity. In each of these areas, ocean waves have consumed hundreds of acres and have destroyed numerous beach houses in the past 20 years. Despite the hazards of storm overwash, flooding, and shoreline erosion, permanent residence and recreational development continues to increase in these areas and structural methods are being used in an attempt to reduce land losses and to provide storm protection.

Figure 2. Comparison of aerial photographs illustrating gulf shoreline erosion in the Cedar Lakes area, Texas, between 1930 and 1974 (Morton and Pieper 1975).

MAJOR CAUSES OF LAND LOSS

The three primary causes of land loss in Texas and elsewhere are (1) reductions in sediment supply, (2) relative sea-level rise and (3) human activities; although listed separately the third category directly affects the other two (Figure 3). Of foremost importance is the natural decrease in sediment supply that accompanied climatic changes over the past few thousand years. Simply put, the major coastal rivers and nearshore currents are no longer delivering the volume of sediment that they once did. This natural decrease in sediment supply has been aggravated to varying degrees by dam construction and entraining of rivers and emplacement of jetties, groins, and seawalls that compartmentalize the coast and disrupt the longshore transport of sand. Hence, these structures have locally contributed to shoreline erosion and their contribution to land loss may be even greater in the future.

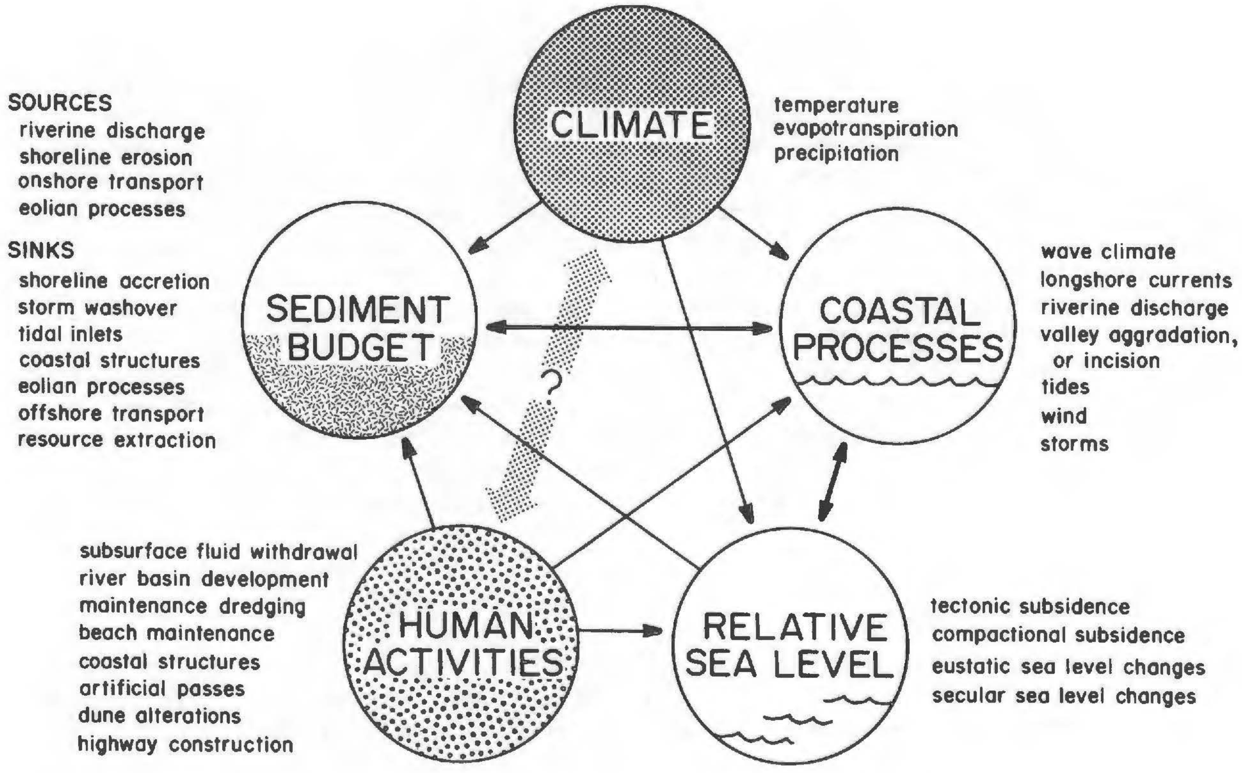


Figure 3. Interaction of factors affecting land losses. Arrows point toward the dependent variables: the number of arrows originating from or terminating at a particular factor indicates the relative degree of independence or interaction. For example, human activities are independent of the other factors, but they affect sediment budget, coastal processes, relative sea-level conditions, and, perhaps, climate (Morton 1977).

Relative sea-level rise refers either to rising of the water level or sinking of the land surface; both processes produce the same effect and both may act simultaneously. The end result is that the land becomes submerged and the shoreline retreats inland. Along the Texas and Louisiana gulf coast relative sea-level rise in recent years averaged between 0.5 and 1 m per century (Hicks 1972). Again both natural processes and human activities are involved. The land surface sinks naturally as the underlying sediments compact, but withdrawal of subsurface fluids (ground water and hydrocarbons) locally accelerates the process and leads to increased land surface subsidence. Added to this is the possible worldwide (eustatic) rise in sea level caused by melting of the polar ice caps. Recent studies indicate that this sea-level rise may also be accelerating because of the "greenhouse effect" produced by CO_2 (Emery 1980) and other gasses that are released to the atmosphere. When viewed collectively, these processes suggest that the long-term outlook for coastal areas is not good because land losses will likely continue to be widespread and vast areas may become submerged.

REVIEW OF COASTAL STRUCTURES IN TEXAS

Bays and Lagoons

Shoreline stabilization projects in Texas bays and lagoons are principally of two types: (1) numerous, relatively low-cost structures such as wooden bulkheads, concrete seawalls, riprap, and small groins that are designed to protect a single waterfront lot or (2) a few expensive reinforced concrete bulkheads designed to protect an entire development. The former group of structures are generally short lived (less than 25 years) because of the materials employed and the exclusion of physical processes from the project design. In contrast, the latter group of structures has only been used for slightly more than a decade and their longevity is uncertain. Common causes of bulkhead/seawall failures are deterioration of the wood, corrosion of the tie-backs, or flanking, overtopping, and undercutting by storm waves and nearshore currents. These processes as well as slope failures are responsible for reducing the effectiveness of most rubble revetments. In addition, most groins are rendered ineffective for bay shore protection because of inadequate sand supplies in the littoral drift system. Effects common to these structures are the acceleration of erosion along adjacent, unprotected shorelines as well as disruption of the offshore bar system and loss of the beach along sandy bay shores.

Gulf Shoreline

Serious attempts to stabilize the gulf shoreline, especially at harbor entrances, began in the mid-1800's when safe navigation into the shallow bays was becoming important to the coastal economy. Perhaps the most famous structure is the Galveston seawall (Figure 4) that was erected not to halt beach erosion, but to prevent overwash and flooding from storms such as the 1900 hurricane that claimed more than 6,000 lives. The seawall has adequately protected the city of Galveston from erosion and storm waves, but in so doing the recreational beach was sacrificed. This is most noticeable along the western part of the seawall where visitors drove on a wide sand beach prior to 1965. Now the seawall toe is protected by riprap, but the adjacent unprotected beach has eroded landward of the seawall and is retreating at fairly high rates.

Other seawalls built on the Texas coast are less massive than the Galveston seawall and they also have been less effective in preventing land loss. Seawalls built by

Figure 4. Western part of massive seawall on Galveston Island. Note lack of sand beach seaward of the seawall.

Figure 5. Remnants of seawall on South Padre Island that failed during Hurricane Beulah.

individuals or corporations on South Padre Island, North Padre Island, and Sargent Beach (Figure 1) have completely failed or have been so severely damaged that costly repairs were required to maintain them. A representative example is found on South Padre Island (Figure 5) where a privately built seawall constructed in 1962 was destroyed by Hurricane Beulah in 1967. This seawall was built by the landowner after a previous seawall, constructed seaward, failed in the early 1960's. The position of the former seawall is now completely submerged by the open gulf. Furthermore, continued erosion has removed the beach in front on the second seawall (Figure 5).

The most recent examples of extensive seawall damage occurred on North and South Padre islands during Hurricane Allen (1980). The fact that a large seawall built with corporate funds did not survive the storm (Figure 6) is important for several reasons. First of all, the seawall failed even though (1) the storm center was more than 130 km (80 mi) away and (2) at landfall the storm was relatively weak by hurricane standards. Secondly, considerable damage occurred on the landward side of the seawall owing to overtopping by storm waves and the hydrostatic head (back pressure) developed by flood waters as the storm surge subsided. Thirdly, this massive and expensive structure needed extensive repairs less than 15 years after it was built to protect a resort development.

Figure 6. Seawall on North Padre Island damaged during Hurricane Allen.

In summary, except for the Galveston seawall built at public expense, most concrete shoreline protection structures erected on the Texas coast in recent years have failed or have been severely damaged. These structures have finite lives, are expensive to construct and maintain, and they commonly transfer the erosion problem elsewhere by locally eliminating the sediment supply. For these and other reasons the U.S. Army Corps of Engineers recommended the use of nonstructural methods, such as beach nourishment, sand bypassing, and dune construction, when feasible for shoreline stabilization projects.

CONCLUSIONS

Attempts to mitigate land loss through the use of permanent structures may not be successful because (1) land losses in adjacent areas will probably accelerate, (2) initial project costs plus maintenance expenditures may exceed the value of the protected property, and (3) the temporary abatement of land loss and attendant sense of security may inadvertently lead to further economic development and the potential for future losses of even greater magnitude. This is analogous to flood-plain development downstream of dams that impound upstream flood waters, but do not prevent severe downstream flooding caused by intense rainfall throughout the drainage basin. Implementation of multiple individual shoreline stabilization projects that (1) lack integration into a more regional plan and (2) are designed without full knowledge of the local geologic setting and coastal processes may prove to be inadequate as long-term solutions to coastal land loss.

ACKNOWLEDGMENT

Publication was authorized by the Director, Bureau of Economic Geology, The University of Texas at Austin.

LITERATURE CITED

Emery, K.O. 1980. Relative sea levels from tide-gauge records. Proc. Natl. Acad. Sci. U.S.A. 77:6968-6972.

Gagliano, S.M., K.J. Meyer-Arendt, K.M. Wicker. 1981. Land loss in the Mississippi River Deltaic Plain. Trans. Gulf Coast Assoc. Geol. Soc. 31:295-300.

Hicks, S.D. 1972. On the classification and trends of long period sea level series. Shore and Beach 40:20-23.

McGowen, J.H., and J.L. Brewton. 1975. Historical changes and related coastal processes, gulf and mainland shorelines, Matagorda Bay area, Texas. Univ. of Texas at Austin, Bureau of Economic Geology Spec. Publ. 72 pp.

Morton, R.A. 1977. Historical shoreline changes and their causes, Texas gulf coast. Trans. Gulf Coast Assoc. Geol. Soc. 27:352-364.

Morton, R.A., and M.J. Pieper. 1975. Shoreline changes in the vicinity of Brazos River Delta (San Luis to Brown Cedar Cut). Univ. of Texas at Austin, Bureau of Economic

Geology Geol. Circ. 75-4. 47 pp.

White, W.A., R.A. Morton, R.S. Kerr, W.D. Kuenzi, and W.B. Brogden. 1978. Land and water resources, historical changes and dune criticality: Mustang and North Padre Islands, Texas. Univ. of Texas at Austin, Bureau of Economic Geology, Report of Investigations 92. 46 pp.

SAND DUNE VEGETATION AND STABILIZATION IN LOUISIANA

Irving A. Mendelssohn

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

ABSTRACT

The sandy barriers that fringe the Louisiana deltaic plain are dynamic and ephemeral coastal features. In terms of development, management, and conservation, these landforms pose many problems unique to the Mississippi River deltaic environment. The abandonment of a major delta by the Mississippi River initiates the development of a Louisiana barrier system. Nearshore marine processes and subsidence become the dominant mechanisms of shoreline evolution. Marine processes erode the abandoned delta and concentrate a restricted quantity of coarse-grained sediments into highly mobile barrier islands, spits, and beaches which overlie unconsolidated delta silts and clays. Subsidence, due to the compaction of these unconsolidated sediments, in concert with a eustatic increase in sea level, generates a rapid apparent sea-level rise, equivalent to 1 m/ 100 yr. This combination of sea-level rise and limited coastal sand supply has produced the most serious barrier island erosion problem in the United States.

The use of hard structures, such as groins, jetties, and seawalls to control or reduce barrier island erosion in Louisiana has met with limited success. The use of vegetation to stabilize substrates offers a sound alternative to the hard structure approach to erosion abatement. This paper introduces Louisiana's barrier dune vegetation and qualitatively describes the use of this vegetation for dune building and stabilization on Timbalier Island, Louisiana.

INTRODUCTION

Critical components of many coastal systems are the low-lying strips of land called barrier islands or beaches that make up the seaward boundary of the estuary and protect it from the direct onslaught of the sea (Godfrey 1976). The combination of an accelerated sea-level rise, due to local deltaic subsidence, and a limited coastal sand supply has produced in Louisiana the most serious barrier island erosion problem in the United States. Louisiana's barrier islands (Figure 1) are migrating landward at rates as high as 50 m/yr while losing total land area at a rate of 65 ha/yr (Mendelssohn et al. 1982).

The environmental and economic consequences of shoreline erosion in Louisiana are immense because of the important functions that barrier islands perform. (1) Barrier islands protect marshes and create estuaries by acting as a marine buffer zone to

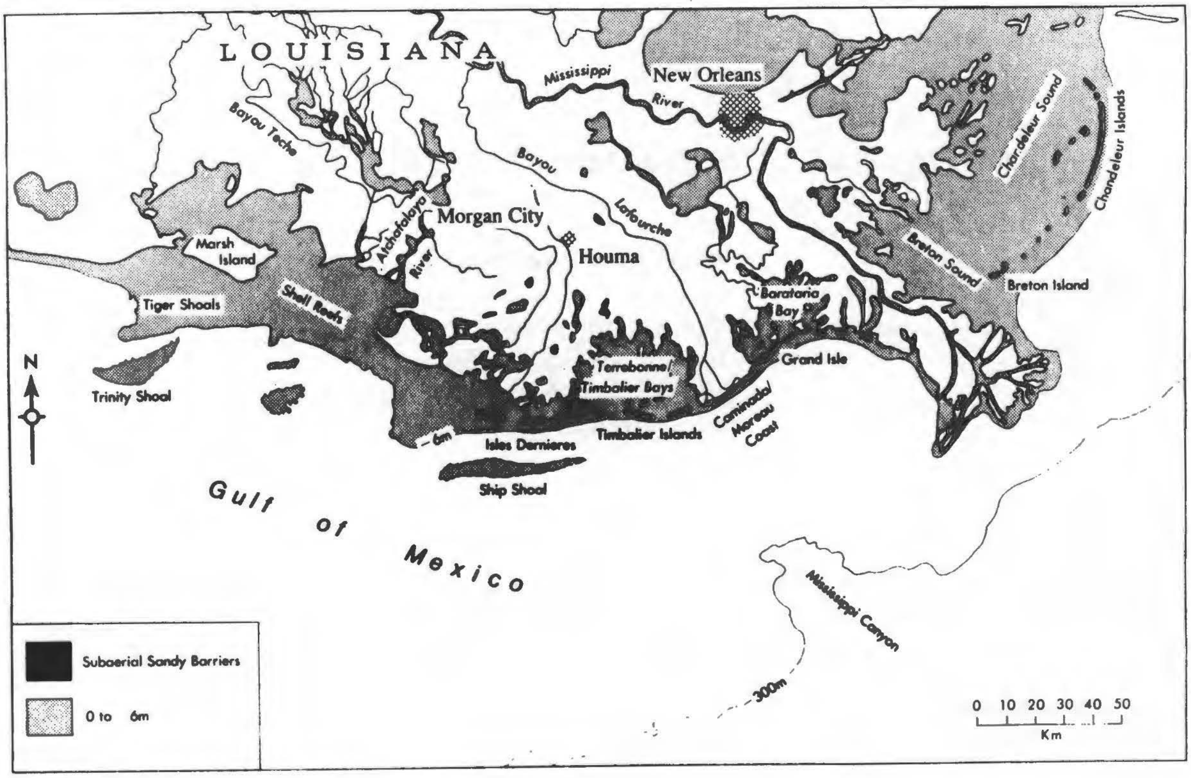


Figure 1. Location of Louisiana's barrier islands.

saltwater intrusion, hurricane storm surge, and deep water wave attacks . In this way, Louisiana's barrier islands help to support a finfish and shellfish industry which accounts for over 25% of the total U. S. commercial catch each year. (2) Barrier islands provide habitat for wildlife and shelter for endangered or threatened species. (3) Barrier islands provide protection for mainland areas, including oil and gas facilities which generate considerable tax revenues for Louisiana. (4) Since the three-mile boundary for Louisiana's territorial waters is measured from the barrier islands, the State is concerned with the problem of continued landward migration of the barrier islands as this migration could result in a reevaluation of the State's three-mile boundary and a net loss of oil and gas leases to the Federal Government. (5) Barrier islands offer recreational opportunities and aesthetic qualities unique to this system.

The use of hard structures (groins, jetties, seawalls) to control or reduce barrier island erosion in Louisiana has met with limited success (Penland and Boyd 1981). In the case of groins and jetties, accretion may result at the updrift side of the structure, e.g., the east end of Grand Isle, but accelerated erosion often occurs at a downdrift location, e.g., the Grand Terre islands. The inherent problems with structures like groins and seawalls are now being recognized (Leatherman 1980). Seawalls, for example, only protect what is landward; accelerated beach erosion often occurs seaward of these structures (Silvester 1977). In addition, these structures destroy the aesthetic qualities that attract so many people to these ecosystems. Sand dune building and stabilization offer a sound alternative to the hard structure approach to erosion abatement.

The objectives of this report are to (1) describe the vegetation of the dune community of Louisiana's barrier islands; (2) indicate plant species that may be used for dune stabilization in Louisiana; and (3) qualitatively discuss an attempt to build and stabilize a foredune ridge on Timbalier Island, Louisiana.

FUNCTION OF STABILIZED DUNES

How do dunes aid in reducing barrier island erosion? Firstly, coastal dunes provide a reservoir of sand to the beach during storm events. Not only does the dune system nourish the beach during storms, but the building of an offshore storm bar from dune sands has the effect of reducing the slope of the beach and lengthening the surf-swash zone so that the maximum energy dissipation of storm waves is achieved (Leatherman 1979a). Both effects tend to reduce erosion of the beachface. Secondly, continuous sand dunes act like levees, retarding overwash and island breaching. Because one of the primary causes of sand loss to an island is due to breaching and subsequent inlet dynamics (Leatherman 1979b), the role of sand dunes in strengthening the island against breaching is very important in controlling the overall erosion of the island. Thirdly, a well-vegetated dune provides a source of vegetation to recolonize overwashed and breached dunes after storms. This vegetation is important in initiating new sand accumulation and dune-building processes.

Some coastal investigators have questioned the function of barrier dunes during storm conditions. Dolan (1972) maintained that large stabilized dunes are detrimental to the long-term stability of the barrier system since they were believed to interfere with beach dynamics by (1) constricting the swash zone so that wave energy is dissipated over a narrower area, resulting in increased turbulence and concommitant beach erosion, and (2) functioning as seawalls and thus concentrating wave energy to increase the scour of adjacent sand beaches. Based on this hypothesis for which no hard data were collected, the U. S. National Park Service has argued that dunes are detrimental to the stability of barrier islands, and in some locations should possibly be breached artificially by bulldozers. As Leatherman (1979b) points out, "This management approach is rather startling, considering that dune conservation programs are essentially ubiquitous worldwide."

Thus, the question exists: Do stabilized barrier dunes increase barrier island erosion? Leatherman (1979a, b, c), who has intensely investigated this question, concluded that Dolan's hypothesis is not substantiated by field measurements or by results from previous research:

> "From laboratory tests and field observations during storm conditions, it has been shown that the barrier dune does not result in steepening of the upper beach foreshore. Instead, the profile continues to flatten asymptotically until a critical minimum value is achieved. Seaward migration and building of the outer storm bar can provide for a wide enough surf-swash zone to achieve maximum energy dissipation and thus define a new equilibrium profile. Dolan's (1972) emphasis on the importance of the subaerial beach profile in energy dissipation and wave reflection neglects the full range of interactions. The presence of a dune line cannot constrict the energy dissipation process since the seaward boundary (storm bar) is not a static feature.

"It is very tempting to draw an analogy between a seawall and an eroding barrier dune. The essential difference appears in their response: static vs. dynamic. Unless a sand dune is essentially structurally controlled by rip-rap or caissons as a seawall, it is free to erode or accrete depending on the environmental conditions. It has long been argued by the U. S. Army Corps of Engineers (1974) that dunes serve as a sand reservoir for beach nourishment in times of need (during storm conditions). In fact, it has been clearly shown that a high sand dune will reduce foreshore erosion during a storm since a greater amount of sand is available to fill the offshore profile and buildup the outer bar to provide sufficient width to dissipate the wave energy (Van der Meulen and Gourlay 1969).

"The case against barrier dunes, artificially induced or totally natural, is not convincing from either a beach or barrier dynamics viewpoint. Much more work needs to be done along these lines, particularly in the case of storm generated beach dynamics" (Leatherman 1979b).

DUNE STABILIZATION IN THE UNITED STATES

There exists a long history of the use of vegetation to retard the erosion of dunes in the United States. Attempts at coastal dune stabilization were made as early as 1703 when colonists of Cape Cod used grasses to control sand erosion due to their own deforestation of sandy areas (Westgate 1904).

In the early 1900's, intense efforts to vegetate existing dunes along the Pacific Northwest coast began. Primarily, European beach grass, Ammophila arenaria, and American dunegrass, Elymus mollis, were planted. These plantings proved to be successful to the point that the dominant dune plant in the Pacific Northwest is European beach grass.

Along the Atlantic coast, large scale planting by the Civilian Conservation Corps (CCC) occurred along the North Carolina coast from 1934-36. American beachgrass, Ammophila breviligulata, was planted extensively in the Bodie Island area of the outer banks. Between 1936-40, the CCC and the Works Progress Administration (WPA), under the direction of the National Park Service, erected almost 1 million meters of sand fencing to create a continuous barrier dune along the outer banks, including Hatteras, Pea, and Bodie islands (Dolan et al. 1973).

After a series of strong hurricanes impacted the Atlantic coast starting in 1954 with "Hazel", new interest in dune erosion control was stimulated. The National Park Service and the Soil Conservation Service began testing various species of grasses on North Carolina's Outer Banks in the late 1950's. Beach grasses, especially American beachgrass, have been planted extensively on the outer banks during the 1950's and 1960's. With the establishment of the Cape Hatteras National Seashore in 1957, the National Park Service felt it was important to protect the dunes making up the park from eroding. Thus, extensive dune plantings continued which augmented the 1930's effort at dune construction. After this effort, an almost continuous vegetational cover existed on these barrier islands making up the outer banks.

Vegetation has been used to stabilize dunes to varying degrees along the Northeast, Middle and Southeastern Atlantic shorelines, Florida, the northern coast of the Gulf of Mexico, and Texas. Although the New Orleans District of the U. S. Army Corps of Engineers and the Soil Conservation Service initiated some dune plantings on Grand Isle in the past, the use of vegetation to build and stabilize dunes along the Louisiana coast has been generally overlooked.

SAND DUNE COMMUNITY

Sand dunes are windblown accumulations which form in the shape of mounds, ridges, and/or bands when a supply of sand is available. Although dunes may be completely unvegetated, such as large mobile dunes which continually move as dictated by eolian forces, the majority of dunes on barrier islands have some degree of plant cover which may vary from exceedingly sparse to highly dense.

Vegetation aids in building dunes by first reducing wind velocity in its lee and this causes the deposition of sand grains. As more and more sand is deposited, these sand grains accumulate into small mounds. Secondly, the roots of dune plants bind the sand which results in varying degrees of substrate stability, depending on root density. In response to newly accreted sands, which provide a fertilizing effect, vegetational growth is stimulated. In many grasses, horizontal rhizomes give rise to tillers which greatly increase the vegetative spread of the plant. As more tillers are produced, more sand is accumulated until the vegetation may be nearly buried. When burial is even more rapid, shoots are killed and rhizomes stop extending laterally, but continue growing vertically until the new surface is reached, when again tillering takes place. This process allows the vegetational growth to keep pace with sand accumulation and create partially stabilized embryo or hummock dunes. As these dunes increase in number, they begin to coalesce to form a dune line. Hence, a foredune is created. The configuration and height of a dune line is a function of the sand supply and intensity and direction of prevailing winds relative to the orientation of the barrier beach. Onshore winds normally form large dunes while alongshore or offshore winds form dune lines which are more open and lower in physiognomy.

The above dune-building processes primarily occur on the backshore (i.e., the horizontal or gently sloping part of the beach that is inundated only by storm waves and extremely high tides) of Louisiana's barrier islands. This zone of the beach often contains small hummock dunes and sparse vegetation. Densely vegetated dunes have been estimated to occupy less than 3% of the total Louisiana barrier island area (Mendelssohn et al. 1982), although the sandy backshore-dune-swale zones account for approximately 18% of the islands' area. Since vegetated sand dunes are important sources of sediments to these islands after storm events, it is clear that in their present state, the barrier islands and beaches of Louisiana only have a limited source of sediments in the form of back beach and dune deposits.

The dunes of Louisiana's barrier islands are poorly developed as a result of a limited amount of eolian transported sand and the high frequency of overwash resulting from hurricanes and storms. Most of Louisiana's barrier islands and beaches have only one primary dune line which is relatively low in profile and only moderately vegetated. Barrier islands without well-developed dunes, such as in Louisiana, have limited sand reserves and, thus, a limited mechanism of reducing net beach erosion. Since vegetation aids in building of dunes and is essential for sand stabilization, dune vegetation plays a key role in maintaining this important source of sediments on the barrier islands.

The sand dune is a relatively inhospitable environment for vegetation establishment. Environmental factors such as salt spray from saline waters of the Gulf of Mexico, soil moisture deficiencies, limited nutrient supply, and soil instability may all negatively affect coastal dune vegetation.

Salt spray occurs when effervescence in the surf generates droplets into the air where they are concentrated and transported inland by the wind (Boyce1954). Impingement on vegetation may result in chlorosis and subsequent death of plants. The active agent of the salt spray is the chloride ion which enters the windward portions of plant parts through cracks and lesions in the epidermis. The degree of injury is related to the windspeed above the critical value of 7 m/sec where an abrupt increase in salt spray intensity occurs as turbulent air flow increases. In addition to affecting growth, it has been demonstrated that airborne salt spray is the primary environmental factor determining the distribution, shape, and zonation of maritime plant species (Wells and Shunk 1937; Oosting and Billings 1942; Art 1971). Many of the grasses that grow on foredunes are resistant to salt entry and hence can survive the intense spray zones of the beach. Those plants that are less adapted are found in the lee of dunes or other vegetation. Salt spray is an important factor preventing the establishment of annual plants on the foredunes (Van der Valk 1974). As found along the Atlantic coast of the United States, the salt spray effect only allows those plants specifically adapted to this environment to inhabit the gulfward edge of Louisiana's barrier islands.

The question of whether the dune environment presents a water deficiency to plants has been greatly debated. Although the top few centimeters of a dune may be completely dry, the sand below this level is often moist. It has been hypothesized that the dry surface sand acts as a vapor trap which prevents deeper drying of the substrate. The water table, per se, which depends on the size of the dune and may be several meters from the active rooting zone, acts as an indirect source of water via vapor phase diffusion upward to the rooting zone. Since the capillary rise of water from a free water surface even in a very fine sand is not more than about 40 cm, the water table in a dune only a few meters high can make no direct contribution to the moisture requirements of most dune plants. Both rainfall and the condensation of soil water vapor provide important sources of water to dune vegetation, but their relative contribution is unknown.

The dune plants themselves play an active role in controlling their water requirements. This may be done by controlling water loss at the leaf surface, as in the shallow rooting pennywort, Hydrocotyle bonariensis, by accumulating large amounts of water in succulent tissue as in the dune elder, Iva imbricata, or by producing roots which penetrate deep into the substrate, as in some of the dune grasses, e.g., Panicum, Uniola.

Dune sands are generally deficient in nutrients essential for plant growth. The major inputs to the dune system are salt spray and precipitation. The mineralization of organic matter in the dunes is of limited importance since eolian processes remove most lightweight organic matter. Fertilizer-addition tests have demonstrated that inorganic nitrogen is the primary nutrient controlling the growth of dune vegetation (Woodhouse and Haines 1966; Dahl et al. 1974). Phosphorus may become secondarily deficient after the nitrogen deficiency has been ameliorated. Although nutrients would appear to be in limited supply, some dunes support lush, productive stands of vegetation. Recently, it has been demonstrated that dune grasses possess sand grain sheaths (rhizosheaths) around their roots. Nitrogen fixation, a process by which microorganisms fix atmospheric nitrogen into plant-available ammonia, is specifically associated with these sheaths

(Wullstein and Pratt 1980) and may be a primary pathway by which nitrogen is provided to dune plants. In addition, some plants such as beach pea, Strophostyles helvola, possess nitrogen-fixing nodules which serve the same function as rhizosheaths.

Soil instability is another problem that dune vegetation must overcome. Plants have a more difficult time establishing themselves in shifting windblown sand than in a stable substrate. In addition, vegetation is often buried by drifting sand. Dune plants have adapted to this environment by having the capacity to grow upward through considerable accumulations of sand. Burial has a stimulatory effect on the growth of dune grasses; too much sand burial can cause plant death, however. The resistance to sand burial varies with species. The grasses are most resistant, while dicotyledonous plants are more susceptable to sand burial. On the outer banks of North Carolina, sand burial was the major factor preventing the establishment of most annual plants on the foredune or any other area of shifting sand (Van der Valk 1974). These plants can survive sand burial of no more than 16 cm. Accumulations of 20 to 30 cm are normal in this foredune.

In Louisiana, the dominant dune vegetation includes salt meadow hay, Spartina patens, bitter panicum, Panicum amarum, seashore dropseed, Sporobolus virginicus, and beach morning glory, Ipomea stolonifera. Of secondary importance, as indicated by their frequency of occurrence, are beach tea, Croton punctatus, seashore paspalum, Paspalum vaginatum, dune elder, Iva imbricata, seaside goldenrod, Solidago sempervirens, sea oats, Uniola paniculata, and pennywort, Hydrocotyle bonariensis. Figures 2, 3, and 4 demonstrate the distribution of these and other species on three Louisiana barrier systems.

Certain species of dune plants are more efficient dune builders than others. For example, in Louisiana species such as panicum, croton, and sea oats can build dunes from 1 to 5 m high, while salt meadow hay normally generates dunes of relatively low profile, less than 1 m. Also, the shape of the dune produced can vary depending upon the vegetation type. For example, beach tea and dune elder produce large hummock dunes, while panicum more frequently generates dune ridges. Even different species of grasses produce different dune forms. For example, in North Carolina, American beachgrass produces a gently sloping dune while sea oats generates a steep dune front; panicum builds a dune intermediate in shape (Woodhouse et al. 1977).

Although most of Louisiana's dune vegetation is ubiquitous, found on all of Louisiana's barrier islands and beaches, there are two notable exceptions. Sea oats is primarily found on the barrier islands east of the Mississippi River delta, specifically the Northern Chandeleur Islands. Sea oats is almost completely absent west of the delta, except for three small populations on the Caminada-Moreau coast and a few plants on Grand Isle. On the other hand, panicum is very prevalent on Louisiana's barrier islands west of the Mississippi delta, but almost nonexistent on the Chandeleur islands. The reasons for these disjunctions are unclear. There are two plausible hypotheses for why sea oats is not appreciably found west of the delta. Since the islands west of the delta are of a much lower profile than the northern Chandeleurs, these islands tend to be overwashed more frequently. Sea oats may not be able to recover from the effects of overwash as rapidly as other species and hence has lost its prominence on these low-lying islands. Because sea oats growing on dunes of lower elevation are closer to the watertable, it has been hypothesized that this plant, which is apparently highly adapted to dry beach sands, is stressed by excess soil moisture which reduces its vigor. The reasons for the panicum disjunction is an even greater mystery. Nonetheless, both plants are potentially good dune builders and sand stabilizers.

CHANDELEUR ISLANDS (CENTRAL)

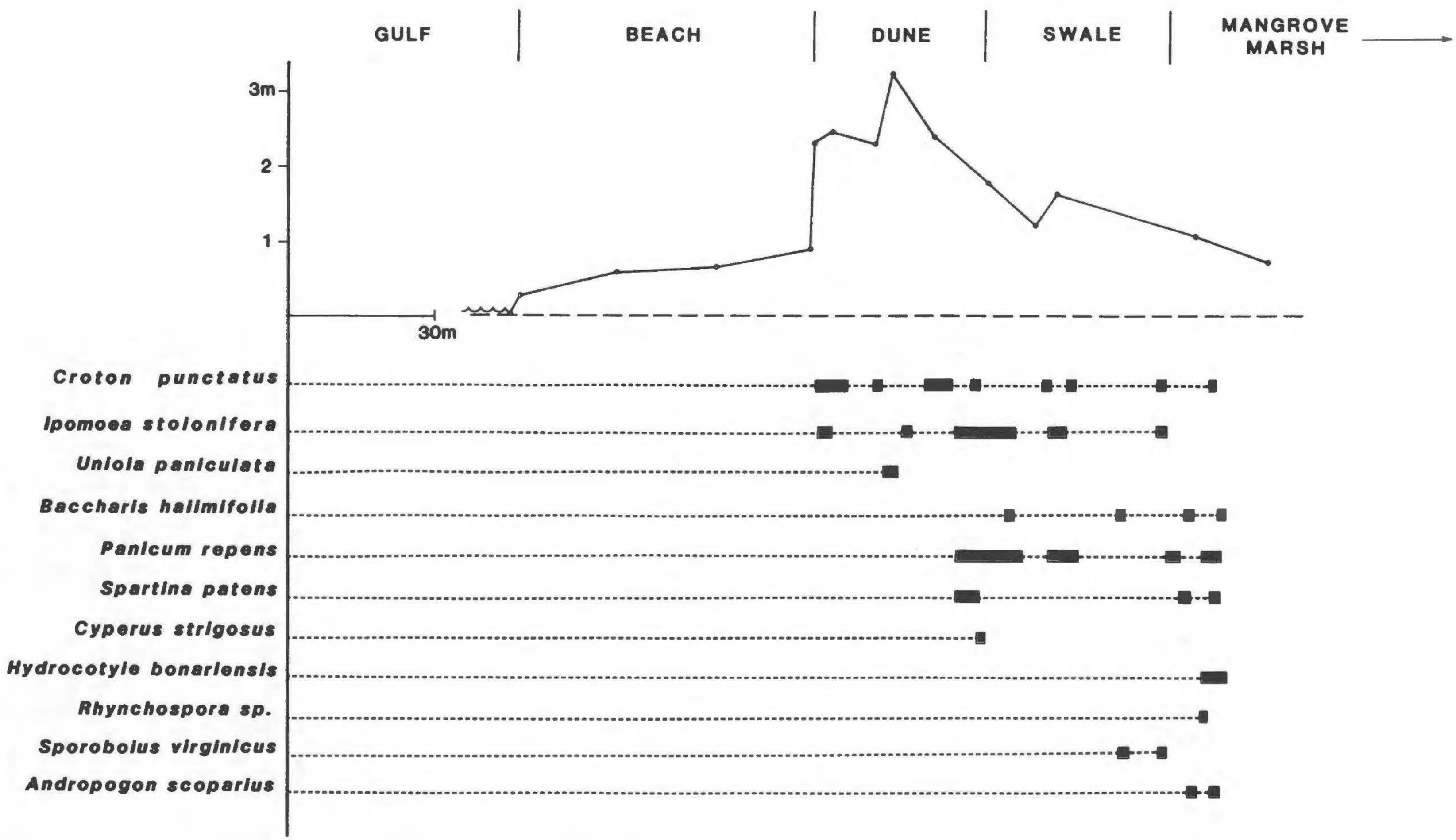


Figure 2. Vegetational distribution-dune profile on the central Chandeleur Islands.

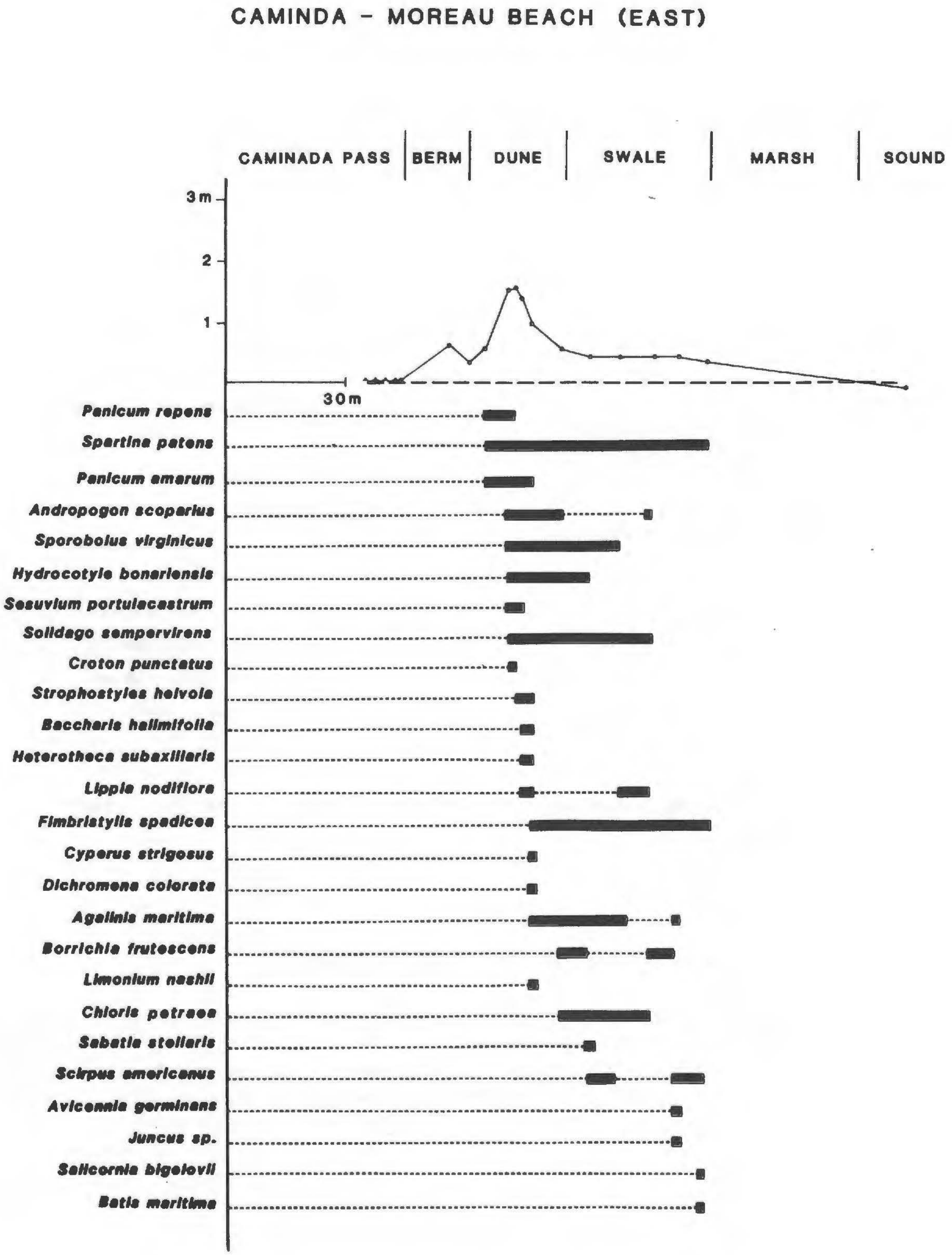


Figure 3. Vegetational distribution-dune profile on the Caminada-Moreau barrier beach east section.

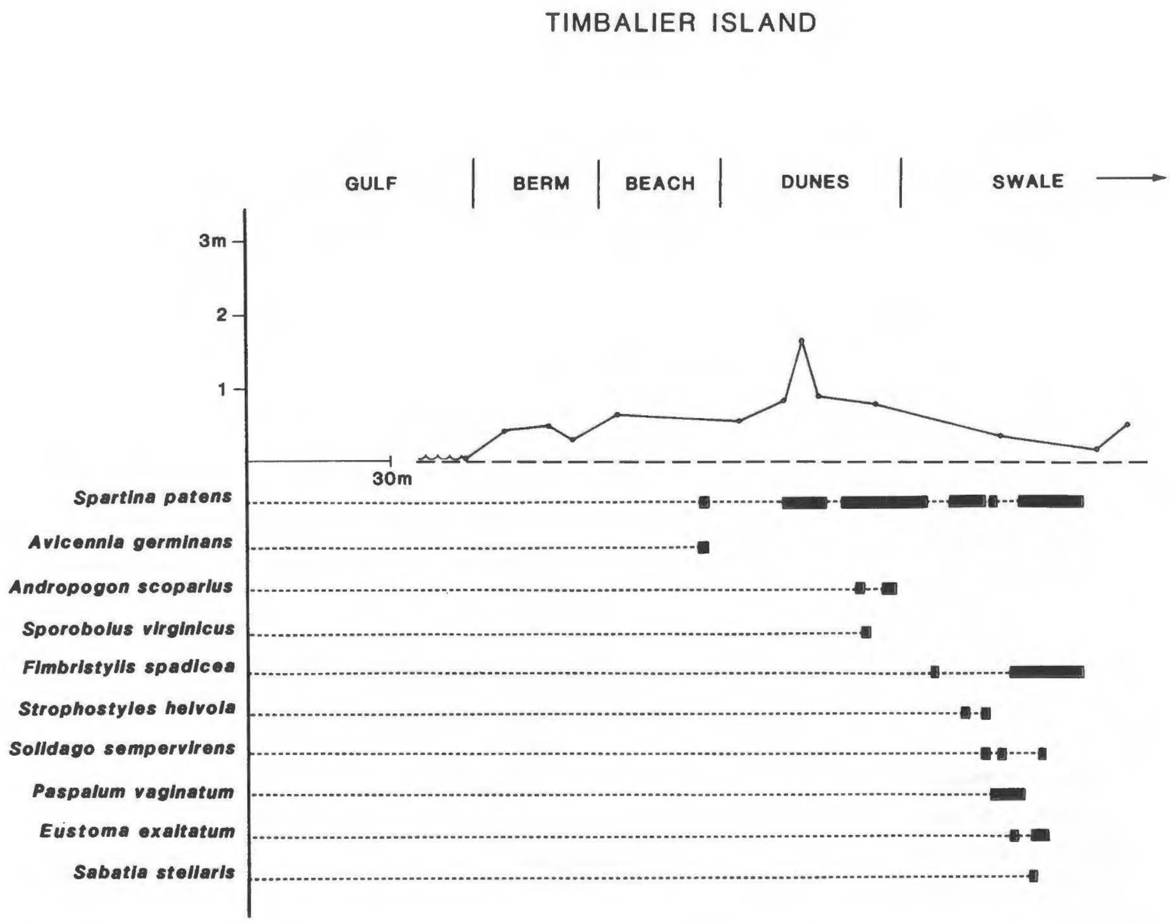


Figure 4. Vegetational distribution-dune profile on Timbalier Island.

VEGETATION FOR DUNE STABILIZATION IN LOUISIANA

Although approximately 462 species of plants inhabit Louisiana's barrier islands and beaches (Montz 1981), only a small percentage of these are suitable for dune building and stabilization. Plants suitable for dune stabilization must of course, be able to grow and procreate where dunes are naturally located, in the path of blowing sand parallel to the high tide line of the backshore. To grow well in this environment along the shoreline of the Gulf of Mexico, a plant must be able to tolerate sand burial, sand impingement, salt spray, saltwater flooding, drought, heat, and low nutrient supply. In addition, these plants must be able to trap and hold sand against wind and wave erosion. The following plants which inhabit Louisiana's coastal dunes meet these requirements.

Spartina patens, salt meadow hay (Figure 5), is a creeping rhizomatous plant (0.5 to 1.5 m tall) forming in small clusters or singly. This plant is distributed in North America along the eastern coast from Quebec to Florida, Texas, and the eastern coast of Mexico and is present in a few localities in Michigan and New York, on islands in the Caribbean,

and is also know in Europe in France, Corsica, and Italy. Salt meadow hay flowers mostly from May to September, but occasionally throughout the growing season. Viable seed is produced in early September.

This perennial grass is the most widespread plant on Louisiana's coastal dunes. While this species is more productive on moist sites, it is often found as the sole dominant on low-lying dunes and washover flats. The grass spreads to make dense stands by a network of slender rhizomes. The aboveground stems are slender and up to 1 m tall with rolled to semirolled leaves less than 0.6 cm wide. Salt meadow hay can be dominant in all three of the major barrier island habitats: dune, swale, and salt marsh (high marsh).

For use along the Louisiana coast, this plant may be thinned from existing stands or ordered from horticultural supply houses. Although the viability of naturally occurring seed has not been tested in Louisiana, if it is similar to what has been found in the Carolinas (Seneca 1969; Graetz 1973), this plant may be suitable for propagation by seed. Plantings of vegetative material can be made in late winter and early spring. Planting stock consists of several stems rooted at the base, preferably with a section of rhizome attached. In vegetating sand flats, the stock is planted 46 cm apart in the center of the planting area, spreading out to 1 to 1.2 m apart at the edges. This graduated planting allows sand to penetrate to the center of the grass in the first two seasons making a wider, flatter dune. Planting depth is about 10 to 13 cm.

Panicum amarum, bitter panicum (Figure 6), has culms 0.3 to 2 m tall that form large or small clumps or solitary plants from rhizomes. This plant is distributed in North America on the Atlantic and gulf coasts from Connecticut to Florida and Texas, in the West Indies, and on the eastern coast of Mexico. Bitter panicum flowers from September to November. According to Gould (1975), P. amarulum, seashore panicum, seems "to represent no more than a growth form or variety of a single species," Panicum amarum. This conclusion agrees with the analysis of Palmer (1975). Therefore, P. amarum should be used as the scientific name for this plant in Louisiana.

Bitter panicum is an important perennial of foredune areas in Louisiana and is a good grass for dune stabilization. Since this plant produces no viable seed, its only means of colonization and propagation is by rhizome. The leaves of bitter panicum are smooth and bluish in color. Seed heads are narrow, compressed, and most often sparsely seeded. The plants grow to an average height of 1 to 1.2 m.

In Louisiana, planting stock may be obtained from cuttings of existing populations or purchased from commercial sources. Planting stock consists of a single stem cut at the base to include a node, a stem with part of the rhizome attached, or 20- to 30- cm lengths of the rhizome without the aboveground parts. The latter must contain at least two nodes per piece of rhizome. Bitter panicum is best planted in the spring through early summer at a depth of 15 to 25 cm for stem material and 10 cm for rhizome. Plants should be spaced at 46 cm.

Sporobolus virginicus, seashore dropseed (Figure 7), is a perennial, strongly rhizomatous plant arising singly or in clusters. In general, this plant is distributed along the eastern coast from Virginia to Florida and Texas, and southward through the West Indies and the Caribbean to Brazil. Sporobolus flowers from May to October, occasionally to December.

Figure 5. Spartina patens, salt meadow hay.

Figure 6. Panicum amarum, bitter panicum.

Seashore dropseed, although not a dominant dune plant in Louisiana, is frequently found in scattered patches colonizing newly accreted sand. This species often forms embryo dunes gulfward of the primary dune line and invades washover sites with salt meadow hay. Sporobolus has an extensive fibrous root system making it suitable for sand stabilization. This low growing, perennial grass spreads by rhizomes and occasional stolons. Culms are stiff and 15 to 20 cm tall. Leaves are numerous and 5 to 10 cm long.

Propagation of this plant is generally by pieces of rhizomes which root readily. Since this plant fowers prolifically in Louisiana, however, the potential for the production of viable seeds is present and plant establishment by seed may be an alternative propagation methods. Seashore dropseed should be planted in early spring either as transplants or rhizome pieces. Plants should be spaced at 46-cm centers and be planted at a depth of approximately 10 cm.

Figure 7. Sporobolus virginicus, seashore dropseed.

Paspalum vaginatum, seashore paspalum (Figure 8), is a perennial plant with culms 10 to 60 cm tall arising from an extensive system of long, slender rhizomes in coastal sands. Its distribution is from North Carolina to Florida and Texas, south to Argentina, and also in the Old World tropics. *Paspalum* flowers between late summer and winter.

In Louisiana, seashore paspalum, occupies environments similar to seashore dropseed, i.e., sand flats and embryo dunes. Both species can also be found in sandy, wetter interdunal areas protected from salt spray effects. Although this species is not a dominant dune plant in Louisiana, its fibrous root system makes it a prime candidate for dune stabilization trials.

Seashore paspalum is a low, creeping grass, resembling coastal bermuda grass, (*Cynodon dactylon*), that spreads by runners as well as rhizomes. The flowering culms of this plant are usually less that 0.3 m high. Although seashore paspalum can endure on very wet sites, even salt water inundated, this plant also builds small hummock dunes on dry flats.

Seashore paspalum can easily be propagated by transplanting runners or rhizomes. Optimum planting time and depth are similar to seashore dropseed. Transplants should be 46 cm apart.

Uniola paniculata, sea oats (Figure 9), is a perennial plant with 1.2 to 2 m tall stout culms arising singly or in small clusters from long, thick rhizomes. This species is found on dunes and sandy flats along the ocean from Virginia to Texas, northern West Indies, and eastern Mexico. Sea oats flowers from June to December, but mostly in late summer and early autumn.

Although sea oats is the most important and widespread grass on coastal dunes in the Southeast United States (Craig 1976), its importance in Louisiana is limited. Sea oats is found on Louisiana's Chandeleur islands, but with the exception of a few small isolated populations, is almost completely lacking on the barrier islands and beaches west of the Mississippi River Delta. The dominance of sea oats is not reestablished until the area of Padre Island, Texas. The reason for this disjunction is unclear, although factors such as the lack of a large seed source, impact of frequent washover events due to hurricanes, and dune formations which are too low in elevation to prevent plant roots from entering the water table are possible causes.

Although sea oats produces viable seeds, which are important in colonizing new areas (Woodhouse et al. 1968), the plant spreads primarily from long extended rhizomes. Sea oats leaves are narrow, pale green, and die back in the winter in more northerly latitudes. The leaves are normally rolled inward. The stems of this plant are slender and up to 1 m tall. The seed heads are compressed spikelets borne at the end of stiff culms. Seeds mature in the fall.

Seed germination is not high, and seedling survival is low (Seneca 1969; Graetz 1973). Thus propagation via transplants will provide the highest success. In Louisiana, sea oats cannot be thinned from existing populations since these populations are already too small. Sea oats transplants can be obtained, however, from commercial supply houses for dune stabilization measures in Louisiana. When replanting, the transplants are set at least 0.3 m deep and packed in tightly. The basal part of the leaves may be buried, but deep planting is desired to keep the roots moist.

Figure 8. *Paspalum vaginatum*, seashore paspalum.

Figure 9. *Uniola paniculata*, sea oats.

Figure 10. *Croton punctatus*, beach tea.

Figure 11. *Iva imbricata*, dune elder.

The best time for planting sea oats is from late winter to early summer. Depth of planting should be 20 to 30 cm. Each plant should be transplanted at 46-cm centers. Plantings can be spaced at 0.6 to 1.2 m intervals at the edges of the planting area to allow for sand penetration into the center of the planting area. Sea oats usually take 2 years to stabilize a dune and hence should be used in conjunction with faster sand stabilizing plants, such as bitter panicum.

Croton punctatus, beach tea (Figure 10), is a woody-based perennial, commonly wide-spreading, and up to 45 cm high. This species inhabits coastal dunes from North Carolina to Florida and Texas, and flowers from March to December or in some cases all year. Seeds, glossy gray with darker mottlings, ripen in October through November.

Beach tea is only sporadically found along the Louisiana coast. Where it is present, e.g., on the Northern Chandeleur islands, this species builds up large hummock-like dunes and is a significant member of the dune community. Beach tea primarily spreads by seed and is characterized by its silvery-colored leaves and pubescence. The stems are tan with cinnamon-colored spots.

This plant can be propagated by planting the seed 2.5 to 5 cm deep during the late fall and up to early spring. Beach tea should only be used for the purposes of dune stabilization with grasses having a more fibrous root system.

Iva imbricata, dune elder (Figure 11), is a woody-based perennial about 60 cm high with fleshy leaves. Dune elder is found on sand dunes of the Atlantic and gulf coasts from Virginia to Florida and Texas, and flowers from August to September.

Dune elder has a similar growth habit to that of beach tea, and thus, forms hummock-like dunes. In specific areas of Louisiana, this plant is a dominant of the dune community. Dune elder has a strong system of rhizomes which allow it to spread and form colonies. In addition, roots develop along the stems if they are buried by sand. The leaves of this plant are fleshy, narrow, and lance-shaped, growing to about 6 cm long. Dune elder is highly adapted to the dune environment. Its thick fleshy leaves are impervious to salt spray and the plant spreads upward and outward as sand accumulates around it.

This plant may be propagated with seed or with stem cuttings. Seed collected, cleaned, and planted in the fall has a good chance of success (Graetz 1973). In cleaning the seed, care must be taken in rubbing away the chafty bracts so as not to injure the fragile seed coats. Seedlings also can be found naturally near the parent plant and can easily be transplanted in the spring. Stem cuttings root easily in peat pots and can be used as transplant stock. Cuttings should be planted in the late winter or early spring, 10 to 15 cm deep.

The best dune-forming plants have both vertically and horizontally elongating stems and a fibrous root system. These characteristics enable the plants to grow vertically through accumulating sand, to spread laterally increasing plant density and cover, and to most efficiently bind sediments. These characteristics plus the ability of dune vegetation to survive and reproduce under relatively harsh environmental conditions makes the above plants nearly perpetual agents for stabilization.

TIMBALIER ISLAND DUNE STABILIZATION PROJECT

At this time there is only one relatively large-scale dune building and stabilization project along the Louisiana coast. This project, located on a washover terrace of Timbalier Island (Figure 12), is a joint effort of Texaco Corporation, U.S. Soil Conservation Service, and Louisiana State University's Center for Wetland Resources. The objective of this pilot project was to determine the feasibility of building and stabilizing dunes along the Louisiana coast without using beach nourishment. This is an important consideration since beach nourishment alone can cost from 2 million to 3 million dollars per linear mile of beach while dune building and stabilization via sand fence and vegetation ranges from $30,000 to 60,000 per mile, 50 to 100 times less expensive. In addition, any beach nourishment project will require sand fencing and vegetation to keep the sand in place, thus, making the expense for the total beach nourishment project even greater.

The Timbalier Island study was initiated in May of 1981 on a 335-m long relatively flat washover channel containing almost no existing vegetation (Figure 13). Sand fencing was first installed to attempt to trap sand and build a small dune. Sand fencing was arranged to test whether diagonal sand fencing accumulated more sand than sand fencing oriented parallel to the beach. Perpendicular side spurs were also tested (Figure 14). In late May, 5,000 bitter panicum transplants, thinned from populations on the Caminada-Moreau barrier beach, were planted to a width of 7.6 m along this 335 m length of backbeach. Percent survival of these transplants after six weeks was good and averaged 84%, ranging from 69% to 93%. Tillering from a single transplant after 6 months was prolific with 8 to 12 new tillers originating from each original culm.

The bitter panicum transplants were only one-third of the total number of plants to be established in this area. Since a mixed planting would provide a greater potential for success, two other species were also established: sea oats and seashore paspalum. Because neither of these species are found in great enough abundance to be thinned from natural populations in Louisiana, they were purchased from a commercial source in Florida. The two species were transplanted in October and November 1981 which resulted in a total of 13,200 plants spaced evenly at approximately 46-cm centers. Survival rates for the seashore paspalum have been estimated at 37% after 7 months and for sea oats at 28% after 6 months.

Fertilizer was added to the transplanting site once during the first growing season in late September at a rate of 227 kg of sodium nitrate and 68 kg of 0-20-20 phosphorus-potassium fertilizer.

As of this writing, a maximum of 1 to 1.2 m of sand has accumulated within the test site depending upon the presence and orientation of the sand fencing (Figure 15). The sand fencing was essential in accumulatng relatively large amounts of sand in a short period. Vegetation, alone, only trapped small quantities of sand. Preliminary data indicated the sand fencing with perpendicular side spurs accumulated the greatest amount of sand on this beach. Bitter panicum, during the first year of this project, has been the most successful of the three species planted. (Figure 16).

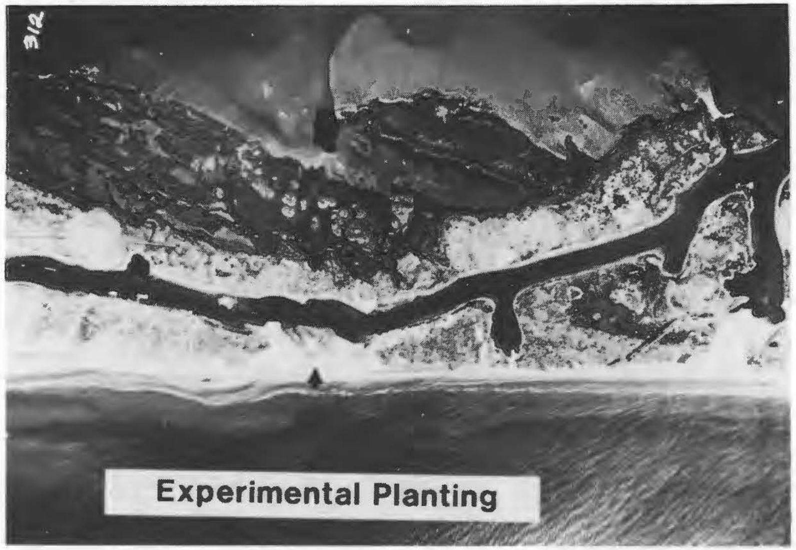


Figure 12. Experimental planting, Timbalier Island.

Figure 13. Planting site before transplanting.

Figure 14. Sand fencing design.

Figure 15. Sand fencing-induced sand accumulation.

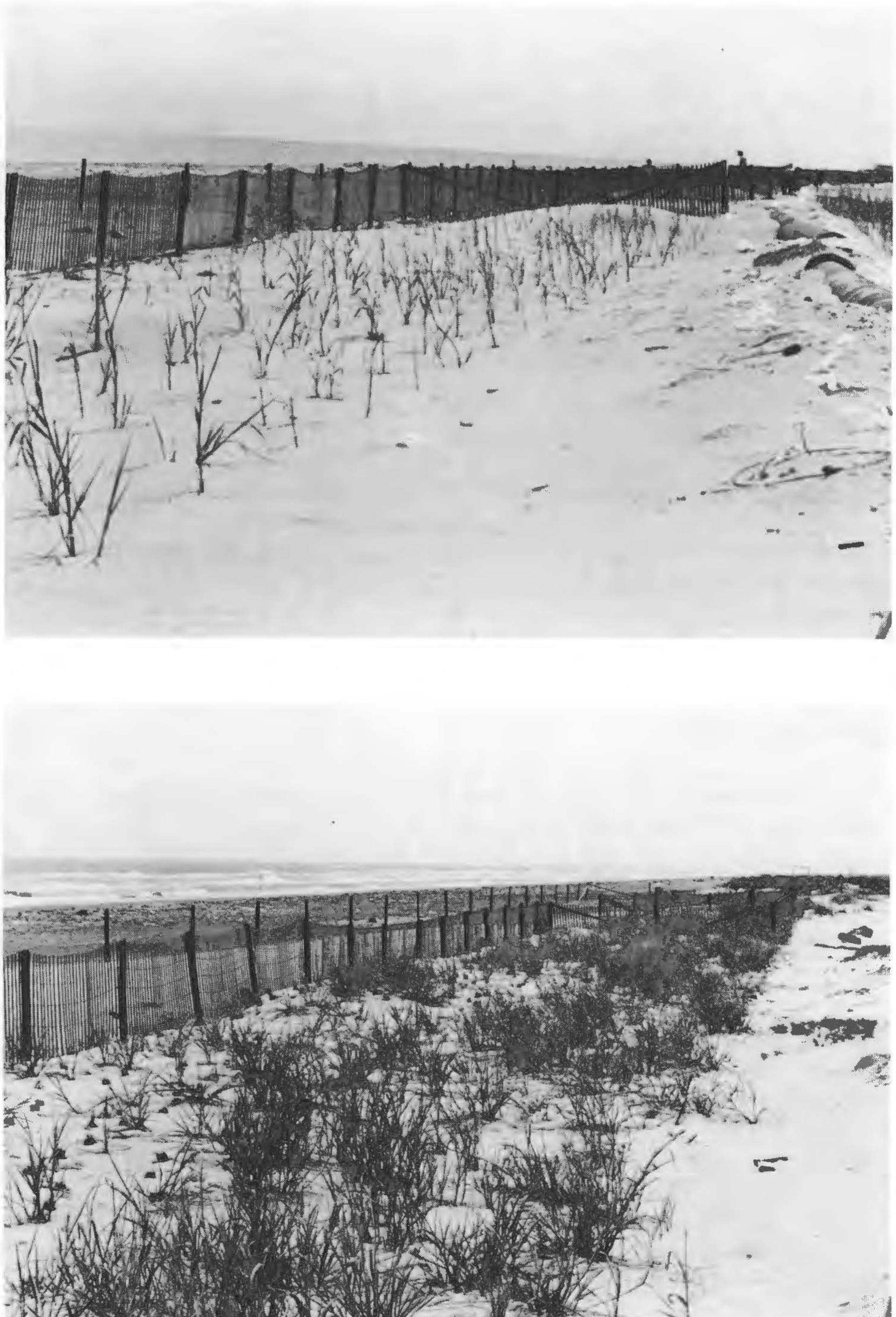


Figure 16. Transplant establishment at 1.5 (top) and 11 (bottom) months after transplanting.

CONCLUSIONS

The use of vegetation for dune building and stabilization in Louisiana offers an erosion control method that is compatible with natural coastal processes and is relatively inexpensive. This method has its best chance of success on islands undergoing some degree of accretion and dune building. But even in transgressive environments, vegetative stabilization in combination with sand fencing and/or beach nourishment offers a viable means for reducing coastal erosion.

ACKNOWLEDGMENTS

The author expresses his appreciation to the Coastal Energy Impact Program of the Louisiana Office of Coastal Zone Management for its financial support of the research from which this manuscript is derived; to F. Monteferrante, M. Hester, D. Carlock, and graduate students of the Department of Marine Sciences, Louisiana State University for carrying out much of the field work; to Mr. J. Jordan of Texaco Corporation; to Mr. C. Starkovich and Ms. F. Talbot of the Soil Conservation Service for coordinating and participating in field plantings on Timbalier Island; and to Texaco Corporation for funding this field planting effort.

LITERATURE CITED

Art, H. 1971. Atmospheric salts in the functioning of a maritime forest ecosystem. Ph.D. Dissertation. Yale University, New Haven, Conn.

Boyce, S. G. 1954. The salt spray community. Ecol. Monogr. 24:29-67.

Craig, R. M. 1976. Grasses for coastal dune areas. Proc. Fla. State Hort. Soc. 89:353-355.

Dahl, B. E., B. A. Fall, A. Lohse, and S. G. Appan. 1974. Stabilization and reconstruction of Texas coastal foredunes with vegetation. Gulf Universities Research Consortium Rep. 139. Galveston, Tex.

Dolan, R. 1972. Barrier dune system along the outer banks of North Carolina: a reappraisal. Science 176:286-288.

Dolan, R., P. J. Godfrey, and W. E. Odum. 1973. Man's impact on the barrier islands of North Carolina. Am. Scientist 61:152-162.

Godfrey, P. J. 1976. Barrier beaches of the east coast. Oceanus 19:27-40.

Gould, F. W. 1975. The grasses of Texas. Texas A&M Univ. Press, College Station. 653 pp.

Graetz, K. E. 1973. Seaside plants of the Carolinas. University of North Carolina. Sea Grant Publ. UNC-SG-73-06.

Leatherman, S. P. 1979a. Barrier dune systems. A reassessment. Sediment. Geol. 24:1-16.

Leatherman, S. P. 1979b. Barrier island handbook. National Park Service, Cooperative Research Unit, The Environmental Institute, Univ. of Massachusetts, Amherst. 101 pp.

Leatherman, S. P. 1979c. Beach and dune interactions during storm conditions. Q. J. Eng. Geol. 12:281-290.

Leatherman, S. P. 1980. Barrier island management. Pages 1470-1480 in Proceedings of the Conference-Coastal Zone '80, Hollywood, Florida.

Mendelssohn, I. A., P. S. Penland, W. H. Patrick, Jr. 1982. Louisiana barrier islands and beaches. Report to the Louisiana Office of Coastal Zone Management. (In preparation).

Montz, G. N. 1981. Final report annotated checklist of plants on the coastal beaches, islands, and barrier islands of Louisiana. U.S. Army Corps of Engineers, New Orleans, La. 43 pp.

Oosting, H. J., and D. W. Billings. 1942. Factors affecting vegetational zonation on coastal dunes. Ecology 23:131-142.

Palmer, P. G. 1975. A biosystematic study of the Panicum amarum - P. amarulum complex (Gramineae). Brittania 27:142-150.

Penland, P. S., and R. Boyd. 1981. Shoreline changes on the Louisiana barrier coast. Oceans. September: 209-219.

Seneca, E. D. 1969. Germination response to temperature and salinity of four dune grasses from the outer banks of North Carolina. Ecology 50:45-53.

Silvester, R. 1977. The role of wave reflection in coastal processes. Pages 639-654 in Proceedings of Coastal Sediments 77.

U. S. Army Corps of Engineers. 1974. Shore protection manual. Coastal Engineering Research Center, Ft. Belvoir, Va.

Van der Meulen, T., and M. R. Gourlay. 1969. Pages 701-707 in Proceedings of the 11th International Coastal Engineering Conference, London.

Van der Valk, A. G. 1974. Environmental factors controlling the distribution of forbs on coastal foredunes in Cape Hatteras National Seashore. Can. J. Bot. 52:1057-1073.

Wells, B. W., and I. V. Shunk. 1937. Seaside shrubs: wind form vs. spray forms. Science 85:499.

Westgate, J. M. 1904. Reclamation of Cape Cod sand dunes. U. S. Dep. Agric. Bureau Plant Ind. Bull. 65:407-411.

Woodhouse, W. W., Jr., and R. E. Haines. 1966. Dune stabilization and vegetation on the outer banks of North Carolina. Department of Soil Science, North Carolina State Univ. at Raleigh. Soil Sc. Ser. 8.

PANEL DISCUSSION

OPTIONS: BARRIER ISLAND AND SHORELINE PROTECTION

Charles G. Groat, Moderator

Dag Nummedal, Irving A. Mendelssohn,
Robert A. Morton, Johannes van Beek, Representative Murray J. Hebert
and **Larry DeMent**, Panelists

Charles Groat: State Representative Murray Hebert has joined the speakers as a panelist. Representative Hebert is from Terrebonne Parish which has an extensive border with the gulf, lined with barrier islands. Consequently, he has been among the most active legislators in matters of shoreline erosion and barrier island protection.

Murray Hebert: First, I want to express my appreciation to LUMCON for holding this conference. It's a good idea for the scientific community to interact with the others representing diverse responsibilities and attitudes regarding the issues of coastal erosion.

As a member of the House Natural Resources and Ways and Means committees I have made coastal restoration my top legislative priority. In Terrebonne Parish alone we have lost 200 mi^2 of marsh and barrier island in the last 40 years. With the possible exception of Plaquemines Parish, Terrebonne and Lafourche parishes are the ones most affected by coastal erosion. One of the ways we used to get legislators concerned about coastal erosion is to prepare some simple map overlays which highlight the area of land loss. For example, this segment of the western Isles Dernieres contained 1,180 acres of barrier island in 1953 and 476 acres in 1978 for a loss of 60 percent. East Timbalier Island suffered a 42% reduction in size in the same period.

The Joint Committees on Natural Resources have recommended projects to slow coastal erosion costing $38 million, including island restoration and stabilization projects, mainly in the Terrebonne-Lafourche area. Also recommended are freshwater diversions in Plaquemines and St. Bernard parishes and shoreline protection and wetlands management projects in southwestern Louisiana. Another project recommended for testing is marine accretion, a process by which calcium carbonate is built on wire through which a weak current is passed. This can be done economically for about one cent per pound in place.

Some projects recommended probably will not work, but the Legislature feels that with the severity of the problems and diverse opionion about what can be done, we will have to go with trial and error. Thus we will need the scientific community to monitor these projects and determine which ones will work and which ones will not.

Mack Mathis: I have been involved in the construction of most of the coastal structural projects discussed here, including the Belle Pass jetties, the Grande Isle jetties, the East Timbalier project and the Holly Beach project.

I do not agree with some of the things said about East Timbalier Island. We began working there in 1965 and it has been virtually an annual experiment financed by Gulf Oil Company. Where were you experts when I needed you? There was a lack of any one willing to make a commitment as to what would work. Gulf made a commitment of between $15 million and $25 million. We have followed the advice of world experts on this project. I do not agree that the riprap seawall has not protected the island; there is a lot of island left. One of our errors was scraping sand from the low dunes of +5 feet to +3 feet msl on the island. This caused some washover channels. Much of the sand has gone to the back protection dike built to an elevation of +6 feet and hard enough for trucks to run on. Another error is the permeable nature of the rock structure, which has allowed tidal flow to erode behind the rocks. Nonetheless, these experiences should now serve as valuable experiments.

Charles Groat: Several speakers brought up the point of the relative sand starvation of the Louisiana barriers. The Legislature's recommendations included geophysical exploration of offshore sand sources which could be used for nourishment.

Dag Nummedal: The Corps of Engineer's Coastal Engineering Research Center has had a successful project to identify sand sources along the east coast. Some sources do exist off the Louisiana coast which could be used. However, if we remove too much sand from these areas disequilibrium will result and the sand may be transported back into these holes.

Murray Hebert: I agree with Mr.Mathis that if it were not for the rocks protecting East Timbalier Island we would have much less of that island remaining.

Jay Combe: I disagree that seawall structures such as the Galveston Seawall cause erosion. If there were no erosion in the first place, there would have been no need for the seawall. Without the seawall the shoreline would have eroded farther into the sand dunes.

Dag Nummedal: That is not true. Most seawalls are erected to protect the land. Any natural shoreline, even if it recedes, maintains a beach.

Robert Morton: The Galveston seawall was built in response to the loss of lives. It has been documented that locally the increased shoreline erosion is attributed to the seawall.

With regard to offshore sand sources, we have surveyed the Texas inner shelf using high resolution seismic methods. In an area off Galveston our seismic survey indicated a lack of viable sand supplies. The Corps of Engineers subsequently looked more intensely only to find a thin veneer of relict sand over Pleistocence mud; an insufficient source of sand for beach nourishment. Offshore sand supplies must be both extensive enough and located near the site of beach nourishment.

Irving Mendelssohn: Sand nourishment should be followed by vegetative stabilization because, in the past, unstabilized sand has often been washed away.

David Stuttz: The Corps of Engineers has had a beach nourishment project at Grand Isle where we have found sufficient offshore sand supplies one-half mile offshore. The dunes created will also be vegetated.

Jake Valentine: When I was a U.S. Fish and Wildlife Service refuge manager at Chincoteague, Virginia, we built a 15-mile dune line with sand fence and vegetation over a period of 5 to 6 years. One January in the early 1960's, a northeaster blew for 5 days and washed the dune line away. I watched the Chandeleur Islands for the last 20 years, including the effects of Hurricane Camille, its subsequent build-up and partial destruction by Hurricane Frederick. Beach erosion control has made more mistakes than virtually any other occupation, primarily because of failure to take into account natural geological processes. Everyone says we must do something and normally, as in the case of the Timbaliers, we do it wrong.

Robert Morton: I have been asked to address the Senate Natural Resources committee in Texas to testify about the mineral accretion process. I would like to ask Representative Hebert to comment about the plans to employ this process in Louisiana.

Murray Hebert: The process works by passing a weak current through a wire and placing an anode in the vicinity, and, like an oyster secretes a shell, the mineral builds up on the negative. This may cut the cost of conventional methods of 70% to 80% in place.

Our intention would be to put out three test projects under different conditions and with different goals. The mineral can accrete as fast as 3½ inches in 12 days, but at this rate the material is soft and weak. Normally material of a strength of 4,200 psi, one-third stronger than concrete, can be grown at a rate of one inch on a single strand over a 2½- to 3-month period. In addition to trapping sand, this process has great potential for protection of metal from corrosion in marine and oil field applications.

Dag Nummedal: It is my understanding that the two field sites where this marine accretion process has been tried are the boat basin of the University of Texas laboratory at Port Aransas and a quiet lagoon in St. Croix. Can this material be accreted fast enough to survive on a relatively high energy beach?

Murray Hebert: I really do not know. We may want to apply this inside islands. But this is why I have suggested a test project, rather than a full-scale application. We definitely need to develop some new technologies for shoreline protection.

H. Dickson Hoese: After the 1973 flood a Corps of Engineers report noted the large biological cost of maintaining levees and suggested that it be included in cost-benefit analyses. Now we realize there is a significant geological cost of the levee system. Is there a study of these long-term costs in existence, and if not, why not?

Larry DeMent: I do not necessarily believe that the leveeing of the river is the fundamental problem. Most accretion takes place near the river when it overtops its banks and relatively little accretion results in a basin at some distance from the source. In fact, we can look at the area between Venice and the Head of the Passes in which there are no levees. There has been tremendous land loss from 1952 to 1971 and significant losses between 1971 and 1978. These losses cannot be

attributed to the construction of levees. Other areas suffering land loss were abandoned delta lobes long before the construction of artificial levees. The Corps is faced with making an overall evaluation of each individual project with regard to its potential contribution to coastal erosion.

Donald Landry: The Corps of Engineers performed a study of the barrier islands in the 1960's and concluded that the cost-benefit ratio did not justify expenditures for barrier island protection. However, this analysis did not take into account the benefits regarding protection of marshlands inside the islands. Of what benefit are the islands in protecting interior wetlands from erosion?

Murray Hebert: From admittedly unscientific studies of land-loss maps it does appear that where barrier islands have been eroded away the interior marsh has eroded much more rapidly than where it is still protected by barrier islands.

I have the feeling that the islands absorb a tremendous brunt of the sea. For instance, where a gap has opened between Timbalier and East Timbalier islands one can almost see a channel opening through Lake Barre to Montegut. A community of 600 Indians in this area is now cut off by road just on a high tide.

Dag Nummedal: It is possible that this is mainly an effect of subsidence. A numerical model study of Moriches Inlet, Long Island, concluded that the change in storm surge would be imperceptible given the quadrupling of the size of an inlet. A similar study in Galveston Bay related to deepening the entrance channel for deepwater draft vessels also concluded that it would have little or no effect on flooding in the bay.

Johannes van Beek: The opening of large bays behind the islands has increased the rate of erosion of interior wetlands because of increased fetch for wind waves. This would be happening even if the barrier islands remained as they are .

Charles Groat: Subsidence, then, is a double villain because in addition to directly causing erosion of wetlands it may have the effect of increasing the water depth and thus the erosive powers of waves generated in the bays.

Irving Mendelssohn: The lack of ability to answer the simple question of the degree to which island erosion affects marsh erosion illustrates the need for more research on basic processes. Unfortunately, we hear that legislators say we have enough studies and action is what we need. I feel this is a short-sighted viewpoint and I think our inability to answer this question exemplifies that.

Murray Hebert: Perhaps in place of studies we can use monitoring. People themselves have gotten tired of the word "studies" and legislators, because they represent people, have also become tired of the word. Nonetheless we need to continue to work with the scientific community to monitor our efforts and to better understand the main causes of erosion.

I might add that there are over 2,000 oil and gas wells inside the barrier islands in Terrebonne Parish. If the barrier islands erode there structures will become vulnerable to the sea, because they were not designed as offshore structures. Some of these fields are old and it would not be feasible to place offshore type platforms in these areas. Because there are about 15,000 jobs in Terrebonne Parish directly or indirectly resulting from the oil industry, the problem is of tremendous importance to our economy.

Frank Atkinson: In Europe, a decision was made on the position of a fortification line and money was spent on shoring up that line. If Louisiana is going to spend money on coastal protection, we have to decide where that fortification line is going to be and then decide how to protect that line. Where is that fortification line going to be?

Johannes van Beek: We have been evaluating that in relation to the rates of land loss being experienced. It is evident that the line must be a considerable distance inward from the present coast. There are two major conditions for the determination of that line: (1) where are the major investments and population centers and (2) where are the major natural levee deposits in order to build structures necessary for permanent protection. Taken together, one can fairly well draw a line along Bayou Teche through Houma to Bayou Lafourche.

Murray Hebert: By their recommendation of $17 million dollars in island stabilization projects, the Joint Natural Resources Committees decided the line will be the barrier islands. With the tremendous amount of revenues which have been generated in Louisiana, it would certainly be a shame if we left a legacy of depleted natural resources, depleted fisheries, an eroding coastline, and a depleted treasury. I would certainly hope that we can get more people involved in solving these problems.

Dag Nummedal: Because there are people and investments which need protection, we obviously need to take some steps, even if short-term to slow the rate of erosion. However these efforts need to be tied into regional or statewide plans for ultimate land use. We need to keep productive resources, but should not build structures which will bring a lot of new people into the threatened areas. The European experience has been different because that coastline is stable. The Louisiana coast is subsiding an order of magnitude faster than the German or Dutch coast.

Irving Mendelssohn: I can not say where the line should be drawn; that is largely a socio-economic and political question. However, to draw the line at the barrier islands is really not looking at the facts. There is no way to permanantly protect some barrier islands which are subsiding, without discovery of huge sand supplies and spending billions of dollars to continuously replenish the islands. We can draw such lines temporarily, but we need a commitment to research on the processes which must be understood for long-term planning.

Larry DeMent: In my mind, we might need two or three fortification lines rather than a single line. The first line may be the barrier islands, which we know are highly dynamic. This may require pumping sand behind the islands in order to maintain a moving line without having the islands disappear. Another line may be inland and aimed at protecting population centers and wetlands.

Johannes van Beek: Even though we have been talking about a line I think that to some extent we can still have the best of both worlds. A line can be drawn and planned for, then we can afford to manage the system outside the line as a dynamic system and reap its benefits.

Charles Groat: Thus, it may be that there are short-term benefits which justify short-term investments which are not long-term answers. But ultimately we have also to strive for the long-term answers.

OPTIONS: LIMITATION AND MITIGATION OF DREDGING AND FRESHWATER DIVERSIONS

REVERSAL OF COASTAL EROSION BY RAPID SEDIMENTATION: THE ATCHAFALAYA DELTA (SOUTH-CENTRAL LOUISIANA)

Harry H. Roberts
Ivor Ll. van Heerden

Coastal Studies Institute and Department of Marine Sciences
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

In early 1950's Atchafalaya Bay began experiencing sedimentation, which marked the initiation of a new major delta lobe in the Mississippi River Delta complex. This new era will be characterized by rapid progradation and marshland growth in parts of coastal Louisiana that have been typified by coastal retreat for hundreds of years. Although the Atchafalaya River has long been a distributary of the Mississippi, it was not until the early 1950's that the Atchafalaya Basin had filled sufficiently to allow significant quantities of sediment to be transported to the bay. The 1950's and 1960's marked the period of subaqueous growth when the bay bottom accreted with prodelta clays and silty clays. As a product of the abnormally severe 1973 flood, the Atchafalaya Delta became a subaerial feature characterized by sand-rich lobes which are prograding at a rapid rate. During 1972-77 approximately 32.5 km^2 (12.6 mi^2) (above low tide level) of new marshland was added to Atchafalaya Bay as a product of sedimentation from Lower Atchafalaya River Outlet. Similar processes are occurring at the mouth of Wax Lake outlet, where, by early 1976, 2.20 km^2 (0.85 mi^2) of new land existed.

Systematic monitoring of changes within the delta system over the last 4 years has shown that delta growth responds directly to flood volume and duration. The years 1976 through 1978 can be characterized as average in terms of discharge. Analysis of LANDSAT imagery reveals that Wax Lake suffered a net loss of subaerial expression during this period owing to the combined effects of subsidence, compaction, and winter erosion. Comparison of aerial photographs for a section of eastern Atchafalaya Delta reveals a similar trend. Land loss was reversed during the major flood in 1979.

The delta has evolved by channel bifurcation and bar fusion, processes by which coarse distributary-mouth bars fuse into larger sand bodies through selective elimination of the delivery network. These processes are accomplished by rapid growth of mid-channel bars and sealing of feeder channels by subaqueous levee growth. The presence of deltas at Lower Atchafalaya River and Wax Lake outlets has elevated water levels near the coast during floods (backwater effect), causing sediment-rich water to be transported into surrounding marshes. A similar response results from setup prior to cold-front passage. The net effect is marsh aggradation and restoration in flood areas. Rapid sedimentation since the 1950's has reversed the traditional trend of coastal erosion in the vicinity of Atchafalaya Bay and is now initiating a new growth phase of the downdrift chenier plain.

INTRODUCTION

During the Holocene, the broad Mississippi River deltaic plain was built by "delta switching" (Figure 1). This fundamental land-building mechanism resulted in a net progradation of the shoreline over the past 6,000 to 8,000 years. The depositional history consists of construction and abandonment of large and complex delta lobes on a time scale of about 1,000 years for each major sedimentation event. During the regressive phase of a delta lobe's history, local progradation of the shoreline and the building of new marshland are maximized. Domination by fluvial processes over marine processes, as is the case in the Mississippi Balize delta lobe, results in rapid progradation of distributaries and associated facies, causing a complicated channel geometry. Between and along the flanks of major feeder channels relatively thin wedges of rapidly deposited sediments create bay fills, which are initiated, fill the bay with marshlands, and deteriorate to an open-bay condition once again on a time frame of generally less than 200 years. At some point, however, the major delivery system diverts sediment and water through a more efficient and generally shorter route to the receiving basin. As diversion takes place the formerly active lobe is starved of sediment. The effects of sediment dewatering and compaction, as well as regional subsidence associated with northern Gulf of Mexico depocenter, become dominant and a phase of rapid land loss is initiated. Since there is generally only one major locus of deposition or active delta lobe along the coast at any given time, the remaining coastal areas are in various stages of retreat, depending on their relative ages. In deltas such as the Mississippi which have been constructed by deposition of dominantly fine-grained sediment in a receiving basin with low wave-current energy, the coastline is always in a state of dynamic change.

The modern Balize delta lobe has been the locus of Mississippi River deposition for the past 600 to 800 years. This delta-building event has resulted in a thick sequence of both subaerial and subaqueous sediments that have prograded onto the Continental Shelf. Because of this extensive progradation and other geological factors, the modern river course has reduced its gradient and general flow efficiency to a point that upstream diversion is favored. Fisk (1952) predicted abandonment in favor of the more efficient Atchafalaya River course by the mid-1970's if the diversion were not controlled. From the point at which the two rivers meet, north of Baton Rouge, the Atchafalaya course to the sea is 307 km shorter and, therefore, is favored by its steeper gradient. Although Mississippi River flow down the Atchafalaya course has been documented as far in the past as the 1500's (Fisk 1952), it was not until the early 1950's that significant quantities of sediment started to arrive at the coast. Shlemon (1975) and Roberts et al. (1980) discussed the basin-filling phase prior to the arrival of abundant prodelta clays in Atchafalaya Bay and along the downdrift coasts. At this time a new phase of delta building in the Mississippi River delta complex was initiated, and areas that have experienced coastal retreat for literally hundreds of years entered a new era of coastal accretion. This paper describes the early stages of Atchafalaya delta growth and the implications of this event with reference to Louisiana's problems of land loss and coastal retreat.

DELTA HISTORY

Delta development in Atchafalaya Bay can be divided into two major stages, subaqueous and subaerial. The subaqueous phase was initiated as deposition in the intricate network of lakes and swamps of the Atchafalaya Basin reached a point such that sediments were fluxed through the system to the coast. This natural catchment

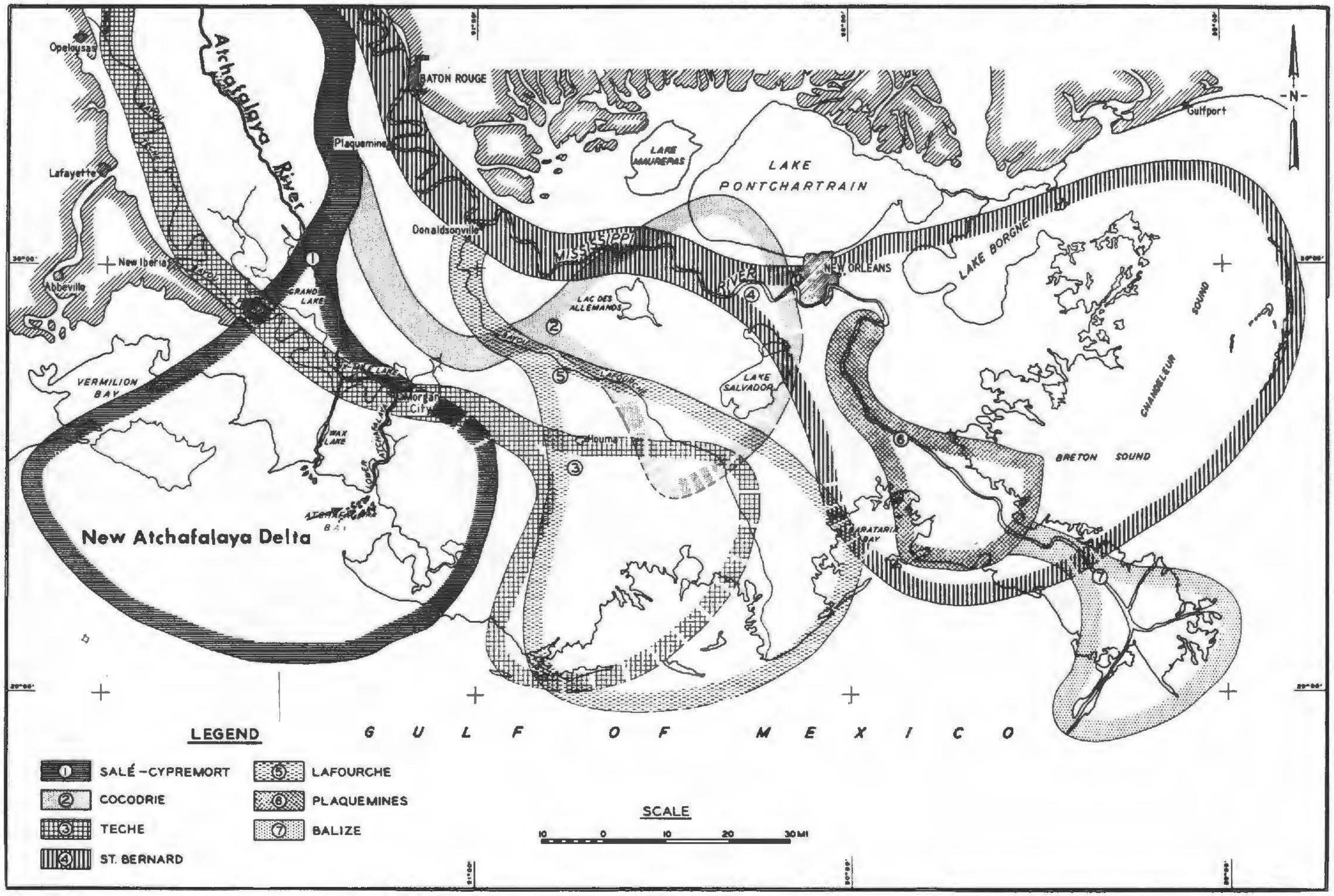


Figure 1. Major delta lobes that have constructed the Holocene Mississippi River deltaic plain (modified from Kolb and van Lopik 1966). Note the location of the most recent lobe in the Mississippi River delta complex, the Atchafalaya delta.

basin filled for hundreds of years, but it was not until the early 1950's that swamp floors and lake bottoms had accreted to a point that fine-grained sediments were transported to the coast in significant quantities. In addition to basin filling, flood-control levees in Atchafalaya Basin have increased the hydraulic efficiency of the river, which is responsible for delivering proportionately higher loads of both fine and coarse sediment to the coast. Starting in about 1952, accelerated sedimentation in Atchafalaya Bay marked the beginning of subaqueous delta growth (Shlemon 1975). From that time to 1973 prodelta clays and silty clays aggraded the bay bottom seaward of both the Lower Atchafalaya River Outlet and the Wax Lake Outlet, an artificial channel dredged in 1942 (Figure 1).

As a product of the abnormal 1973 flood, a disproportionate quantity of sediment was transported to Atchafalaya Bay. Prior to this time only a few small shoals were exposed at low tide, and these areas were primarily composed of dredge spoil from the navigational channel which is maintained from the Lower Atchafalaya River Outlet through the Point Au Fer shell reefs. After the massive 1973 flood (Figure 2), however, numerous coarse subaerial lobes appeared on both the eastern and the western sides of the river outlet. This event initiated the sand-rich subaerial phase of delta development. Since that time sands have been prograding over finer prodelta clays and silts. As a product of subaerial delta growth, marshlands expanded rapidly in Atchafalaya Bay.

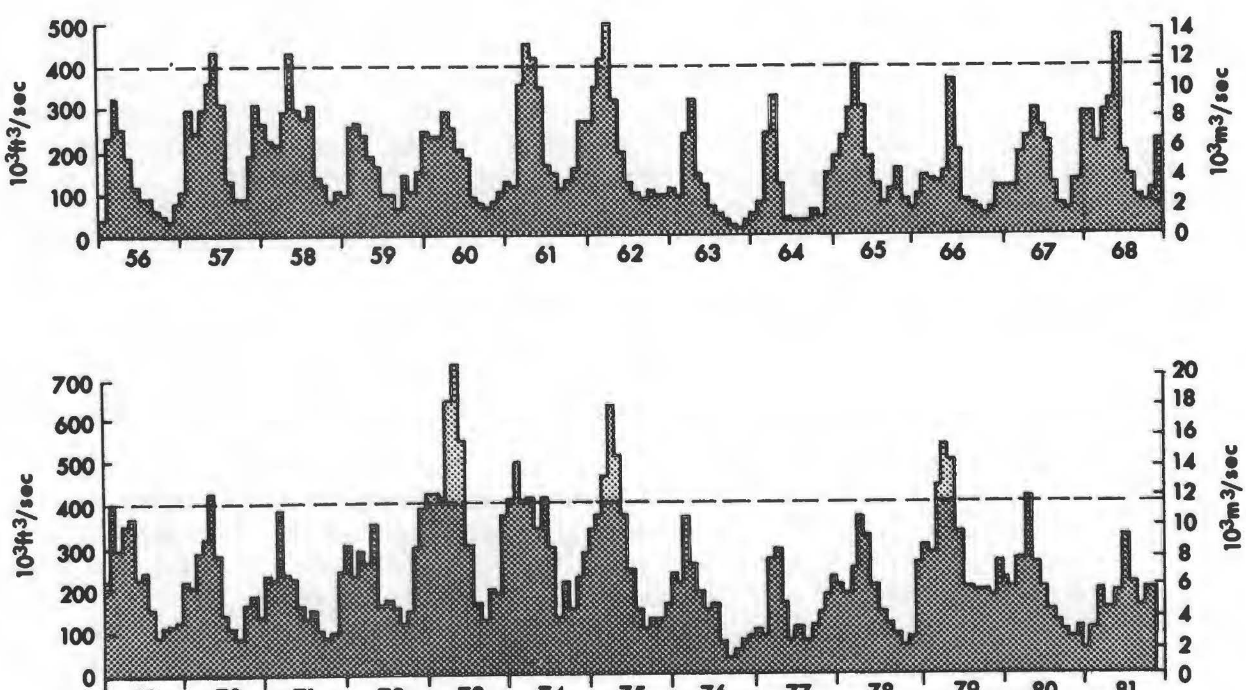


Figure 2. Mean monthly discharge for the Atchafalaya River at Simmesport, Louisiana, for 1956-1981. The dotted line represents average annual peak flow, which is approximately 400,000 ft^3/s. Note the abnormal discharge years 1973, 1975, and 1979.

WATER AND SEDIMENT INPUT

Thirty-four years of hydrographic data collected on Atchafalaya River flow at Simmesport, Louisiana, show that the average annual flow over the sample period (1938-72) was 5,126 m^3/s (181,000 ft^3/s) (U.S. Army Corps of Engineers 1974). Within this data collection period, the average annual peak flow that occured in the spring was approximately 11,300 m^3/s (400,000 ft^3/s). About 70% of this flow arrived at the coast through the Lower Atchafalaya River Outlet, while the remainder was transported through the man-made Wax Lake Outlet. During the years of subaqueous delta growth (early 1950's to 1972), flood levels only occasionally exceeded the 11,300 m^3/s (400,000 ft^3/s) level (Figure 2); from 1973 to 1980, however, this level was significantly exceeded three times, in 1973, 1975, and 1979. These abnormal floods also transported a proportionately higher-than-average sediment load to Atchafalaya Bay. Flow velocities during flood are such that the coarsest particles available (generally fine-sand size) can be transported as suspended load (Roberts et al. 1980). In response to abnormally high discharge during the 1970's, deposition and subsequent subaerial growth of the Atchafalaya Delta have been impressive, as is illustrated by a 1976 photomosaic (Figure 3). The most recent flow measurements (1979-81) made in the lower reaches of Atchafalaya River and in the main arteries of the newly formed delta indicate that approximately 67% of the water and sediment transported from the Lower Atchafalaya River mouth goes down the western branch (dredged navigation channel), while about 27% is conducted through the eastern branch (Figure 3). Minor passes near the river mouth account for the remaining 6% of the flow.

Roberts et al. (1980) present a sediment budget for the Atchafalaya system from 1967 to 1975; the annual suspended sediment load nearly doubled during the three high-water years of the early 1970s. It was estimated that much of the suspended-load sand was derived from scouring and resuspension of previously deposited sediments in the Lower Atchafalaya River course. The net change in the dominance of sediment reaching the bay from clay and silt to silt and fine sand over the last 30 years has resulted in the construction of sizable sand-rich sediment lobes that have been rapidly colonized by marsh plants as soon as they build to the low-tide level.

SPATIAL-TEMPORAL CHANGES IN MARSH LAND

Bathymetric changes in Atchafalaya Bay have been impressive. The 1967 bathymetric map shows distributary-mouth bar deposits whose limits are roughly represented by the 4-ft (1.2-m) depth contour. At this time these deposits were beginning to prograde into the bay, forming broad, shallow platforms which front the natural channels of Lower Atchafalaya River and Wax Lake outlets (Figure 4). By 1972 the distributary-mouth bar platform had extended over most of the bay (Roberts et al. 1980). The natural channel of the Lower Atchafalaya River mouth showed a pronounced seaward extension and development of a major bifurcation to the east.

The 1977 bathymetric map of Atchafalaya Bay (Figure 5) emphasizes the tremendous volume of predominantly coarse-grained material deposited in the decade 1967-77. An extensive network of distributary-mouth bar deposits formed in both the complex Wax Lake and Atchafalaya delta lobes. Roberts et al (1980) estimated that 16 km^2 (6.55 mi^2) of new land had developed above mean sea level by 1977. When estimated from the low tide level, a net land gain of 32.5 km^2 (12.6 mi^2) over the same period was calculated (Rouse et al. 1978).

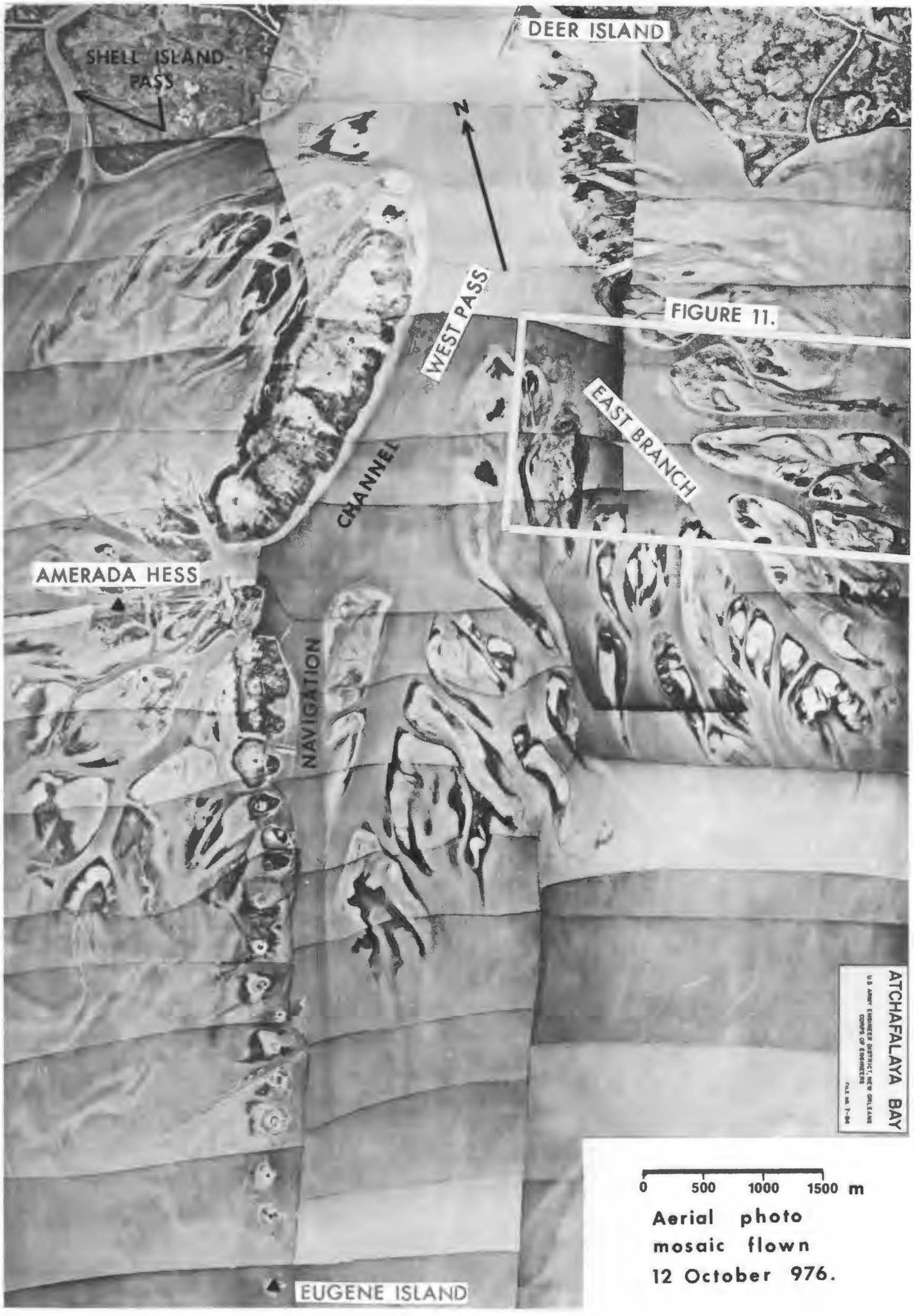


Figure 3. Photomosaic of Atchafalaya delta (12 October 1976).

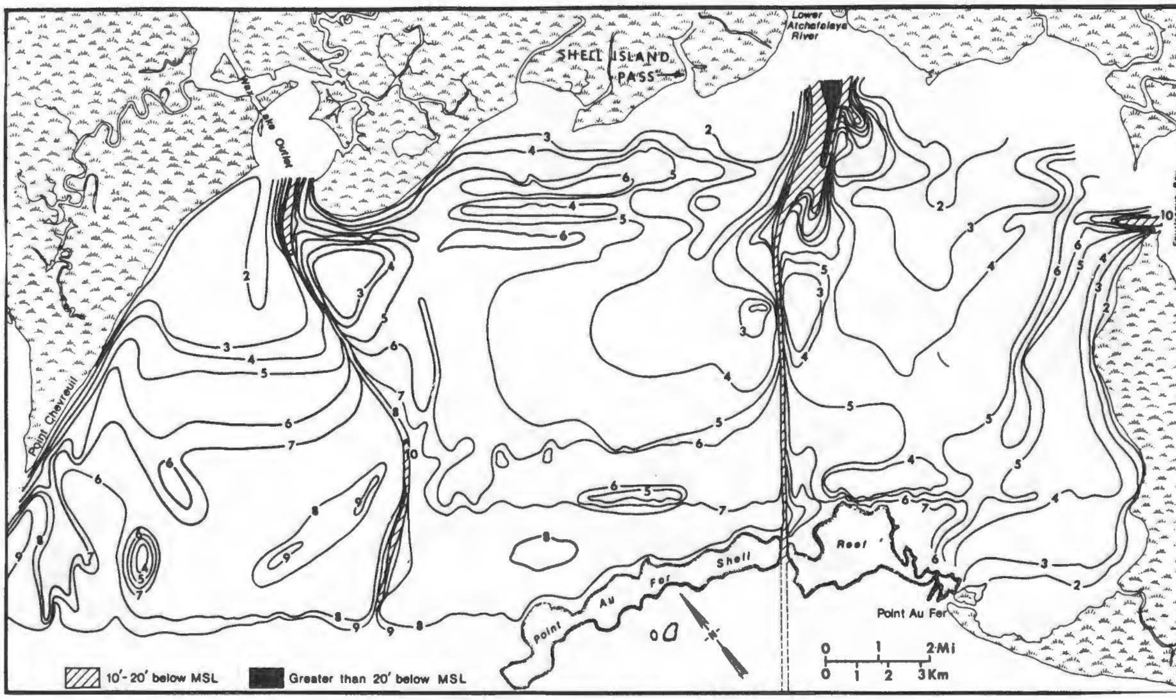


Figure 4. Bathymetric map of Atchafalaya Bay in 1967 (Roberts et al. 1980).

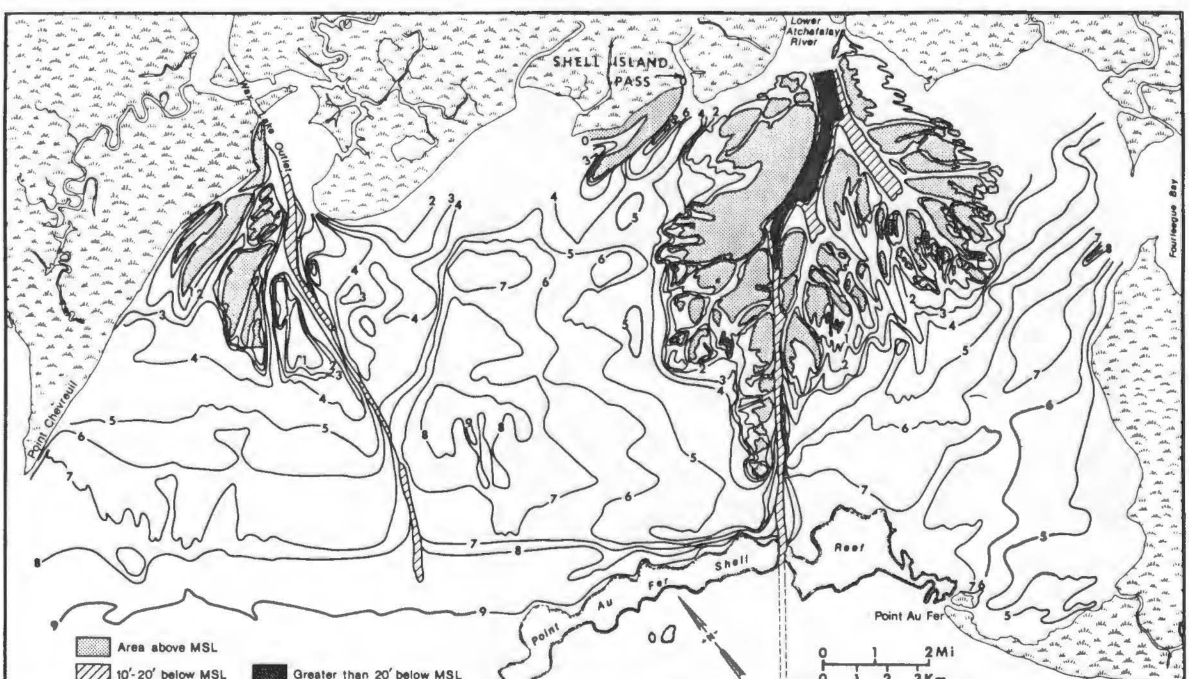


Figure 5. Bathymetric map of Atchafalaya Bay in 1977 (Roberts et al. 1980).

The extent and evolving pattern of new subaerial marsh in the Atchafalaya delta lobe is illustrated in Figure 6. Unusual hydrologic conditions during the first 3 years of subaerial exposure played an important role in the rapid development of this dynamic phase of Atchafalaya Delta growth. Rouse et al. (1978) showed that by early 1976, 19.0 km^2 (7.3 mi^2) of new land had formed above mean sea level, corresponding to an average growth rate of 4.75 km^2/yr (1.8 mi^2/yr) (Figure 7). Through aerial-photo mapping of the eastern half of the delta, van Heerden (1980) confirmed the dramatic growth rate in 1973, 1974, and 1975 and the major flood in 1979. During average floods the growth rate is somewhat reduced, however.

Through analysis of LANDSAT imagery a growth curve has been developed for Wax Lake delta lobe (Figure 8). Unpublished data (Susan Chinburg, Coastal Studies Institute, Louisiana State University, Baton Rouge, 1981, personal communication) suggest that the Atchafalaya Delta exhibits the same growth trends, although on a larger scale. Subaerial expression of new marsh land increased steadily from 1973 to 1976, but decreased during 1977 and 1978. This reduction in surface area reflects the average-sized floods during these years, but more importantly reveals the dynamic effects of wind-wave-induced erosion during the passage of winter cold fronts (van Heerden and Roberts 1980a). The cumulative effects of the passage of cold fronts spaced at approximately 1-week intervals are erosion and denudaton of new marsh surface. During minor floods this loss may not be completely replenished. During major floods, however, the marsh surface aggrades significantly, offsetting any land loss resulting from cold-front-related erosion.

DELTA LOBE RESPONSE CHARACTERISTICS

Systematic monitoring of land accretion, changes in channel cross sections, and sediment characteristics have shown that delta growth responds directly to flood volume and duration. Reductions in channel cross section are most dramatic during major floods (van Heerden and Roberts 1980b). Distributary channels experience mid-channel shoaling and bar formation at their seaward ends (Figure 9). This bifurcation mechanism results in a complex network of sand lobes, separated by branching distributaries, characteristic of deltas whose river mouths are frictionally dominated and are generally building into unstratified, low-energy, shallow-water environments (Welder 1959; Wright and Coleman 1974).

As the fluvial effluent passes from the confined distributary channel to the shallow, unconfined bay, it rapidly experiences a reduction in velocity. Associated with the frictional deceleration of the flow is a reduction in turbulence and the coarsest part of the suspended load is deposited, initiating a mid-channel bar (Figure 10a). Once initiated, shoaling bayward of the mouth causes an increase in the friction-induced deceleration and effluent spreading, which in turn increases the shoaling rate (Bates 1953; Wright 1977). The overall effect of the differential sedimentation is a branching of the channel into two distributaries (Figure 10b). Velocities also decrease away from the center line of the divergent current field. Deposition occurs at the outer edges of the effluent plume, giving rise to subaqueous levees. The levee ridges flare away from the mouth, reflecting the divergent current field that results from the abrupt transition to unconfined flow (Figure 10c). The same process may then be repeated on the two newly formed channels (Figure 10d). In the above manner, the subaerial components of the emergent delta have evolved into a complex network of sand lobes separated by branching distributaries.

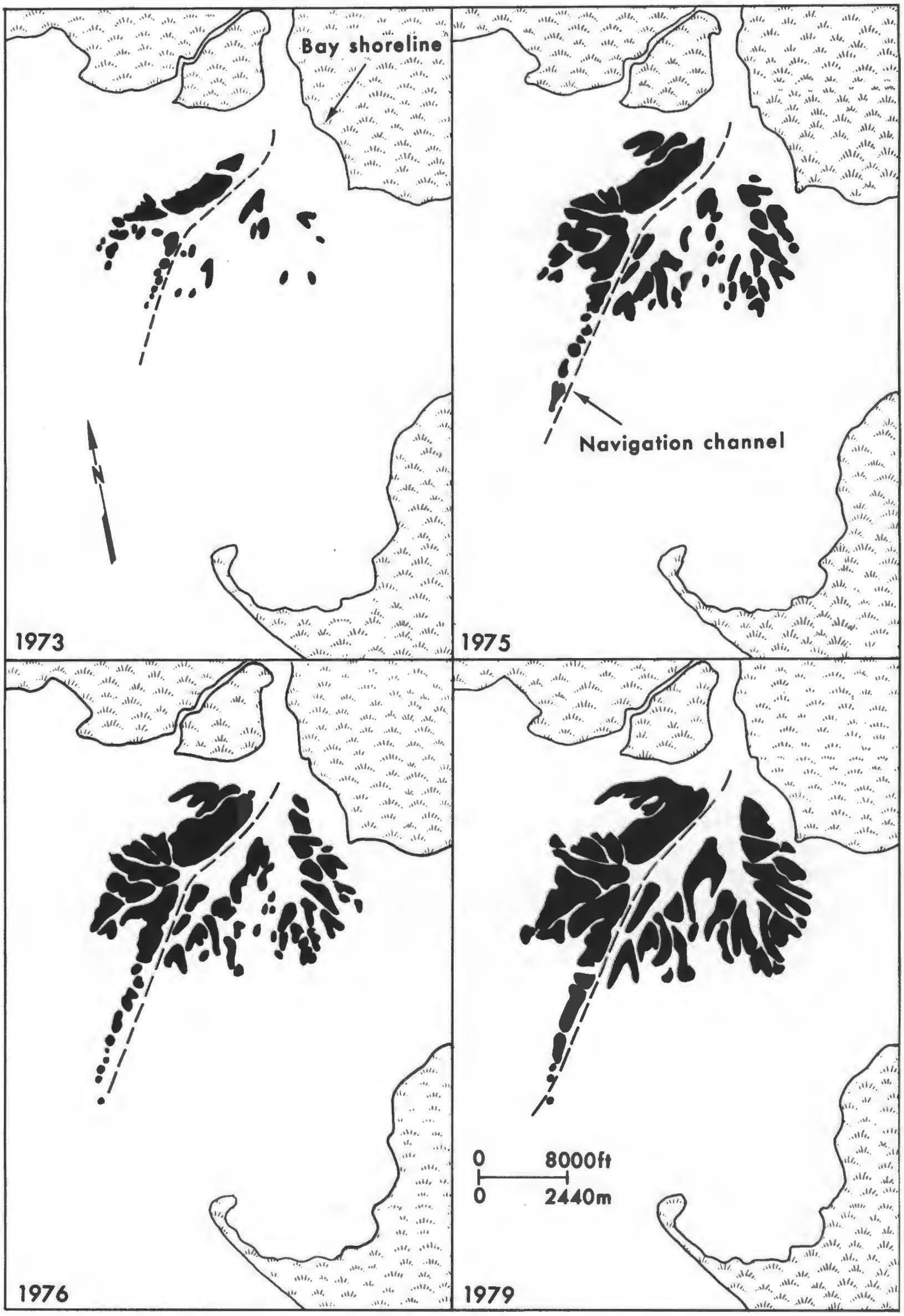


Figure 6. Areas of subaerial exposure obtained from LANDSAT images and aerial photographs depicting progressive evolution of the Atchafalaya delta.

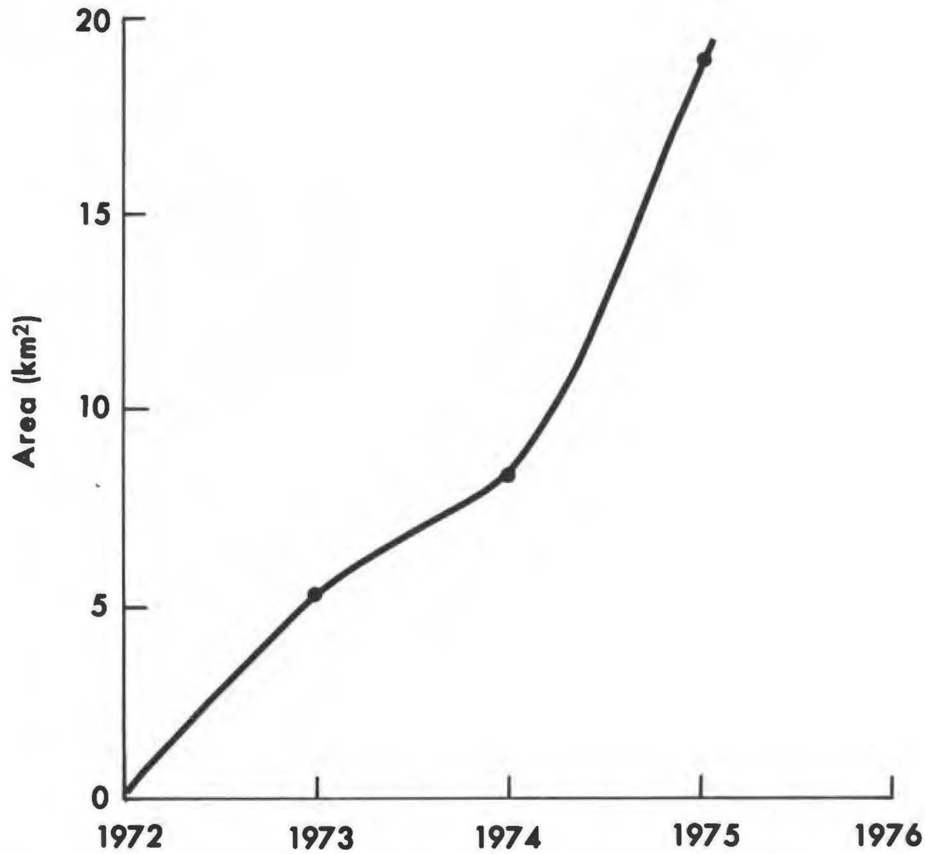


Figure 7. Exposed area (above msl) of the Atchafalaya delta (modified from Rouse et al. 1978).

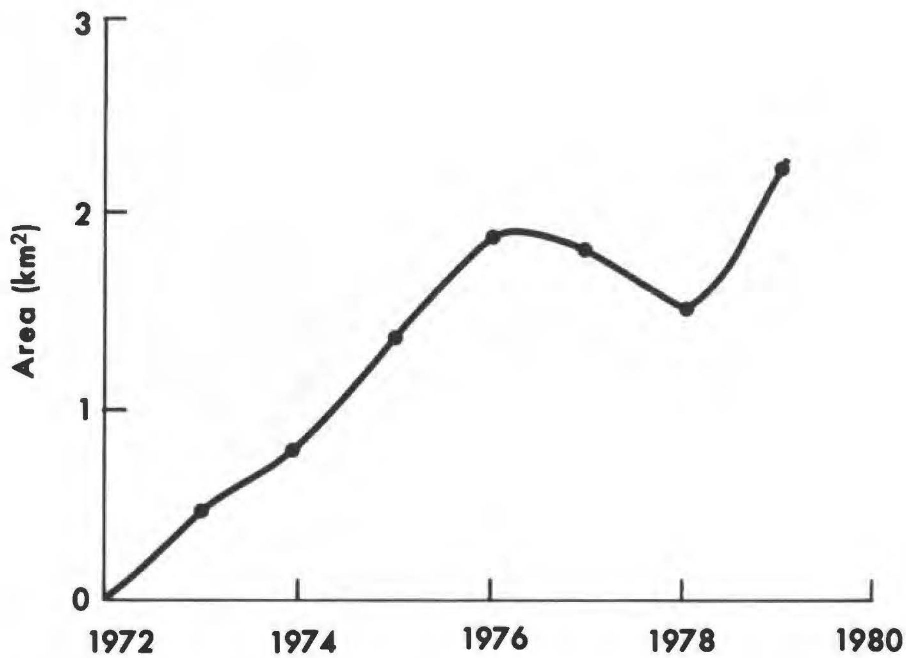
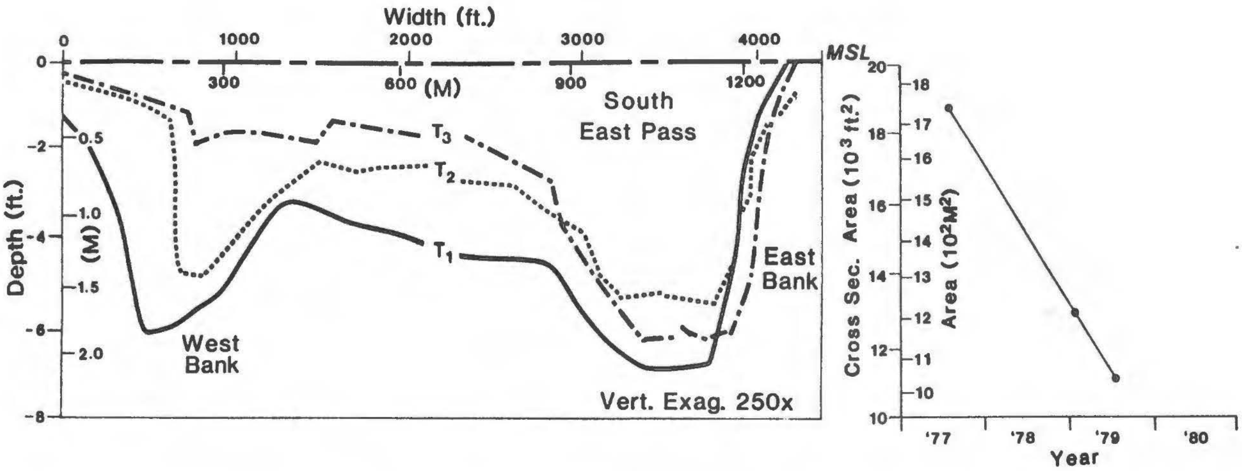


Figure 8. Exposed area (above msl) of the Wax Lake delta. Data from LANDSAT imagery analysis.



PROFILE	DATE	CROSS SECTIONAL AREA ft^2 (m^2)
T1	AUG'77	18,732.4 (1,740.30)
T2	JAN'79	12,936.5 (1,201.84)
T3	JUL'79	10,870.3 (1,009.86)

Figure 9. Profile of cross section in East Pass (see Figures 3 and 11 for location) showing the development of a mid-channel bar.

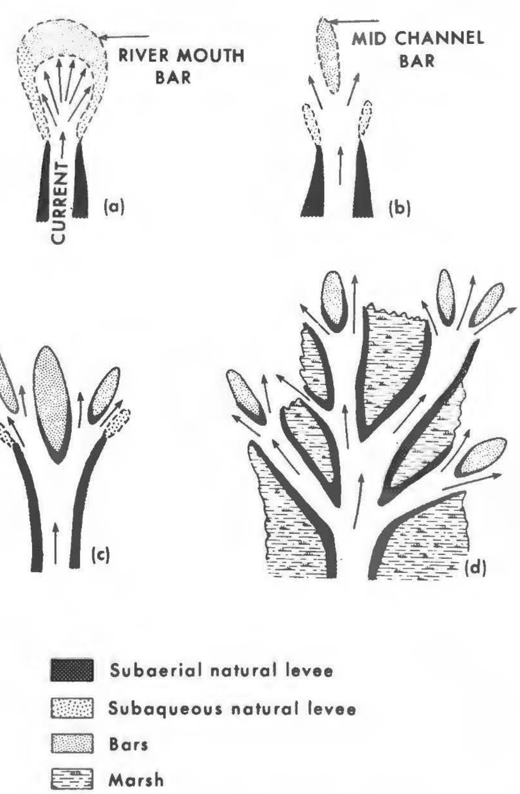


Figure 10. Schematic diagram of delta development.

Generally one of the channels formed in a bifurcation is smaller than the other. The smaller slowly loses hydrodynamic efficiency and eventually seals owing to subaqueous levee formation. Thereafter it fills with fine-grained sediment and fuses with adjacent lobes. Thus larger lobes form as a result of coalescence of numerous smaller distributary-mouth bars and adjacent channels (Figure 11).

IMPLICATIONS OF DELTA BUILDING

Diversion of Mississippi River fresh water and sediment to the central coast of Louisiana will steadily influence the future character of coastal environments in the immediate vicinity of Atchafalaya Bay and its adjacent downdrift coasts. In conjunction with man-made flood control measures, filling of the Atchafalaya Basin, a natural sediment sink, has promoted transport of sediments in significant quantities to the coast since the early 1950's. The initial sediments to impact the central Louisiana coast from this progression of events associated with "delta switching" were fine grained. They started a regressive phase that will replace the traditional erosional trends that have characterized central and western Louisiana coasts for hundreds of years.

In addition to simply supplying sediment to nearshore depositional sites, aggraded bay bottom and resulting delta development have influenced the hydrography of surrounding marshlands. For example, flood levels at Morgan City and in adjacent marshes average over 0.3 m (1.0 ft) higher than in pre-delta years (U.S. Army Corps of Engineers 1974). This change has resulted from the inefficient dispersal of flood waters because of the obstructive effects of deltas at the mouths of both the Lower Atchafalaya River and Wax Lake outlets. Elevated flood levels have the net effect of driving sediment-laden water into marshes lying generally between the Grand Lake-Six Mile Lake complex and the coast (Baumann and Adams in press). It is suggested that this process tends to cause an increased increment of yearly sedimentation which results in aggradation of the marsh surface at a higher rate than in pre-delta years.

Another set of processes, winter cold-front passage, also accounts for abnormal elevation of water levels in coastal marsh areas surrounding Atchafalaya Bay. Figure 12 illustrates a record segment (January 1978) from a tide gauge located at the Amerada Hess platform (Figure 3) on the western side of the Atchafalaya Delta. Water level changes in the bay associated with a cold-front passage and tidal effects are shown on this figure. Winds preceding a cold front generally blow from a southerly quadrant, which promotes setup or water-level elevation in the bay (Figure 12, up to 2100 hr on 16 January). It is during this phase in cold-front-related events that local wave action suspends sediments and high water levels force turbid water into the coastal marshes. As the cold front crosses the area from northwest to southeast, winds switch to a northerly quadrant and cause rapid setdown (Figure 12, after 2100 hour on 16 January). Swift movement of water out of the bay, coupled with wind-wave action, is responsible for erosion and redistribution of sediment within the delta (van Heerden and Roberts 1980a).

The similarity of water level response to cold-front passages at three sites in Atchafalaya Bay is illustrated in Figure 13. The magnitude of the mean fluctuations decreases from Eugene Island to the Lower Atchafalaya River mouth. Maximum average water levels at Deer Island, near the mouth, were nearly 92 cm (3.0 ft) above mean sea level during this study period (January 1979-April 1980). These elevated coastal water levels initiate overbank flooding of surrounding marshes, which promotes aggradation of the marsh surface.

Figure 11. Aerial photograph of an eastern delta area showing coalescence of delta lobes and position of cross section in East Pass (Figure 9).

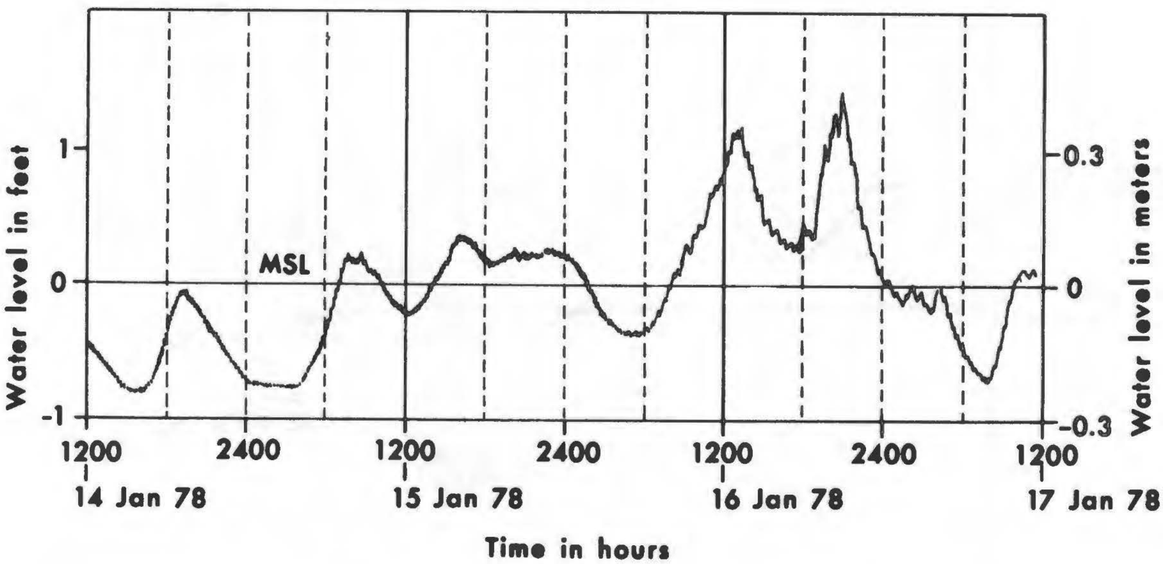


Figure 12. A tide gauge record segment from the western side of the Atchafalaya delta (Amerada Hess platform, Figure 3) showing the setup and setdown of bay water levels associated with cold-front passage (14-17 January 1978).

Figure 14 summarizes the suggested sedimentological impacts that diversion of fresh water and sediment down the Atchafalaya system will have on the central and western coasts of Louisiana. One of the initial effects of sedimentation in the bay (1950's) was to diminish and finally eliminate a once-productive oyster fishery, Point Au Fer and Marsh Island oyster reefs. With increased sedimentation of highly organic clays and silty clays both in the bay and on the inner continental shelf, the shrimp fishery potential is steadily increasing, however.

As the deltas from both Lower Atchafalaya River and Wax Lake outlets continue to fill the bay and build onto the shallow continental shelf, delta lobes will merge to form extensive new marsh lands that will protrude into the marine environment. At the present rate of nearly 3 km^2 (1.16 mi^2) of new marshland added above mean sea level to the Atchafalaya deltas yearly (average 1975-81), by the end of this century, it is estimated, bay filling will be complete and the subaerial delta will be prograding onto the continental shelf. The mean drift system, as well as the wave-induced longshore drift, in this part of the northern Gulf of Mexico favors an east-to-west transport direction. It is safe to assume that the major areas of coastal progradation will be in the immediate vicinity of the delta and along the downdrift coasts. New data concerning the important effects of significant currents generated after the passage of cold fronts suggest that the coarse facies (fine sands) may be skewed somewhat to the southeast after the delta starts supplying coarse sediment to the continental shelf (Adams et al., submitted for publication). However, even assuming that cold-front effects will modify coarse-sediment transport on the shelf, the clays, silty clays, and silts will be spread in front of the prograding subaerial delta and along the chenier coasts to the west (Figure 14). In the short time since the 1950's coastal progradation has replaced coastal retreat in many downdrift sites. Sedimentation rates should increase in these areas as Atchafalaya Bay fills and the delta progrades onto the shelf.

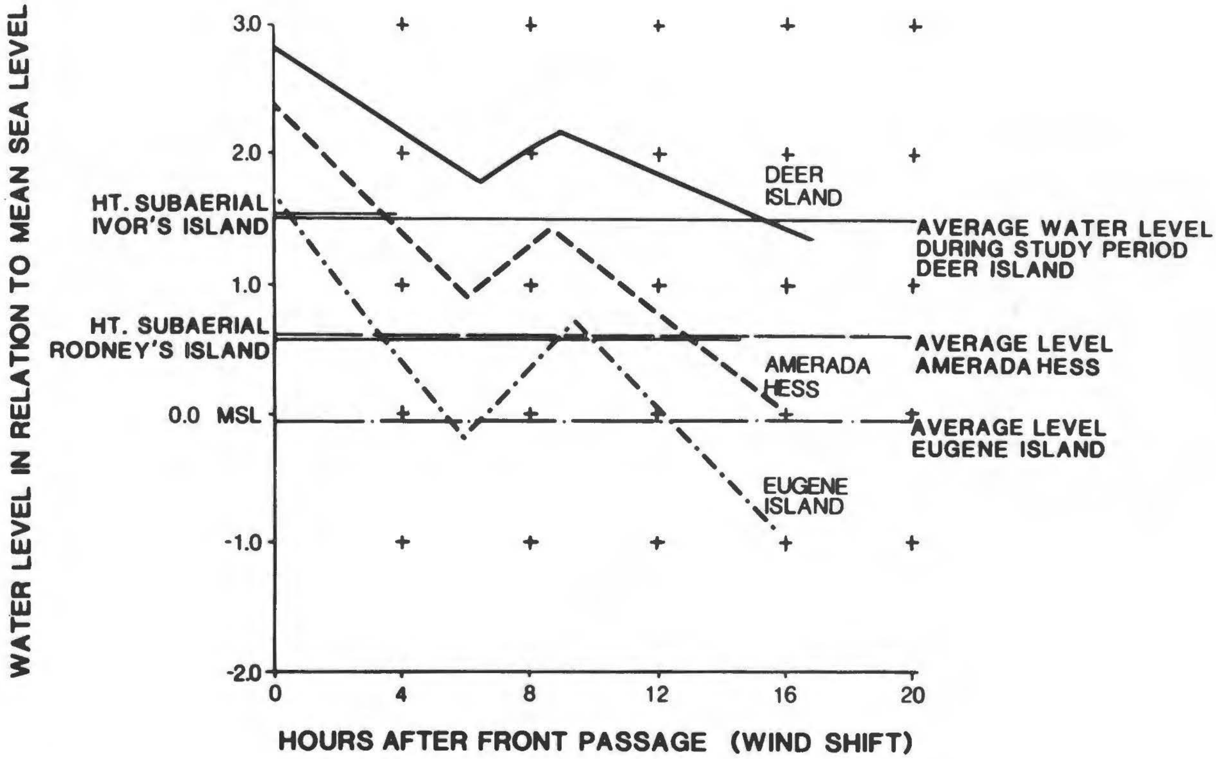


Figure 13. Mean water levels in Atchafalaya Bay following cold fronts. These data are summarized for 35 cold fronts between 1 January 1979 and 30 April 1980.

Additional effects associated with water-level elevation near the coast will tend to offset marsh deterioration caused primarily by the numerous processes collectively described as subsidence. These "backwater effects" are caused by deltas at the mouths of major flood-water outlets at the coast. This process, plus similar effects produced by water-level elevation during the passage of cold fronts, provides a new supply of sediment to the marshes, causing aggradation of the surface.

In summary, diversion of Mississippi River water and sediment to the coast through the Atchafalaya system has led to the following conclusions concerning impacts on central and western Louisiana coasts:

(1) New marsh lands are being added in the vicinity of the active Lower Atchafalaya River and Wax Lake Deltas at an average rate of about 3 km^2/yr (1.16 mi^2/yr) (average 1973-81). This trend will continue as long as present flow levels are maintained.

(2) Downdrift coastlines are starting to accrete as a product of advected clays and silty clays from the Atchafalaya River source. The rate of coastline progradation should increase as the delta builds onto the continental shelf and makes sediments more available to the downdrift areas.

(3) "Back-water effects" result from water-level elevation during cold-front passages and inefficient dispersal of sediment-rich flood waters at the coast

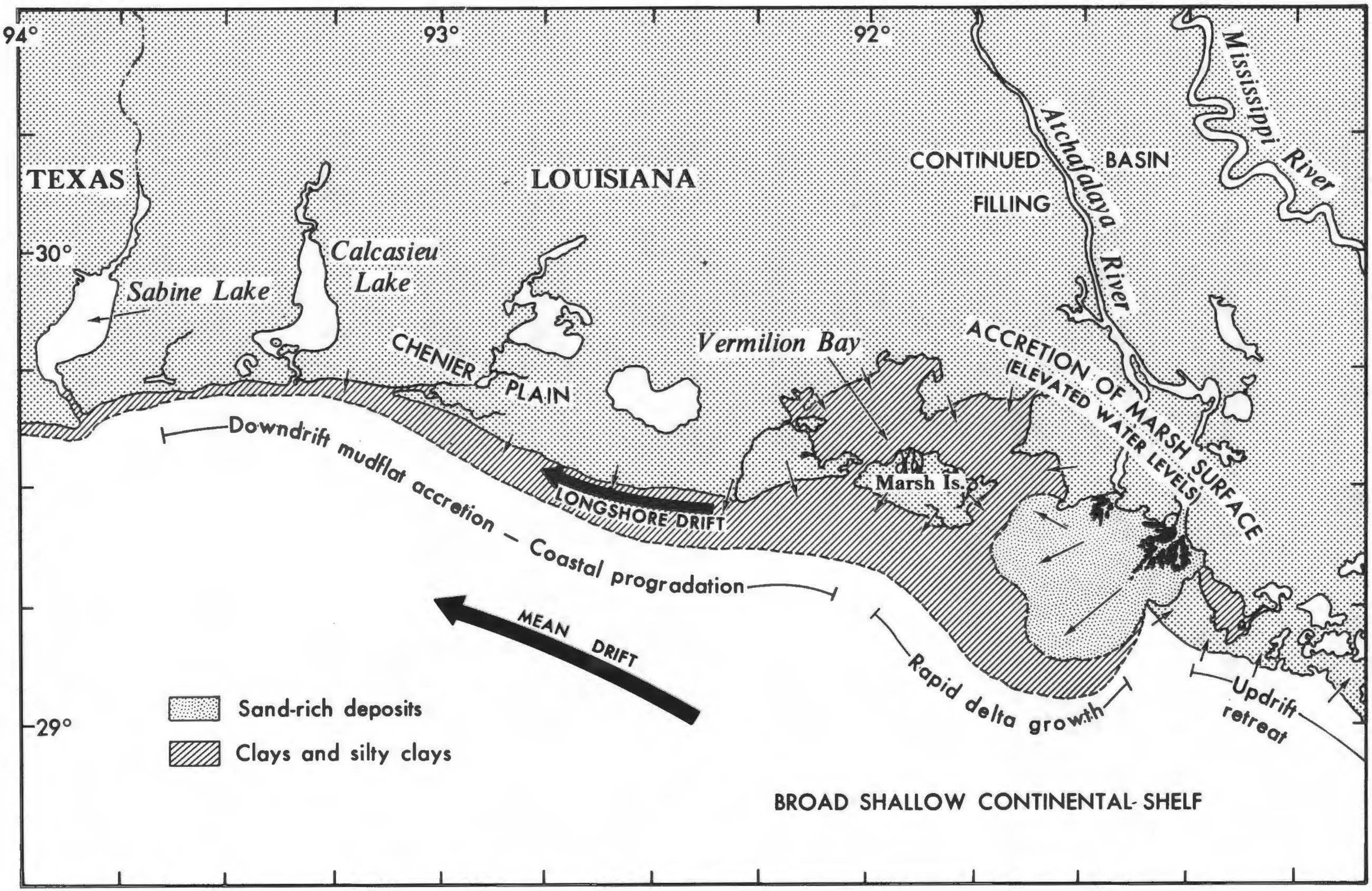


Figure 14. Summary of the effects of Atchafalaya sedimentation on the central and western coasts of Louisiana.

owing to delta building at the Lower Atchafalaya River and Wax Lake outlets. These processes encourage marsh restoration.

ACKNOWLEDGMENTS

This research was supported by the U.S. Army Corps of Engineers, Contract No. DACW 29-77-C-0163, and the Coastal Sciences Program, Office of Naval Research, Arlington, Virginia 22217. Part of the research was also supported by the Louisiana Sea Grant Program, a part of the National Sea Grant Program, maintained by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Special recognition should be given to R.H.W. Cunningham, R.D. Adams, and R.H. Baumann, who collected and processed data from reports and files of the U.S. Army Corps of Engineers, New Orleans District. Some of these data appear in this paper. Mrs. G. Dunn is cited for her drafting of figures and Mr. K. Lyle for photography.

LITERATURE CITED

Adams, C.E., Jr., J.T. Wells, and J.M. Coleman. Submitted for publication. Sediment transport on the central Louisiana Continental Shelf: implications for the developing Atchafalaya River Delta. Contrib. Mar Sci.

Bates, C.C. 1953. Rational theory of delta formation. Bull. Am. Assoc. Petrol. Geol. 37:2119-2161.

Baumann, R.H., and R.D. Adams. In press. The creation and restoration of wetlands by natural processes in the lower Atchafalaya River system: possible conflicts with navigation and flood control objectives. Proceedings, 8th Conference Wetland Restoration and Creation, Tampa, Fla., May 8-9, 1981.

Fisk, H.N. 1952. Geological investigation of the Atchafalaya Basin and the problem of Mississippi River diversion. U.S. Army Corps Engineers, Mississippi River Commission, Vicksburg, Miss. v. 1. 145 pp.

Kolb, C.R., and J.R. Van Lopik. 1966. Depositional environments of the Mississippi River deltaic plain - southeastern Louisiana. Pages 17-61 in Deltas in their geologic framework. Houston Geological Society.

Roberts, H.H., R.D. Adams, and R.H. W. Cunningham. 1980. Evolution of the sand-dominant phase, Atchafalaya Delta, Louisiana. Bull. Am. Assoc. Petrol. Geol. 64:264-279.

Rouse, L.J., Jr., H.H. Roberts, and R.H.W. Cunningham. 1978. Satellite observation of the subaerial growth of the Atchafalaya Delta, Louisiana. Geology 6:405-408.

Shlemon, R.J. 1975. Subaqueous delta formation - Atchafalaya Bay, Louisiana. Pages 209-221 in M.L. Broussard, ed., Deltas. Houston Geological Society.

U.S. Army Corps of Engineers. 1974. Preliminary draft environmental impact statement, Atchafalaya Basin floodway. New Orleans, La.

van Heerden, I. Ll., and H.H. Roberts. 1980a. The Atchafalaya Delta: rapid progradation along a traditionally retreating coast (south-central Louisiana). Z. Geomorph. N.F., 34:188-201.

van Heerden, I. Ll. and H.H. Roberts 1980b. The Atchafalaya Delta: Louisiana's new prograding coast. Trans. Gulf Coast Assoc. Geol. Soc. 30:497-506.

Welder, F.A. 1959. Processes of deltaic sedimentation in the Lower Mississippi River. Louisiana State Univ., Coastal Studies Inst., Baton Rouge. Tech. Rep. 12. 90 pp.

Wright, L.D. 1977. Sediment transport and deposition at river mouths: a synthesis. Bull. Geol. Soc. Am. 88:856-868.

Wright, L.D., and J.M. Coleman. 1974. Mississippi river mouth processes: effluent dynamics and morphologic development. J. Geol. 81:751-778.

COMPARISON OF EFFECTIVENESS OF MANAGEMENT OPTIONS FOR WETLAND LOSS IN THE COASTAL ZONE OF LOUISIANA

J.W. Day, Jr.
N.J. Craig

Center for Wetland Resources
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

The coastal wetlands of Louisiana, an area of 14,000 km^2 (5,400 mi^2), are currently experencing an overall net loss of approximately 130 km^2/yr (50 mi^2/yr). Various management options have been suggested to combat the problem of wetland loss. This paper examines the effectiveness of three management options: (1) management of the current land building of the Atchafalaya River, (2) controlled diversion schemes on the lower Mississippi River and (3) strict regulatory control of canals within the coastal zone. Strict regulatory control of new canals could reduce future land loss rate by 30 to 40 km^2/yr. This compares with 1 to 3 km^2/yr for controlled diversion plans, and 18 km^2/yr for the land-building processes of the Atchafalaya River. We conclude that if the problem of wetland loss is to be properly addressed by regulatory agencies, they must make a serious attempt to control canal construction.

INTRODUCTION

The coastal wetlands of Louisiana, an area of approximately 14,000 km^2, are experiencing an overall net loss of about 130 km^2/yr. This includes a loss rate of 102 km^2/yr in the Mississippi deltaic plain (Gagliano 1981) and 26 km^2/yr in the chenier plain along the southwest Louisiana coast (Gosselink et al. 1979) (see Figure 1). The loss is cumulative resulting from both natural and artificial causes. Natural causes include land subsidence, the deterioration of abandoned river deltas, and erosion by wave energy and storms. Human-induced land losses result from flood control practices, impoundments, and the dredging of canals and channels (Craig et al. 1979). Wetland loss in turn creates significant problems: (1) hydrologic changes in the wetland-estuarine system which exacerbates saltwater intrusion and eutrophication; (2) losses in the storm buffering capacity of the wetlands; (3) a decrease in waste assimilating capacity of wetlands; and (4) a diminished nursery area for Louisiana's coastal finfish and shellfish (Craig et al. 1979; Hopkinson and Day 1979; Kemp and Day in press).

The objectives of this study are to describe the factors leading to wetland loss in the Louisiana coastal zone and to evaluate several different management options for dealing with the problem.

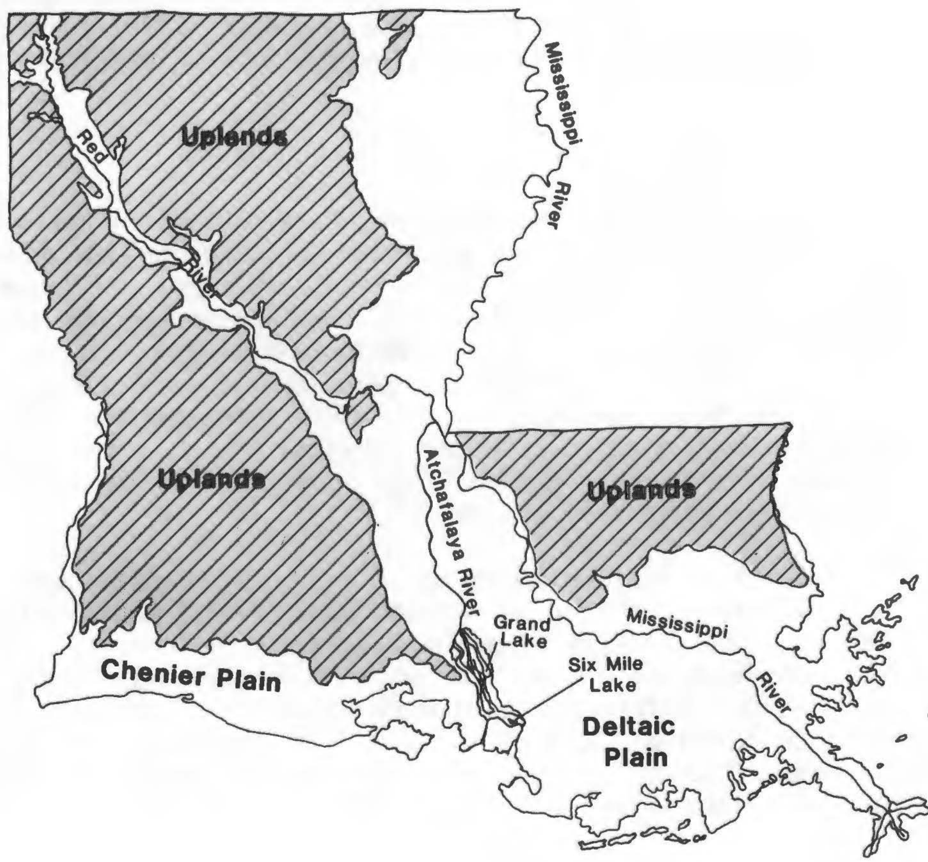


Figure 1. Major geomorphic provinces in Louisiana.

Natural Factors Leading to Land Loss

The Mississippi deltaic plain is a large area of dynamic geomorphic change. Over the past several thousand years Mississippi River sedimentation has formed the coastal wetlands of Louisiana, building seven major deltaic lobes since the stabilization of sea level. Within this process of overall growth were large-scale cycles of land growth and decay of land.

In an active delta, sedimentation exceeds erosion and there is a net land gain. Land building occurs at the mouth of the river's channel, through overbank flooding, and through sedimentation in older deteriorating marshes (Baumann and Adams 1982). But as its channel lengthens, the Mississippi seeks a new, shorter course to the Gulf of Mexico and ultimately abandons the older channel. During this phase, active land building ceases in the old delta and there is a net loss of land from erosion and subsidence. Historically, land loss in old Mississippi River deltas was compensated for by land gain in the active delta.

There are three major natural mechanisms involved in the process of land loss: (1) Gulf of Mexico beach retreat, (2) lateral erosion of streamside marsh shores, and (3) gradual sinking of inland marshes. Wave action is the primary cause of shoreline retreat

and erosion. Inland marsh loss is caused primarily by lack of sufficient sedimentation to offset apparent sea level rise. Studies done by DeLaune et al. (1978) and Baumann (1980) showed that only streamside marshes are accreting fast enough to offset the effects of subsidence.

Artificial Causes of Land Loss

Flood control, navigation improvements, agricultural impoundments, and canalization interact with natural geologic processes to accelerate wetland loss. Lack of adequate sediment supply is caused largely by the construction of levees along the Mississippi; these have almost eliminated overbank flooding and caused the closure of a number of minor distributaries. The modern delta has grown out to the edge of the continental shelf and most of the river's sediment load is deposited in deep Gulf of Mexico waters. These flood control measures have interrupted the balance between riverine and marine processes which built and stabilized marsh and swamp areas. The only significant land building along the Louisiana coast is in Atchafalaya Bay where a new delta is being formed (Roberts et al. 1980).

Canals constructed for such activities as oil exploration and recovery, navigation, and drainage significantly contribute to wetland loss. Aerial photography of coastal Louisiana gives a stunning image of wetlands densely webbed by canals. The construction of canals leads directly to land loss through dredging and spoil deposition. Indirect influences include such factors as changes in hydrology, saltwater intrusion, and altered sedimentation patterns (Craig et al. 1979; Cleveland et al. 1981). The highest rates of marsh erosion occur in areas with the highest density of dredged canals (Blackmon 1979; Craig et al. 1979; Turner et al. 1982).

MANAGEMENT OF WETLAND LOSS

A number of management approaches have been suggested to combat the problem of wetland loss. The creative use of riverine sediments to help build new wetland areas or infill decaying marshes is one mitigation technique that has been suggested. This could be accomplished through controlled diversions along the lower Mississippi River (Gagliano and van Beek 1974), and through proper management of sediment flows into the newly forming Atchafalaya delta region. Another management option is stricter regulatory controls on canal construction within the coastal zone. In this paper, we will assess the effectiveness of these various approaches in reducing wetland loss rates.

Atchafalaya Delta

The Atchafalaya River is a major distributary of the Mississippi and carries about 30% of the total flow. It is currently creating new wetlands in the Atchafalaya Bay Delta, as well as restoring deteriorating wetlands in adjacent areas. There is also a measurable accretion of sediments along the chenier plain associated with the deposition of fine sediments from the Atchafalaya River. The amount of sediment required to fill Atchafalaya Bay could be deposited in a 60-year period given the flood regimes of the period 1851 to 1967. If abnormally high floods of 1970-77 are included in this long-term average (i.e. 1951-77) the estimated time for this to occur is 42 years. The recurrence in the 1980's of the extremely high flood stages of 1970-77, would reduce the time needed to fill the bay to less than a decade (Baumann and Adams 1982).

Before the emergence of the Atchafalaya delta during the floods of the 1970's, existing wetlands adjacent to the lower Atchafalaya River were deteriorating at a rapid rate. During 1972-78, the loss rate was reversed and the wetland area grew. Baumann and Adams (1982) examined quadrangle maps for the area and found a net loss during 1955-72 of 7,805 ha (4.88 km^2/yr). The interval between 1972 and 1978, by contrast, had a much reduced rate of land loss and some areas experienced wetland gain (Baumann and Adams 1982). Nonflotant marsh in the examined area experienced a net gain of 1,676 ha (0.28 km^2/yr) during 1972-78, with 1,277 ha (0.21 km^2/yr) attributable to formation of the new delta in Atchafalaya Bay. The same area lost a total of 6,736 ha (0.42 km^2/yr) of wetlands from 1955 to 1972. The marshes peripheral to Atchafalaya Bay experienced a reversal from 0.42 km^2/yr loss to a 0.07 km^2/yr gain (Baumann and Adams 1982). In summary, the net wetland gain in the Atchafalaya Bay area is caused by two factors: (1) the creation of new land in Atchafalaya Bay in the form of the new delta and (2) the reversal of land loss in deteriorating marshes adjacent to the bay by infilling with riverine sediment.

Table 1. Effects of different mitigation techniques for reducing land loss (see text for derivation).

Activity	Reduction in land loss rate (km^2/yr)
Atchafalaya River	
New delta growth	11.9
Reversal of chenier plain beach retreat[a]	1.1
Infilling of older marshes	4.9
TOTAL	17.9
Controlled diversions lower Mississippi River	1-3
Regulatory control of new canals	30-40

[a]This value assumes that 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).

An additional impact of Atchafalaya River sediments is the reduction of beach retreat along the chenier plain coast west of Atchafalaya Bay. During most of this century, there has been a net shoreline retreat in this area (Adams et al. 1978). Fine-grained sediments from the Atchafalaya are now being deposited along this coast, however, and it is estimated that within 50 years there will be a net growth (Wells and Kemp 1981).

Future growth of the Atchafalaya delta, assuming the flow regimes of 1851-1977, will take place at the rate of 11.9 km^2/yr (Baumann and Adams 1982). The infilling of older marshes adjacent to the Atchafalaya as previously discussed, is occurring at 4.9 km^2/yr (Baumann and Adams 1982). A reversal of the chenier plain beach retreat, which will stabilize the situation and result in no net loss for that area, is occurring at a rate of 1.1 km^2/yr (Adams et al. 1978; Wells and Kemp 1981). Therefore, the accretion from Atchafalaya River sediments is responsible for a total reduction in land loss of 17.9 km^2/yr (Table 1).

Controlled Diversions

As a means of introducing river water and sediment to offset wetland loss, plans have been developed for controlled diversions of the Mississippi River. "Basically, it would re-establish the overbank flow regime of the deltaic plain, presently disrupted by flood protection levees, and restore more favorable water quality conditions to the highly productive deltaic estuaries" (Gagliano and van Beek 1974). According to Gagliano et al. (1971), the feasibility of controlled diversion is indicated by the relatively small input of energy and materials needed to build a subdelta. Several sites for controlled diversions are presently being developed along the lower Mississippi River. According to Gagliano (1981) the potential reduction in land loss rate using controlled diversion is between 1 and 3 km^2/yr.

Regulatory Control of New Canals

The highest rates of marsh loss occur in areas with the highest density of canals. Land loss rates were determined for the seven management basins in Louisiana and it was estimated that when canal, spoil area and indirect losses were included (Craig et al. 1979), 44% to 54% of the total annual loss of 102 km^2 (39.4 mi^2) in the deltaic plain was caused by canals.

Canals contribute to wetland loss both directly and indirectly. The direct impact of canals can be easily measured. For example, unpublished data from U.S. Fish and Wildlife Service records show that 397 permits for dredging of Louisiana marshes were granted to oil companies in 1975, with a direct loss of 772 ha (1,907 acres) of marsh; in 1976, 435 permits resulted in a direct loss of 981 ha (2,424 acres); and during the first 6 months of 1977, 206 permits were issued resulting in a direct loss of 524 ha (1,295 acres). Thus, in 2.5 years there was a direct loss of 2,227 ha (5,626 acres) of Louisiana marsh just to the petroleum industry (Lindall et al. 1979). Spoil deposition from canal construction is generally two to three times greater than the canal area itself. Craig et al. (1979) estimated that the indirect impacts of canals can cause wetland loss in an area three to four times the initial canal area. Therefore, the total loss of wetlands caused by industrial access canals for the 2.5-year period mentioned above will ultimately be 6,000-8,000 ha (15,000 to 20,000 acres). One of the mechanisms by which this additional loss takes place is the widening of canals with time. Annual increases in canal widths of 2% to 14% in the Barataria Basin have been documented, indicating width doubling rates of 5

to 60 years (Craig et al. 1979).

As a regional network, canals result in: (1) higher rates of wetland loss (Craig et al. 1979); (2) increased saltwater intrusion, which further exacerbates the wetland loss problem (Van Sickle et al. 1976); (3) changes in the hydrology of the wetland system (Hopkinson and Day 1979, 1980a, 1980b; Craig et al. 1979; Kemp and Day in press); (4) a reduction in capacity for wetlands to buffer the impacts of large additions of nutrients (Hopkinson and Day 1979, 1980a, 1980b; Kemp and Day in press); (5) a loss in storm buffering capacity; and (6) loss of important fishery nursery grounds (Turner 1977; Lindall et al. 1979; Chambers 1980).

Turner et al. (1982) have recently extended the analysis of the relationship of canal density and wetland loss by examining U.S. Fish and Wildlife Service habitat maps for 1955 and 1978. The change in marsh as shown by 260 quadrangle maps in the deltaic plain and the extent to which canals attributed to this change were examined. Again, a strong relationship between canal density and wetland loss was found. Turner et al.(in press) have estimated that if no additional canals were constructed in the wetlands, that the loss rate would be 30 to 40 km^2/yr less over the next 20 years.

ADVANTAGES AND DISADVANTAGES OF DIFFERENT MANAGEMENT OPTIONS FOR CONTROLLING WETLAND LOSS

In managing the Atchafalaya River's contribution to wetland gain, a large area of the Louisiana coast -- from western Terrebonne Parish to the Texas border -- will benefit and a minimum amount of engineering aid will be required to accomplish land building. The disadvantages are that this sediment nourishment is area-specific and does not seem to be effective in flotant marshes (Baumann and Adams 1982).

Controlled diversions of the Mississippi River have several advantages: (1) the areas affected have high wetland loss rates; (2) there will be a possible improvement in fisheries; and (3) advanced planning can be done and operational experience can be gained. The disadvantages of controlled diversions are that: (1) they are area-specific and can affect only the lower Mississippi River; (2) engineering costs are high; and (3) there would be pollution problems associated with toxic substances in the Mississippi River.

Regulatory control over canals has the advantages of: (1) affecting all areas of the coastal zone; and (2) addressing the major human cause of wetland loss. The disadvantages are: (1) the opposition to such strict regulation by the political and private sector; and (2) lack of complete information on the relationship between canals and wetland loss.

CONCLUSIONS

Comparison of the effects of the different management options and mitigation techniques for reducing wetland loss in Louisiana reveal that regulatory control of new canals could reduce the loss rates approximately 30 to 40 km^2/yr, in contrast to 1 to 3 km^2/yr for controlled diversion plans, and approximately 18 km^2/yr for land building by the Atchafalaya River. If the problem of wetland loss is to be properly addressed by regulatory agencies, they must make a serious attempt to control the construction of canals (see Table 1).

To combat wetland loss, we advise: (1) management of the Atchafalaya River for maximum land building; (2) use of controlled diversions along the Mississippi River; and (3) strict regulatory control of canals within the Louisiana wetland system.

ACKNOWLEDGMENT

This work was partially supported by funds from the Louisiana Department of Natural Resources, Coastal Resources Unit. This is contribution no. LSU-CEL-82-22 of the Coastal Ecology Laboratory, Center for Wetland Resources, L.S.U.

LITERATURE CITED

Adams, R., P. Banas, R. Baumann, J. Blackmon, and W. McIntire. 1978. Shoreline erosion in coastal Louisiana: inventory and assessment. Final Report to Louisiana Department Transportation and Development. 139 pp.

Baumann, R.H. 1980. Mechanisms of maintaining marsh elevation in a subsiding environment. M.S. Thesis. Louisiana State Univ., Baton Rouge.

Baumann, R., and R. Adams. 1982. The creation and restoration of wetlands by natural processes in the Lower Atchafalaya River System: possible conflicts with navigation and flood control objectives. Proceedings Eighth Annual Conference on Wetlands Restoration and Creation. 8:1-24.

Blackmon, J. H., Jr. 1979. A detailed analysis of marsh deterioration for selected sites in the Barataria Basin. Pages 211-226 in J.W. Day, Jr., D.D. Culley, Jr., R.E. Turner, and A.J. Mumphrey, Jr., eds. Proceedings Third Coastal Marsh and Estuary Management Synmposium. Louisiana State Univ., Div. of Continuing Education, Baton Rouge.

Chambers, D.G. 1980. An analysis of nekton communities in the upper Barataria Basin, Louisiana. M.S. Thesis. Louisiana State Univ., Baton Rouge.

Cleveland, C., C. Neill, and J. Day. 1981. The impact of artificial canals on land loss in the Barataria Basin, Louisiana. Pages 425-435 in W. Mitsch, R. Bosserman, and J. Klopatek, eds. Energy and ecological modelling. Elsevier Scientific Publ., New York.

Craig, N.J., R.E. Turner, and J.W. Day, Jr. 1979. Land loss in coastal Louisiana (USA). Environ. Manage. 2:133-144.

DeLaune, R.D., W.H. Patrick, Jr., and R.J. Buresh. 1978. Sedimentation rates determined by ^{137}Cs dating on a rapidly accreting salt marsh. Nature 275:532-533.

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 Natural Resources and Jesse Guidry, Secretary, Louisiana Department Wildlife and Fisheries. Coastal Environments, Inc. Baton Rouge, La. 13 pp.

Gagliano, S.M., P.P. Light, and R.E. Becker. 1971. Controlled diversion in the Mississippi River Delta system: an approcah to environmental management. Louisiana

State Univ., Center for Wetland Resources, Baton Rouge. Hydrologic and Geologic Studies of Coastal Louisiana Rep. 8. 146 pp.

Gagliano, S.M., and J.L. van Beek. 1974. An approach to multiuse management in the Mississippi Delta systems, delta models for exploration. Houston Geological Society.

Gosselink, J.G., C.L. Cordes, and J.W. Parsons. 1979. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas. 5 vol. U.S. Fish and Wildlife Serivce Office of Biological Services. FWS/OBS-78/9 thru 78/11.

Hopkinson, C.S., and J.W. Day, Jr. 1979. Aquatic productivity and water quality upland estuary interface in Barataria Basin, La. Pages 291-314 in R.L. Livingston, ed. Ecological processes in coastal marine systems. Plenum Press, New York.

Hopkinson, C.S., and J.W. Day, Jr. 1980a. Modeling hydrology and eutrophication in a Louisiana swamp forest ecosystem. Environ. Manage. 4:325-334.

Hopkinson, C.S., and J.W. Day, Jr. 1980b. Modeling the relationship between development and storm water and nutrient runoff. Environ. Manage. 4:315-324.

Kemp, G.P., and J.W. Day. In press. Nutrient dynamics in a Louisiana swamp receiving agricultural runoff in cypress swamps. Univ. of Florida Press, Gainesville.

Lindall, W., A. Mager, G. Thayer, and D. Ekberg. 1979. Estuarine habitat mitigation planning in the southeast. In Mitigation Symposium: a National Workshop on Mitigating Loss of Fish and Wildlife Habitat. Colorado State Univ., Ft. Collins, Colo. GTRM-65.

Roberts, H., R. Adams, and R. Cunningham. 1980. Evolution of sand dominant subaerial phase, Atchafalaya Delta, Louisiana. Am. Assoc. Petrol. Geol. Bull. 64:264-279.

Turner, R.E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Am. Fish. Soc. 106:411-416.

Turner, R., R. Costanza, and W. Scaife. 1982. Canals and wetland erosion rates in coastal Louisiana. Pages 73-84 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, Biological Services Program, Washington, D.C. FWS/OBS-82/59.

Van Sickle, V.R., B.B. Barrett, T.B. Ford, and L.J. Gulick. 1976. Barataria Basin: Salinity changes and oyster distribution. Louisiana State Univ., Center for Wetland Resources, Baton Rouge. Sea Grant Publ. LSU-T-76-002.

Wells, J.T., and G.P. Kemp. 1981. Atchafalaya mud stream and recent mudflat progradation: Louisiana chenier plain. Trans. Gulf Coast Assoc. Geol. Soc. 31:409-416.

PANEL DISCUSSION

OPTIONS: LIMITATION AND MITIGATION OF DREDGING AND FRESHWATER DIVERSIONS

Kai Midboe, Moderator

John W. Day, Harry H. Roberts, Sherwood M. Gagliano, Peter Hawxhurst, Senator Samuel Nunez and **Gerald Voisin**, Panelists.

Kai Midboe: We will now be joined by two additional panelists, State Senator Samuel Nunez and Mr. Gerald Voisin of Louisiana Land and Exploration Company. Senator Nunez represents St. Bernard and Plaquemines parishes and obviously has a vital concern over land loss and is Chairman of the Senate Natural Resources Committee.

Samuel Nunez: Of course I have many reasons to try to protect St. Bernard and Plaquemines parishes which are disappearing at a rapid rate. That is now recognized in the Legislature and at a local level. In 1964 the people of one of my parishes passed a special bond issue to fund a freshwater diversion structure at Caernarvon, which has not been built yet, but I think we can solve that.

This week we will present a report from the Joint Natural Resources Committees to the Legislature and the Governor on what we should do about the problem of coastal land loss. We asked the Mineral Board to estimate the effect of a retreat of one-half mile of the coast on State revenues from oil and gas production. They indicated a loss of at least $52,000/day. It is vital to protect our coastal environments, not only from the standpoint of revenues to the State, but also from the standpoint of recreational value, commercial seafood industry, and protection of our estuaries.

Our report is based on extensive expert testimony and recommends the expenditure of revenues to the Enhanced Mineral Trust Fund, which is set aside as a percentage of State oil and gas revenues. I can think of no better use of those funds than the protection of the resource which produced them.

The approach the Committees have taken is to propose specific projects and estimate their costs. Our recommendations include as a beginning: freshwater and sediment diversion at Caernarvon, barrier island revegetation in Terrebonne, Jefferson and Lafourche parishes, cybernetic architecture or artificial creation of reefs, rock structures and jetties and sand restoration on barrier islands, beach protection at Holly Beach, and wetland management programs. These programs total over $38 million. But given the loss of natural resources and revenues, this has to be only a beginning. If we do not take some of the revenue from coastal oil and gas production and dedicate it to the restoration of marsh lands and protection of the fragile estuarine system and coastline we will be doing ourselves and our grandchildren an injustice.

Gerald Voisin: The property Louisiana Land and Exploration Company owns is located in nine coastal parishes in southeastern Louisiana. The company adopted a marsh management plan in 1952 in cooperation with the U.S. Soil Conservation Service. Following this plan we have constructed 385 water control structures or weirs, dams, earthen plugs, and shoreline stabilization structures. These management approaches have been successfully applied to freshwater, intermediate, and brackish marshes. I wholeheartedly support plans for freshwater diversion which is the only answer to improving the marsh. The proof is the rapid accretion of marsh in western Terrebonne Parish. On the other hand, in lower Plaquemines Parish there is serious saltwater intrusion and rapid subsidence where there has been a reduced river input.

Unidentified speaker: Senator Nunez, how much of the $38 million do you think will become available?

Samuel Nunez: Hopefully all of it. We are probably not asking for enough but we are trying to be realistic.

Linda Deegan: What will be the effects of the pollutants present in high concentrations in Mississippi River water in the wetlands receiving freshwater diversions?

Samuel Nunez: Oysters do very well in areas where fresh water is diverted in Plaquemines Parish and they are monitored by the Board of Health. The only problem seems to be increased coliform bacteria counts during certain periods. Improvements in sewage treatment along the lower river will hopefully clear this up.

Sherwood Gagliano: Water quality can be monitored and the structure can be closed in a short period of time. Furthermore, the structures only operate during high flow conditions when water is generally better. The Nation is committed to achieving certain water quality standards and by agressively using the water for environmental management purposes we help force the issue of meeting those water quality standards.

Michael Halle: Some of the techniques proposed in the Legislature's report are questionable, based on the opinions of scientists and the presentations made at this conference, including cybernetic architecture, groins and jetties. Why were scientists not used to draw up plans that will work?

Samuel Nunez: We are not going to be married to any particular plan. We invited many scientists before the committees for their advice. Many of the projects are of the pilot scale to determine whether they will work. Our recommendations include pilot- and full-scale projects in five different approaches: freshwater and sediment diversion, nourishment and revegetation of beaches, artificial reef structures, rock structures, and wetlands management.

Unidentified speaker: Mr. Voisin, would you clarify your company's policy on backfilling canals?

Gerald Voisin: We have no problem with backfilling, but do with a blanket policy requiring backfilling. Not every marsh type can support backfilling. In some circumstances it is useless and may destroy more marsh than if the canal were left alone. We agreed with the Coastal Management Section to backfill two canals in every marsh type in which we work and study the effectiveness of these.

Samuel Nunez: Comprehensive pipeline crossing legislation previously passed was also meant to look into this, but funding of implementation of this program was vetoed.

Walter Sikora: Because there are areas where the shoreline will retreat and others, such as the Atchafalaya delta, where the shoreline will prograde, could we enter an agreement with the Federal Government to fix the Federal-State boundary?

Samuel Nunez: The courts have decreed that the boundary is ambulatory and subject to judicial review, but I agree that it would be good to fix a boundary.

Kai Midboe: With a net land loss of 40 mi^2/yr, the Federal Government has little incentive to negotiate a fixed boundary.

R. Eugene Turner: I am pleased by the approach of experimental backfilling canals which Mr. Voisin described. I believe that generic investigations and projects on marsh and canal management should be included in the coastal protection program Senator Nunez described.

Unidentified speaker: Based on John Day's comparisons of the effectiveness of various approaches to slow land loss, should management focus only on canal impacts because the effects of freshwater diversions are inconsequential?

John Day: We can save more land by better regulating canals than can be gained by Atchafalaya delta building or freshwater diversion. Canals are widespread whereas controlled or natural diversions are site specific. If we do not address the issue of canals we will not address the main cause of land loss, but all of these approaches should be used in combination.

Joan Phillips: Directional drilling can reduce the need for canals, however, industry spokesmen indicate it is impractical or too expensive. The Coastal Management Section does not have the expertise to evaluate this claim and reportedly cannot solicit the advice of the Office of Conservation of the Department of Natural Resources. If the Office of Conservation cannot advise the Coastal Management Section on this matter, the Coastal Management Section should develop its own expertise in this field.

Michael Lyons: Generally a directional hole costs 50% more than a straight hole. Straight holes can more effectively reach the several stratigraphic objectives of an exploratory well. Directional drilling would clearly save marsh land, but would not reduce the needed number of wells. Most offshore drilling is directional because of the large investment of the platform from which a number of directional wells can be drilled.

Linda Deegan: Then the decision of whether to use directional drilling is based solely on economics, but these economics exclude environmental costs.

Kai Midboe: Can a distinction be made between those canals near the ocean and those farther inland?

R. Eugene Turner: The relationship between canal density and land loss is more severe the closer to the coast and the newer the delta.

Samuel Nunez: If we had no canals at all would we still have a problem? Would not subsidence still result in land loss?

R. Eugene Turner: I think that at least 50% of the wetland loss is directly or indirectly attributable to canals. Disruption of the natural hydrology seems to be the primary mechanism causing wetland loss indirectly as a result of canals.

Donald Moore: A recent presentation was made concerning the use of hovercraft for accessing oil and gas locations in wetlands in order to reduce the need for canals. Several companies are ready to build such craft, but apparently no one in the industry is willing to make a commitment to use them.

Kai Midboe: When I worked with the House Coast Guard Subcommittee we studied the use of hovercraft by the Coast Guard. Hovercraft are very expensive to build and operate. This is probably the main reason for the reluctance to use them for oil and gas activities.

Donald Moore: Hovercraft are already being used in oil and gas development on the North Slope of Alaska. I think they are certainly worth looking at in this instance.

Sue Hanes: Regarding the effects of major Corps of Engineers projects compared to oil field canals, while reviewing a 5-mile canal in the Barataria Basin we found nearly 56 miles of oilfield canals within a small triangular area. The Corps does build some canals, but oilfield canals are so much more extensive.

Samuel Nunez: The Corps' Mississippi River Gulf Outlet is probably the largest canal I have ever seen dredged.

Peter Hawxhurst: The Corps only builds canals when asked to, they don't do it on their own. To get these constructive efforts, such as river diversion, off the ground is going to take a concerted and coordinated effort by Federal, State and local government as well as the users of the marsh areas. We need to view our activities in a broad context with respect to resources. As was mentioned earlier, we need to evaluate the social costs of individual activities. For example, an oil company wishes to dredge a canal because it is cheaper than directional drilling. We need to set limitations on activities, such that all the quantifiable costs and less readily identifiable social costs are considered in cost-benefit analysis. At one time the Corps could consider such social well-being costs, but I understand revised regulations under the Reagan administration will make that more difficult.

Charlotte Fremaux: What agency will resolve whether privately owned lands will be used for a purpose such as river diversion?

Gerald Voisin: Right now we have to deal with about 14 agencies, but no one has proposed a better marsh management plan than that we developed with the Soil Conservation Service in 1952. The regulatory agencies operate independently, sometimes with different objectives.

Sherwood Gagliano: The property right considerations depend on the type and magnitude of the project. The existing freshwater diversions on the east side of the river are cooperative efforts between local land owners and local government and, to some

extent, the State government. The Violet experience suggests that works very well provided there is a framework for discussion of problems. The coastal zone management framework is good for that because it includes local advisory committees, parish and State government and interfaces with the Federal Government. Larger projects are public works projects which have to be inplemented much as an interstate highway, including taking of properties and easements. The mechanisms for this are very well established and should not be an obstacle for implementing an environmental management project. There is a framework for compensating individuals whose ownership or use is displaced.

Kai Midboe: Having worked so heavily on the Governor's Atchafalaya Basin plan, I can tell you though, that the land-use issue is probably the most politically difficult. Even though the mechanisms such as eminent domain are there, they are politically difficult to exercise.

Samuel Nunez: The large land owners in the wetlands seem to be willing to cooperate because they will benefit. For example, the Delacroix Corporation will donate or give easements for the Caernarvon structure. Many of these corporations lease these lands for trapping and hunting and, furthermore, when their land erodes it reverts to State ownership.

Tommy Michot: Would anyone care to speculate on what the shape of the coastline will be in 50 or 100 years given the absence of man-made structures or control?

Sherwood Gagliano: It would take quite a while for a diversion to the Atchafalaya to occur. The river might maintain its present course, at least partially, for a long time. Commonly more than one river distributary has been functioning at the same time during the history of the delta. The Atchafalaya Delta will continue to grow and should produce a large delta lobe because the continental shelf is shallow and the underlying land is relatively stable. The chenier plain would expand significantly. The intervening areas between the active delta areas would continue to deteriorate.

Joan Phillips: I would hope Senator Nunez's committee would remain active and begin planning how we would like the coastal zone of Louisiana to be in the future and how this can be achieved.

Samuel Nunez: Presently we have addressed mainly short-range goals. We cannot afford to quit longer-term efforts when we have been told that Plaquemines Parish will disappear in 49 years. If the wheat fields of Kansas were disappearing at the alarming rate experienced by the marshes of Louisiana, it would be declared a national disaster.

John Day: I would like to reiterate that two things, which are not in Senator Nunez's list, that have to be addressed are the management of canals and the Atchafalaya delta.

Samuel Nunez: Would you care to elaborate on how to deal with canals? Do we stop new canals all together? How do we deal with existing canals?

John Day: I would like to know what would happen if there were a near-blanket prohibition of new canals? I have a feeling that we would get all of the oil out of the ground that we could anyway.

Samuel Nunez: I am not going to disagree with you, but I will simply point out that these current efforts represent what we can realistically gain legislative approval for. If, as was indicated earlier, canals account for 50% of the land loss, we are trying to address the other 50%. The Legislature will eventually address the issue of canals, but if we prohibited them today we would run into difficulties related to concern about energy shortages. Rather than going forward, I am concerned we would go backward.

Linda Deegan: The approaches to backfilling Mr. Voisin mentioned constitute a constructive proposal to deal with the issue of canals. This is the type of positive approach which could be included in the Legislature's recommendtions.

Samuel Nunez: Perhaps backfilling should have been a condition for permitting 50 years ago. I agree we have to address the canal problem. I have addressed the pipline problem by passage of an act for which the funding was vetoed. This program could help address the canal issue.

Lee Black: It is probably too late to amend the report prior to the Special Session three weeks away. Therefore we should support the plan and develop efforts for other projects for subsequent legislative sessions.

Kai Midboe: The Enhanced Mineral Trust Fund has probably been spent 100 times over, so a concerted effort is required to obtain these funds for coastal erosion.

Samuel Nunez: There is no better way to spend funds generated from mineral extraction in coastal Louisiana than to use them to protect the area from which they come, if the extraction is acknowledged to be part of the cause of the problems. The oil industry is important to Louisiana and generates 30% to 40% of State revenues and provides much employment. As a legislator I must balance all these benefits and detriments.

Len Bahr: Most issues have two sides, an environmental cost and an economic cost. Quantifying the environmental cost is a prime area of research. There are exciting new techniques for placing a dollar cost on environmental effects. When the environmental costs of dredging a canal can be expressed in dollars, then political and regulatory decisions will become clearer.

Sherwood Gagliano: Senator Nunez said that the Legislature's program is a start. It is more than that. It is a turning point. The coastal zone management plan was an important first step, but this is the second step in which we are making a commitment to manage renewable resources based on substantial funding. The program is a package of approaches which we can start implementing and monitoring. Clearly not everything will work, but we will never know until we try. At the present rates of deterioration we can not afford to wait any longer.

Peter Hawxhurst: The efforts to implement programs and publicize the coastal erosion problem are necessary to generate the grass roots support needed to attract State and Federal funding.

SUMMARY COMMENTS OF PANEL MODERATORS

CAUSES: CHANGES IN DISPERSAL OF FRESH WATER AND SEDIMENTS

Mr. Gerald G. Bordelon, Chairman, Louisiana Coastal Commission

The various alterations which man has made to Louisiana's coastal environment for flood protection, navigation, and mineral resource extraction have had many consequences which were not perceived when they were undertaken. This has largely resulted from interruptions of the natural flow of water and sediment on which our estuarine and coastal areas depend.

The most pervasive alterations have been the control of the Mississippi River flow, including impoundments up in the watershed, which have reduced to half the previous sediment load of the lower river; leveeing of the river for flood protection, which has prevented the flux of sediments and fresh water in the interdistributary basins adjacent to active delta lobes; and regulated division of the river between the Atchafalaya River and the Mississippi River proper. Over the years, we have also taken various steps to control the coastline itself, such as jetties and seawalls, some of which we now discover have had some serious negative consequences. All of these alterations have been made to benefit mankind, but now we find that there are also eventual human costs as well. At the same time, nature takes its course, where it takes away it can also give, as in the case of the rapid progradation of the Atchafalaya River delta and the chenier plain coast.

The coastal wetlands of Louisiana need good supplies of fresh water and sediments to maintain their integrety and vitality. We have seen in presentations and discussions, that marshes need a continued sediment supply to offset subsidence and sea-level rise. This is a particularly profound observation, given the possibility of increased sea-level rise in the future. Furthermore, wetlands and estuaries need fresh water, literally the life blood of Louisiana. Fresh waters carry sediments and nutrients, but are particularly needed to maintain the salinity gradients in the estuaries. Saltwater intrusion has caused serious problems for the oyster industry and has caused rapid deterioration of freshwater wetlands.

Various approaches have been discussed to deal with the problem of restoring fresh water and sediment supplies to our coastal areas. These range from river diversions of various scales, either for maintenance of salinity levels or wetlands accretion, to management of the Atchafalaya delta to maximize the creation of productive habitats, and to nourishment of sand-starved barrier islands. Although the panelists and audience differed widely in their preferred approaches, all seemed to agree that whatever is done should be in concert with natural processes rather than in vain attempts to defeat them.

In summary, natural processes exacerbated by alterations to freshwater and sediment flows have caused major problems which have such significant consequences that we as a society must challenge them. It appears that we need to take immediate action on a number of necessary long-range plans and accomplish the societal adjustments which will be required.

CAUSES: PHENOMENA DIRECTLY RELATED TO HUMAN ACTIVITIES

Dr. Roger Saucier, U.S. Army Engineer Waterways Experiment Station

I would like to depart from strictly summarizing the excellent presentations made in the session I moderated and present my reflections on the underlying common concerns which I heard voiced during many of the conference discussions.

A great deal of concern has been expressed about the formidability and inevitability of certain natural processes. We are not likely to do anything about the processes of regional subsidence and sea-level rise; however this is not justification for a defeatist attitude. Many natural and man-induced processes are controllable, and perhaps even reversible. I am quite impressed, not just about what we know about these processes, but how we have taken steps to apply this knowledge. In the past, our management decisions have been made, all too frequently, not out of ignorance of the processes, but more often out of disregard of them, perhaps influenced by the thought that we could do nothing about them.

Several concepts for erosion control have been discussed, such as freshwater diversion and marsh creation. I am particularly impressed by the potential of these, because they are not brute force, man-against-nature approaches. They recognize what nature, itself, has done and can do with assistance by man. This view is obviously influenced by my background in geography, a science once referred to by a prominent geographer as human ecology. This definition recognizes man as part of the ecosystem, rather than a force apart from the ecosystem. Man, thus, should optimize his use of natural resources -- in this case water and sediment -- to achieve those conditions and values he desires. There may come a time when man has to turn exclusively to concrete and steel approaches, but I do not think we are near this point. Concrete and steel now have their place, but as means of influencing natural processes, not of preventing them.

In the near future, I see the need to field-test and demonstrate rather than procrastinate. As scientists, we believe certain things can work, but decisionmakers and the public have to be convinced. Also, rough spots on the road between theory and practice have to be smoothed out.

We must realize that coastal Louisiana of tomorrow will not be the same as today. But certainly today it was not the same as it was yesterday or the day before. Man often reacts adversly to change, feeling the present is optimal. We can look to the future with optimism, but it would help if we can continue to investigate the consequences of the change. I fear that while we will be able to dramatically influence erosion and land loss, vast geomorphic changes nevertheless are taking place. We must probe the consequences of these, which may be profound on a regional scale, insofar as climate, ocean currents, marine fisheries, waterfowl migration, and many other factors are concerned.

CONSEQUENCES: EFFECTS ON NATURAL RESOURCE PRODUCTION

Dr. James G. Gosselink, Center for Wetland Resources, Louisiana State University

There was general agreement among panelists that wetland loss has resulted in changes in vegetation and changes in secondary consumers, such as waterfowl, alligators and furbearers that use the marsh directly. In fact there was not much argument that estuarine-dependent fish and shellfish resources have also already been affected. The key to this estuarine dependence is habitat availability. If the habitats are available and healthy, then their associated living resources will also be. The question then becomes how to deal with the loss and change of habitat.

I will not present a complete and coherent summary, but will highlight some of the questions raised. What are the prospects for freshwater diversions? The prospects are good for limited areas and for controlling saltwater intrusion but there appear to be socio-economic limitations. What is the optimum marsh-water edge interface ratio and can this be engineered in canal design? More broadly, can we manage the marshes for improved habitat? What is the optimum type of marsh (e.g., brackish marsh) and can we engineer to maximize this type of marsh? Who is the savior of the wetlands, in the sense of their conservation and management? The feeling I get is that it better be all of us, from the grassroots to the politicians and decisionmakers.

In the long run, abandoned deltas will erode away. Is it economically sound to pour money into them for freshwater diversion, etc., or would it be better to develop plans for replacing eroding wetlands with new areas, such as in the Atchafalaya delta? Considering, the relative value of wildlife and petroleum resources, how can environmentalists hope to compete in the political arena of environmental conservation?

I do not know how to answer all these questions, therefore I will try to relate my personal perspective on our current situation as reflected in the conference. There is a growing change in attitude toward the environment, which translates to political reality in a new conservatism. Previously, environmentalists were on the defensive and considered radicals. Resources were abundant and the popular and dominant paradigm was that development was good, and that natural resources were plentiful and free, the burden was on the environmentalist to show that an activity was destructive to the environment and should be terminated. A new more conservative view is that as nonrenewable resources are rapidly depleted, and reliance on renewable resources in Louisiana becomes increasingly important, thus we must conserve and foster them. The onus of environmental modification thus lies with the developer. He is now on the defensive, must prove that the change is environmentally safe and must pay for the whole cost of the change.

CONSEQUENCES: SOCIAL AND ECONOMIC

Mr. Edward W. Stagg, Council for a Better Louisiana

The Council for a Better Louisiana and I have for sometime been interested in water resource problems in Louisiana, particularly with regard to ground water and surface water. These concerns share common ground with those concerns about coastal erosion. In the past, our water problems were primarily two-fold: one, to get rid of it, and secondly, to pray that we did not have a hurricane to give us too much. I believe,

however, we are moving into a new era because of our population growth and the type of industries we now have, where we are much more concerned about water conservation. One of the brightest people I have ever known, told me 10 or 12 years ago that in the future of Louisiana, we would be without our cheap natural energy resources -- oil and gas. He said that for the eventual development of Louisiana, the one unique resource, if we conserved it, would be water. The utilization and conservation of water is of great long-term importance.

In our panel deliberations, we first considered property rights. If I could summarize that discussion, I would say that individual property rights are in danger, in so far as water is concerned. Erosion tends to work against the private owner and against the State in favor of the Federal Government. State law allows private land owners to restablish claims to eroded land if, at his own expense, he rebuilds it. This is, of course, an expensive proposition. Thus my impression is that the interest of private land owners are in considerable jeopardy in coastal Louisiana.

Furthermore, there is a lack of property rights to water in Louisiana. We have some riparian rights established in law, but there is nothing comparable to the mineral code for oil and gas in so far as water is concerned. This is principally a concern regarding ground water, where a well drilled on other property may deplete ground water under an individual's property. We do not have protection regarding groundwater rights and it is an issue the legal and academic communities should investigate.

Other legal issues related to coastal erosion concern regulations, which may have been erected to protect the environment, but which also may become an impediment to activities designed to control erosion or saltwater intrusion. We heard a horror story about an attempt to erect control structures initiated in 1972, which has been held up by permitting problems through 1981. The environmental assessment process should be streamlined by shortening the time of review by Federal and State agencies.

The economic and social impacts of continued coastal erosion in Louisiana are indeed likely to be enormous. Dr. Davis developed sobering scenarios about the tremendous economic costs of declining renewable natural resources, and increased flood protection and how this may affect society in south Louisiana.

OPTIONS: BARRIER ISLAND AND SHORELINE PROTECTION

Dr. Charles Groat, Louisiana Geological Survey

Barrier islands are literally at the forefront of the coastal erosion problem, being out in front of the land mass. It is necessary to consider options available to slow barrier island erosion within the frame work of the natural processes which have created and are destroying the islands. Barrier islands are as much, if not more than other parts of the coast, a part of the death process of a delta. Any attempt to stop erosion must face up to that process of dying and the options available must be carefully considered in that context.

Having considered the processes which form and destroy Louisiana's barrier islands, speakers then discussed various attempts which have been made in the past in Louisiana, Texas, and other parts of the world to stop shoreline erosion and preserve the integrity of barrier islands. We considered structural methods such as groins to pin down the ends of

the islands, rock jetties, seawalls, etc., and some of the more passive methods, such as vegetation stabilization and sand fences, intended to maintain the sand which is there. One of the problems faced in shoreline and barrier islands preservation is the maintenance of sediments there, either by preventing sediment from escaping the system or by furnishing new supplies.

We also found the dichotomy that I believe is present throughout the conference. Members of the academic community offered the opinion that the barrier islands and coastal processes are not as well understood as is necessary. In order to develop ultimate solutions which are long-term as well as short-term, economically justifiable, and, effective, coastal processes must be much better understood. On the other hand, others including Representative Murray Hebert, stated that people in Louisiana know there is an erosion problem, many studies have been conducted, many people are living along eroding shorelines and near marshes which are disappearing. They feel that, particularly with the money which may be available from the State, it is time to take some action. They don't necessarily deny that more studies are needed, but feel that we ought to do the best we can based on the information available.

In fact it is the approach of immediate action which is being taken. The Louisiana Joint Natural Resources Committees of the Louisiana Legislature have recommended a program, a large portion of which deals with stabilizing and slowing the erosion of Louisiana's barrier islands. On the other hand, Representative Hebert, speaking for the Legislature, admitted that we don't know everything we need to know. While conducting these immediate, short-term approaches to protecting barrier islands, we also need to conduct studies to help understand the ultimate possibilities and long-term strategies for coastal protection.

The long-term coastal conditions and methods to deal with them have to be considered in light of global phenomena. Dr. Nummedal suggested we may be facing major sea-level rises that could make many of our attempts to stop shoreline erosions very difficult. Are we facing other overwhelming natural forces, such as rapid subsidence attributable to natural destruction of some parts of the delta system. We must sort out and understand these large-scale phenomena.

To summarize, the need to do something is very apparant in a political sense and in the eyes of the people who live in coastal Louisiana. In the eyes of the academic community, we need to know much more than we do. Perhaps we will also learn much from our initial attempts, which no one claims are going to solve all our coastal problems. Some attempts will not work, but they may teach us as much as those that do. Undoubtedly because of the highly dynamic nature of the barrier islands, much attention must be focused on these environments in the future.

OPTIONS: LIMITATION OF DREDGING AND FRESHWATER DIVERSIONS

Mr. Kai Midboe, Governor's Office of Intergovernmental Affairs,

It is difficult to quickly summarize the presentations and discussions of such complex subjects, particularly when one is not an expert, but must summarize experts.

The panel basically addressed the question of what activities would be most effective in retarding or correcting coastal land loss. The three primary activities

discussed were the delta building of the Atchafalaya River, freshwater diversions along the Mississippi River, and control of canals in wetlands.

The Atchafalaya River is building a large lobate delta in the Atchafalaya Bay and also causing land accretion along the coast of southwestern Louisiana. The question is how do we realize the maximum benefits from these natural processes. Interestingly, the new delta has been built since 1950, most of it since 1970. There have been three 100-year floods during that period, however. Is this phenominal delta growth, in fact, unusual and will it continue at the recent rates?

There were three main issues discussed in reference to freshwater diversion: (1) how to recreate the natural overflow patterns which cause land accretion and retard saltwater intrusion; (2) how to initiate new areas of delta growth; a delta lobe is really a series of small lobes which can be recreated with selective freshwaters diversions; (3) how can water and sediment brought over or through the levee be managed and be directed to the interior of wetlands where they are needed. With regard to freshwater diversions, the point was made, which I think is a very good point, that enough research has been done to allow implementation. Granted, further research will occur in the future, but we are far enough along to allow affirmative action. Dr. Gagliano made the very good point that we are wasting a very valuable resource in Louisiana by allowing the shunting of most of the Mississippi River's fresh water and silt off the edge of the continental shelf by confining it until it reaches the active distributary system at the river's mouth.The water, sediments, and nutrients are the bases of our agriculture, marsh development, and most of our natural resources.

Two problems related to freshwater diversions were raised. An important one which cannot be overlooked is the concern of the people impacted by the diversion. The benefits which may accrue because of the diversion may not accrue to the communities and local governments impacted. There have been occasions where local governments have actively resisted plans for freshwater diversion because of this. Another problem is that control structures upriver have been very effective, there is much less sediment transported by the river available for diversion.

An issue that I was really surprised about is the degree to which the coastal erosion problem is a result of canal dredging. Gene Turner estimated that at least 50% of the coastal land loss is a direct or indirect result of canal dredging for the oil and gas industry, navigation, and other purposes. If this is so, how can we better manage these activities, where must they be stopped, etc.

Senator Nunez discussed the study recommendations made by the Joint Natural Resources Committees of the Louisiana Legislature. They make specific recommendations for projects to stem coastal erosion and estimate the costs of these activities. The Corps of Engineers is also working on a series of studies regarding implementation of freshwater diversion. Clearly the "bottom line" in all these efforts is one which appears consistently in government, and that is dollars. How will we pay for it? How does it fit in with competing needs for these funds? The Governor and Legislature now appear ready to devote considerable sums of State resources from the Enhanced Mineral Trust Fund for coastal protection.

This briefly summarizes our delibrations. I want to complement the panelists for excellent presentations and discussion and the audience for their provocative questions.

LIST OF ATTENDANTS

Rodney D. Adams, Center for Wetland Resources, Louisiana State University
D. Jane Allan, Louisiana State University
Frank Atkinson, Tri-Lock Erosion Control
Peggy Autin, Louisiana Geological Survey
Whitney J. Autin, Louisiana Geological Survey

Lloyd Baehr, U.S. Army Corps of Engineers
Len Bahr, Center for Wetland Resources, Louisiana State University
Buddy Baker, Louisiana Cooperative Fisheries Unit
Barney Barrett, Louisiana Department of Wildlife and Fisheries
Joy Bartholomew, Louisiana State Planning Office
Ronald E. Becker, Center for Wetland Resources, Louisiana State University
Heino Beckert, U.S. Bureau of Land Management
Vernon Behrhorst, Louisiana Intracoastal Seaway Association
C. Lee Black, Louisiana State University
Bob Blackmon, Coastal Management Section, Louisiana Department of Natural Resources
Gary Blaize, Terrebonne Parish Coastal Advisory Committee
Gerald Bodin, U.S. Fish and Wildlife Service
Ed Bodker, Louisiana Department of Transportation and Development
Donald F. Boesch, Louisiana Universities Marine Consortium
Donald Bollinger, Secretary, Louisiana Department of Public Works
Gerald Bordelon, Louisiana Coastal Commission
Ron Boyd, Louisiana Geological Survey
Joseph C. Branco, U.S. Soil Conservation Service
Charles E. Broussard, Flying J. Ranch
Toni Brown, Louisiana Department of Wildlife and Fisheries
Bill Burke, Coastal Managment Section, Louisiana Department of Natural Resources
Janet Burt, League of Women Voters of Louisiana

Jane Caffrey, Center for Wetland Resources, Louisiana State University
David F. Carney, Louisiana Department of Wildlife and Fisheries
Keith L. Casanova, Center for Wetland Resources, Louisiana State University
Jim Catallo, Center for Wetland Resources, Louisiana State University
Robert Chabreck, School of Forestry and Wildlife Management, Louisiana State University
David Chambers, Coastal Management Section, Department of Natural Resources
Gary W. Childers, Southeastern Louisiana University
Susan Chinberg, Coastal Studies Institute, Louisiana State University
Darryl Clark, Coastal Management Section, Department of Natural Resources
Danny S. Clement, U.S. Soil Conservation Service
James M. Coleman, Coastal Studies Institute, Louisiana State University
Jay Combe, U.S. Army Corps of Engineers
Will Conner, Center for Wetland Resources, Louisiana State University
Carroll L. Cordes, U.S. Fish and Wildlife Service
Windell Curole, South Lafourche Levee District
Mary Curry, Jefferson Parish

Jack Daggett, Louisiana Deaprtment of Tranportation and Development
Thomas Davidson, Department of Geography, Louisiana State University
Donald W. Davis, Earth Sciences Department, Nicholls State University
John Day, Center for Wetland Resources, Louisiana State University
Linda Deegan, Center for Wetland Resources, Louisiana State University
Ronald DeLaune, Center for Wetland Resources, Louisiana State University
Larry DeMent, U.S. Army Corps of Engineers
John D. deMond, Louisiana Department of Wildlife and Fisheries
Andre Delflache, Lamar University
Tom Denes, Center for Wetland Resources, Louisiana State University
Chris Dionigi, Department of Biology, University of Southwestern Louisiana
Ronnie Duke, T. Baker Smith and Son

Mary-Ann Eames, Department of Marine Science, Louisiana State University
Rod E. Emmer, Coastal Environments Inc.
Betty Everitt, Department of Zoology and Physiology, Louisiana State University

Doris Falkenheimer, P.L.U.G.
Monica Farris, U.S. Army Corps of Engineers
Michael Flynn, Department of Biology, University of Southwestern Louisiana
Paul Fournier, Terrebonne Parish School Board
Charlotte Fremaux, League of Women Voters of Louisiana

Sherwood M. Gagliano, Coastal Environments, Inc.
Albert Gaude, University of Southwestern Louisiana
Bob Gerdes, Louisiana Geological Survey
Linda Glenbeski, U.S. Army Corps of Engineers
Laurel Gorman, Louisiana Geological Survey
James Gosselink, Department of Marine Science, Louisiana State University
C.G. Grant, Louisiana Geological Survey

Christana Haas, Center for Wetland Resources, Louisiana State University
Michael Halle, Sierra Club
Sue Hanes, U.S. Army Corps of Engineers
Richard Hatton, Department of Geology, Louisiana State University
Peter Hawxhurst, U.S. Army Corps of Engineers
John L. Haydel, Terrebonne Parish School Board
Murray Hebert, Louisiana House of Representatives
Mike Hess, Louisiana State University
Mark Hester, Center for Wetland Resources, Louisiana State University
Eileen Hill, Coastal Information Repository, Louisiana State University
Rocky Hinds, Louisiana Department of Wildlife and Fisheries
H. Dickson Hoese, Department of Biology, University of Southwestern Louisiana
Richard Hoogland, National Marine Fisheries Service
Norman Howden, Center for Wetland Resources, Louisiana State University
Paul Hribernick, Law Center, Louisiana State University
Mary Hungate, U.S. Fish and Wildlife Service

James G. Johnson, Louisiana State University
James B. Johnston, U.S. Fish and Wildlife Service
Claire Joller, Terrebonne Magazine

Brenda Jones, U.S. Fish and Wildlife Service

Richard Kaswa, Jr., Department of Marine Science, Louisiana State University
Raphael Kazmann, College of Engineering, Louisiana State University
Peggy M. Keney, National Marine Fisheries Service
Helen Kennedy, Center for Wetland Resources, Louisiana State University
Cary W. Kerlin, Aminoil USA, Inc.
Eric Knudsen, Louisiana Cooperative Fisheries Unit, Louisiana State University
Wilfred Kucera, U.S. Fish and Wildlife Service

Donald P. Landry, Terrebonne Parish Police Jury
Martha Landry, Terrebonne Parish Police Jury
Francisco Ley, Center for Wetland Resources, Louisiana State University
Michael Lindsay, Louisiana State University
Joel L. Lindsey, Coastal Management Section, Department of Natural Resources
Michael Loden, Jefferson Parish
Astrid Lolan, Louisiana Senate Staff
Clarke L. Lozes, Plaquemines Parish
Michael Lyons, Mid-Continent Oil and Gas Association

Chris Madden, Center for Wetland Resources, Louisiana State University
Brian Marotz, Louisiana Cooperative Fisheries Unit, Louisiana State University
Pat Mason, Louisiana Coastal Commission
Michael Materne, U.S. Soil Conservation Service
Paul I. Mathemeier, Department of Microbiology, University of Southwestern Louisiana
Mack Mathis, Anthony J. Bertucci Construction Company
Amy Maynard, Department of Geology, Louisiana State University
Karen L. McKee, Center for Wetland Resources, Louisiana State University
David A. Mekasski, St. Charles Parish
Earl Melancon, Biology Department, Nicholls State University
Irving A. Mendelssohn, Center for Wetland Resources, Louisiana State University
Charlie Mestarer, Louisiana Department of Wildlife and Fisheries
Kai Midboe, Louisiana Governor's Office
Thomas C. Michot, U.S. Fish and Wildlife Service
Carolyn Miller, Center for Wetland Resources, Louisiana State University
Frank Monteferrante, Center for Wetland Resources, Louisiana State University
Donald Moore, National Marine Fisheries Service
Timothy Morrison, Louisiana Department of Wildlife and Fisheries
Bob Morton, Bureau of Economic Geology, University of Texas

Chris Neill, Center for Wetland Resources, Louisiana State University
Dag Nummedal, Department of Geology, Louisiana State University

Michael Osborne, National Wildlife Federation

Robert Parker, Freeport Sulphur
Elaine Parton, Center for Wetland Resources, Louisiana State University
Shea Penland, Center for Wetland Resources, Louisiana State University
Susan Peterman, Center for Wetland Resources, Louisiana State University
Joan Phillips, Sierra Club
Amy Prior, Coastal Studies Institute, Louisiana State University

Rene Randon, Louisiana Land and Exploration Company
Steve Risotto, Center for Wetland Resources, Louisiana State University
Harry H. Roberts, Coastal Studies Institute, Louisiana State University
George Robichaux, Louisiana Department of Health and Human Resources

Roger Saucier, Waterways Experiment Station, U.S. Army Corps of Engineers
Harry Schafer, Louisiana Department of Wildlife and Fisheries
Freda Schnitzler, Department of Biology, University of Southwestern Louisiana
Walter B. Sikora, Center for Wetland Resources, Louisiana State University
Terry Slattery, U.S. Fish and Wildlife Service
Chris Smith, Center for Wetland Resources, Louisiana State University
Albert So, Department of Geography, Louisiana State University
David Soileau, U.S. Fish and Wildlife Service
Ronald S. Sonegut, Louisiana Deparment of Wildlife and Fisheries
Edward Stagg, Council for a Better Louisiana
David Stuttz, U.S. Army Corps of Engineers
Victoria Sullivan, Department of Biology, University of Southwestern Louisiana
Eric Swenson, Center for Wetland Resources, Louisiana State University
Laura J. Swilley, U.S. Army Corps of Engineers

Kenneth G. Teague, Center for Wetland Resources, Louisiana State University
John Teal, Woods Hole Oceanographic Institution
Paul H. Templet, Coastal Environments Inc.
R. Dale Thomas, Department of Biology, Northeast Louisiana University
Bruce Thompson, Center for Wetland Resources, Louisiana State University
Dana W. Toups, Bradley Matierals
Drukell B. Trahan, Louisiana Geological Survey
R. Eugene Turner, Center for Wetland Resources, Louisiana State University

Denny Ufuell, Louisiana State University
John Uhl, Jefferson Parish Coastal Zone Management

Jacob M. Valentine Jr., U.S. Fish and Wildlife Service
Johannes L. van Beek, Coastal Environments, Inc.
Jack Van Lopik, Center for Wetland Resources, Louisiana State University
Virginia Van Sickle, Louisiana Geological Survey
R.J. Varnell, Plaquemines Parish
Gerald Voisin, Louisiana Land and Exploration Company
Michael Voisin, Louisiana Oyster Growers and Dealers Association

Paul W. Wagner, Burk and Associates
Flora Wang, Center for Wetland Resources, Louisiana State University
John T. Wells, Coastal Studies Institute, Louisiana State University
Mike Windham, Louisiana Department of Wildlife and Fisheries
John Woodard, Tenneco LaTerre Company

Paul Yakupzack, U.S. Fish and Wildlife Service

Cathy Zapel, Department of Geology, Louisiana State University