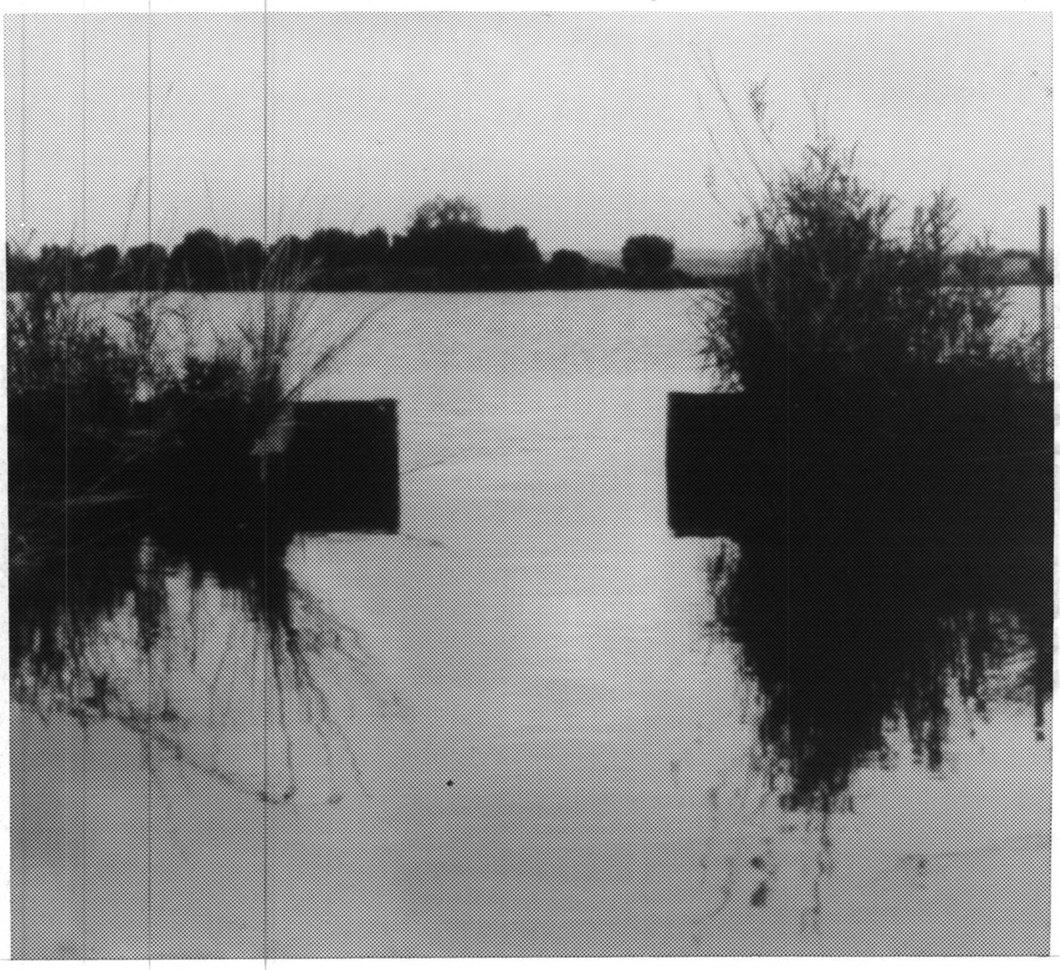
OCS Study
MMS 90-0077

A Study of Marsh Management Practice in Coastal Louisiana

Volume III: Ecological Evaluation



U.S. Department of the Interior
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OCS Study
MMS 90-0077

A Study of Marsh Management Practice in Louisiana

Volume III: Ecological Evaluation

Editors

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PREFACE

The role of marsh management in combatting wetland loss has been viewed with increasing importance in recent years. During the 1980s there was a dramatic increase in the use of marsh management techniques to mitigate coastal wetland loss in Louisiana. The popularity of this technique as a mitigative tool is indicated by the number of marsh management projects submitted for consideration in the Governor's Coastal Wetlands Conservation and Restoration Plan, which was approved in March of this year. However, there is growing concern about the potential environmental impacts, particularly cumulative impacts, of this type of wetland management. Because of this concern, the U.S. Army Corps of Engineers is developing a programmatic environmental impact statement on marsh management in coastal Louisiana. At public scoping meetings held in February 1988, the Corps of Engineers determined that public opinion about the effectiveness and environmental impacts of marsh management varies widely.

This study is the first detailed review and analysis of the effectiveness of marsh management in coastal Louisiana. The findings will be incorporated into the Corps of Engineers' programmatic environmental impact statement. While no single study provides all the answers, we hope that these results will clarify many of the issues raised at the scoping meetings. Management policies should be based on objective, scientific data. The information gathered during this study will be useful in refining and revising current management policies and will contribute to the better management of our wetland resources.

Donald R. Cahoon
C. G. Groat
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December 1990

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TABLE OF CONTENTS

LIST OF FIGURES

Figure | Page

VOLUME II: TECHNICAL DESCRIPTION

VOLUME III: ECOLOGICAL EVALUATION

LIST OF TABLES

LIST OF PLATES
(in map packet)

Plate

ACKNOWLEDGMENTS

Project Management

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PART V

MONITORING MARSH MANAGEMENT EFFECTIVENESS

Chapter 9

INTRODUCTION TO THE MONITORING PROGRAM

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Every permit issued by the Louisiana Department of Natural Resources since 1983 for structural marsh management requires that the permittee monitor the environmental conditions of the managed marsh (see chapter 3). Monitoring is conducted to obtain data that can be used in evaluating the management design's effectiveness in achieving stated objectives and, if necessary, in redesigning the management regime.

Controversy has risen over the need for and quality of the data being collected. According to Ensminger (1989), most landowners regard much of the data they are required to collect as unnecessary and of little help to them in managing their land. Scientists counter that the effectiveness of management can be evaluated objectively only if data are collected and analyzed scientifically. They argue that data related to basic ecological processes of wetland loss and habitat change, organic production, nutrient cycling, flux of water and matter, accretion and accumulation of matter, and soil conditions are needed to properly evaluate the consequences of management and its ability to mitigate wetland loss along Louisiana's rapidly subsiding coast.

This part of the report analyzes environmental impacts to evaluate the effectiveness of structural management in achieving stated objectives. Our approach was twofold: (1) we collated and evaluated existing monitoring data provided by permittees (chapter 10), and (2) we evaluated new data collected through remote sensing (chapter 11) and direct field observations and measurements (chapter 12). These evaluations were directed at providing answers to six major regulatory concerns and associated questions (table 47) identified by a technical advisory panel (the Technical Steering Committee) consisting of regulatory agency personnel, private landowners holding marsh management permits, and university researchers. The questions reflect a concern that management promote marsh quantity and health, and secondary production, while minimizing impacts to estuarine-dependent fisheries and cumulative impacts to surrounding wetlands. The questions are presented in order of importance as determined by the committee. As many questions were addressed as time and funding allowed.

Table 47. Questions relating to the environmental impacts of current marsh management practices.

I. To what extent will the marsh management plan influence marsh loss and marsh health?

A. What influence does structural marsh management have on ratios of viable emergent marsh to open water?

1. What are the differences in the loss of emergent vegetated wetlands and aquatic vegetation between areas with and those without structural marsh management using weirs, flap gates, and manipulated impoundments?

2. What impact does structural marsh management have on sediment transport, vertical accretion, erosion, and organic matter accumulation within manipulated impoundments compared to unmanaged areas?

B. How does structural marsh management influence the ability of marsh to maintain long-term primary productivity?

1. How does water-level manipulation affect plant health?

a. How does management influence vascular plant production (emergent, floating, and submerged) compared to that in unmanaged areas?

b. How effective are different types of water control structures in reducing saltwater intrusion and salt concentrations (influence of evapotranspiration)? That is, are salinities within the managed area significantly different from those outside it?

c. How do the various water control structures influence water levels and frequency and duration of inundation in manipulated impoundments compared to unmanaged areas?

d. Do manipulated impoundments influence the rate of sediment and nutrient exchange between the impoundment and the marsh outside it?

2. What impact do soil chemical factors and morphologic criteria (redox, organic and mineral soils, textural class, internal drainage, etc.) have on the effectiveness of marsh management projects (i.e., on wetland loss and productivity)?

a. What are the surface elevation changes (i.e., subsidence rates) in managed sites compared to unmanaged sites?

Table 47. Questions relating to the environmental impacts of current marsh management practices (continued).

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b. Do water-level drawdowns affect the decomposition of soil organic matter, soil salinity, and soil subsidence?

c. How does structural marsh management influence soil oxidation state (i.e., redox potential), presence of toxic compounds, and cycling of nutrients between plants, soil, and water?

II. To what extent will the marsh management plan impact fisheries (e.g., access, production)?

A. What influence does marsh management have on the ability of the marsh to maintain long-term fisheries productivity?

1. How does management affect fisheries production, standing crop, species composition, access to nursery and foraging areas, and harvest of commercially important species?

2. How do the various water control structures and management in general affect ingress/egress of estuarine-dependent fisheries and nekton?

3. What size and type of openings in structures allow optimal movement of organisms?

4. To what extent do managed areas interfere with transport of detritus out of the enclosed area?

5. How does management affect benthic meiofauna, and how do these effects influence fisheries production?

B. Do provisions for ingress and egress of marine organisms result in or contribute to adverse impacts to the managed area caused by increases in salinities, breakdown of soils, loss of vegetation, etc.?

C. If water circulation is reduced, what effect does this have on water quality and consequently on fisheries production in manipulated impoundments?

III. To what extent will the marsh management plan affect wildlife (e.g., habitat quality, production)?

A. What influence does structural marsh management have on the ability of the marsh to maintain long-term wildlife productivity?

Table 47. Questions relating to the environmental impacts of current marsh management practices (continued).

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1. How does management affect wildlife usage compared to usage in control sites?

2. How does management affect standing crop and diversity of waterfowl and furbearers?

B. Does management for waterfowl contribute to wetland loss?

IV. To what extent will the marsh management plan change the marsh type?

A. Is structural marsh management best suited to reverse the course of vegetative succession or to maintain the status quo?

1. What are the differences in plant species diversity, dominance, and composition in managed versus unmanaged areas?

2. How does marsh management affect habitat diversity within the enclosed area?

3. How are the rate of change of species composition and dominance different in managed and unmanaged sites?

4. How does water-level manipulation by various water control structures influence annual and perennial plant species?

5. How effective are the different types of water control structures in reducing saltwater intrusion and salt concentrations (influence of evapotranspiration)? That is, are salinities within the managed areas significantly lower than those outside?

6. What are the surface elevation changes (i.e., subsidence rates) in managed sites compared to unmanaged sites?

7. Does aquatic vegetation in the open-water ponds speed up the rate of encroachment of perennial emergent plant species?

B. Should management that causes a change from one type of marsh to another be considered positive management or a cause of loss of wetland habitat?

V. What is the impact of the marsh management plan on water quality as related to vegetation, fish, and wildlife?

A. How does marsh management affect turbidity, degree of eutrophication, dissolved oxygen content, biological oxygen demand, and concentration of toxics in tidal waters?

Table 47. Questions relating to the environmental impacts of current marsh management practices (continued).

VI. Will the marsh management plan contribute to off-site cumulative effects?

A. How does water-level management affect landscape changes and ecological processes within marshes near the managed area?

B. What is the cumulative effect of using many marsh management plans within one basin or sub-basin? What are the up-basin and down-basin effects?

C. What is the long-term impact of implementing and then abandoning a marsh management plan?

Chapter 10

EVALUATION OF MARSH MANAGEMENT EFFECTIVENESS: MONITORING BY LANDOWNERS

Donald R. Cahoon
Louisiana Geological Survey
Louisiana State University

INTRODUCTION

This evaluation reviews the data base generated from landowner monitoring to determine: (1) the intensity and quality of monitoring, (2) the suitability of the data base for evaluating the effectiveness of structural management, and (3) the effectiveness of structural marsh management in achieving stated objectives. The results of this evaluation will be used to answer as many of the questions posed in table 47 in chapter 9 as possible.

METHODS

We determined the extent of monitoring by reviewing the Louisiana Department of Natural Resources' permit files and noting monitoring data submitted by the permittees. The methods employed in this analysis are described in chapter 7. All data found in the files as of May 15, 1989, were included in the analysis. A monitoring report for Amoco West Black Lake dated September 1989 also was included in the analysis. The quality of the data was determined from the variables measured and the techniques and experimental design used in data collection. We assessed the suitability of the data base for evaluating the effectiveness of structural management by comparing the types and quality of data to the management goals. Management effectiveness was determined by synthesizing all available data.

RESULTS

Review of the permit files revealed that environmental monitoring data were submitted for nine permitted management areas (see chapter 7). Two basic approaches to monitoring were employed in these plans: (1) the landowner conducted the monitoring program in-house with existing personnel or with the assistance of a commercial or government consultant, or (2) the monitoring program was designed and conducted by government personnel from the U.S. Soil Conservation Service and Louisiana Department of Natural Resources with assistance from the landowner. The intensity of monitoring (i.e., frequency and duration of sampling) and the number and types of variables monitored varied considerably between the two approaches. Therefore, for our evaluation we grouped the file reports into two categories on the basis of the monitoring approach (hereafter referred to as the landowner and government-assisted monitoring programs, respectively). A detailed description of most of these management areas is presented in chapter 11.

Some general trends are apparent in the data. Both monitoring programs have focused on measuring plant species composition, water parameters (level and salinity), and habitat change. However, no wetland loss data have been submitted as part of the landowner monitoring data base. Even though health of the marsh, particularly growth of the vegetation, is a primary concern of the managers, neither the landowner or government-assisted monitoring programs provide data on plant growth or on abiotic factors that may affect plant growth, such as water and matter flux, nutrient cycling, sediment distribution and accretion, soil conditions, and evapotranspiration. Nearly all the monitoring programs fail to compare data collected from the managed marsh with data from a nearby unmanaged marsh. Usually, samples collected outside the managed area were collected from the adjacent canal near the water control structure, not from the neighboring marsh.

Landowner Monitoring

Review of the permit files revealed that four landowners conducted the monitoring themselves or with the help of a professional consultant: Cameron Parish Gravity Drainage District No. 4, McIlhenny Company, Little Pecan Wildlife Management Area, and Lafourche Realty Company. The intensity of monitoring and types of variables monitored varied considerably between landowners. Consequently, each monitoring program will be discussed separately.

A review of the file data reveals some general trends. If data were collected outside the managed area, the samples were taken from the canal or adjacent waterway and not from neighboring marsh, except those collected by the Lafourche Realty Company. Only the Lafourche Realty Company monitoring program collected data in nearby unmanaged marshes for comparison or compared post-implementation data with pre-implementation data, if any existed. However, monitoring of the Little Pecan Wildlife Management Area project was more intense and thorough than the file data indicated (Hess et al. 1989; Paille et al. 1989). This report presents extensive monitoring data for this project. Apparently the data have not been filed with the permitting agency, or the data have been lost from the files.

Cameron Parish Gravity Drainage District No. 4

The Cameron Parish project is also known as the Rutherford Beach Restoration project. The project employs active management of water levels (typical two-phase operation) and was implemented in August 1985. A detailed description of this project is presented in chapter 11 (in which it is called Cameron Parish-Creole Canal management area).

Goals. The goals of this plan are to increase marsh habitat (mitigate land loss), improve human access to the marsh, improve waterfowl and furbearer production, and allow for production of marine species (e.g., brown shrimp).

Monitoring effort. Monitoring data on file at the Department of Natural Resources reveals that weekly salinity readings were made at one location inside the managed area and one location outside the managed area in Creole Canal (presumably at the water control structure) for 21 months from October 1985 to July 1987. Water level was measured daily during the same period at one location inside, but no locations outside, the managed area. Monitoring apparently ceased in mid-1987. These data were not reduced or analyzed for statistical trends. Interpretation of the data consisted of evaluating hurricane impacts on marsh salinities and water levels. Heavy rainfall associated with hurricane Juan depressed water salinity in the managed area throughout the fall and winter. In the spring, salinity increased substantially because of low rainfall levels. Hurricane Bonnie in June 1986 breached the management area and increased water and salinity levels. Water levels and water salinity remained high until the managed area could drain and rainwater could dilute the standing water. In 1989, a fisheries study was commenced in the managed area and a nearby unmanaged area. Preliminary results after five months of sampling indicate that more migratory species are present outside than inside the managed area and that the opposite is true for the unmanaged area (Pittman and Piehler 1989). Data for two migratory species, white shrimp and Atlantic croaker, indicate that even though fewer individuals are present in the managed area, they are often larger than those outside the area and relative biomass is often the same at both locations.

Data usefulness. The type of data collected cannot be used to evaluate directly the impact of management on wetland loss or on waterfowl, furbearer, and fisheries production. Data on habitat loss and change, plant growth and species composition, and waterfowl and furbearer harvests are needed from within the managed and a nearby unmanaged marsh, to evaluate the effectiveness of this plan in achieving its objectives.

McIlhenny Company

The McIlhenny Company's project employs fixed-crest weirs to passively manage water levels. The first weir was installed in 1981 in the logging canal (permit Number P810233 in chapter 7). Two additional weirs were installed, one in Three Bayou and the other in Banana Bayou, in 1983 (permit number P821514 in chapter 7). A detailed description of this management area is presented in chapter 11.

Goals. The goals of this plan are to improve waterfowl and furbearer habitat by encouraging the growth of fresh plant species, as well as human access to interior marshes.

Monitoring effort. Monitoring data on file at the Department of Natural Resources shows that monthly salinity readings were taken in the channel above and below the weirs during the 17 months from November 1983 to March 1985. The three letter reports do not indicate how many readings were taken each month. The reports state that vegetation conditions improved substantially and migratory waterfowl and alligator populations increased, but no data were presented to support these statements.

A report by the Soil Conservation Service presents vegetation and salinity data for this management area covering 1982-1986 (U.S. Soil Conservation Service 1986). The results of this four-year survey are summarized in Craft and Kleinpeter (1989). They report that, on average, salinity was lower above the weir. The difference in average annual salinity between the above- and below-weir readings ranged from 0.2 to 1.2 ppt. Vegetation surveys conducted annually from 1982 to 1986 revealed that woody species were gradually being replaced by emergent herbaceous wetland species. Presumably the woody species are being flooded out by increased water levels caused by the weir.

Data usefulness. The data suggest that management has reduced salinity slightly and increased herbaceous plant cover at the expense of woody plant cover. However, the data cannot be used to evaluate directly the impact of management because salinity and plant cover were not compared to an unmanaged area.

Little Pecan Wildlife Management Area

This management area is subdivided into several subunits in which water levels are actively managed with gated structures. Management was implemented in the late 1970s, but not in all subunits at the same time. Because the owners of this property declared bankruptcy in 1987, management has probably been less intense since that year. A detailed description of subunits 6 and 9 is presented in chapter 11.

Goals. The goals of management are to combat wetland loss and to improve waterfowl and wildlife resources.

Monitoring effort. Monitoring data on file at the Department of Natural Resources reveals that in March, April, and May 1984 weekly water-level, salinity, and secchi disk readings were taken at a single station inside and outside (in the canal) the managed area. The short sampling period and lack of comparison data from an unmanaged site severely limit the usefulness of these data for evaluating the effectiveness of management in achieving the plan's goals. However, Hess et al. (1989) and Paille et al. (1989) present monitoring results spanning the 13 yr (1975-1987) since management was implemented. They report extensive measurements of water levels and water salinities. The report states that management promoted the growth of high-quality food plants and the encroachment of emergent vegetation into shallow open-water ponds. No data were presented on plant species composition and growth, however, or on marsh-to-water ratios. Harvests of waterfowl, furbearers, and alligators were monitored annually over the 13 yr. Once management was fully implemented, harvest rates for waterfowl, furbearers, and alligators remained fairly constant.

Data usefulness. The data on file are of little use in evaluating the effectiveness of management at the Little Pecan Wildlife Management Area. The report by Hess et al. (1989), however, indicates a marked improvement with time in vegetation characteristics (although no data were presented to support this conclusion) and a relatively constant harvest rate of waterfowl, furbearers, and alligators. The impact of management on waterfowl, furbearers, and alligators cannot be fully evaluated without data on the production rates in nearby unmanaged marshes.

Lafourche Realty Company

It is the intent of the Lafourche Realty Company's project to actively manage water levels, but all structures are not yet fully operational. Implementation of the management scheme began in 1984 and continues to date. A detailed description of this management project is presented in chapter 11.

Goals. The goals of this management plan are to combat wetland loss and improve furbearer and waterfowl resources.

Monitoring effort. Monitoring data on file at the Department of Natural Resources includes annual monitoring summaries for 1984-1988. Vegetation composition, aquatic fauna composition and standing stock, and hydrology and water chemistry were monitored each year. Data on plant species composition and aquatic fauna were collected from both managed and nearby unmanaged marsh. Plant species composition and marsh-to-water ratios vary considerably in both the managed and unmanaged marshes. Open water is increasing at various locations within the managed area, but decreasing at others. Vegetation at some areas of the managed marsh is becoming less saline in nature. The number of individuals and the mean weight per sample of aquatic fauna are greater (but not significantly) in the managed marsh, but individuals are larger and species diversity is greater in the unmanaged marsh. Water-level fluctuations and flows have been reduced within the managed marsh.

Data usefulness. The monitoring data collected at Lafourche Realty Company is useful for evaluating the effectiveness of marsh management and the overall structural management design. In fact, the management design has been revised several times in response to monitoring data to improve hydrologic conditions within the managed area. Specifically, monitoring has shown that the passive drawdown described in the original management design is not working as intended. Therefore, it is being removed from the operation schedule. In addition, control structures are being redesigned to provide a capability of creating a net through-flow of water across the management area by using tidal energy.

Government-assisted Monitoring

The U.S. Soil Conservation Service and Louisiana Department of Natural Resources are assisting in the monitoring of four management programs: Fina LaTerre Mitigation Bank Site, Vermilion Corporation Platform 1, Avoca Island, and Amoco West Black Lake. Unlike the landowner programs, the intensity of monitoring and types of variables being monitored are very similar at these four sites because the same organizations are monitoring them all. The following variables have been measured for at least one full year at each site: plant species composition, water levels, water salinities, rainfall, wetland loss and habitat change, and hunting/trapping pressure.

Review of the file data revealed some general trends. As in the landowner monitoring programs, if data were collected outside the managed marsh, the samples were taken from the canal or adjacent waterway. Data have not been collected in nearby unmanaged marsh for comparison with the managed marsh. Nor have monitoring data been compared with pre-implementation data except for historical aerial imagery analysis.

The reports by the Soil Conservation Service and Department of Natural Resources identify numerous variables as important to understanding management impacts, from which the above variables were selected (U.S. Soil Conservation Service 1987). However, one variable on the list that is not included in their monitoring programs is primary production of emergent and aquatic vegetation. This appears to be a significant omission because one of the underlying assumptions of structural marsh management is that it enhances plant production. Yet no plant production or biomass data appear in any of the file monitoring programs. Instead, plant biomass and production rates are inferred from estimates of plant cover and/or plant diversity (U.S. Soil Conservation Service 1988c). This methodology is suspect because there is not necessarily any relationship between dominance or diversity and plant biomass or productivity. Some of the most productive systems in the world are monocultures (e.g., *Spartina alterniflora* salt marsh and corn or sugarcane agriculture [Odum 1971]). Wheeler and Giller (1982) demonstrated that species diversity was negatively correlated with aboveground standing crop biomass for 34 stands of herbaceous wetland vegetation. Moore and Keddy (1989) found a negative correlation between species richness and standing crop in their analysis of a broad range of wetland vegetation types from 15 sites encompassing 224 quadrats. In short, a more diverse wetland community is not necessarily more productive than a less diverse community. Management effects on plant growth and biomass should be evaluated on the basis of direct measurements of plant biomass and productivity.

Several other issues related to plant production presented in these reports need to be clarified. The terms "plant biomass" and "plant productivity" are sometimes used interchangeably, which is incorrect. "Plant biomass" is a measure of the amount of plant tissue present at any given moment of an annual cycle, and "plant productivity" is a measure of annual plant production derived from measurements of the turnover of plant tissue. Second, if a net change of water to marsh habitat occurs, calculations of total marsh production must reflect not only the increase in emergent vegetation production, but also the decrease in aquatic vegetation production. Third, increases in marsh acreage should not be interpreted as increases in annual productivity. The area under production has no relationship to the rate at which plants grow. Fourth, an underlying assumption exists in these reports that increased organic production will lead to increased organic matter accumulation and compensate for relative sea level rise (Craft 1989). The accumulation of organic matter will depend on the rate of organic matter production (above- and belowground), the flux of matter into and out of the marsh, and the rate of decomposition of organic matter. These processes either have not been measured or have been measured only indirectly in these reports.

Amoco West Black Lake

The Amoco West Black Lake project actively manages water levels via gravity drainage (i.e., flap-gated, variable-crest structures) and forced drainage (i.e, pumps). The project is described in detail in chapter 11. Management was implemented in fall 1987.

Goals. The primary goals of this management project are to restore marsh in an area that was once marsh but now has become an impounded open-water lake and improve the habitat for waterfowl.

Monitoring effort. Monitoring data on file at the Louisiana Department of Natural Resources includes information on plant species composition and hydrology (e.g., water levels, water salinities, and rainfall) for 1988-1989 and wetland loss measured from aerial photography taken in 1940, 1953, 1968, 1978, 1983, 1985, and September 1988. Trapping/hunting data were provided for the past three seasons. By mid-1989, vegetative cover, area of marsh habitat, and numbers of waterfowl and alligators markedly increased in the managed marsh. The managed marsh had lower water levels and lower salinities (2 vs. 5 ppt).

Data usefulness. This monitoring program provides data useful in evaluating the effectiveness of management because of the site's unique habitat conditions (open-water impoundment with very little marsh). Marsh is being restored at the site. Once the marsh-to-water ratio improves, however, the monitoring program should include measurements from nearby unmanaged marsh and data on the relevant variables not presently being measured (e.g., exchange of matter, plant growth, accretion, etc).

Avoca Island

The Avoca Island project began actively managing water levels in fall 1987. This management area is described in detail in chapter 11 (in which it is called "Avoca Bayou Lawrence").

Goals. The goals of this project are to prevent land loss through erosion control and enhance plant productivity.

Monitoring effort. Monitoring data on file at the Department of Natural Resources includes information on plant species composition, water levels, and land loss. Monitoring data cover fall 1987 through fall 1988. No salinity data were collected because the area is freshwater marsh located along the edge of the Atchafalaya River. On average, water levels are higher within the managed area. There is only one year of plant species composition data and no data from an unmanaged marsh, so no comparisons can be made of these data. Marsh-to-water ratios were calculated from aerial photographs for the years 1940, 1952, 1957, 1971, 1978, 1983, 1985, and 1988. From 1940 to 1985 the ratio of marsh to water decreased from 87:13 to 50:50. By 1988 the ratio had increased to 78:22.

Data usefulness. Plant productivity was not measured, and the data set for plant species composition is too short to be used in an evaluation of marsh management effectiveness. Therefore, the goal of enhancing plant productivity cannot be evaluated. The 1985-1988 data on the marsh-to-water ratio suggest that management enhanced marsh development. However, this can be verified only if the data are compared to data collected during the same period from an unmanaged marsh nearby.

Vermilion Corporation: Platform 1

The Vermilion Corporation project began actively managing water levels in 1987. The area consists of brackish-water marsh that 50 yr ago was freshwater marsh.

Goals. The goals of this project are to restore 1:1 marsh-to-water ratios to 4:1 and improve wildlife and fisheries habitat.

Monitoring effort. Monitoring data on file at the Department of Natural Resources includes information on plant cover, water-level and water salinity measurements taken every two weeks inside and outside the managed marsh from January to August 1988, and land loss calculated from aerial photographs for 1950, 1964, 1980, 1985, and 1988. Analysis of plant and water cover revealed a 37:63 marsh-to-water ratio in 1988. Analysis of aerial imagery revealed that the ratio of marsh-to-water in the managed marsh was 98:2 in 1950 and 51:49 in 1988. The marsh-to-water ratio did not change from 1985 to 1988. The average annual water level was 0.1' higher (1.0' vs. 0.9') and salinity 2 ppt lower (3.8 vs. 5.7 ppt) in the managed marsh.

Data usefulness. Plant cover, water levels, and water salinity data from a managed marsh only are not sufficient to evaluate the effectiveness of management. The aerial imagery analysis can be used for evaluation, but the data collected since implementation of management are very limited, and no data are presented for an unmanaged marsh.

Fina LaTerre Mitigation Bank

The Fina LaTerre Mitigation Bank project has actively managed water levels since 1985. This management area is described in detail in chapters 11 and 12.

Goals. The goals of this project are to reverse land loss trends by encouraging plant growth and controlling water levels and salinities, and to improve waterfowl and wildlife habitat while accommodating fisheries utilization. Specifically, the goals are to reverse the evolution of marsh to open water, reverse the trend toward increased salinity, enhance productivity of the marsh, increase freshwater and sediment inflow, stabilize water levels, and improve water circulation (Kerr and Associates 1987; Soileau 1984).

Monitoring effort. Monitoring data on file at the Department of Natural Resources includes information collected in 1986, 1987, and 1988 on plant species composition, weekly water-level and water salinity measurements, water turbidity, hunting/trapping pressure, and wetland loss calculated from aerial photographs taken in 1953, 1971, 1983, 1985, and 1988, and thematic mapping data (satellite imagery) from December 1984 and January 1988. The thematic mapping analysis included an evaluation of habitat change in a nearby unmanaged marsh. Water salinity was measured at 12 sampling stations within the managed area and on both sides of the water control structures and in Falgout canal and Lake DeCade. Water levels were measured on both sides of the drawdown structure.

No meaningful difference existed between the annual average water salinity inside and outside the managed area. Water salinity inside the managed area was significantly higher in 1988 than in 1987. This was attributed to the approximately 50% less rainfall in 1988. Water-level fluctuations were reduced in the managed marsh, but the annual average water level was slightly higher in the managed marsh. Turbidity of the water inside and outside the structure was not substantially different. The prevalence (diversity) index of plant species increased slightly (3%) from 1986 to 1988. Waterfowl and furbearer harvests remained constant in 1986 and 1987, but declined in 1988. The decline was attributed to decreased hunting effort. Alligator harvests increased consistently all three years, but the degree of hunting effort was not reported. Harvest data from the managed marsh were not compared to data from unmanaged marsh.

Analysis of aerial photographs revealed that the managed marsh originally contained very little open water (99:1 in 1953), but by the time of management implementation in 1985 the marsh-to-water ratio had changed to 66:34. Analysis of aerial imagery for 1985-1988 revealed an increase in the marsh-to-water ratio to 72:28, representing an increase in marsh area of 421 acres. Analysis of LANDSAT thematic mapping data for 1984-1988 revealed a similar trend; the managed marsh had a net increase of 334 acres, but an unmanaged marsh nearby had no increase in marsh habitat.

Data usefulness. This monitoring program has provided more information than most of the others. However, except for aerial imagery analysis, managed and unmanaged marsh data are not compared, nor are pre- and post-implementation conditions. Hence, most of the data cannot be used as proof that the changes are caused by management. As in all the other monitoring programs, plant productivity was not measured directly. Hence, discussions related to plant growth should be interpreted with caution. Rates of freshwater and sediment inflow were not measured, nor were water circulation patterns or soil salinities.

The data presented indicate that the goal of reversing land loss is being achieved and suggest that water levels are being stabilized. However, salinities are not being reduced, and plant and fish production and sediment and freshwater inflow were not measured.

DISCUSSION

The intensity and quality of monitoring data on file at the Department of Natural Resources varies greatly. The intensity of monitoring efforts varies from intermittent to continuous. Some efforts are dedicated to creating long-term data bases; other monitoring efforts have ceased. This lack of uniformity in sampling intensity coupled with the short duration of most monitoring efforts makes it difficult to compare monitoring programs and limits the usefulness of the data for evaluating the overall effectiveness of management.

The quality of monitoring efforts varies because not all programs monitor the same variables. In addition, all monitoring programs are limited in their ability to evaluate the effectiveness of management because they have not monitored all variables in nearby unmanaged marsh. Consequently, even if the monitoring program was of sufficient intensity and quality to detect important changes within the managed marsh, it cannot be concluded unequivocally that management was the cause for the change. For example, was it a good or bad year for ducks, alligators, water level, water salinity, plant growth, and rainfall everywhere within that region, or just within the managed marsh?

The monitoring data base on file at the Department of Natural Resources is small in relation to the number of implemented management areas (approximately 20 fully and 30 partially implemented) and of limited usefulness for evaluating the effectiveness of management. Three monitoring programs, however, provided data of sufficient intensity and quality for use in evaluating the effectiveness of structural marsh management--Lafourche Realty, Fina LaTerre, and Amoco West Black Lake. The data on vegetation cover and aquatic species diversity from Lafourche Realty Company reveal trends within the managed marsh because they have been compared to an unmanaged marsh nearby. Vegetation composition varies widely between stations and years at the Lafourche Realty Company site, but saline species appear to be gradually being replaced by brackish species in the managed marsh. The pattern for the unmanaged marsh is less clear because only three stations exist, and samples have been collected for fewer years. In general, however, the marsh outside does not appear to be getting more saline in nature. At the Lafourche Realty Company property, the aquatic fauna had more and smaller individuals in the managed marsh. The managed marsh also had less diversity of aquatic fauna.

The land loss analysis of Fina LaTerre marshes indicates that the managed marsh gained marsh habitat after management was implemented, whereas the unmanaged marsh acreage did not change. At Amoco West Black Lake, water-level management, particularly when assisted by pumps, clearly can be used to induce colonizing of open-water habitat by vegetation because the area was essentially an impounded open-water lake when management was implemented.

The data from Fina LaTerre can be used to address question I.A.1 in table 47 of chapter 9; Lafourche Realty data are germane to Questions II.A.1 and IV.A.1; and Amoco West Black Lake results can be applied to Question IV.A.2. Most of the other questions cannot be addressed because they require data from unmanaged marsh to answer them or because no data were collected for that variable. However, data from only managed marshes can be used to suggest a trend (questions I.A.1, I.B.1.b and c, and III.A.2). Aerial imagery analysis from Avoca Island suggests that management improved marsh-to-water ratios, whereas results from Vermilion Corporation suggest no effect on marsh-to-water ratios after one year of management. At Amoco West Black Lake and Vermilion Corporation, salinities were lower in the managed marsh than in the canal, whereas at Fina LaTerre salinities at the two locations were not appreciably different. Annual average water levels are higher in managed marshes (Avoca Island, Vermilion Corporation, and Fina LaTerre) than in adjacent canals. Only Amoco West Black Lake, which is undergoing consecutive drawdowns, achieved partly by pumping, had lower annual average water levels within the managed marsh. Harvest data from Fina LaTerre and Little Pecan Wildlife Management Area suggest that waterfowl and furbearer standing crops in managed marshes have changed little with time.

Chapter 11

EVALUATION OF MARSH MANAGEMENT EFFECTIVENESS: ANALYSIS OF HABITAT CHANGE

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INTRODUCTION

Data presented here examine habitat change over time at 16 different managed and corresponding unmanaged marsh areas (table 48; figure 43). This chapter examines differences within managed and unmanaged marshes in marsh-to-water ratios and major marsh classes. Two major concerns addressed by management plans are land loss and change in marsh habitat type--often signatures of salinity change when true measurements are unavailable. This section relies extensively on analysis of historical trends from 1956 to 1988 in marsh-to-water ratios and major marsh types (fresh, intermediate, brackish, and saline) as representative measures. While other factors not represented in the data may be present, our assumption is that deviations from historical trends beyond those expected from random noise or anomalies are attributable to management plans. Managed and unmanaged locations are referred to as "areas." The managed and unmanaged areas, when considered as a pair for comparison to other managed and unmanaged areas are referred to as "sites."

METHODS

Site Selection

The coastal marshlands of southern Louisiana have an undocumented number of dams, levees, and water control structures in diverse physioecological conditions and locations. Weirs and manipulated impoundments implemented since 1980 have been regulated by the Louisiana Department of Natural Resources and the Army Corps of Engineers (see chapter 7). These management locations have been mapped along with state and federal refuges in plate 7. Using this data base, plus knowledge of management efforts prior to 1980

Table 48. Physical characteristics for 16 structural marsh management sites in coastal Louisiana.

Physical Factors	Amoco West Black Lake	Creole Canal	Little Pecan Unit 6	Little Pecan Unit 9
Owner	Amoco, Inc.	Cameron Parish Drain. Dist. 4	Little Pecan Properties	Little Pecan Properties
Physiographic region	CP[1]	CP	CP	CP
Basin	Calcasieu	Mermentau	Mermentau	Mermentau
Parish	Cameron	Cameron	Cameron	Cameron
Major marsh type (1955/1988)				
Managed	F/B	B/B	F/B	F/I-B
Unmanaged	F/I	B/S	F/B	F/I-B-F
Size (ha)				
Managed	2741	1131	173	450
Unmanaged	1305	734	163	399
Implementation date	10/87	08/85	1978	1977
Mgt goals	LL WF, FB	LL, IA WF	LL WF	LL
Management type	A	A	A	A
Control structure type	9 FV PM	1 FV 1 VC	2 FV	2 FG
Distance from coast (km)	32	1	15	15
Relative sea level rise (cm/yr)	0-0.5	1.5-2.0	1.5-2.0	1.5-2.0

Table 48. Physical characteristics for 16 structural marsh management sites in coastal Louisiana (continued).

Rockefeller Refuge	Vermilion Corp	Vermilion Bay Land	State Wildlife Refuge	McIlhenny Co.	Marsh Island Refuge
State of Louisiana	Vermilion Corp.	Vermilion Bay Land	State of Louisiana	McIlhenny Company	State of Louisiana
CP	CP	DP	CP	DP	DP
Mermentau	Mermentau	Vermilion-Teche	Vermilion-Teche	Vermilion-Teche	Vermilion-Teche
Cameron	Vermilion	Vermilion	Vermilion	Iberia	Iberia
B-I/I B/B	I-F/I F/I	B-I/B I/B	B/B B/B	I-F/B I/B-I	B/B B/B
2084 1604	379 156	444 282	1470 1540	793 867	680 749
1958	06/66	08/87	1967	1983	1959
WF FB	LL, WF FB	WF, FB LL	WF	WF, FB IA	WF FB
A	A	A	P	P	P
2 FV	2 DG	1 FV	2 FC	3 FC	1 FC
5	6	4	1	1	3
1.5-2.0	1.0-1.5	0.5-1.0	0.5-1.0	0.5-1.0	1.0-1.5

Table 48. Physical characteristics for 16 structural marsh management sites in coastal Louisiana (continued).

	Avoca Bayou Lawrence	Fina/Falgout Canal	Louisiana Land and Exploration
Owner	Avoca, Inc.	Fina Laterre, Inc.	Louisiana Land and Exploration Co.
Physiographic region	DP	DP	DP
Basin	Atchafalaya	Terrebonne	Terrebonne
Parish	St. Mary	Terrebonne	Terrebonne
Major marsh type (1955/1988)			
Managed	F/F	F/F-I	I-F/B-S
Unmanaged	F/F	F/F-I	B/B-S
Size (ha)			
Managed	248	2768	3001
Unmanaged	261	692	2270
Implemantation date	10/87	04/85	1956
Mgt goals (cm/yr)	LL WF	LL	LL WF
Management type	A	A	P
Control structure type	1 VC 1 DG	4 FC 1 VC	20 FC 3 PG
Distance from coast (km)	44	16	11
Relative sea level rise	1.0-1.5	>2.5	>2.5

Table 48. Physical characteristics for 16 structural marsh management sites in coastal Louisiana (continued).

Fina Bayou Chauvin	L. H. Ryan	Lafourche Realty Co.
Fina Laterre, Inc.	L. H. Ryan Estates	Lafourche Realty, Co.
DP	DP	DP
Terrebonne	Barataria	Barataria
Terrebonne	Lafourche	Lafourche
F/I F/I	B/B-S B/B-S	I/S F/S-B
241 273	92 210	1359 2704
12/84	03/86	08/84
LL	LL, IF IW, AT	LL, FB WF, AT
P	A	P
2 FC	2 FV	4 CL 2 SF
14	5	6
2.0-2.5	1.0-1.5	1.0-1.5

[1]The abbreviations used in this table have the following meanings:

Table 48. Physical characteristics for 16 structural marsh management sites in coastal Louisiana (continued).

Physiographic region

DP - deltaic plain; CP - chenier plain

Management goals

LL - land loss
WF - waterfowl
FB - furbearer
IW - indigenous wildlife
IF - indigenous fish
IA - improved access
AT - anti-trespassing

Structure types

FC - fixed-crest weirs
VC - variable-crest weirs
FG - flap-gated culverts
PM - pumps
PG - plugs, dikes, or dams
FV - flap-gated structure with a variable-crest weir on the other end
SF - slotted fixed-crest weir
FL - flood gate, usually a guillotine-type structure
DG - double flap-gated structure, with or without a culvert
CL - culvert
CG - circulation gap (usually cut in spoil banks to allow water flow)
BK - blockade/fence (usually cut in spoil banks to allow water flow)
WS - unspecified water control structure

Marsh type

F - fresh
I - intermediate
B - brackish
S - saline (where more than one designation appears, the first marsh type is dominant while the second type is a significant position)

Net habitat change

\+ - net increase
\- - net decrease
0 - no change

Management type

A - active
B - passive

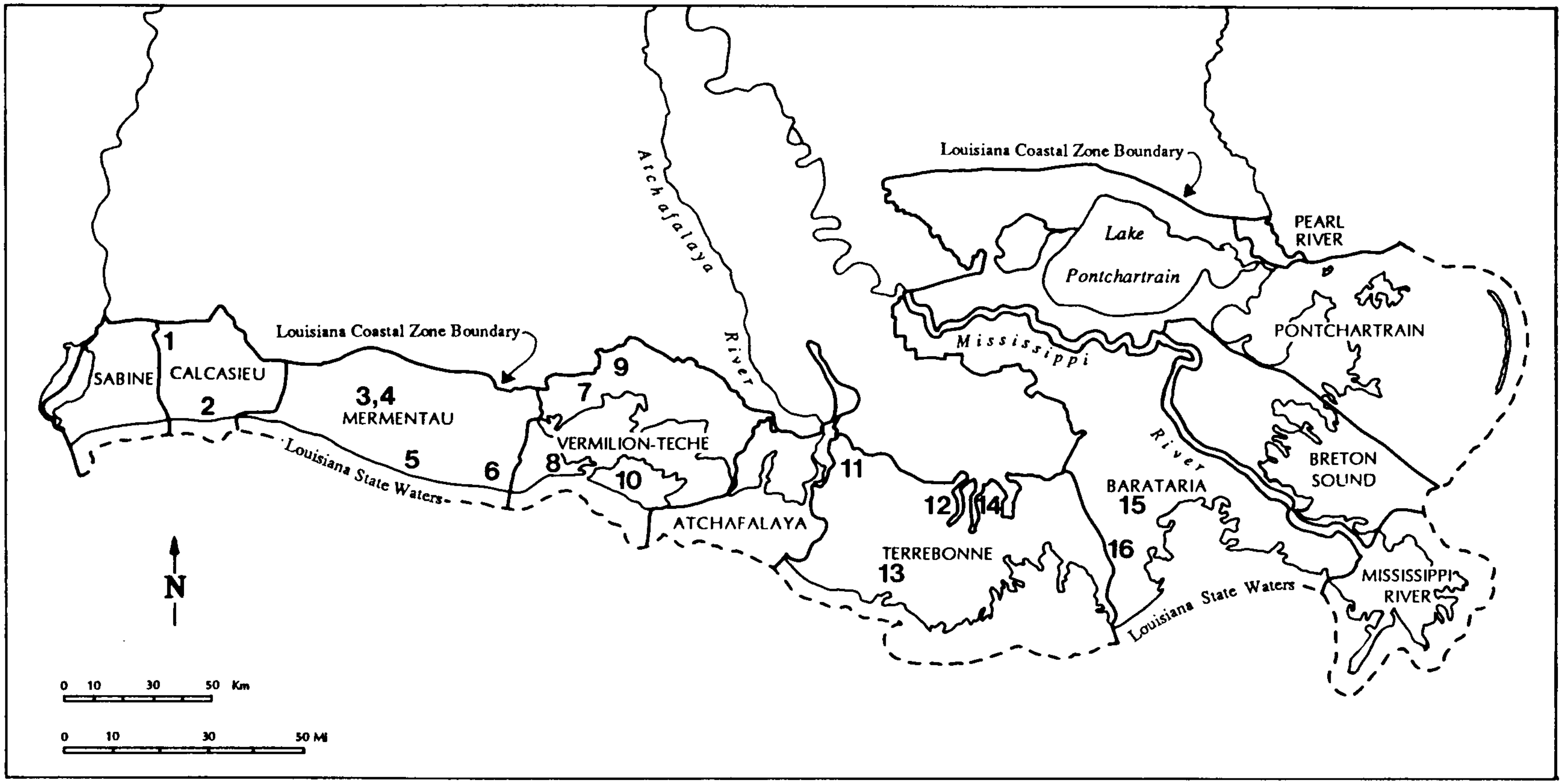

Figure 43. The 16 study sites.

(e.g., weir management implemented by the Louisiana Land and Exploration Company), with the assistance of the Technical Steering Committee, we selected sites that offered the most balanced combination of biological, ecological, and physical factors.

Study sites were first considered on the basis of physiographic region (delta plain, chenier plain), hydrologic basin, type of management (active or passive), degree of monitoring history, major marsh type (fresh, intermediate, brackish, or saline) and operational status (fully or partially implemented). We attempted to include two sites from each marsh type in each physiographic region for a total of 16 sites. However, integrating critical site-to-site selection criteria such as degree of plan implementation, maintenance, and duration of implementation resulted in less-than-optimal representation of some criteria (e.g., chenier plain). Managed areas were then paired with unmanaged areas, which were chosen for compatibility based on equivalent size, marsh type, degree of environmental degradation, physical proximity to managed marsh, and degree of hydrologic alteration. Historical and personal knowledge from government, university, and landowner representatives both within and outside of the Technical Steering Committee, as well as technical information derived from U.S. Geological Survey 1:24,000 topographic maps, were drawn upon for verification of site characteristics. The sites selected for this study represent the best available examples of operational marsh management plans in Louisiana.

Habitat Map Preparation

Historical habitat maps, covering five periods for both the managed and unmanaged areas at the 16 sites, were prepared by a team under the direction of Karen Wicker of Coastal Environments, Inc. Coastal Environments performed both the photointerpretation and digitizing for the Environmental Protection Agency through a subcontract with Lee Wilson and Associates. Much of the following description of the methods used was taken from Wicker (1989).

Habitat maps were prepared at a scale of 1:24,000; U.S. Geological Survey quadrangles were used as the control or base map. Unit boundaries were delineated on each new, 1:24,000 map and a pre-cut sheet of mylar taped onto the 1:24,000 map for tracing the mapping unit outline. Once several geographical features were drawn to serve as control points for alignment with the 1955-1956 series of photographs, the mylar was removed from the quadrangle map and placed directly over the 1955-1956 photographs. The 1955-1956 photo series consisted of quad-centered, 1:24,000, black-and-white controlled photomosaics prepared by Ammann International Corporation (now Petroleum Information Service) or Tobin Aerial Surveys, Inc. These photographs were in the files of Coastal Environments and had been used in the previous wetland mapping projects sponsored by the U.S. Fish and Wildlife Service and the Department of Natural Resources (Wicker et al. 1980, 1981). Photomosaics were composed of photographs taken in 1955 and 1956 or a combination of photographs from both years. A light table was used to illuminate the photomosaics and facilitate habitat delineations. As a final check, the mylar map was repositioned over the quadrangle topographic map in order to correct the positions of features distorted on the 1955-1956 photomosaics. The 1955-1956 map, once registered with the quadrangle topographic map, became the control base for subsequent maps. Six sets of longitude-latitude tic marks outside the perimeter of each unit were marked for alignment during the photointerpretation and digitizing processes.

Habitat designations on the 1955-1956 series of maps corresponded with the 1955-1956 habitat maps prepared for the U.S. Fish and Wildlife Service and the Department of Natural Resources (Wicker et al. 1980, 1981). The alphanumeric labeling system for habitat identification was adapted from Cowardin et al. (1979) and expanded to include more modifiers (Wicker 1980, 1981). The interpretation of marsh zones relied heavily on a Louisiana coastal vegetation map prepared by O'Neil (1949) and personal communication with O'Neil in 1980. However, the most recent 1955-1956 series is more detailed in that it depicts habitat polygons as small as 0.1 ha and as narrow as trappers' ditches (4-6 m).

The 1978 habitat series was prepared by taping a sheet of mylar to the 1955-1956 habitat map and positioning the mylar set over the 1978 color infrared photograph to delineate habitat boundaries. The 1978 color infrared photographs were at a scale of 1:24,000 and bound into volumes especially prepared by the National Aeronautics and Space Administration and on file with R. H. Chabreck (Professor, School of Forestry, Wildlife, and Fisheries, Louisiana State University). The photographs were often dark, making it difficult to distinguish water bodies, even with the use of light tables. Because some photographs were distorted, especially on the edges, the habitat map had to be frequently checked against the quadrangle topographic map to ensure alignment of features, such as canals, levees, and water bodies not present on the 1955-1956 interpretations. In some instances, the flight lines did not overlap, thereby resulting in missing coverage. In these cases, interpretations were extrapolated using the topographic maps and the next series of aerial photographs (1981-1983). Marsh zones were depicted on the 1978 interpretations primarily on the basis of habitat data that Chabreck provided to Coastal Environments during the previous mapping project funded by the U.S. Fish and Wildlife Service and Department of Natural Resources (Wicker et al. 1980, 1981).

The marsh zones for the 1981-1983, 1985, and 1988 series were designated using data from a variety of collateral sources (i.e., maps, reports, land managers, coastal scientists) and field identification of photographic signatures. Maps of the individual units were sent to Greg Linscombe of the Department of Wildlife and Fisheries for delineation of marsh zones because of his work with Chabreck in preparing the 1988 Louisiana coastal vegetation map (Chabreck and Linscombe, in press). As originally planned, marsh zones for the 1981-1983 and 1985 map series were to be extrapolated using the 1978 and 1988 maps prepared by Chabreck and Linscombe in combination with photographic signatures. Data on salinity and vegetation were very limited in the monitoring reports for 10 of the 16 management units.

A photographic signature is the characteristic appearance of a habitat that can be described in terms of color, tone, texture, shape, size, pattern, site (location), association, and shadow (Avery 1969; Ray 1960; Reeves et al. 1974). Previous mapping reports provide examples of habitat signatures for coastal Louisiana (Wicker 1980, 1981). Distinguishing brackish from saline marsh zones is very difficult, however, in coastal Louisiana, where these zones are shifting because of changes in environmental conditions caused by management practices, saltwater intrusion, and freshwater introduction (as in the vicinity of the Atchafalaya River).

Delays in preparation of the 1988 "Vegetation type map of the Louisiana Coastal Marshes" (Chabreck and Linscombe, in press) required us to map some units solely on the basis of habitat signatures and the general trend of inland movement of the saline marsh zone. When we received the last marsh zonation maps for 1988 from Linscombe, it was evident that there were inconsistencies in several of the last units sent to him for marsh zone delineation: the Louisiana Land and Exploration Company, Lafourche Realty-Bayou Lafourche, L.H. Ryan-Bayou L'Ours, Amoco West Black Lake, and McIlhenny Company sites. Consultation with Linscombe verified that in several instances the saline-brackish interface had remained stable between 1978 and 1988 rather than regressing at the 1956-1978 rate. However, one unit, L.H. Ryan-Bayou L'Ours, was shown as entirely saline in 1978, but designated as brackish marsh in 1988 (Chabreck and Linscombe, in press). We know of no major shift in the vegetation zone in this area during the past 10 yr and therefore assume that the difference in mapping is more attributable to the field sampling grid size and marsh zone delineation methodology than to actual marsh zone shifting.

The saline-brackish boundary on the Louisiana Land and Exploration Company property shows a shift between 1978 and 1988 that may also reflect the difference in the grid sampling network. The intermediate marsh remaining on the Amoco West Black Lake property is on higher ground, as denoted by the presence of pimple mounds, in an area that has become brackish and eroded. The intermediate zones were not, however, distinguishable by photographic signatures in 1988 imagery.

The control site for the Lafourche Realty unit was mapped as saline marsh because of the 1956-1978 transgressive trend of saline marsh movement and the dominant saline marsh signatures. This unit has continued to break up and does have <u>Spartina</u> <u>alterniflora</u>, a saline marsh indicator. With the use of a finer sampling grid, however, Chabreck and Linscombe depicted a narrow zone of brackish marsh commonly characterized by <u>Spartina</u> <u>patens</u> near the hurricane protection levee east of Bayou Lafourche. As with the L.H. Ryan unit, this unit has pockets of <u>Spartina</u> <u>patens</u> on the slightly higher, subsiding ridges within the saline marsh zone. Because of the variation in signatures from year to year and even from photograph to photograph on the same flight line, these smaller marsh zones cannot consistently be accurately determined solely from aerial photointerpretation. The 1978-1988 habitat maps were corrected to correspond to the 1988 zones designated by Linscombe and Chabreck for redigitizing.

These units exemplify problems associated with comparing changes in saline and brackish marsh zones through time on the basis of data acquired at different grid sizes and mapped at different scales. The absence of detailed, site-specific collateral information and field checking (ground truthing) of aerial photographs near the time of the flight may preclude accurate identification of zones in areas where fluctuating salinity regimes are associated with management practices. The habitat maps are, however, a good measure of land loss to the extent that they reflect the water levels when the photographs were taken. High water levels are associated with a prevalence of open water or aquatic vegetation cover in fresher areas. Low water levels reveal flats in areas where the water levels have been lowered as part of the management plan or where water has been blown out of the marsh by offshore winds. The latter commonly occurs during winter in marshes without water control structures. The flats may be bare, if they have been recently exposed or are intertidal, or vegetated if they have been exposed for several weeks. The origins of flats, either vegetated or unvegetated, and aquatic beds must therefore be considered in conjunction with management objectives in evaluating land loss.

Preparation of Digital Databases

We used the digitized data base to calculate the areal extents of each habitat in 1955-1956, 1978, 1981-1983, 1985, and 1988, and then depict them on computer-generated maps (see procedure described below) of the 16 managed and unmanaged areas.

The data base used to produce the maps and two primary data sets (habitat and habitat change) for the major habitats was compiled by aggregating habitats described in the U.S. Fish and Wildlife Service coding system into 15 basic habitat classes for the analyzed periods from 1956 to 1988 (Cowardin et al. 1979: vol. 6, table 6, pp. 223-27; Wicker 1980). We used 15 habitat classes because most coastal projects do not require the level of detail of the Cowardin system. These 15 aggregated habitat classes are natural water bodies, artificial water bodies, aquatic vegetation, fresh marsh, intermediate marsh, brackish marsh, saline marsh, swamp forest, forest, shrub/scrub, shrub/scrub spoil, agricultural/pasture, developed, inert (primarily flats), and beach. Chapter 6 lists these major habitat types with their U.S. Fish and Wildlife Service Cowardin codes.

The digital habitat data were incorporated into the vector-based geographical information system and map overlay and statistical system (MOSS) of the Coastal Management Division (Department of Natural Resources) and converted from a MOSS vector to an ERDAS (Earth Resources Data Analysis System) cell format. These habitats can be more quickly and efficiently compared with ERDAS than with MOSS, especially if large areas are involved. The habitat data for 1955-1956, 1978, 1981-1983, 1985, and 1988 were converted to ERDAS format for comparison of the managed and unmanaged areas, and habitat change statistics were generated from the data base by comparing the five periods.

Imagery (either film or satellite) may reflect variations in weather and tidal conditions that affect water levels and therefore influence habitats. The comparisons based on the data sets derived from the imagery may also reflect these variations, and thus the total area covered in all five periods for a given site may vary because of slightly different interpretations caused by the weather.

Because of differences in classifications between years, habitats were aggregated into water, marsh, and land categories for between-year comparisons. The water class comprises natural and artificial water bodies and aquatic vegetation; the marsh class comprises fresh, non-fresh, intermediate, brackish, and saline marshes, and swamp; and the land class comprises forest, shrub/scrub, shrub/scrub spoil, agriculture/pasture, inert, and beach.

We used the ERDAS matrix routine to create a nine-class change map by hydrologic unit for 1956-1988 by comparing water, marsh, and land classes for each date. The recoded classes used to create change maps of each managed or unmanaged unit were aggregated to produce the most informative depiction. The change matrix was restricted to nine classes because a larger matrix would have generated a confusing number of classes and required excessive storage space on the computer system. In most cases, an analyst familiar with Louisiana's wetlands can determine the types of habitat changes occurring from the change maps.

Data Reduction

Two primary data sets, habitat category and habitat change, were generated and reduced to four secondary data sets detailing historical habitat change in both managed and unmanaged areas (major marsh type change, marsh-to-water ratios, 1985-1988 marsh change and net water-to-marsh change, and aggregated habitat change since management implementation). Historical changes in four major marsh types (fresh, intermediate, brackish, and saline) were graphed from the values contained in the habitat category data set for all managed and unmanaged areas. From the raw data set, which was divided into the 15 habitat categories, habitat occurrences were noted and synthesized to create a measure of habitat diversity based on the number of different habitats occurring at a given area during the analysis periods. We particularly noted effects of management and subsequent habitat gains or losses. Because of possible errors in registration and digitization, we did not count habitats of less than 0.75 ha.

We used the marsh-to-water ratios and marsh-type graphs to analyze temporal and spatial trends, with emphasis on comparing managed to unmanaged areas and assessing site-to-site differences. From the habitat category data set, an aggregate of marsh (fresh, intermediate, brackish, saline, and aquatic vegetation) and water (natural and artificial water bodies) were synthesized into graphs showing marsh-to-water ratios over time in all managed and unmanaged areas. Here again analysis focused on post-implementation trends as compared to historical trends in both managed and unmanaged marsh, as well as on site-to-site differences. Log scales were found to be more suitable for visual delineation of trends and quantification because of the often small increments of change. It should be noted that care must be exercised in analyzing marsh-to-water ratios because of compression and expansion of slopes created by the log scale.

We created table 49 from the habitat category data so that net habitat change since management implementation could be examined. For this change analysis, the 15 habitat classes were aggregated into 6 key habitats: marsh (fresh, intermediate, brackish, and saline); aquatic vegetation; water bodies (natural and artificial); total water bodies (natural, artificial, and aquatic vegetation); non-spoil shrub/scrub; and other (forest, swamp, spoil shrub/scrub, agriculture/pasture, developed, beach, and inert). This allowed ready insight into where habitat changes had occurred and, to a certain extent, how the areas were reclassified. Site-to-site and intersite comparisons could then be made. Where possible, we chose the data point nearest to, but not after, the management implementation date for comparison to the 1988 data. For some sites (e.g., Lafourche Realty Co.), however, we chose a date slightly after implementation because a large gap existed between

Table 49. Net habitat change since implementation at managed and unmanaged areas. (Changes of less than 3% should be interpreted with caution.)

	Amoco West Black Lake 1985-1988[a]				Creole Canal 1985-1988				Little Pecan Island 6 1978-1988			
	Managed		Unmanaged		Managed		Unmanaged		Managed		Unmanaged	
Classification	ha	%[b]	ha	%	ha	%	ha	%	ha	%	ha	%
Water	-207	-8	-25	-2	-81	-7	-6	-1	16	9	5	2
Aquatic vegetation[c]	0	0	0	0	0	0	0	0	0	0	0	0
Total water	-207	-8	-25	-2	-81	-7	-6	-1	16	9	5	2
Marsh	25	1	4	<1	65	6	-6	-1	-17	-12	-7	-6
Shrub/scrub	<1	<1	<1	<1	0	0	0	0	0	0	0	0
Other[d]	184	7	19	1	17	1	12	2	5	3	7	4

	Little Pecan Island 9 1978-1988				McIlhenny Co. 1983-1988				Marsh Island Refuge 1956-1988			
	Managed		Unmanaged		Managed		Unmanaged		Managed		Unmanaged	
Classification	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Water	1	<1	-1	-<1	-1	-<1	15	2	120	18	95	12
Aquatic vegetation	<1	<1	0	0	0	0	0	0	0	0	0	0
Total water	2	<1	-1	-<1	-1	-<1	15	2	120	18	95	12
Marsh	-6	-1	-6	-1	-15	-2	-9	-1	-135	-20	-125	-17
Shrub/scrub	0	0	0	0	9	1	7	1	0	0	0	0
Other	3	1	5	1	5	1	-12	-1	16	2	35	4

Table 49. Net habitat change since implementation at managed and unmanaged areas (continued).

	Avoca Bayou Lawrence 1985-1988				Fina/Falgout Canal 1985-1988				Rockefeller Refuge 1956-1988			
	Managed		Unmanaged		Managed		Unmanaged		Managed		Unmanaged	
Classification	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Water	-72	-29	-112	-43	-80	-3	10	1	377	18	156	10
Aquatic vegetation	-1	<1	104	40	41	1	8	1	0	0	0	0
Total water	-73	-29	-9	-3	-39	-1	18	3	377	18	156	10
Marsh	6	2	-11	-4	-80	-3	-29	-4	-428	-20	-163	-10
Shrub/scrub	2	1	-1	<1	93	3	<1	<1	0	0	0	0
Other	65	26	20	7	24	1	12	2	46	2	5	<1

	Vermilion Corp. 1956-1988				Vermilion Bay Land 1985-1988				State Wildlife Refuge 1956-1988			
	Managed		Unmanaged		Managed		Unmanaged		Managed		Unmanaged	
Classification	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Water	15	4	-8	-5	-49	-11	-6	-2	203	14	109	7
Aquatic vegetation	1	<1	0	0	0	0	0	0	0	0	0	0
Total water	16	4	-8	-5	-49	-11	-6	-2	203	14	109	7
Marsh	-20	-6	-51	-34	-13	-3	-5	-2	-221	-15	-120	-8
Shrub/scrub	0	0	0	0	0	0	0	0	0	0	0	0
Other	6	2	62	39	63	14	11	4	20	1	11	1

Table 49. Net habitat change since implementation at managed and unmanaged areas (continued).

Classification	Louisiana Land and Exploration Co. 1956-1988 Managed ha	%	Unmanaged ha	%	Fina/Bayou Chauvin 1982-1988 Managed ha	%	Unmanaged ha	%	L.H. Ryan 1985-1988 Managed ha	%	Unmanaged ha	%
Water	419	14	202	9	76	32	122	45	-5	-5	5	2
Aquatic vegetation	0	0	0	0	-18	-8	3	1	0	0	0	0
Total water	419	14	202	9	59	24	125	46	-5	-5	5	2
Marsh	-482	-16	-200	-9	-49	-21	-104	-38	4	4	-2	-1
Shrub/scrub	0	0	0	0	-15	-6	-31	-11	0	0	0	0
Other	63	2	1	<1	7	3	10	4	1	1	-3	-1

Classification	Lafourche Realty Co. 1985-1988 Managed ha	%	Unmanaged ha	%
Water	52	4	135	5
Aquatic vegetation	0	0	0	0
Total water	52	4	135	5
Marsh	-62	-5	-121	-5
Shrub/scrub	0	0	-14	-1
Other	11	1	-9	-<1

[a]Intervals were chosen to match the managed period as closely as possible to the interval for which aerial photographs were available.
[b]Percentages may not balance due to slight errors in rounding values and the digitizing process.
[c]Values for aquatic vegetation are included in total water.
[d]Habitat category "other" includes forest, swamp, shrub/scrub (spoil), agriculture/pasture, developed beach, and inert classifications.

the closest pre-implementation data point and management implementation. Only where the duration of management was not thought to have substantially affected pre-management habitat composition (e.g., no drawdown) were these adjustments made.

The 1985 and 1988 photointerpreted data were subjected to statistical analysis by randomization tests (Fisher 1973; Siegel and Castellan 1988) to compare managed and unmanaged marsh at the 16 sites. The null hypothesis was that the managed marsh differed from unmanaged marsh with respect to marsh area change. One-tailed tests (alpha, .05) were appropriate because the plans are designed to retain or increase marsh area. Two methods were used. The first analyzed the difference between the percentage of the area that was marsh in 1985 and the percentage that was marsh in 1988. Second, water-related marsh change was analyzed by calculating the difference between the percentage of area that changed from water to marsh ("marsh gain") and the percentage of area that changed from marsh to water ("marsh loss") during the same interval.

RESULTS AND DISCUSSION

Data interpretation is presented in two parts: a description of each of the 16 sites based on aerial photographs and topographic maps, and intrasite comparisons based on marsh-to-water ratios, marsh type change, and other data sets described in the methods section of this chapter. The site descriptions serve two functions. First, they introduce the reader to physical factors affecting local hydrology and the comparisons made (e.g., distance between managed and unmanaged marsh) for each site. Second, they describe habitat change data within sites both from historic and from pre- and post-management perspectives. The site descriptions are followed by intersite comparisons and discussion of trends.

Site Descriptions

Site names and a basic physical description of site parameters are presented in table 48. Locations for the 16 sites are shown in figure 43.

Amoco West Black Lake

The managed area of Amoco West Black Lake (site 1, figure 43) is located south of the Intracoastal Waterway west of Black Lake in the Calcasieu basin. The unmanaged area is adjacent to the managed. A dense concentration of oil field canals borders both sites on the east, but almost no canals exist within site boundaries. The area is characterized by broad expanses of open water and broken marsh. Local hydrology is largely dominated by the Calcasieu Ship Channel and the Calcasieu Lake system. The active management plan addresses the primary goal of controlling or reversing land loss through the use of variable-crested structures with flap gates. Management commenced in 1987. Managed and unmanaged soils are Hapaquolls-Hydraquents association (moderately saline). (Chapter 6 discusses soil taxonomy.)

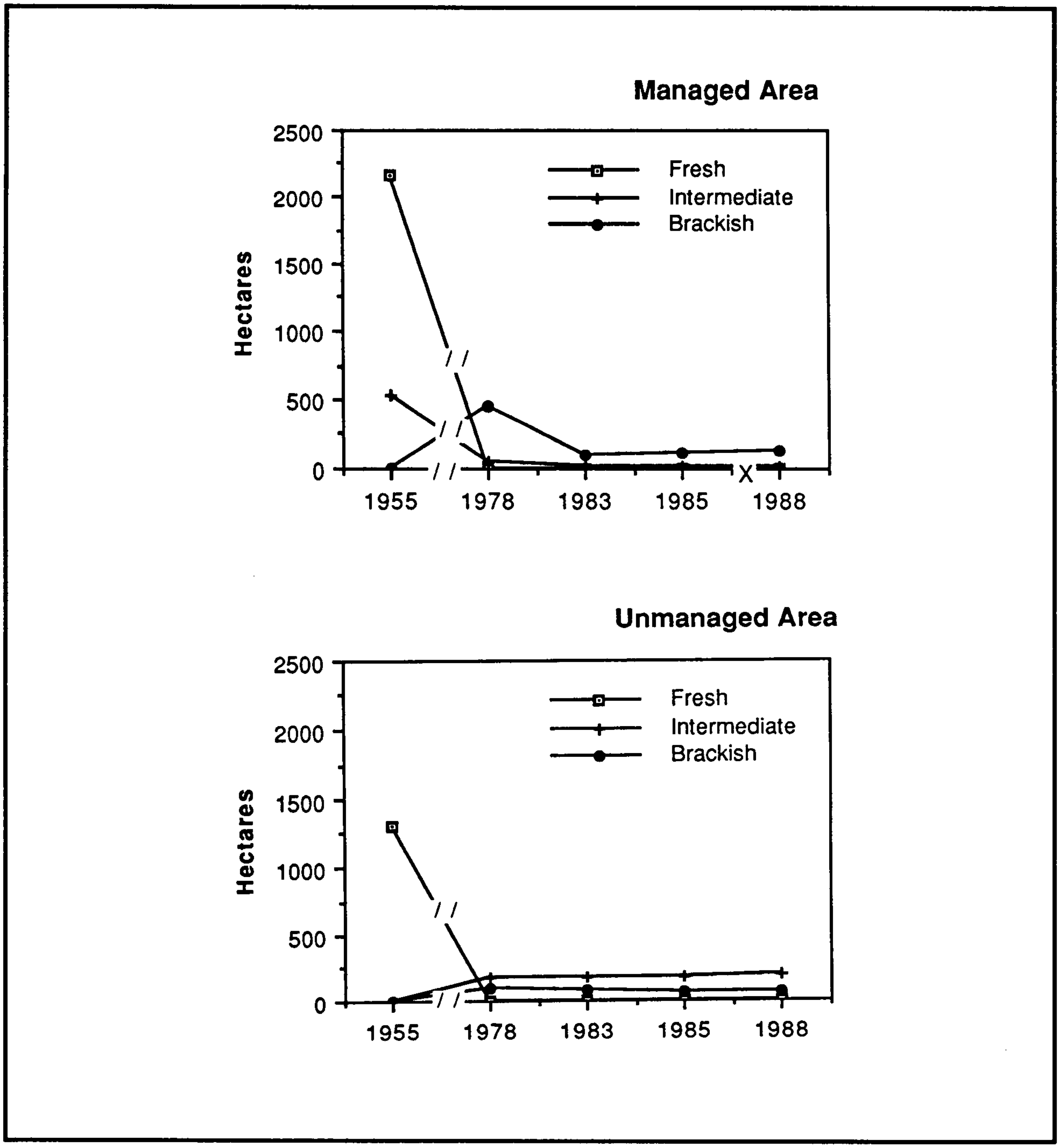

Figure 44. Areas of major marsh types in the managed and unmanaged areas at Amoco West Black Lake, 1955-1987. The "X" denotes the date of management implementation.

Pronounced habitat changes occurred during 1955-1978 in the unmanaged area (figure 44). For example, 78% of the nonwater habitat converted to open water. A similar conversion of nonwater habitat to open water, affecting 57% of the nonwater habitat, occurred during the same period in the managed site before management. Salinity changes are indicated by conversion of once predominantly fresh marsh to intermediate and brackish marshes at both sites. Both managed and unmanaged areas declined by more than three orders of magnitude during 1956-1978. Ratios of unmanaged marsh to water remained comparatively stable during 1978-1988 (figure 45). Before management, the marsh-to-water ratio in the managed area continued to decline during 1978-1983 and reached a low of approximately 0.04:1. The managed marsh improved slightly from 1983 to 1988, though marsh:water remained below 0.1:1 (management began in 1987). Marsh-to-water ratios are currently extremely low at both areas. Since management implementation, habitat diversity has increased slightly at both managed and unmanaged areas. The artificial water bodies, spoil shrub/scrub, and inert categories account for the managed area increases. The habitat diversity increase in the unmanaged area was attributable to increases in inert habitat.

Since plan implementation, the major habitat transition has been the loss of water habitat. Table 49 shows the corresponding increase in the "other" category arising from classification of flats as "inert" or land. Such habitat changes can reasonably be interpreted as the result of seasonal or weather changes (such as drought, offshore winds) or planned drawdowns. These conditions would create mud flats or a number of different partially vegetated flat habitat classes. The absence of ground-truthing data precludes confirmation of this interpretation. Anomalies of this nature can be expected to occur during the course of data retrieval.

Results of management are difficult to interpret for this site because of the late date (October 1987) of implementation. However, habitat change does not appear to differ between managed and unmanaged marsh. Habitat stability reflected in data since 1983 render Amoco West Black Lake particularly suited to further monitoring. More specifically, the preponderance of water at the managed area presents the opportunity for careful observation of emerging habitats.

Creole Canal

The Creole Canal management area is in a swale between two chenier ridges in the southwestern portion of the Mermentau basin (site 2, figure 43). Its boundaries are formed by Front Ridge Road to the north, Creole Canal to the east, portions of the Mermentau River, and an unnamed road to the south. Sections of this unnamed road as well as three canals bisect the center of the managed area. Located 8 km to the east, the unmanaged marsh can be differentiated from the managed marsh, in part, by the absence of a southern chenier boundary. The unmanaged area's boundaries are Hog Bayou to the south, a canal spoil bank to the east, Louisiana highway 82 to the north, and an unnamed road on the western perimeter. Two location canals, three primary oil canals, and many abandoned and overgrown canals cross the control site interior. Hog Bayou and the lower Mermentau River represent the major potential sources of salinity increases. The plan's objectives are to reduce land loss, enhance waterfowl and furbearer habitat, and improve access (table

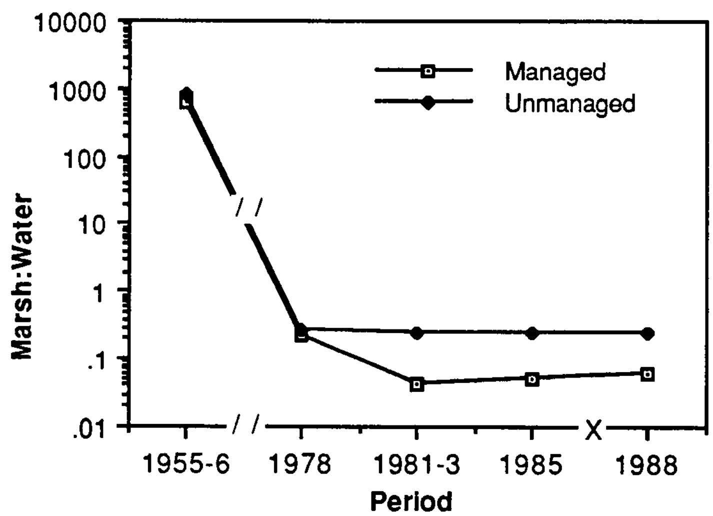

Figure 45. Marsh-to-water ratios in the managed and unmanaged areas at Amoco West Black Lake, 1955-1987. The "X" denotes the date of management implementation.

48). Four flap-gated, variable-crest weirs and a single open culvert have been used in implementing this active management plan. Both managed and unmanaged soils are Haplaquolls-Hydraquents association (moderately saline). (Chapter 6 discusses soil taxonomy.) Management commenced in 1985.

In contrast to the marsh type change in the unmanaged marsh, no changes have occurred in the managed marsh (figure 46). In addition to the influence of management, this difference may be attributable in part to the distance between areas (8 km), the absence of a southern chenier ridge at the unmanaged area, and the fact that the unmanaged area has not been removed from higher-salinity influences of the Mermentau River. Marsh-to-water ratios (figure 47) show trends of increasing rates beginning after the 1985 analysis period in the managed marsh and after 1978 in the unmanaged. The 1988 increase in the marsh-to-water ratio at the managed area resulted primarily from the net gain of 65 ha of marsh in combination with an 81-ha loss of water (table 49). The increase in managed marsh reverses a previous 8-yr gradual decline. The changes causing marsh to increase at the two areas are quite different. Increases in managed marsh-to-water ratios resulted from the above-mentioned marsh gain and water loss, whereas the increase in the unmanaged area was created by a 6-ha loss in both marsh and water. This observed difference evidences the influence of even small losses of water on marsh-to-water ratios. Marsh-to-water ratios in the managed area have historically been lower than those in the unmanaged area at this site. Since implementation in 1985, the managed area's marsh-to-water ratio has had increases similar to those in the unmanaged area. The addition of spoil shrub/scrub at the managed area increased post-management habitat diversity. Diversity did not change at the unmanaged area. Overall changes occurring at Creole Canal seem to indicate positive management effects.

<u>Little Pecan Unit 6</u>

Both the managed and unmanaged areas of Little Pecan Unit 6 are bordered to the north by Little Pecan Bayou and to the southeast and west by oil exploration canals (site 3, figure 43). The sites are situated adjacent to one another 6 km south of Grand Lake and 6 km east of the Mermentau River. Hydrology is dominated by the Little Pecan Bayou drainage and by that of the Mermentau River and Grand Lake systems. Several oil exploration canals are in the immediate area, and 3 km to the east many canals intersect a major oil exploration canal that connects to the southern perimeter of Grand Lake. Two location canals enter the interior of both managed and unmanaged areas from Little Pecan Bayou. Controlling land loss and enhancing wildlife habitat are the management objectives. One flap-gated, variable-crest culvert and one variable-crest are used for water control in this active management plan, which commenced in 1978. Haplaquolls-Hydraquents soil associations are present at both managed and unmanaged sites.

By 1978, both areas had changed from entirely fresh marsh habitat to mixed intermediate/brackish marsh (figure 48). Between 1981 and 1985 intermediate habitat was transformed into brackish habitat at both areas. Changes occurring after management implementation were similar at both managed and unmanaged areas. In both areas, marsh was converted to water and "other." The main components of the "other" category showing gains were spoil shrub/scrub and developed. However, the magnitude of marsh loss and water

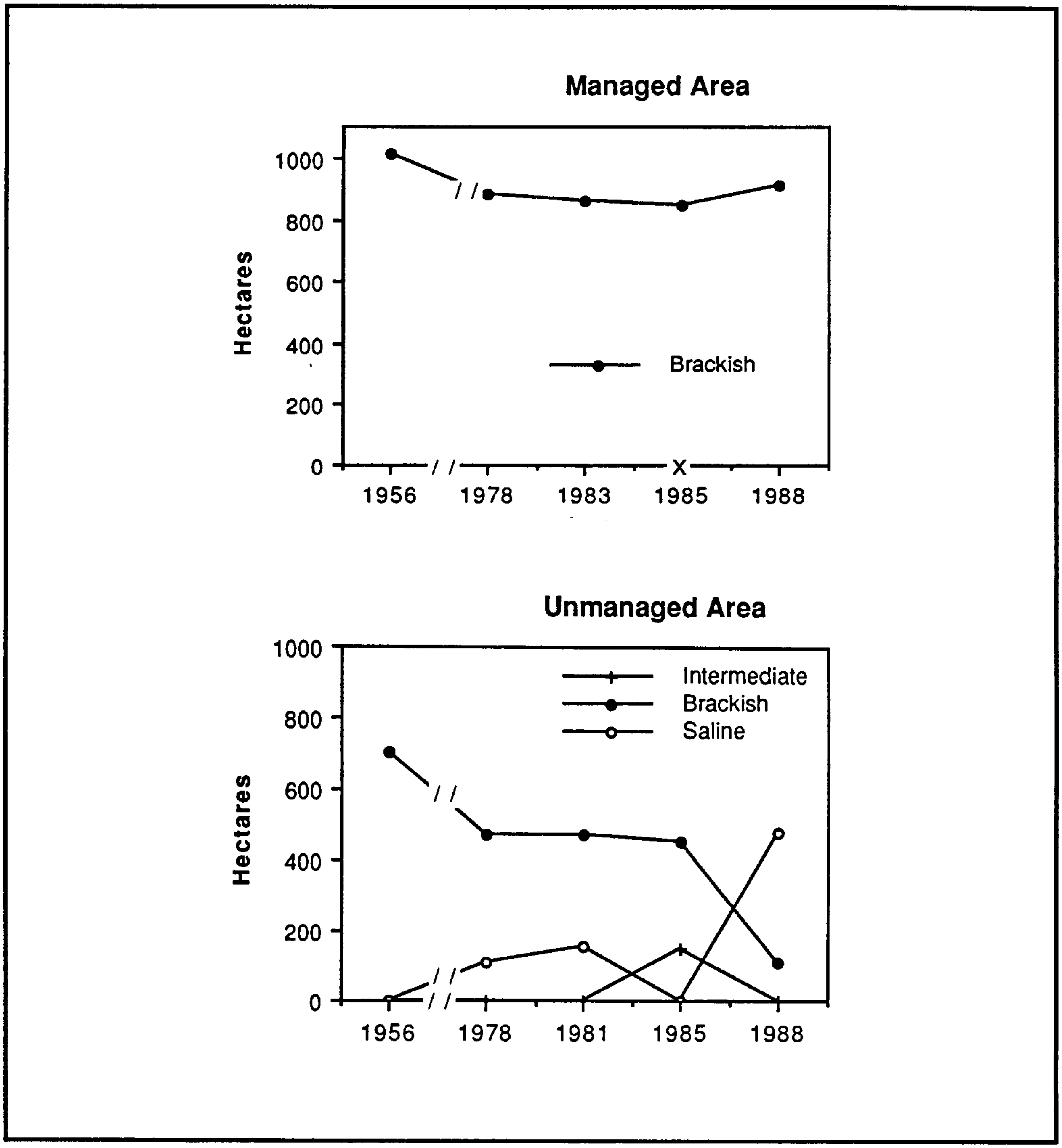

Figure 46. Areas of major marsh types in the managed and unmanaged areas at Creole Canal, 1956-1988. The "X" denotes the date of management implementation.

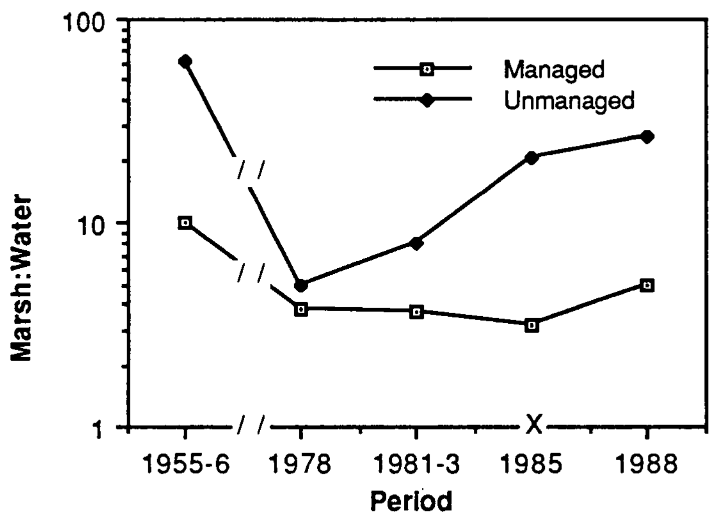

Figure 47. Marsh-to-water ratios in the managed and unmanaged areas at Creole Canal, 1956-1988. The "X" denotes the date of management implementation.

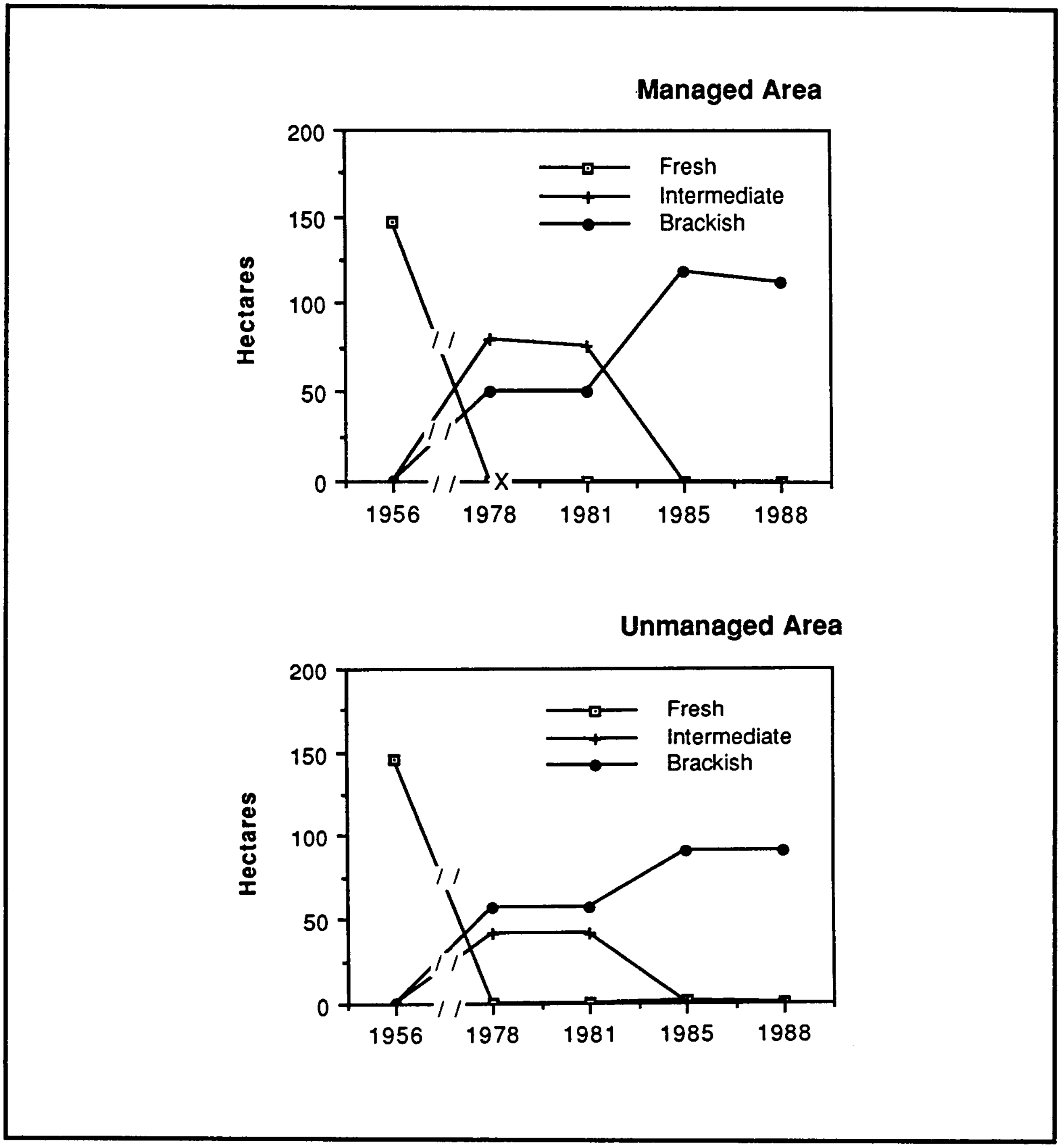

Figure 48. Areas of major marsh types in the managed and unmanaged areas at Little Pecan Island Unit 6, 1956-1988. The "X" denotes the date of management implementation.

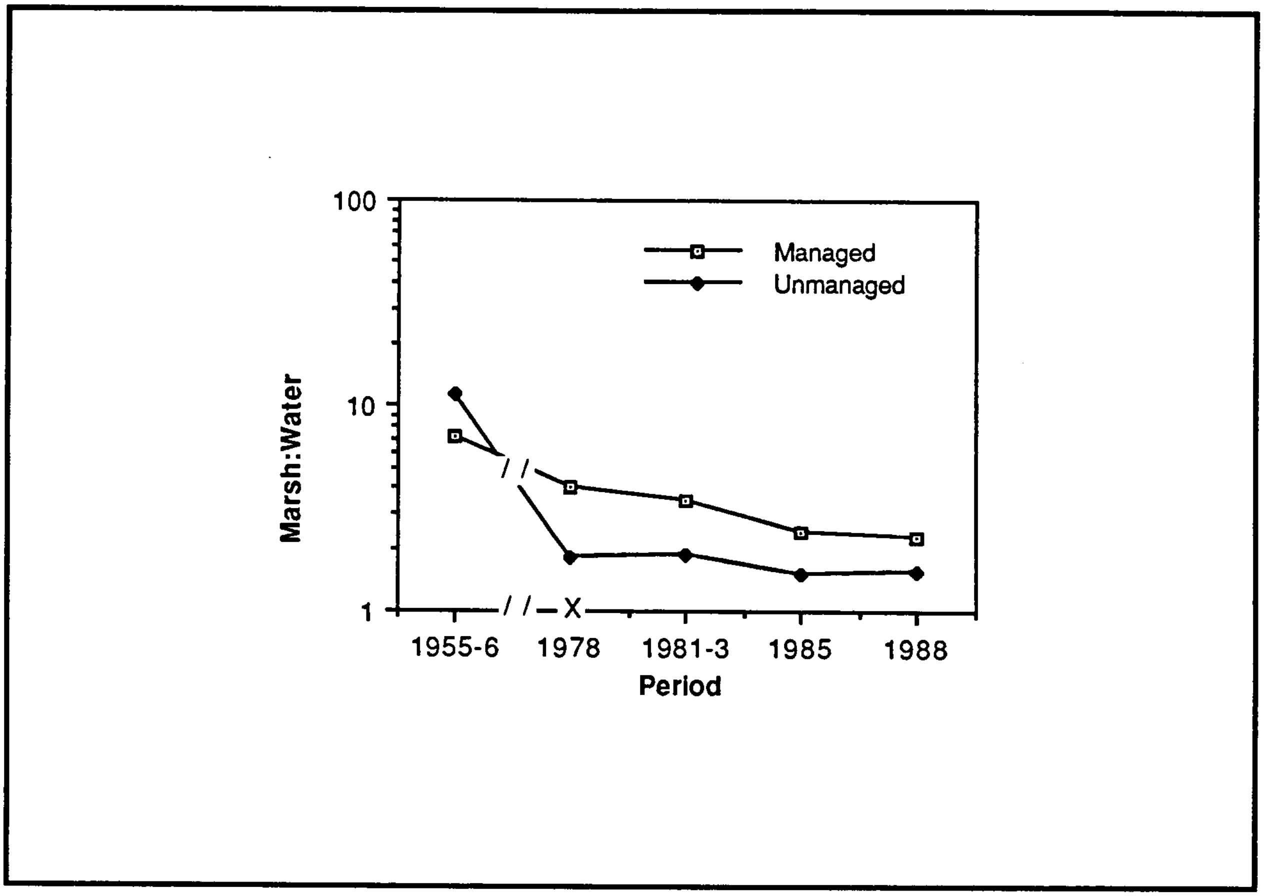

Figure 49. Marsh-to-water ratios in the managed and unmanaged areas at Little Pecan Island Unit 6, 1956-1988. The "X" denotes the date of management implementation.

gain was noticeably higher in the managed area (table 49). Marsh-to-water ratios have not increased substantially at either site. The general trend for both areas has been declining ratios from 1956 to 1988 (figure 49). Habitat diversity has changed little since management began. Both managed and unmanaged areas lost a marsh type. The managed area also lost inert habitat and gained spoil shrub/scrub habitat. The unmanaged area gained only inert habitat. Management does not appear to have effectively controlled land loss or maintained habitat. Trends at the management area do not appear to vary from those at the adjacent unmanaged area. However, differences between the areas are apparent in the magnitude of the habitat changes. The managed area lost twice as much marsh (table 49) as the unmanaged area (12% vs. 6%). More of this marsh loss was converted to water at the managed area (9%) than at the unmanaged area (2%).

<u>Little Pecan Unit 9</u>

The managed area at Little Pecan Unit 9 is located 2 km south of Grand Lake in the Mermentau River basin (site 4, figure 43). Grand Lake, Little Pecan Bayou, and the Mermentau River are major hydrological influences in the area. Boundaries of the managed area are formed by canals and trenasses on all sides. Artificial water bodies and their spoil banks define the perimeter of the adjacent unmanaged area except for the south perimeter, which is open marsh. Primary plan goals are enhancing wildlife habitat and controlling land loss (table 48). Two flap-gated culverts are used to manage water levels. Management commenced in 1977. Medisaprists-Haplaquolls soil associations are characteristic of the areas.

As of 1985, marsh habitat was diverse and ranged from fresh to brackish in both managed and unmanaged areas; intermediate was the dominant marsh habitat (figure 50). Marsh type began to change during 1978-1981 at both sites. Fresh habitat decreased dramatically, and intermediate marsh increased. Marsh type stabilized by 1988, and unmanaged marsh retained a larger portion of fresh marsh habitat. Habitat diversity has slowly increased since 1956 in both areas. But the areas accounting for the increases shown in the 1988 data are quite small and consist of habitat types that are often transitory (e.g., aquatic vegetation, inert). Since management implementation, habitat diversity has increased at both managed and unmanaged areas as spoil shrub/scrub and marsh habitats associated with higher salinities have developed. Marsh-to-water ratios have fluctuated less since the decline during the 1956-1978 interval (figure 51), as evidenced by a marsh loss at both areas of only 6 ha (table 49) during 1978-1988. This moderation is not always translated precisely into static marsh-to-water ratios. Following implementation, marsh-to-water ratios in the managed area fell from 13.2:1 to 10.8:1 before recovering slightly to 12.6:1 in 1988. The unmanaged areas' ratios performed in a reverse manner, rising then falling in 1988. Table 49 indicates the overall stability of all major habitats at both areas since implementation. More fresh marsh habitat was retained in the unmanaged marsh, but no other significant differences were apparent between managed and unmanaged areas.

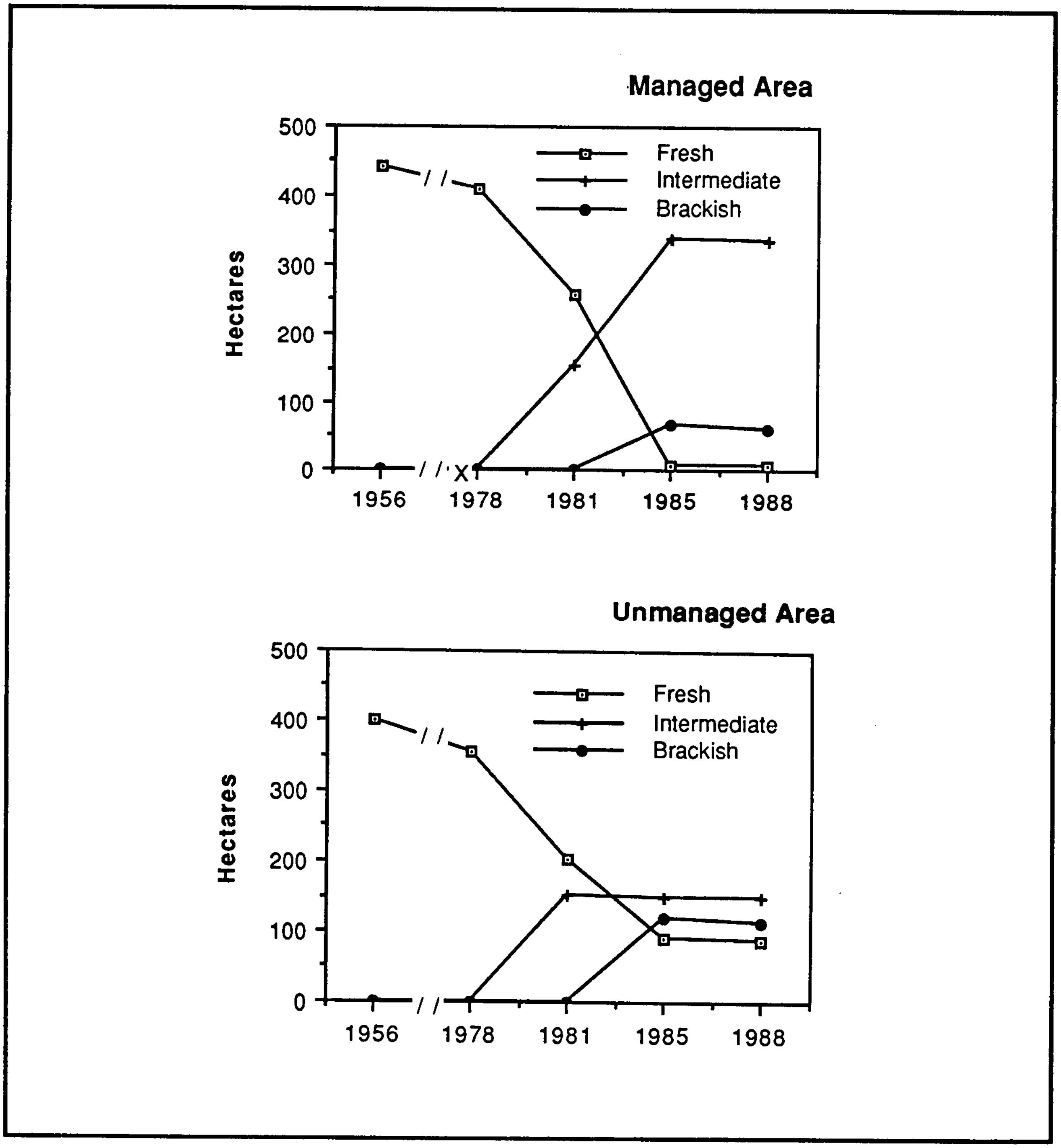

Figure 50. Areas of major marsh types in the managed and unmanaged areas at Little Pecan Island Unit 9, 1956-1988. The "X" denotes the date of management implementation.

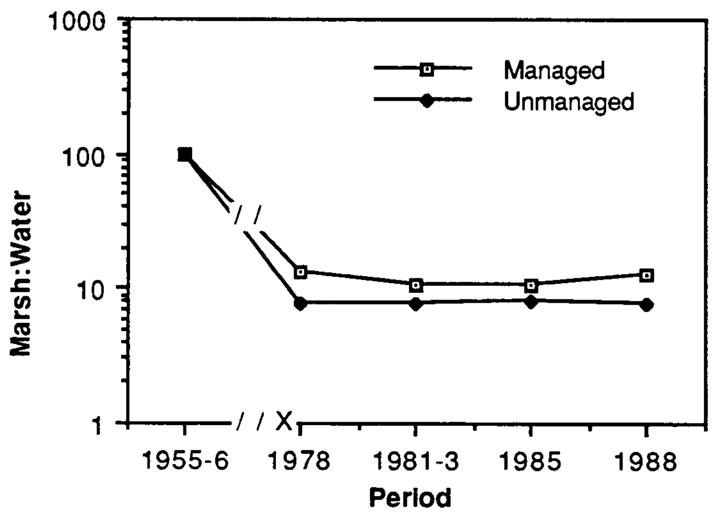

Figure 51. Marsh-to-water ratios in the managed and unmanaged areas at Little Pecan Island Unit 9, 1956-1988. "X" denotes the date of management implementation.

Rockefeller Refuge

The managed marsh at Rockefeller Refuge is arguably the most intensely managed of the 16 study sites. Since the state acquired it in 1920, the refuge has undertaken an ambitious program to counteract the effects of saltwater intrusion and altered hydrological regimes. Before management, construction of the Old Intracoastal Waterway and Louisiana highway 82 north of the refuge altered the historical north-south drainage. Located in the Mermentau basin (site 5, figure 43), management unit 4 is bordered by canals on all sides. Improving waterfowl habitat is the primary management objective of the active management scheme (table 48). Enhancing estuarine fisheries is a more recent objective of management practices. Management commenced in 1958.

The unmanaged marsh is 15 km east of the managed area. East Little Constance Bayou facilitates hydrological exchange between the Gulf of Mexico and the unmanaged area. The northern border is formed by an unnamed canal's spoil bank that supports a variable-crest flap-gated culvert for controlled introduction of fresh water from the north. Soils in both the managed and unmanaged areas are classified as Haplaquolls-Hydraquents association.

From 1956 to 1985 the managed area consisted of approximately equal areas of brackish and intermediate marsh (figure 52). During 1985-1988, however, the area became entirely intermediate marsh. Since the loss of all intermediate habitat during 1956-1978, the unmanaged area has remained brackish. Since management implementation, gains of artificial water bodies and inert habitats, coupled with losses of brackish and saline marsh, have resulted in no net change in habitat diversity at the managed area. Losses of intermediate marsh and a gain of inert habitat produced no net change in diversity at the unmanaged area. Habitats present in 1988 in managed marsh but not in unmanaged marsh were limited to shrub/scrub (spoil), intermediate, and water (artificial). Marsh-to-water ratios have historically been higher in the unmanaged than in the managed marsh (figure 53). Overall marsh changes since management implementation (table 49) show a 428-ha loss (24%) of managed marsh compared to a 163-ha loss (11%) in the unmanaged area. Marsh-to-water ratios in the unmanaged area increased slightly during 1978-1985, but during 1985-1988, ratios in the unmanaged area declined, and those in the managed marsh continued to increase. This growth is apparently the result of management practices that converted open water to marsh. Field observations indicate that Spartina alterniflora dominates the new marsh formed. Analysis of data for the 1985-1988 interval reveals a net gain of 240 ha (22%) in the managed area versus a net loss of 45 ha (3%) in the unmanaged marsh (appendix K). The data suggest positive results at the managed site, particularly in the elimination of brackish marsh in favor of intermediate marsh and the continued positive growth of marsh-to-water ratios. The inability of management to withstand forces producing the 1956-1978 decline in ratios should be examined further for clues to managing future salinity increases or altered hydrological regimes.

Vermilion Corporation

The Vermilion Corporation managed area is located in the eastern portion of the Mermentau basin (site 6, figure 43) adjacent to Freshwater Bayou Canal.

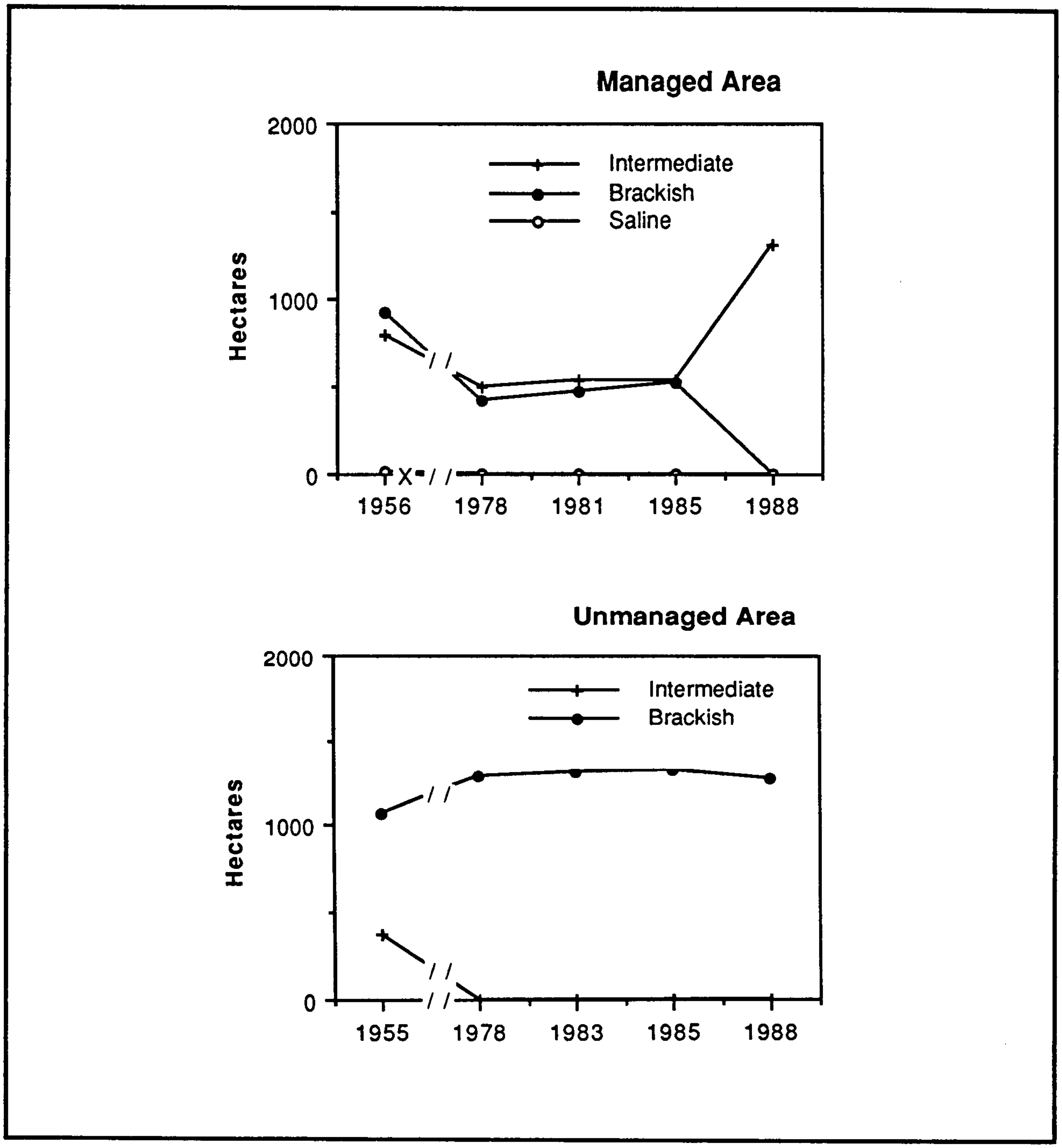

Figure 52. Areas of major marsh types in the managed and unmanaged areas at Rockefeller Refuge, 1956-1988. "X" denotes the date of management implementation.

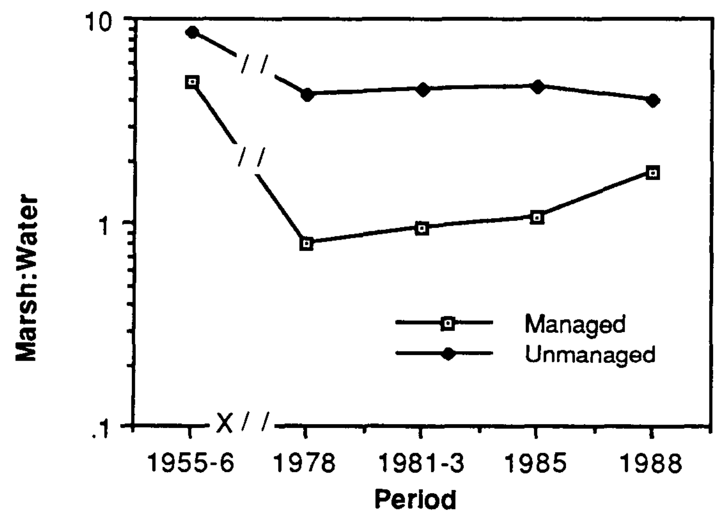

Figure 53. Marsh-to-water ratios in the managed and unmanaged areas at Rockefeller Refuge, 1956-1988. "X" denotes the date of management implementation.

Its southern and eastern boundaries are defined by spoil levees of man-made canals. Western and northern boundaries are loosely defined by the drainage influence of the old Freshwater Bayou channel and an existing water control structure. No major engineered hydrologic alterations are within the managed area. However, several trenasses and a pipeline canal, which appear to be revegetated and abandoned, may influence local hydrology within the managed marsh. The unmanaged marsh, 1 km to the east, is entirely surrounded by canals, one of which is a borrow pit for the road leading to Freshwater Bayou Locks. A location canal extends into the interior from the east. This unmanaged site was at one time managed for waterfowl habitat but abandoned in the late 1950s (Lynch 1989). Local and regional hydrology were significantly altered by construction of Freshwater Bayou Canal, DeWitt Canal, and the canals associated with nearby oil fields. Controlling land loss and enhancing wildlife habitat are the goals of this plan (table 48). A double flap-gated culvert is used to manage water levels in the area. Management commenced in 1966. Soils of the area are moderately saline Haplaquolls-Hydraquents.

Significant changes in marsh type occurred during 1956-1983 at the managed area (figure 54). Between 1956 and 1978, fresh marsh habitat disappeared, and 50% of the managed marsh became brackish. By 1983 this brackish habitat had been replaced by intermediate marsh. From 1978 to 1983 fresh marsh habitat was replaced by intermediate habitat in the unmanaged marsh. Little difference in habitat diversity between managed and unmanaged areas could be detected. Habitat change not induced by humans included the loss in both areas of fresh marsh and the loss of aquatic vegetation in the managed area and of intermediate marsh in the unmanaged area. During 1956-1983 most habitat alterations observed at both locations involved the marshes. Marsh-to-water ratios declined slightly during 1956-1985 (figure 55) in the managed unit. This decline was followed by an increase during 1985-1988. Analysis of managed marsh pre-implementation (1956) and post-implementation data (1988) indicates net marsh loss of 20 ha (6%) and a corresponding gain of 15 ha (4%) of water habitat (table 48). Other non-marsh and water categories have changed only marginally. During 1956-1988 the unmanaged area lost 51 ha (34%) of its marsh. After a significant decline during 1956-1978, due to a 43-ha water increase and a 43-ha marsh decrease, marsh-to-water ratios in the unmanaged area stabilized until 1985 (figure 55). The unmanaged marsh-to-water ratio for 1988 is probably an artifact created by climatic events on the day photographs were taken. Habitat previously interpreted as water was labeled as inert (flats) in the 1988 photograph. In fact, no water habitat was identified in the 1988 aerial survey of the unmanaged area. Exposure of marsh pond bottoms, creating flats, is common during winter months when winter cold fronts emanate from the northwest and coincide with low tides. The 1988 marsh-to-water ratio is probably similar to that of 1985.

Management may have sustained higher marsh-to-water ratios, though unmanaged ratios stabilized during 1978-1983. Both areas are now entirely intermediate marsh habitat, but the introduction of brackish habitat and its subsequent disappearance appears to be a positive result of management practices.

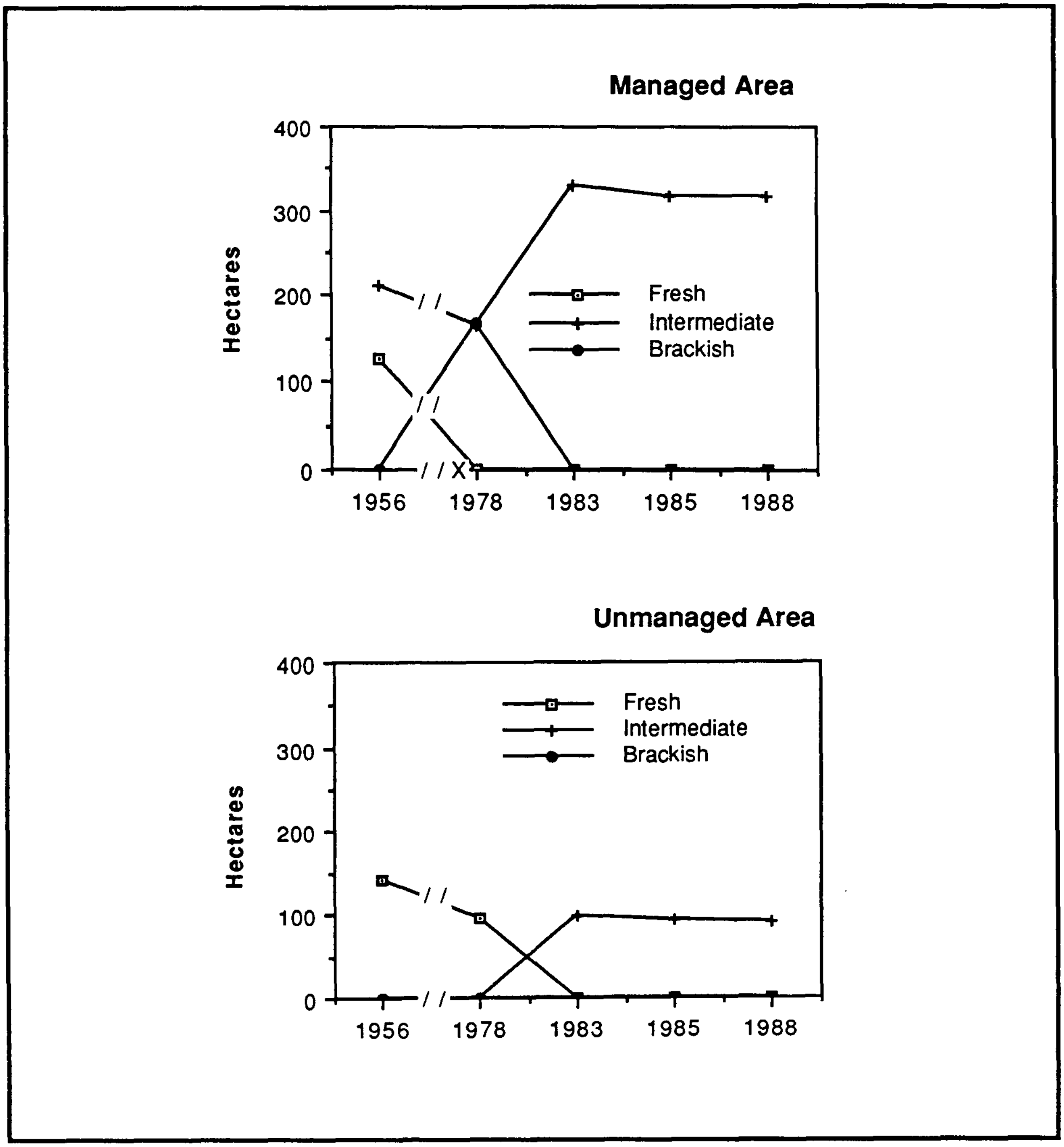

Figure 54. Areas of major marsh types in the managed and unmanaged areas at Vermilion Corporation, 1956-1988. "X" denotes the date of management implementation.

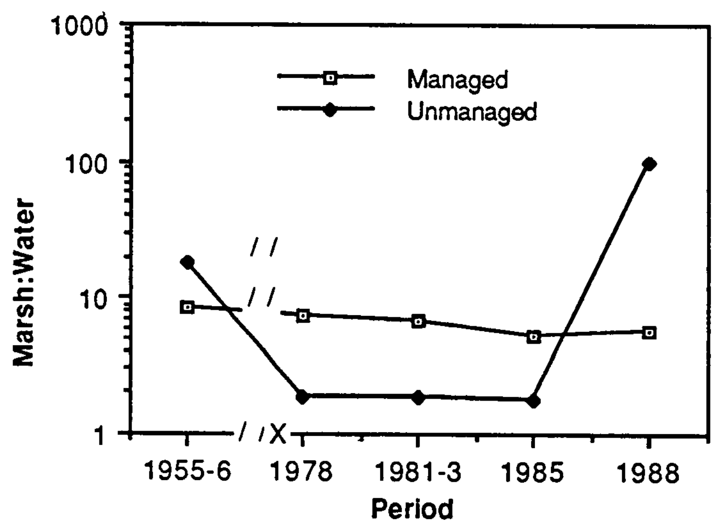

Figure 55. Marsh-to-water ratios in the managed and unmanaged areas at Vermilion Corporation, 1956-1988. "X" denotes the date of management implementation.

Vermilion Bay Land

The managed and unmanaged areas of the Vermilion Bay Land site are adjacent to each other in the Vermilion-Teche basin (site 7, figure 43), on the northern bank of the Gulf Intracoastal Waterway, 4 km north of Vermilion Bay. Managed primarily as waterfowl habitat (table 48), this area is defined by Deer Bayou on the west, Landry Canal on the north and east, and the Gulf Intracoastal Canal to the south. Two location canals enter the managed marsh from Deer Bayou. The northern location canal contains a flap-gated, variable-crest water control structure capable of active management. Management goals are to enhance waterfowl and furbearer habitat and reduce land loss. Management commenced in 1987. Three structures of unknown origin and installation date passively augment the active management from locations on Landry Canal. The perimeter of the unmanaged area is defined by a southern boundary at the Gulf Intracoastal Waterway, Deer Bayou to the east, Boston Canal to the west, and a location canal to the north. Several location canals are in the interior. Vermilion Bay and the Gulf Intracoastal Waterway are major hydrological forces in the area. Additional influences are Boston Bayou and Canal, Deer Bayou, and other canals connecting the Gulf Intracoastal Waterway with the northern marshes of the area. Soils are Haplaquolls-Hydraquents.

Brackish marsh has replaced intermediate marsh at both managed and unmanaged sites (figure 56). This transition was complete by 1988 in the managed marsh and by 1985 in the unmanaged location. Little difference can be detected between habitat diversity in the managed and unmanaged marshes. The marsh-to-water ratio in the unmanaged area, after falling below that of the managed area in 1983, steadily increased during 1983-1985 and 1985-1988 (figure 57). Habitat transitions in both areas (table 49) indicate losses of both marsh and water, and resulting gains in "other" (predominantly "inert" or flats) habitats. Unusually low water levels at the unmanaged area in both 1985 and 1988 may have resulted in artificially high marsh-to-water ratios. Analysis of aerial photographs indicates that similar physical conditions may have been present at the managed and unmanaged areas in 1955. This phenomenon may also be reflected in the 1955 habitat maps of both the managed and the unmanaged areas. Since management implementation, elimination of intermediate marsh in the managed area has decreased habitat diversity. Because of similarities in the trends in the managed and unmanaged marshes and the limited duration of plan implementation, the effects of management could not be assessed.

State Wildlife Refuge

Both the managed and unmanaged areas of the State Wildlife Refuge site are located in the Vermilion-Teche basin (site 8, figure 43) west of Marsh Island at the interface between southern Vermilion Bay and the Gulf of Mexico. This study site lies mostly within the Paul J. Rainey Wildlife Sanctuary owned and managed by the National Audubon Society. Both areas share a northern boundary with the southern shore of Fearman Lake. The perimeter of the managed area is further defined by McIlhenny Canal to the west, the southernmost point of Nicks Lake to the south, and the Big Island Bayou-Tom's Bayou watershed divide to the east. The unmanaged area is composed of the

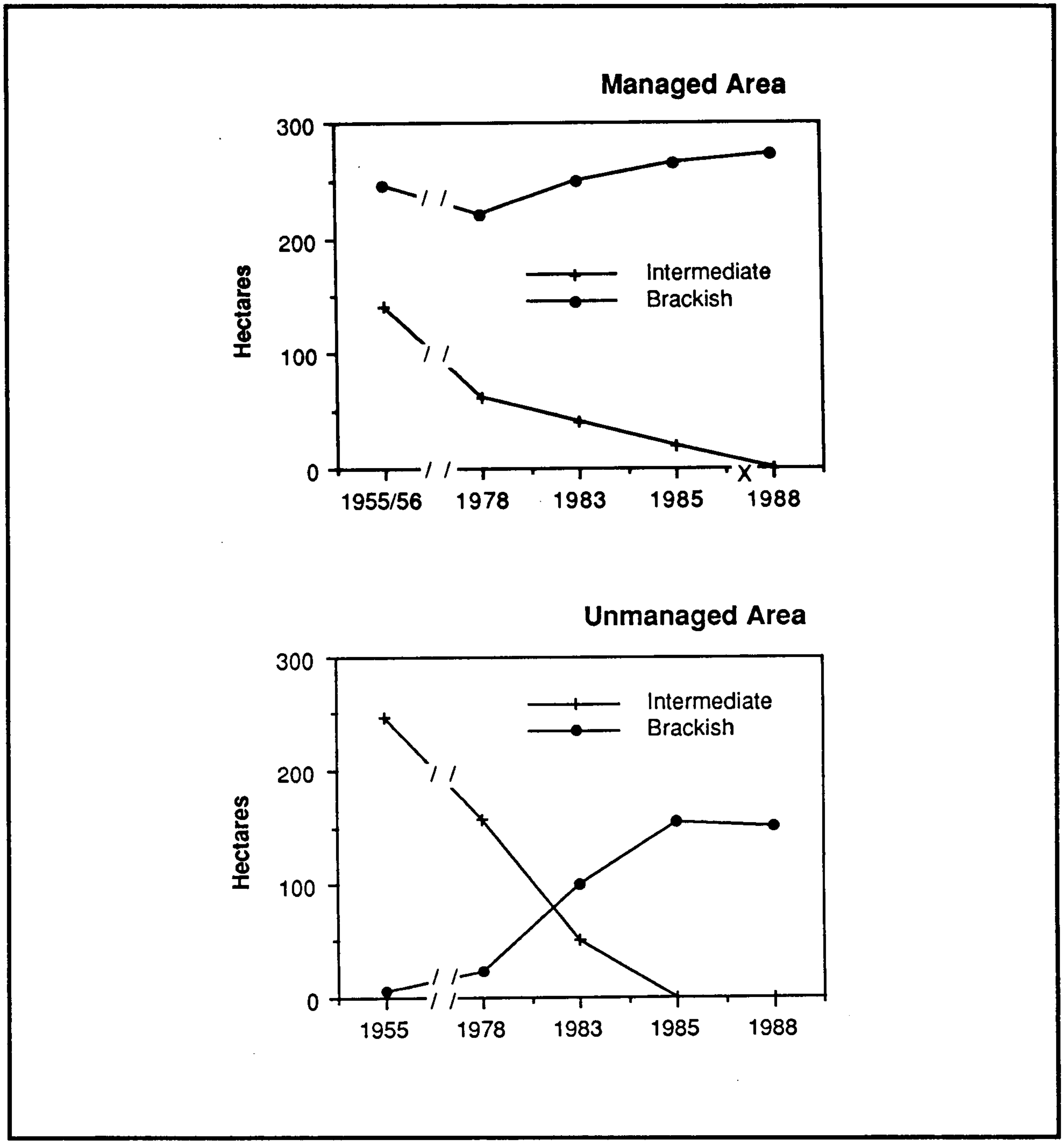

Figure 56. Areas of major marsh types in the managed and unmanaged areas at Vermilion Bay Land, 1955-1988. "X" denotes the date of management implementation.

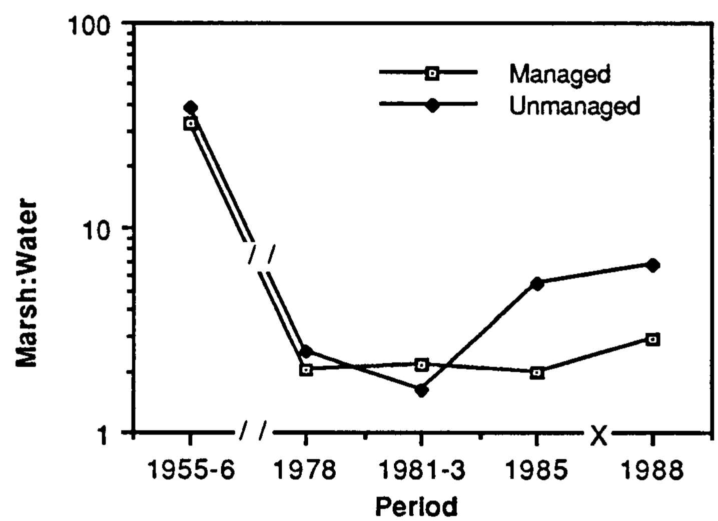

Figure 57. Marsh-to-water ratios in the managed and unmanaged areas at Vermilion Bay Land, 1955-1988. "X" denotes the date of management implementation.

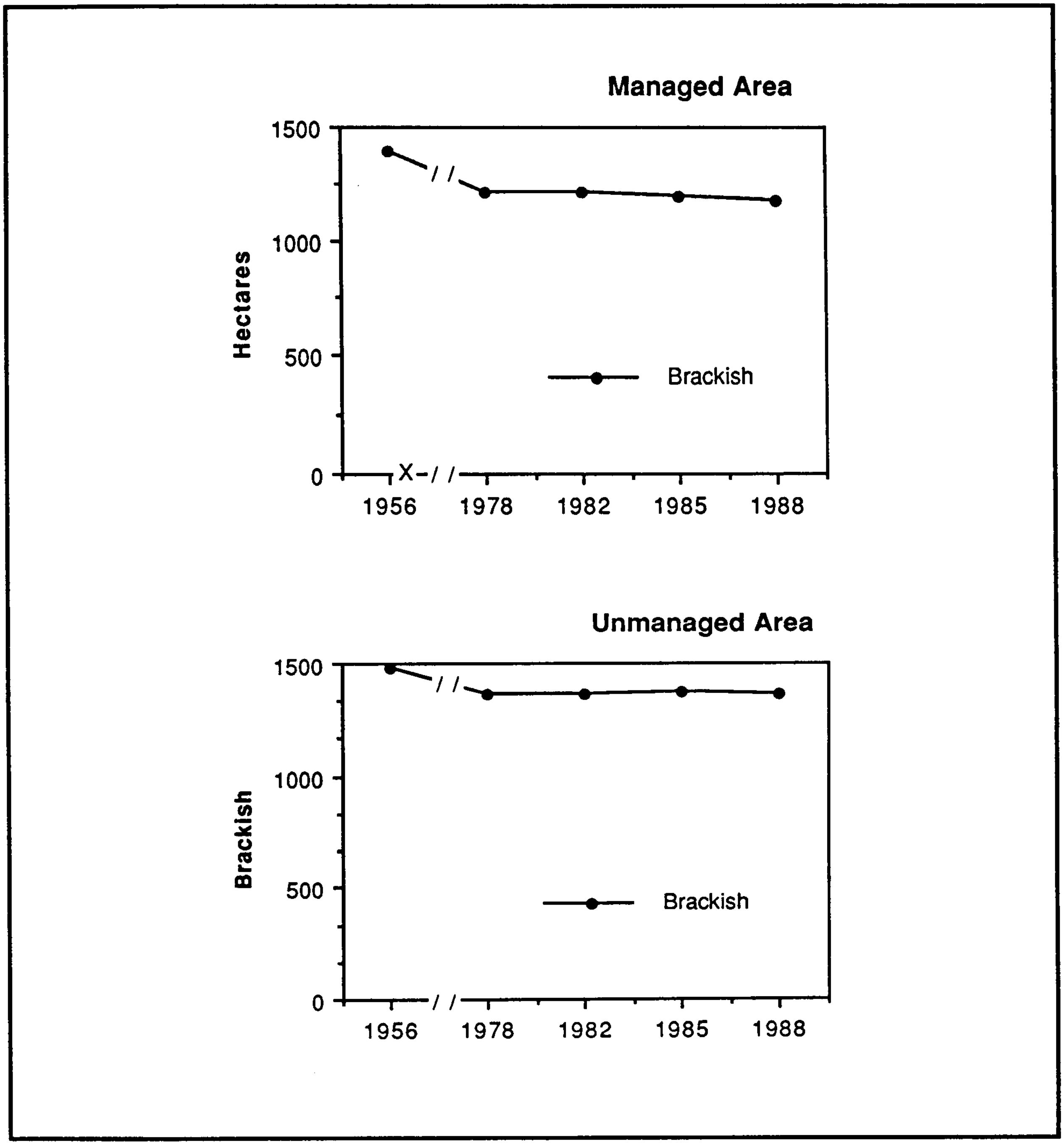

Figure 58. Areas of major marsh types in the managed and unmanaged areas at State Wildlife Refuge, 1956-1988. "X" denotes the date of management implementation.

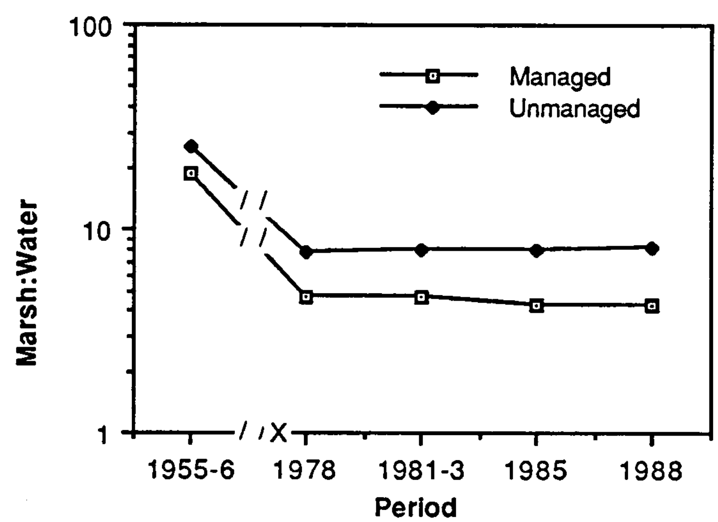

Figure 59. Marsh-to-water ratios in the managed and unmanaged areas at State Wildlife Refuge, 1956-1988. "X" denotes the date of management implementation.

Tom's Bayou watershed. In addition to hydrological influences produced by Vermilion Bay to the north and the Gulf of Mexico to the south, numerous artificial and natural waterways provide water exchange in the area. Of the artificial waterways, Southwest Pass, McIlhenny Canal, Freshwater Bayou Canal, and Last Point Canal most affect area hydrology. This site is primarily managed as waterfowl habitat through a passive management plan that utilizes fixed-crest weirs (table 48). Haplaquolls-Hydraquents soils dominate the site. Management began in 1967.

Brackish marsh habitat in both areas remained unchanged throughout the periods analyzed (figure 58). Both managed and unmanaged areas had declining marsh-to-water ratios; the unmanaged marsh has historically maintained higher marsh-to-water ratios (figure 59). Differences in habitat diversity between the managed and unmanaged marsh are minor. Existing differences in habitat diversity are associated with habitat created by canal dredging and subsequent spoil deposition.

Similar trends of marsh loss and water gain (table 49) exist at both the managed and unmanaged areas. Although the rate of marsh loss in the managed area is twice that found in the unmanaged area, the comparison date (1956) must be taken into account. The implementation date (1967) required choosing a comparison date which either included nine years of management effects in the lease line data or attributed the effects of eleven years of nonmanagement to management. The influence of nine years of management was determined to be more important, thus the comparison was made from 1956 to 1988. After 1978 little difference in marsh or water change is noted.

McIlhenny Company

Both the managed and unmanaged areas of the McIlhenny Company site are located adjacent to each other south of Avery Island and north of the Gulf Intracoastal Waterway. This site is approximately 1 km from the north shore of Vermilion Bay in the Vermilion-Teche basin (site 9, figure 43). A distinct hydrologic management unit has been formed through hydrologic control of the north fork of Three Bayous. Boundaries consist of marsh influenced by the Three Bayous watershed and a pipeline canal to the north. This unnamed canal also forms the northern boundary of the unmanaged unit. The unmanaged area's boundary is primarily defined by a watershed formed by Bayou Cassmer, which discharges into the Gulf Intracoastal Waterway from the unmanaged area's southern boundary. Major hydrological impacts are associated with the Gulf Intracoastal Waterway, New Iberia Southern Drainage Canal, and the Avery Canal connection. These waterways, along with Bayou Petite Anse, provide for water exchange from Vermilion Bay into both areas. The management plan is passive, using fixed-crest weirs to enhance waterfowl and furbearer habitats (table 48). Management commenced in 1983. Soils consist of a Lafitte association with slight influence from the Maurepas association circling the southeastern portion of Avery Island, a Pleistocene surface overlying a salt dome.

The managed unit historically consisted of intermediate to fresh marsh (figure 60). Changes during 1956-1978 resulted in the managed area's current composition of predominantly brackish marsh with a residual trace of intermediate marsh. Marsh types in the unmanaged area have been similarly altered, except for a larger portion stabilizing as intermediate marsh. Marsh habitat in both areas has remained comparatively stable since 1978, though

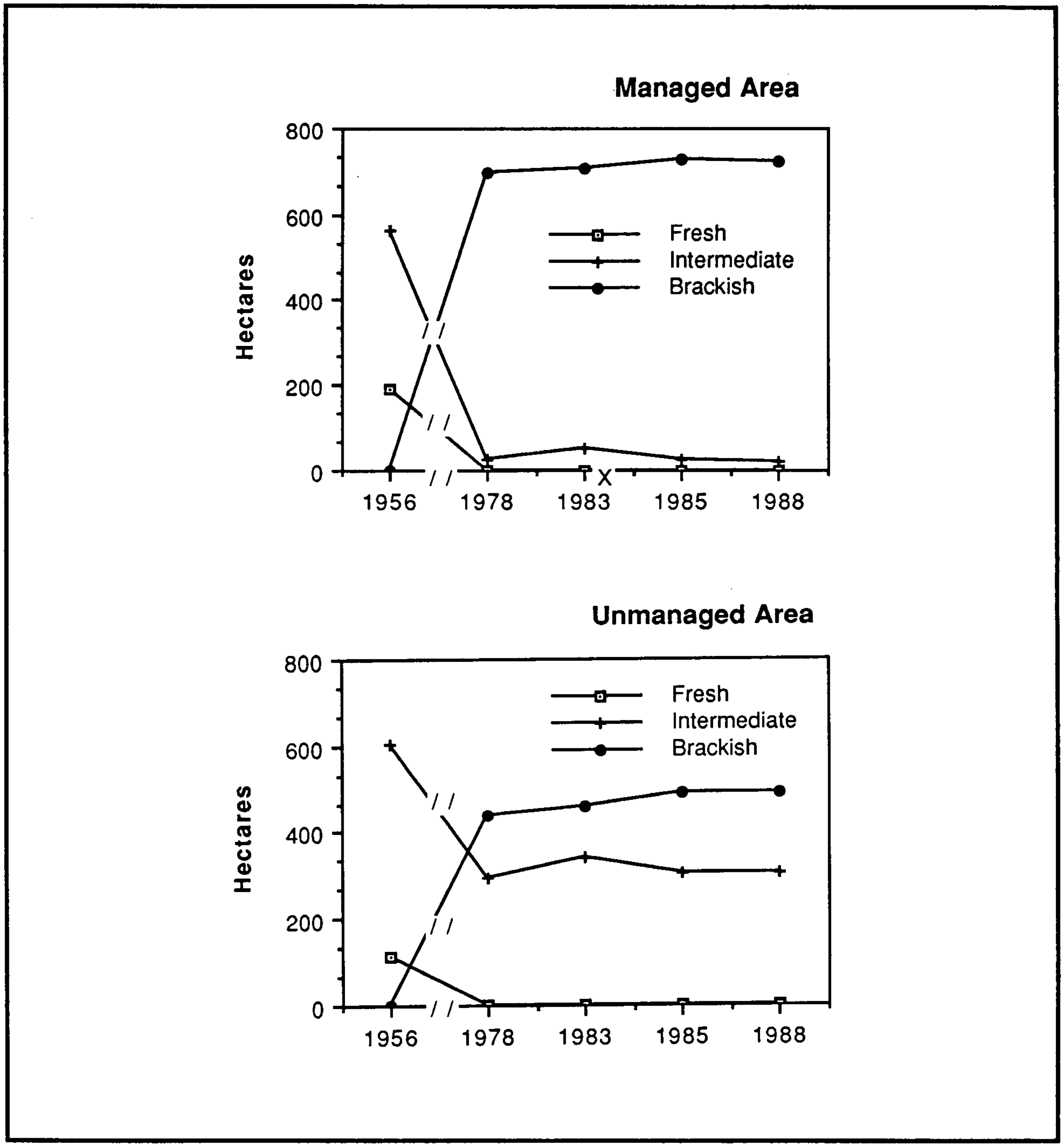

Figure 60. Areas of major marsh types in the managed and unmanaged areas at McIlhenny Company, 1956-1988. "X" denotes the date of management implementation.

some fluctuations in shrub/scrub (spoil) and water bodies (artificial) have been noted. Changes in habitat diversity since management implementation consist of a loss of spoil shrub/scrub in both areas. The unstable marsh-to-water ratios (figure 61) may be the result of low water in 1983 and 1985 at the times the photographs were taken. Normal marsh water levels may have produced marsh-to-water ratios significantly different from those shown in figure 61. Marsh-to-water ratios at both sites increased after a 1978 low, then declined during 1983-1988 in the unmanaged area and during 1985-1988 in the managed. Of the 16 sites, the McIlhenny Company's managed and unmanaged areas had the marsh-to-water ratios that declined the least and current marsh-to-water ratios that are among the highest. Both managed and unmanaged areas decreased habitat diversity by the loss of spoil shrub/scrub. The lack of substantial differences in the data for managed and unmanaged areas indicates few positive effects of management. The marsh-to-water ratio for the managed area is difficult to interpret because of the possible influence of inoperable weirs during 1987-1988 (Simmons 1990).

Marsh Island Refuge

Marsh Island is located on the extreme western edge of the delta plain (site 10, figure 43), below Vermilion Bay and within the Vermilion-Teche basin. Managed and unmanaged areas are adjacent to each other, separated by a canal. Southern and eastern managed area boundaries are formed by spoil levees of exploration canals, as are eastern and southern unmanaged area borders. Water levels in Long Lake and associated water bodies (managed area) are passively managed by one fixed-crest weir to enhance waterfowl and furbearer habitat (table 48). Managed marsh hydrology is influenced via marine connections of the west branch of Oyster Bayou and Bird Island Bayou. Lucien Bayou provides additional hydrological ingress and egress to the unmanaged area. Scatlake and Lafitte soils can be found in both areas. Management commenced in 1959.

Both managed and unmanaged areas maintained their historically brackish habitat (figure 62) from 1956 to 1988. This may be largely attributable to the freshwater input from the Atchafalaya River. Marsh-to-water ratios in both managed and unmanaged areas have steadily declined since 1956, except for a very small increase in 1985 in the managed area (figure 63). Analysis reveals that the managed area increase resulted from a 5-ha loss of water combined with a 7-ha gain in brackish habitat (appendix K, 1983-1985). This 1985 increase in the managed area was followed by a decline that resulted in a smaller marsh-to-water ratio than in 1983. Historically, marsh-to-water ratios have been marginally lower in the managed area, though little variation is evident between managed and unmanaged areas. Since implementation both areas have gained water habitat at the expense of marsh habitat (table 49). Minor increases in habitat diversity at the managed area are attributable to canal dredging. Canal impacts and increases in inert habitat have produced small gains in habitat diversity at the unmanaged marsh. No recent change in marsh type composition is apparent from the analysis (figure 62). Habitat classification and detection may have been affected by water levels that were higher in 1983 than in 1988 and submerged aquatic beds, some marsh, and flats. The data presented here do not indicate any substantial differences between managed and unmanaged marsh.

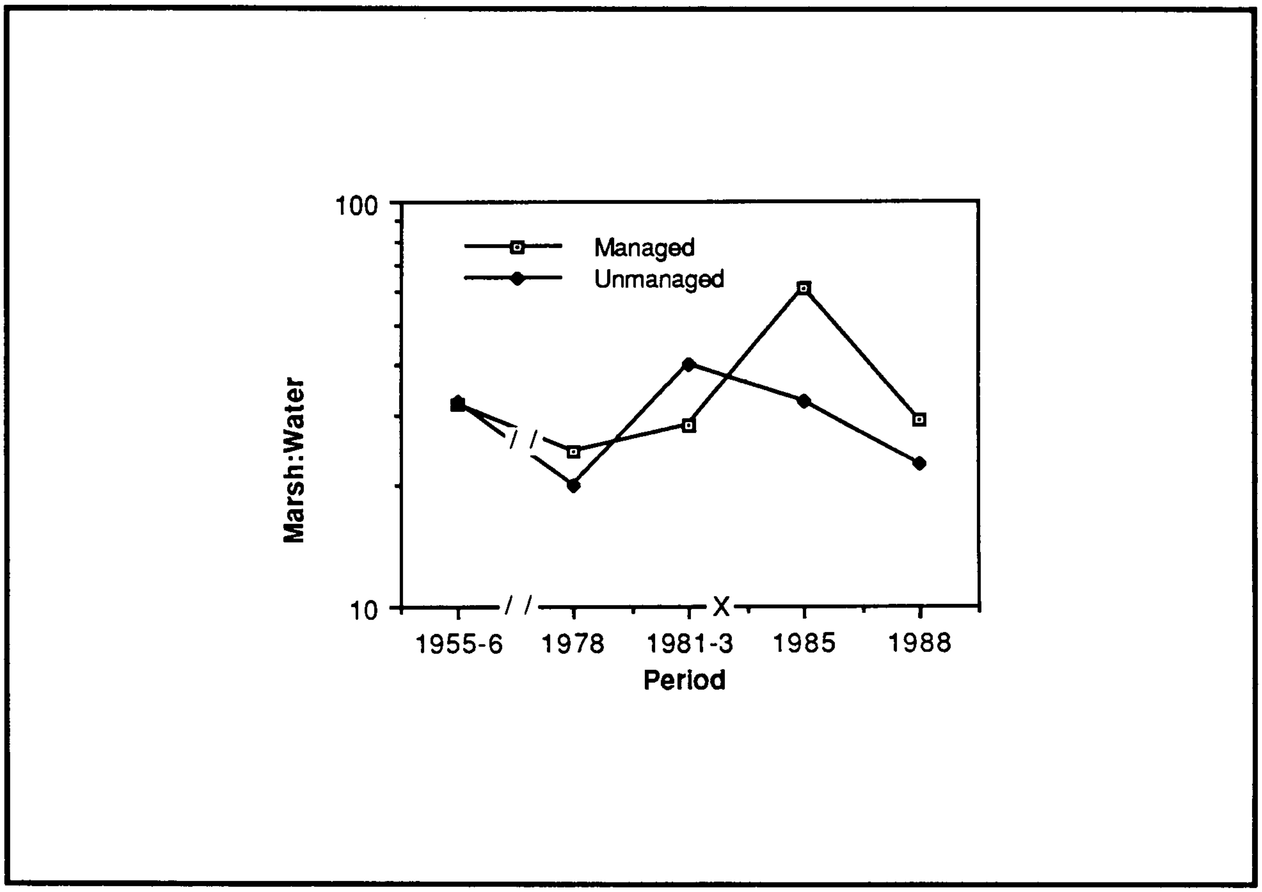

Figure 61. Marsh-to-water ratios in the managed and unmanaged areas at McIlhenny Company, 1956-1988. "X" denotes the date of management implementation.

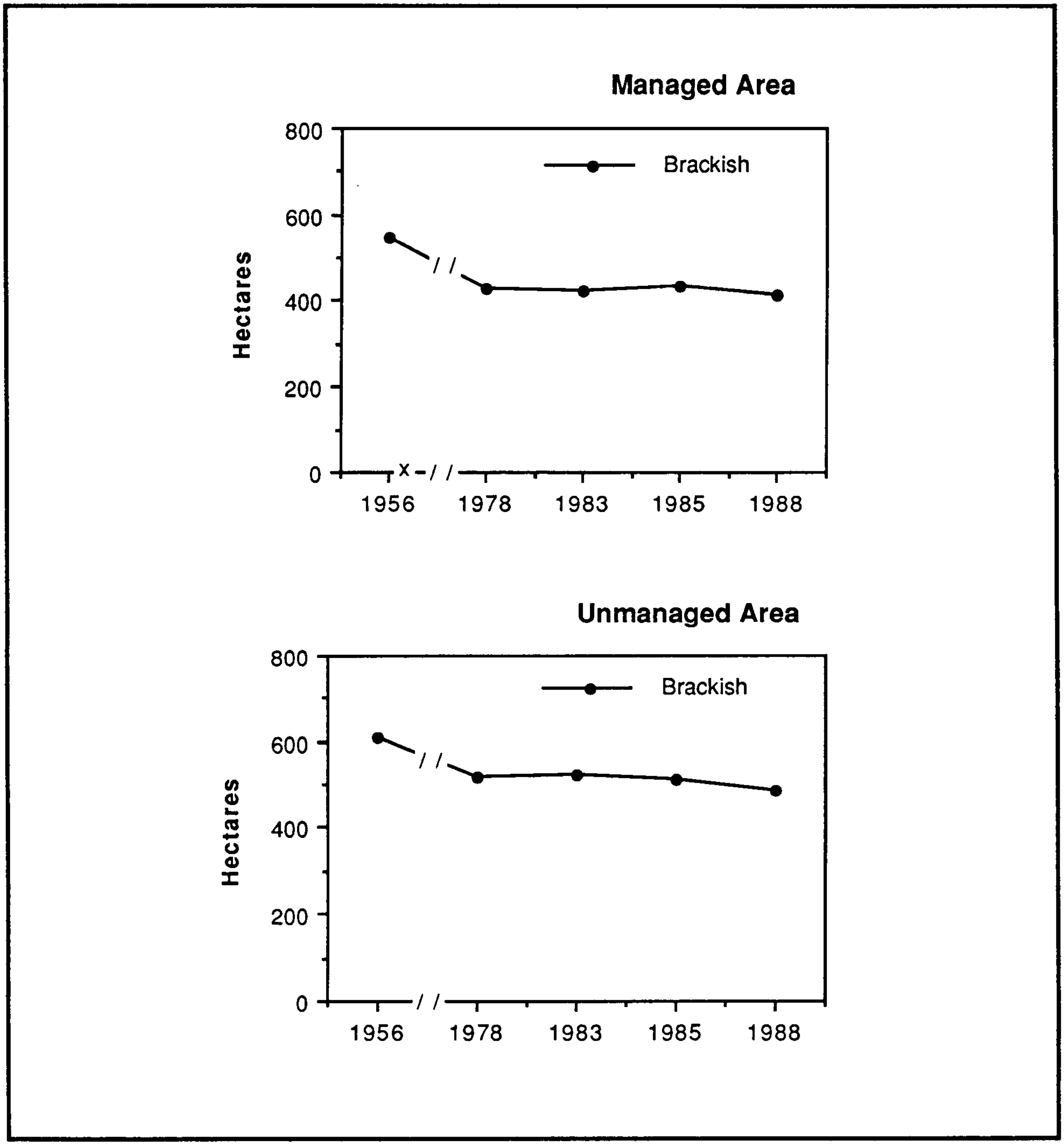

Figure 62. Areas of major marsh types in the managed and unmanaged areas at Marsh Island Refuge, 1956-1988. "X" denotes the date of management implementation.

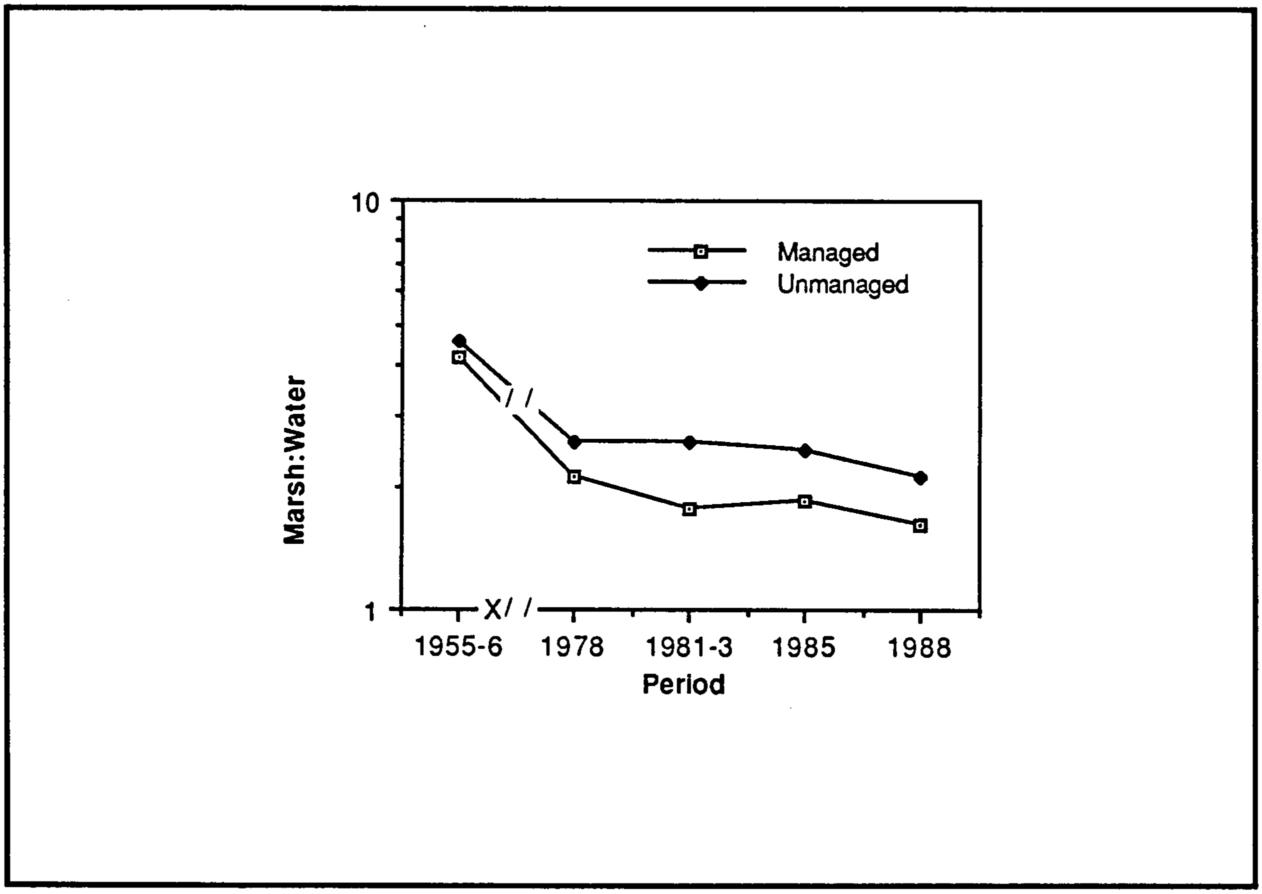

Figure 63. Marsh-to-water ratios in the managed and unmanaged areas at Marsh Island Refuge, 1956-1988. "X" denotes the date of management implementation.

Avoca Bayou Lawrence

Both the managed and unmanaged areas of Avoca Bayou Lawrence are located adjacent to each other east of the Atchafalaya River below Morgan City (site 11, figure 43). The location was once an active sugarcane farm, which was abandoned after the 1927 Mississippi River flood. This area of the Terrebonne basin is characteristically freshwater swamp or marsh because of the pervasive influence of the lower Atchafalaya River and its associated distributaries. The managed area is bound on the northwest by Glen Orange Canal and on the northeast, southeast, and southwest by unnamed canals. The unmanaged area adjacent to the north is dissected by two canals and has an open border with Avoca Lake. Current management goals are to control land loss and erosion and to enhance waterfowl habitat (table 48). The active management plan uses two variable-crest weirs and one double-flap-gated culvert for hydrological control. Area soils are Medisaprists-Hydraquents. Management began in 1987.

Both managed and unmanaged areas maintained uniformly fresh habitat as well as measurable amounts of aquatic vegetation (figure 64) throughout the study period. Managed marsh aquatic vegetation has changed little since 1983, whereas aquatic vegetation at the unmanaged area increased by 104 ha from 1985 to 1988 (table 49). Since plan implementation, habitat diversity in both areas has increased only by the addition of inert habitat. The managed site contains the second most diverse habitat of the 16 sites studied. The 1988 increase in the marsh-to-water ratio (figure 65) in the managed area is probably a result of low water levels, as is evidenced by the significant increase in the other habitat category whose major component is the inert type (i.e., flats). The minor increase (6 ha) in managed marsh from 1985 to 1988 (table 49) does not explain the substantial increase in the marsh-to-water ratio shown in figure 65. The decrease in water (leading to an increase in the inert category) appears to account for the increase in the ratio of marsh-to-water. Therefore, whether the marsh-to-water ratio presented in figure 65 represents the normal habitat composition of the managed area in 1988 is questionable. Marsh-to-water ratios declined after 1956 at the unmanaged site (figure 65) to a 1988 low of 0.1:1. Overall results from table 49 reveal that the managed area improved slightly between 1985 and 1988 for the reasons stated above. One year elapsed between implementation of this plan and the data point used for comparison (1988). This leaves a 3-yr span to interpret, which includes only 1 yr of management. For these reasons, the effects of management at Avoca should be interpreted with caution.

Fina-Falgout Canal

The Fina Falgout Canal (formerly Tenneco) site is west of Bayou du Large in the Terrebonne basin (site 12, figure 43). The managed area is bordered on the north by Marmande Ridge, on the west by Minors Canal, on the east by Thibodeaux Canal, and to the south by Falgout Canal. Three oil field access canals extend into the managed area from Falgout Canal. The unmanaged area comprises two parts, one dominated by brackish marsh, the other by fresh marsh. The fresh marsh unmanaged area is west of Minors Canal between Minors Canal and Marmande Ridge. The unmanaged brackish marsh is on the south side of Falgout Canal and contains similar hydrologic alterations in the form of oil exploration canals, which form the southwest perimeter. Falgout Canal is

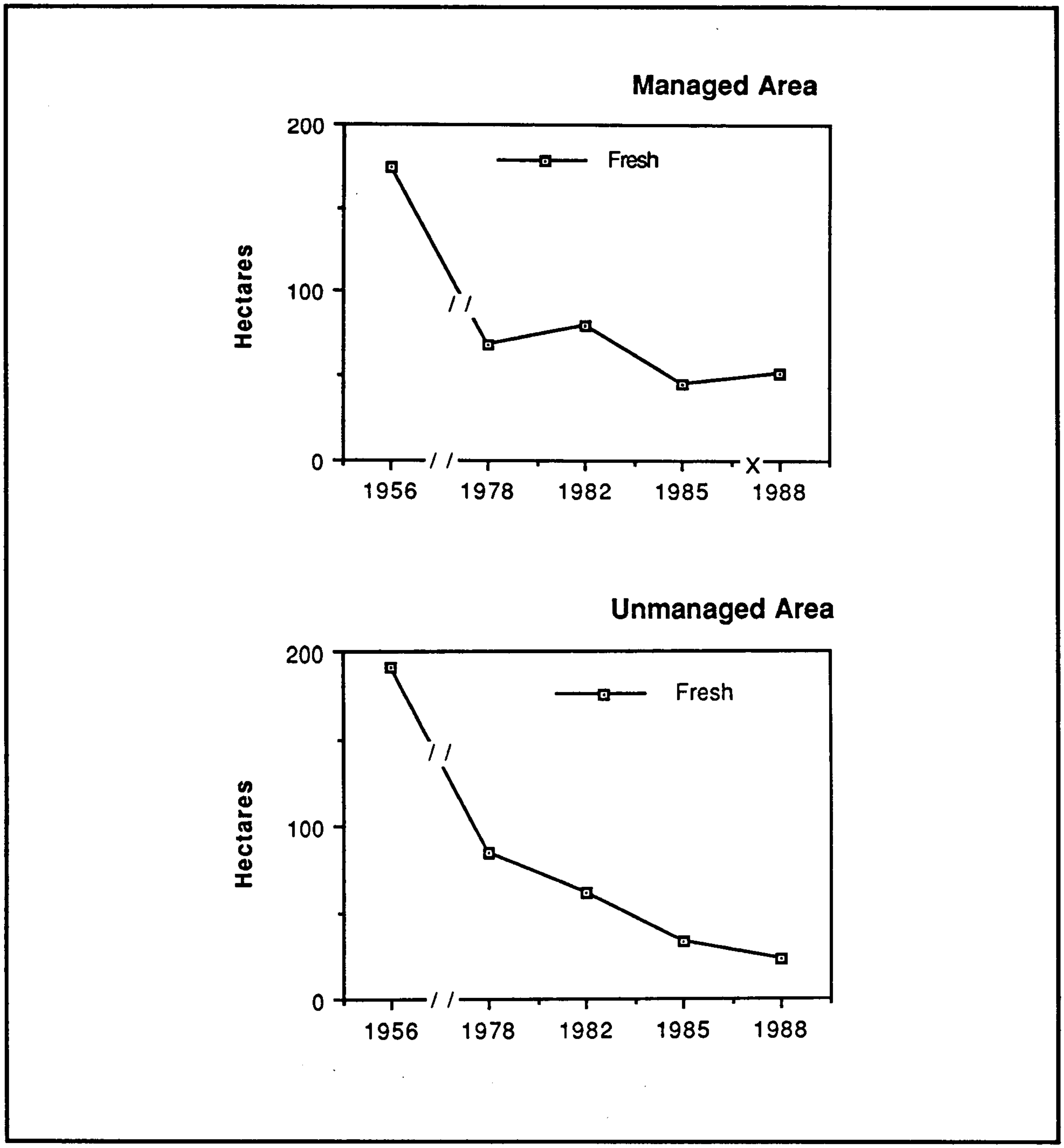

Figure 64. Areas of major marsh types in the managed and unmanaged areas at Avoca Bayou Lawrence, 1956-1988. "X" denotes the date of management implementation.

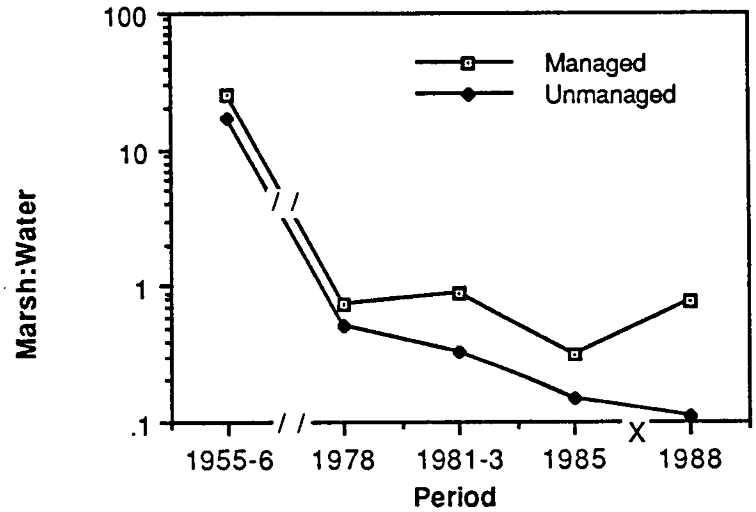

Figure 65. Marsh-to-water ratios in the managed and unmanaged areas at Avoca Bayou Lawrence, 1956-1988. "X" denotes the date of management implementation.

a potential saltwater intrusion route from the Houma Navigation Canal. The primary management goals are to decrease or reverse land loss and control or reduce salinity (table 48). Four fixed-crest weirs on the northern boundary and one flap-gated, variable-crest weir to the south are used to control water levels. Soils in both the managed and unmanaged areas consist of Medisaprist characterized by peat/flotant substrate. Management commenced in 1985.

Fresh marsh habitat converted to intermediate habitat in both areas during 1956-1978 (figure 66). Since 1978, the proportion of fresh to intermediate marsh has remained virtually unchanged in both areas. Brackish habitat increased slightly from 1985 to 1988 in both the managed and unmanaged areas. Both areas have more diverse habitats than any of the other study sites. Significant areas of aquatic vegetation were present in both managed (13%) and unmanaged (18%) areas during 1978. Subsequent losses reduced this acreage to 2% (managed) and 1% (unmanaged) by 1988. Habitat diversity decreased after the date of management implementation at both managed and unmanaged areas as brackish marsh disappeared. Swamp habitat declined slightly prior to management implementation, but management had no apparent effect on habitat diversity. After significantly declining during 1956-1978, marsh-to-water ratios have remained relatively stable at approximately 2:1 in both the managed and unmanaged areas (figure 67). In the managed marsh the 1956-1978 decrease in marsh-to-water ratios was the result of marsh (1,157 ha) habitat converting to open water, shrub/scrub, and aquatic vegetation. Marsh losses (260 ha) in the unmanaged area during the same period were predominantly the result of conversion to aquatic vegetation and water habitat. Marsh-to-water ratios in the managed area changed little after management implementation.

Changes occurring in the managed area are very similar to those occurring in the unmanaged area (table 49). Since management implementation, both the managed and unmanaged areas have lost similar amounts of marsh (3%-4%) and gained similar amounts of aquatic vegetation (1%) and other habitats (1%-2%) (table 49). The most apparent difference in habitat change in the managed marsh is a loss of water (3%) and a gain of shrub/scrub habitat (3%).

Louisiana Land and Exploration Company

The Louisiana Land and Exploration Company management area lies at the northeastern edge of Lake Mechant southwest of Lake De Cade in the Terrebonne basin (site 13, figure 43). Managed area boundaries are defined by levees of Bayou du Large, Small Bayou la Pointe, a plugged pipeline canal, and the upper end of the drainage basins of Bayou Chevreau, Little Bayou Chevreau, and Bayou Dufrene. Across Lake Mechant to the southwest is the unmanaged area, whose boundaries are defined by Buckskin Bayou and Bayou du Large and Lake Mechant's shoreline. Blue Hammock Bayou, Bayou du Large, and Grand Caillou Bayou all affect local hydrology via connections to Lake Mechant. No oil exploration canals penetrate the interior of the unmanaged area. Approximately 2 km of canals within the managed area contain three plugs. Twenty-five fixed-crest weirs are used in a passive management plan (table 49) to control land loss. Management commenced in 1956. Area soils are Medisaprists-Hydraquents (moderately saline) and are characterized by the presence of peat.

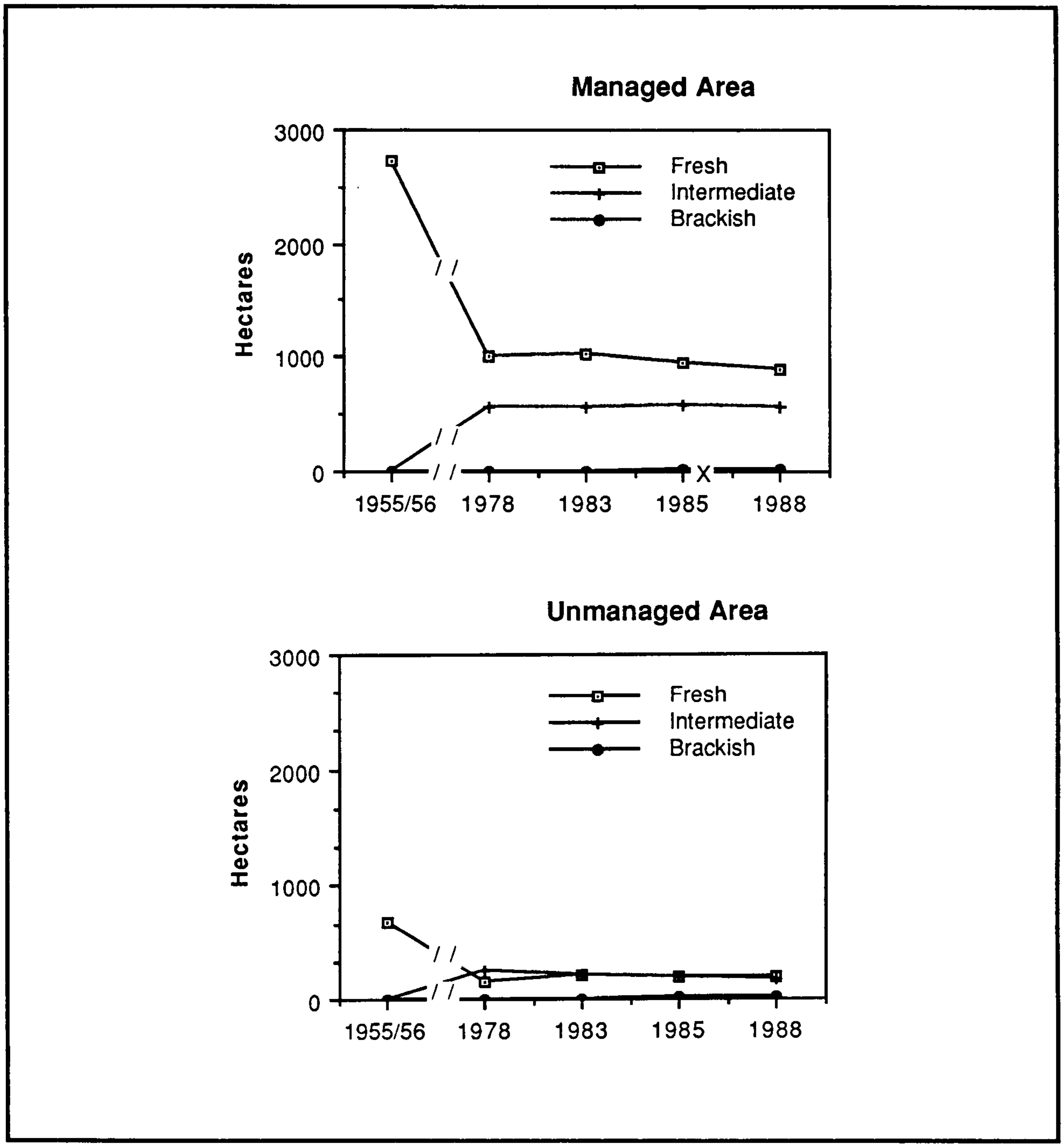

Figure 66. Areas of major marsh types in the managed and unmanaged areas at Fina Falgout Canal, 1956-1988. "X" denotes the date of management implementation.

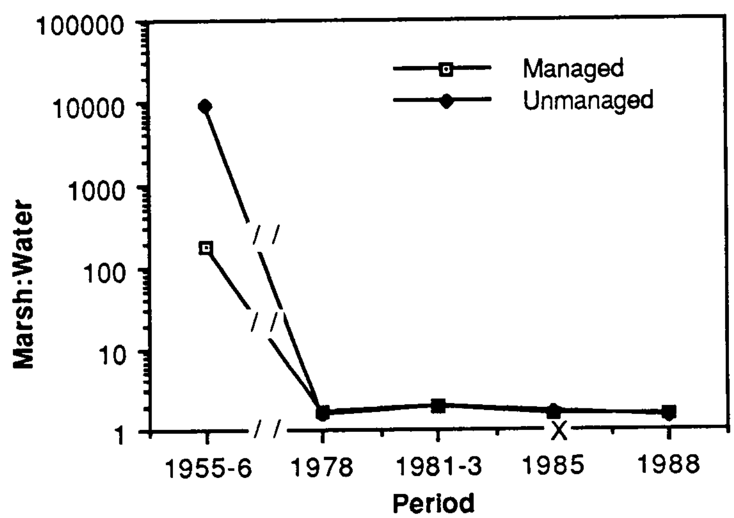

Figure 67. Marsh-to-water ratios in the managed and unmanaged areas at Fina Falgout Canal, 1956 - 1988. "X" denotes the date of management implementation.

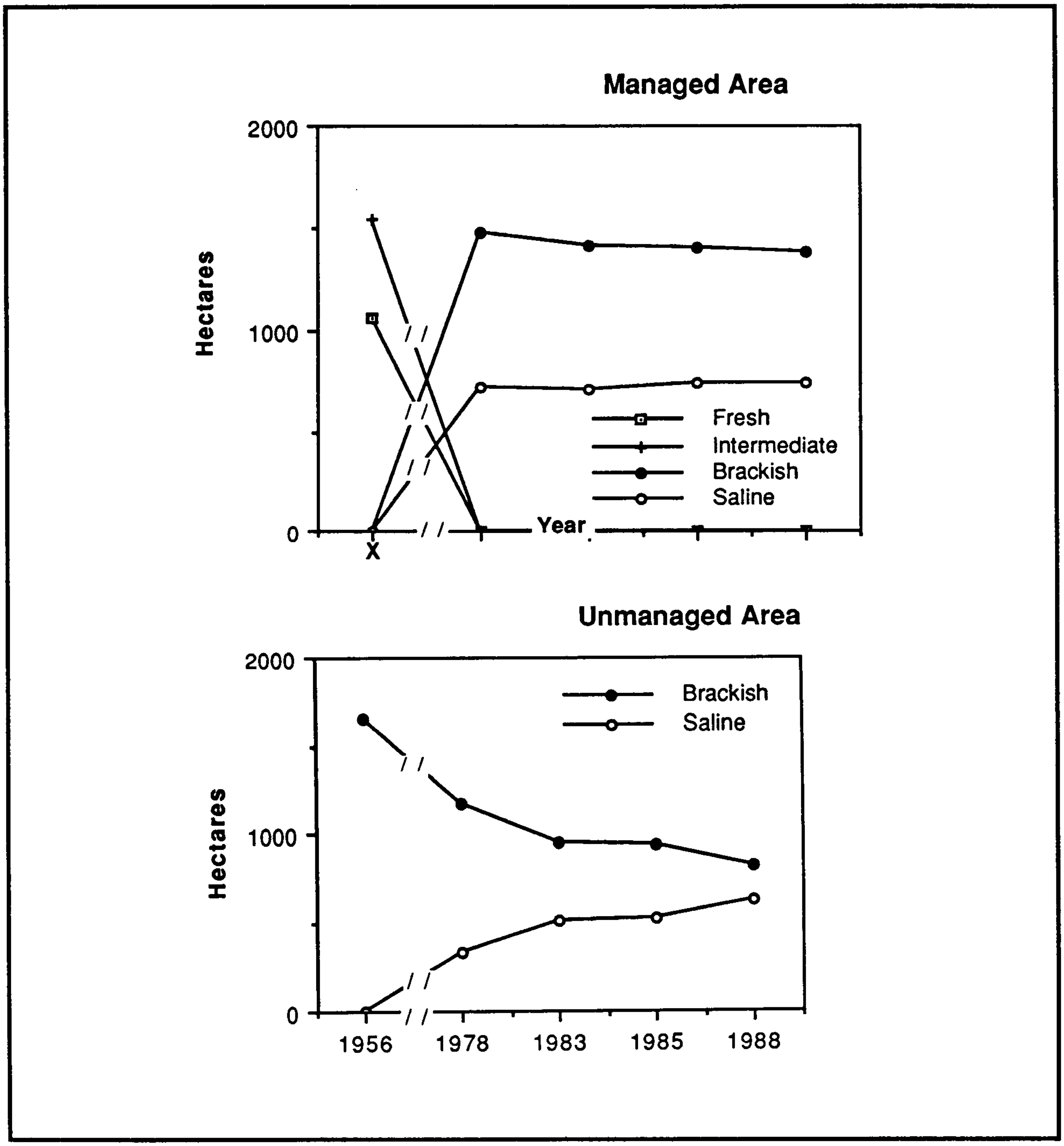

Figure 68. Areas of major marsh types in the managed and unmanaged areas at Louisiana Land and Exploration site, 1956-1988. "X" denotes the date of management implementation.

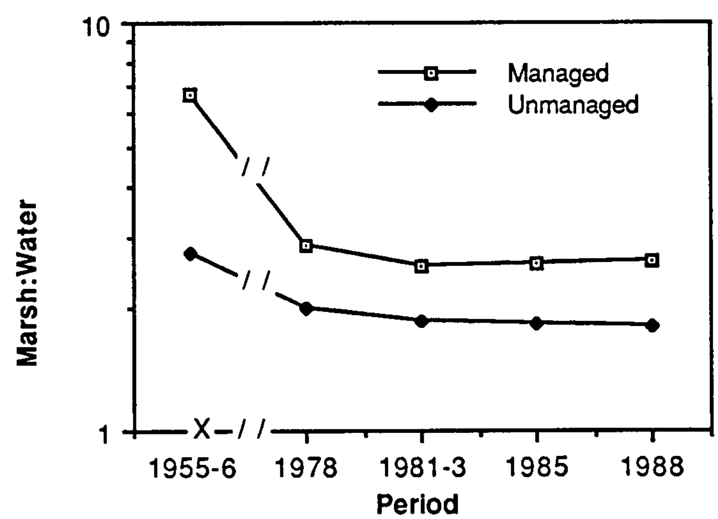

Figure 69. Marsh-to-water ratios in the managed and unmanaged areas at the Louisiana Land and Exploration site, 1956-1988. "X" denotes the date of management implementation.

Since implementation, managed habitat changes have resulted in a marsh loss rate roughly twice that of the unmanaged area (table 49). Changes in managed habitats indicate eradication of fresh and intermediate marsh during 1956-1978 that resulted in a brackish/saline habitat (figure 68). During 1956-1978, a gradual intrusion of saline habitat in the unmanaged area replaced 628 ha of brackish habitat. We extrapolated the boundary of the saline/ brackish marsh in this unit from the 1978 and 1988 isohalines provided by Linscombe. Since 1978, both areas have maintained a larger brackish habitat component than saline. Habitat diversity has increased at the managed site since implementation, as evidenced by the addition of forest, developed, water body (artificial), shrub/scrub (spoil), and inert habitats. Additions in the artificial water body and spoil shrub/scrub classes account for habitat gains in the unmanaged area.

Marsh-to-water ratios declined in the unmanaged marsh throughout the study period, whereas they improved slightly in 1985 and 1988 in the managed area (figure 69). These trends arise from habitat reallocation between marsh and water habitats (table 49). The observed differences do not reflect a strong deviation between managed and unmanaged marsh-to-water ratio observations. Other habitats, while present, have played no significant role in the alterations taking place in either area. Management appears to have been effective in maintaining a stable relationship between brackish and saline habitats, whereas saline habitat increased in the unmanaged marsh. No such positive effects are apparent in managed marsh-to-water ratios.

Fina-Bayou Chauvin

Located in the Terrebonne basin, both the managed and unmanaged areas of the Fina-Bayou Chauvin site are situated in the lower Bayou Chauvin watershed above Lake Boudreaux (site 14, figure 43). Two inactive distributaries of the Mississippi River define the watershed, Bayou Grand Caillou to the west and Bayou Petite Caillou to the north and east. Both the managed and unmanaged areas contain oil exploration canals leading into their interiors. Numerous canals traverse the watershed; each site is bordered on three sides by oil exploration canals. Additional hydrologic alterations resulted from the construction of Louisiana highway 57 parallel to Bayou Grand Caillou, Louisiana highway 56 along Bayou Petite Caillou, and the Houma Navigation Canal. Fixed-crest weirs are used in a passive management plan to stabilize land loss (table 48). Medisaprist-Hydraquents soils in the locations are characterized by moderate-to-deep peat. Management began in 1984.

Both the managed and unmanaged areas underwent a shift from entirely fresh marsh to their current intermediate marsh habitat during 1956-1978 (figure 70). Analysis of the changes in marsh types reveals that management may have played a role in the disappearance of brackish habitat between 1985 and 1988. Since management implementation, habitat diversity in the managed area has increased as a result of the additions of inert and developed habitats. Diversity did not change in the unmanaged area during this time. The periods 1956-1978 and 1985-1988 reflect measurable downward trends of marsh-to-water ratios at both areas, though the unmanaged marsh had a greater reduction (figure 71). Since implementation, the primary habitat transitions contributing to changes in the marsh-to-water ratio at the managed area have been the conversion of marsh and aquatic vegetation to water. Losses in the

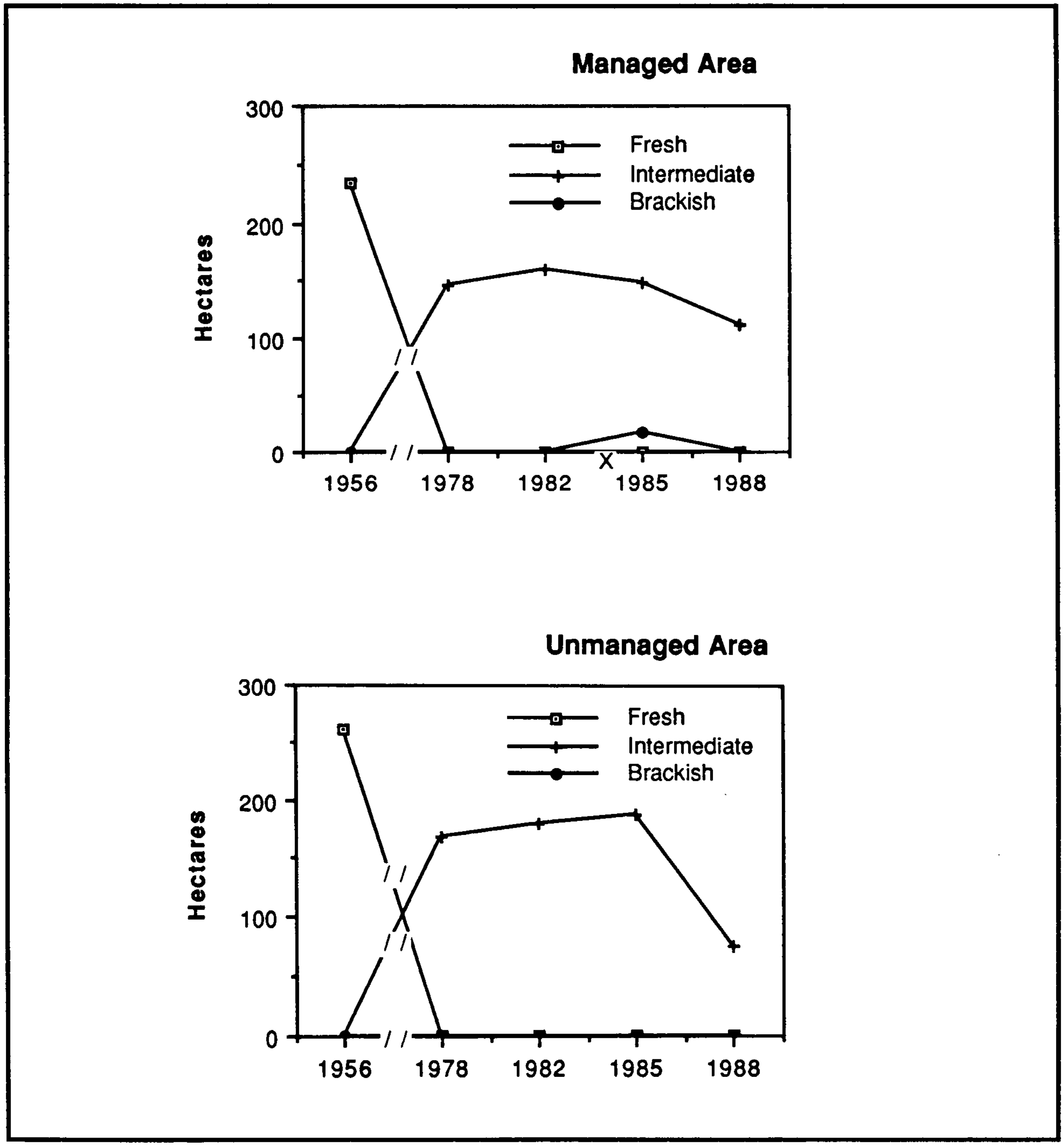

Figure 70. Areas of major marsh types in the managed and unmanaged areas at Fina Bayou Chauvin, 1956-1988. "X" denotes the date of management implementation.

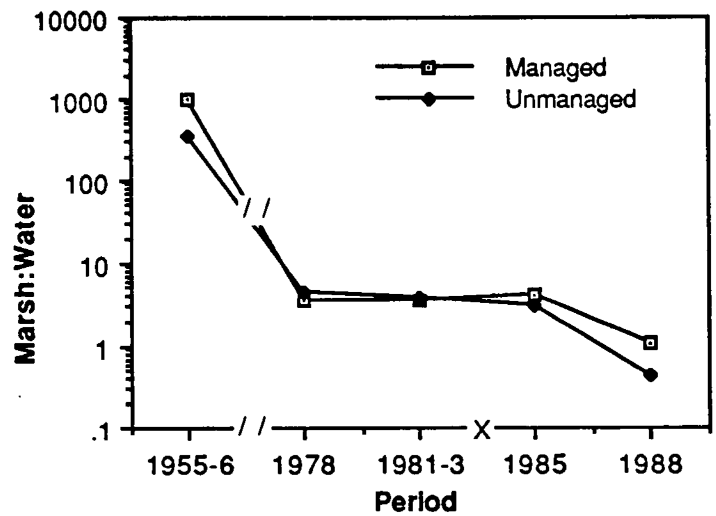

Figure 71. Marsh-to-water ratios in the managed and unmanaged areas at Fina Bayou Chauvin, 1956-1988. "X" denotes the date of management implementation.

unmanaged area include 31 ha of shrub/scrub habitat. Habitat modifications at the unmanaged area were similar, though they occurred at a slightly higher rate. The effects of management on the Fina-Bayou Chauvin marsh are unclear. Changes in the managed and unmanaged areas appear similar (table 49). Management has been unable to counteract the forces causing the declining marsh-to-water ratios at this site. On the other hand, the managed marsh is deteriorating more slowly than the unmanaged marsh. These changes have not affected habitat diversity.

L.H. Ryan

Located in the Barataria basin (site 15, figure 43), the L.H. Ryan study areas comprise several small managed and unmanaged units. Except for one unmanaged unit that contains a bisecting pipeline canal, all other areas, managed and unmanaged, have no interior canals and are bordered by oil exploration canals on two sides. The L.H. Ryan sites are situated inside a semi-enclosed basin formed by abandoned Mississippi River distributaries (Bayou L'Ours) west of Hackberry Bay. Many oil exploration canals connect the area with Hackberry Bay and upper Caminada Bay, providing a source of higher-salinity water to the site. Each of the two subunits forming the managed area is actively managed via hydrological manipulation by variable-crest weirs with flap gates (table 48). The L.H. Ryan management plan addresses land loss and habitat enhancement for indigenous fish, wildlife, and waterfowl, as well as anti-trespassing goals. Site soils are a Timbalier-Belle Pass association. Management commenced in 1986.

In 1956 both the managed and unmanaged areas had brackish marsh only. By 1978, saline marsh had appeared in both areas (figure 72). Since 1978 the proportion of saline to brackish habitat has remained constant throughout both study areas. Marsh-to-water ratios in the managed area have been unstable since 1956. Before management implementation, ratios increased in 1983, then decreased. Since implementation, the marsh-to-water ratio in the managed marsh has improved because open water has converted to marsh and "other" habitats (table 49). Such fluctuations make it difficult to attribute change to management. However, the 1988 marsh-to-water ratio in the managed area is the first instance in which the trends of marsh-to-water ratios in the two areas diverge. This increase in the marsh-to-water ratio in the managed area and decrease in the unmanaged area ratio may be a result of management influence. Managed area marsh-to-water ratios (figure 73) have stayed at approximately 1.2:1 since the dramatic reduction that occurred in 1956-1978. Marsh habitat composition has remained exceptionally stable since 1978 in both areas (figure 72; table 49). Since implementation changes in habitat diversity have been small. No change occurred in the unmanaged area, and the managed area gained inert habitat.

Lafourche Realty Company

The managed and unmanaged areas of the Lafourche Realty Company site are adjacent to each other south of Yankee Canal along Bayou Lafourche east of Golden Meadow in the Barataria basin (site 16, figure 43). Oil exploration canals border all sides of the managed marsh, and from these, 10 location canals enter the site. A pipeline canal bisects the east central portion of the managed area. The unmanaged marsh boundaries consist of canal spoil banks to the northeast and west. The remaining western line is defined by the eastern bank of Bayou Lafourche. A total of 11 oil exploration canals are in the unmanaged area, two of which penetrate deep into the interior. Management is conducted by use of four culverts and two slotted fixed-crest weirs (table 48). Plan goals are to control land loss and enhance waterfowl and furbearer habitats. This management plan may not be fully implemented. Current information indicates that this area will be actively managed in the future. Area soils consist of a Timbalier-Belle Pass association. Management commenced in 1984.

During 1956-1978, managed marsh (figure 74) converted from essentially intermediate to entirely saline and has remained a saline marsh. Unmanaged marsh changed from fresh/intermediate to saline/brackish between 1956 and 1978 (figure 74). After management implementation, habitat changes consisted mainly of loss of marsh to open water at both the managed and unmanaged areas. Distribution of marsh loss and water gain are equivalent at the areas (table 49). Analysis of habitat data reveals that shrub/scrub (spoil) increased in 1988 in the managed area, presumably as a result of additional canal construction as indicated by the increase (7 ha) in water (artificial). These data provide insight into changes causing the continued decline in marsh-to-water ratios in the managed and unmanaged areas (figure 75). Since management implementation, habitat diversity has increased in the management area with the addition of inert habitat. During the same time, shrub/scrub and forest habitats have been lost in the unmanaged area. Recent (1978-1988) trends in marsh-to-water ratios of both areas suggest somewhat more stable conditions than those during 1956-1978. Current management practices have not improved marsh-to-water ratios or habitat composition at this site. No substantial differences between the managed and unmanaged areas are apparent in the habitat changes that occurred after management implementation (table 49).

SITE COMPARISONS

The following is a general analysis of major trends and relationships of the 16 sites. Several habitat trends were apparent coastwide in both marsh-to-water ratios and salinity transitions as represented by major marsh types. The coastwide trends fall into two distinct phases: 1956-1978 and 1978-1988. Site results are considered from a pre- and post-implementation perspective as well as managed versus unmanaged effects. A more specific statistical analysis and a summary of management influences are then presented.

Habitat Trends and Management Influences on Marsh Type

There was a general trend of change toward higher-salinity marsh types during 1956-1978. Transitions towards higher-salinity marshes were reduced during 1978-1988. There were few consistent differences between managed and unmanaged areas during these intervals. The high number of sites (managed and unmanaged areas) exhibiting similar behavior after management implementation indicates that management did not greatly affect marsh type changes.

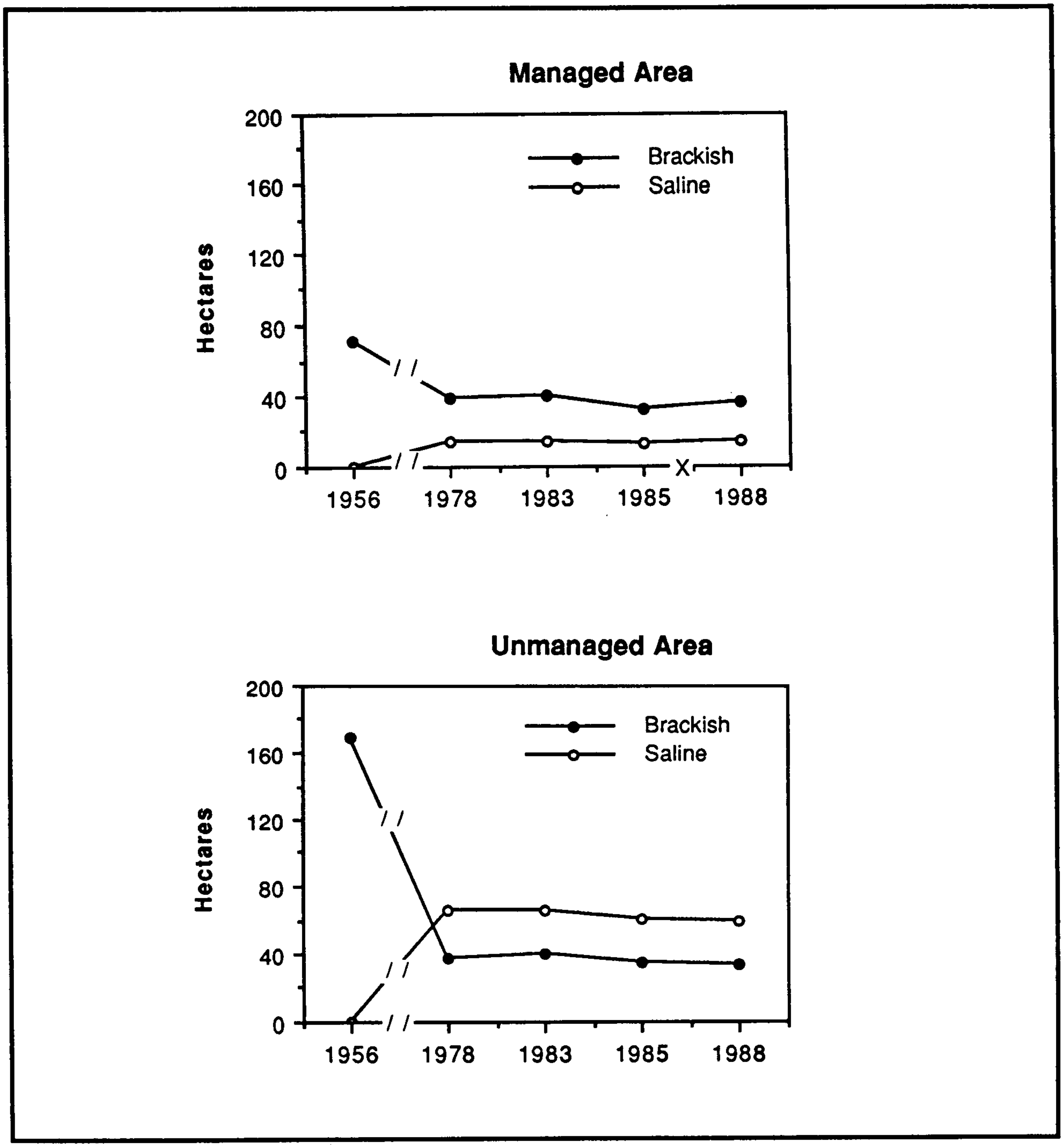

Figure 72. Areas of major marsh types in the managed and unmanaged areas at L.H. Ryan, 1956-1988. "X" denotes the date of management implementation.

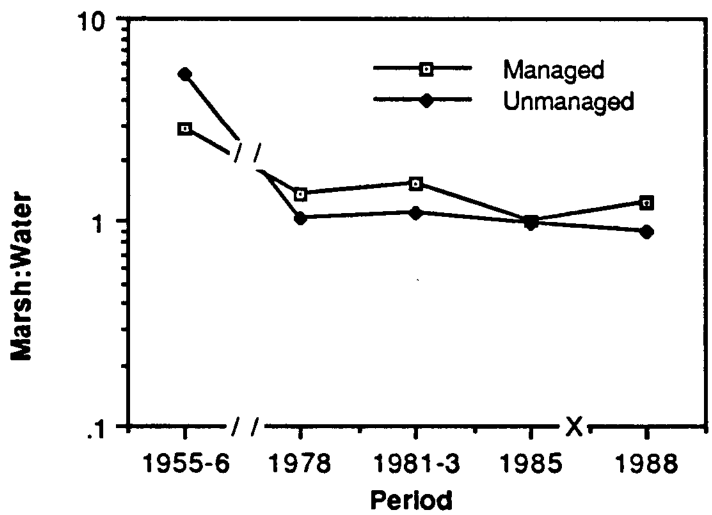

Figure 73. Marsh-to-water ratios in the managed and unmanaged areas at L.H. Ryan, 1956-1988. "X" denotes the date of management implementation.

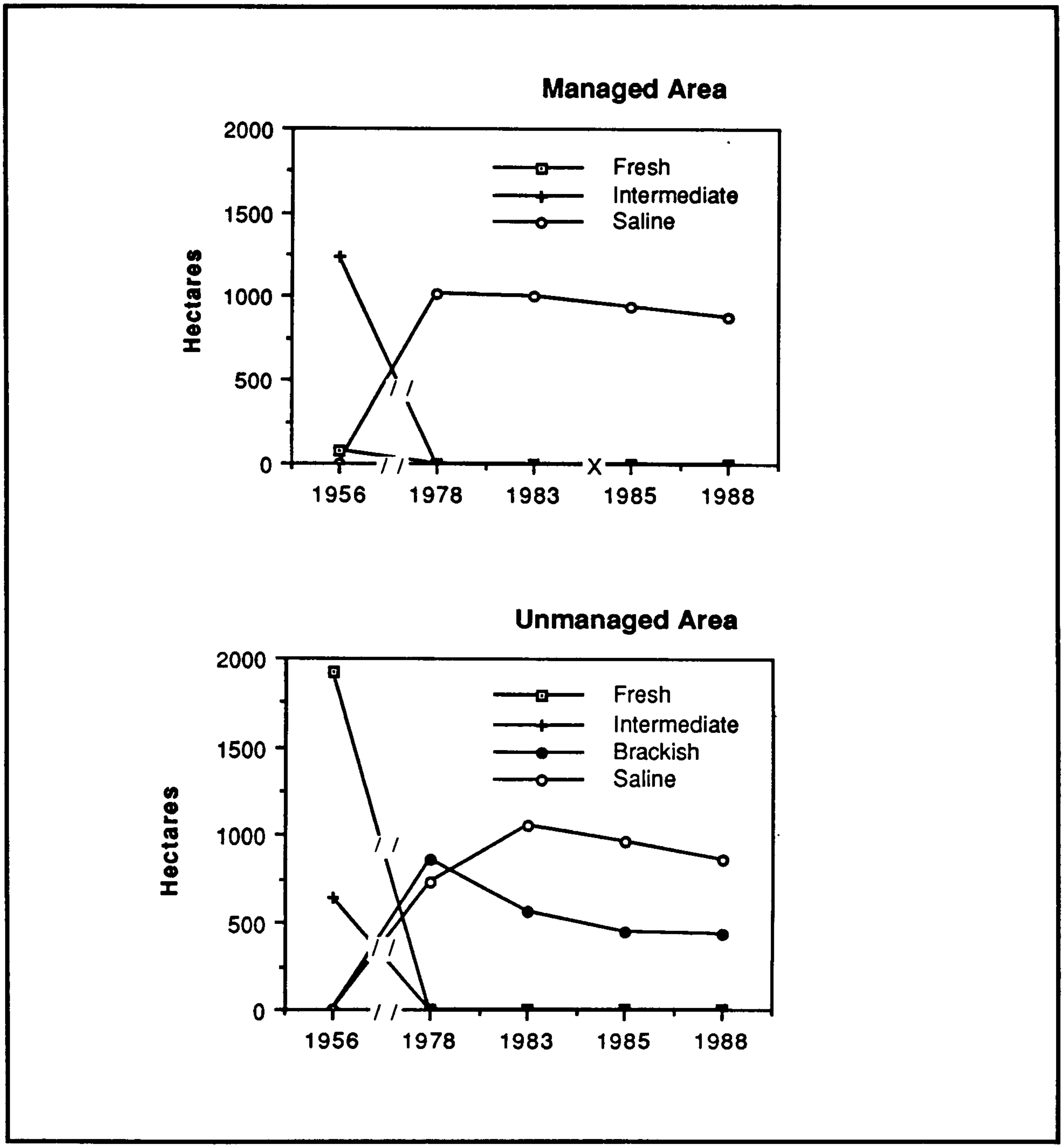

Figure 74. Areas of major marsh types in the managed and unmanaged areas at Lafourche Realty, 1956-1988. "X" denotes the date of management implementation.

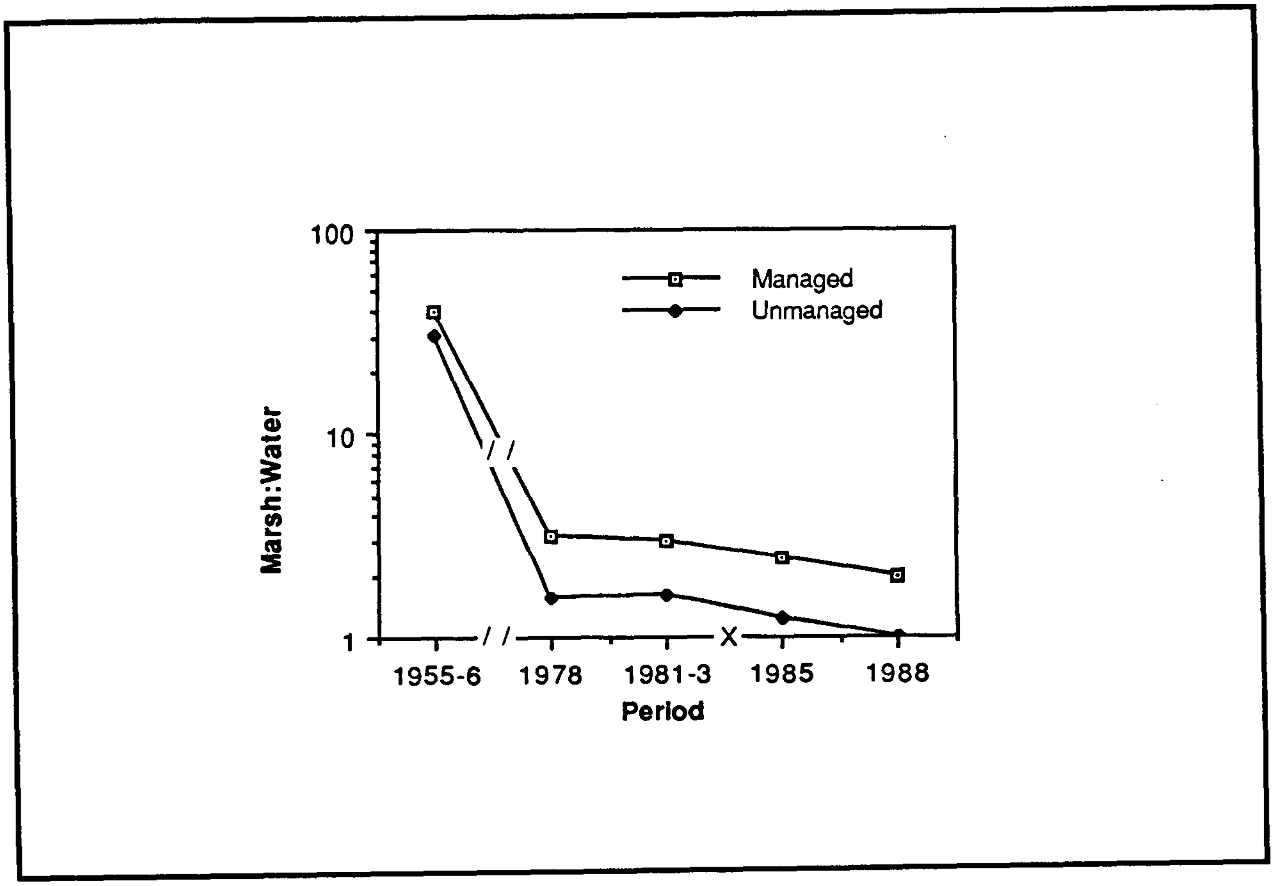

Figure 75. Marsh-to-water ratios in the managed and unmanaged areas at Lafourche Realty, 1956-1988. "X" denotes the date of management implementation.

Results of 1956-1978 habitat analysis indicate a similar change throughout the sites from lower- to higher-salinity habitats. Overall marsh changes indicate similar or identical marsh type trends at 13 of 16 sites. Similar or identical trends occur when both managed and unmanaged areas at a site increase, decrease, or do not change with respect to the habitat parameter considered. Of these 13 sites exhibiting similar trends, three sites, Louisiana Land and Exploration Company (1956), Marsh Island Refuge (1959), and State Wildlife Refuge (1967), were managed for all or more than 50% of this time. Changes toward higher-salinity marshes occurred in both managed and unmanaged areas at 9 of the 16 sites. However, four sites (Avoca Bayou Lawrence, Little Pecan Island Unit 9, Marsh Island Refuge, and State Wildlife Refuge) showed no salinity-dominated marsh habitat change in either managed or unmanaged areas during this period. Additionally, one unmanaged area (Vermilion Corporation) and two managed areas (Rockefeller Refuge and Creole Canal) had few or no marsh type habitat modifications from 1956 to 1978. In three of the sites undergoing no change in marsh type between 1956 and 1978 in either managed or unmanaged areas, marsh types did not change throughout the entire study period (i.e., Marsh Island Refuge, State Wildlife Refuge, and Avoca Bayou Lawrence). This may be a result of local riverine influence (Atchafalaya River) not associated with influences from structural management plans.

After 1978, fewer changes in marsh type occurred. This stability is exhibited by the 8 sites (managed and unmanaged pairs) undergoing no change during 1978-1988. Of the 32 areas, 20 had no changes in marsh type. Fewer areas, 10 of 32, became more saline between 1978 and 1988 than between 1956 and 1978 (21 of 32 areas).

Comparisons of marsh type changes in managed and unmanaged areas after plan implementation (figure 76), reveal few strong management effects. Eleven sites exhibited similar tendencies at both managed and unmanaged areas after management implementation. The influence of management was apparent, however, at the remaining five sites. Eight of the sixteen sites (both managed and unmanaged areas) did not become more fresh or less fresh after management implementation. After management, no changes in marsh type were apparent at 19 of the 32 areas. Three sites increased in higher-salinity marsh at both managed and unmanaged areas, whereas only one site (Fina-Bayou Chauvin) developed lower-salinity marsh in the managed area (the unmanaged marsh remaining unchanged). At the remaining four sites, trends for the managed and unmanaged areas diverged (i.e., Rockefeller Refuge, Vermilion Corporation, Creole Canal, and Vermilion Bay Land). The managed marsh at Vermilion Corporation and Rockefeller Refuge became less saline after implementation, while higher-salinity marshes increased at their unmanaged areas. The process of change at Vermilion Corporation (figure 54) was not simple. The replacement of fresh marsh by brackish marsh followed by conversion to intermediate marsh indicates a desirable effect (i.e., reversal of the trend toward replacement of formerly fresh marsh with brackish marsh). No change occurred at the Creole Canal managed area, while the unmanaged marsh became more saline. The managed area at Vermilion Bay Land became a more saline habitat, but no change occurred in the unmanaged marsh.

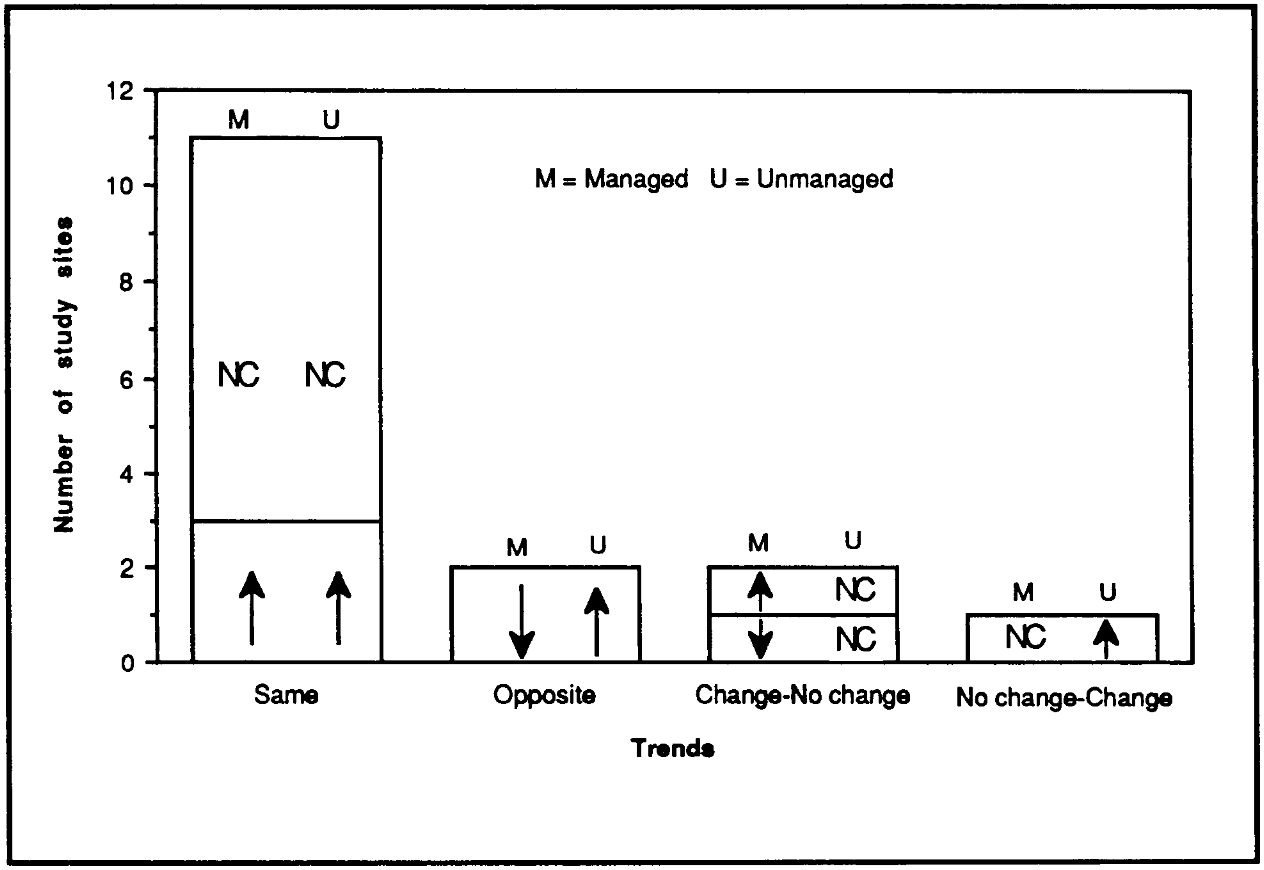

Figure 76. Trends in marsh type changes at the 16 sites since implementation. NC indicates there was no change in marsh type since implementation. An upward-pointing arrow indicates that the marsh changed to a more saline type. A downward-pointing arrow indicates that the marsh changed to a less saline type.

Influences on Habitat Diversity

Analysis of habitat diversity based on the 15 aggregated classes reveals that the managed areas had more overall increases after implementation than did the unmanaged areas. What is most apparent from a categorical perspective, however, is the nature of these habitat transitions. Most of the changes in habitat diversity were not due to emergence of habitats that could be identified with coastal marsh evolution or management goals, but rather to those identified with human landscape alteration (i.e., artificial water bodies, spoil shrub/scrub) or transitional habitats (i.e., inert) associated with tidal cycles or climatic conditions at the time of aerial photography. Habitat change phenomena related to influences from the inert habitat category (primarily mud flats) should not be entirely discounted. Also of note is the small role of aquatic vegetation in overall habitat composition. Throughout the entire study period, aquatic vegetation was identified in seven managed areas and five unmanaged areas. After management implementation, aquatic vegetation played a part in habitat changes at only five managed and three unmanaged areas. The general absence of aquatic vegetation is probably an artifact of the aerial photography methods employed in the data retrieval as well as the time of year (fall) when the photos were taken. Field studies by Chabreck and Nyman (1989) have shown that fixed-crest weirs (passive management) can enhance aquatic vegetation growth.

Of the 16 managed areas, 12 had net increases in habitat diversity after implementation, while only 6 of 16 unmanaged areas had net gains (figure 77). At three managed (Avoca Bayou Lawrence, L.H. Ryan, and Lafourche Realty) and two unmanaged (Amoco West Black Lake and State Wildlife Refuge) areas, the sole source for the increase was inert habitat. In fact, at areas where overall habitat diversity increased, inert habitat contributed to these increases at 9 of 12 managed units and 4 of 6 unmanaged areas. Habitat types directly related to human intervention, such as artificial water bodies (canals, trenasses), shrub/scrub (spoil), developed, and inert, dominated habitat diversity changes. When the inert or flats class is included, human-induced habitat types were the sole source of diversity increases at 9 of 12 managed areas and 4 of 6 unmanaged areas. A majority of the habitat gains (37 of 45) from 1956 to 1988 in both managed and unmanaged areas arose from habitats created by human intervention (21) or inert (16). Human-induced habitats arising from canal dredging and development activities are widespread in coastal Louisiana. While these can be useful components of an ecosystem, their creation is separate from the objectives of marsh management. In all, the managed and unmanaged areas at 8 of 16 sites exhibited the same trend (figure 77). At six of the remaining sites, habitat diversity increased in the managed area compared to the unmanaged area. Seven unmanaged areas and one managed area had no change in net habitat diversity after management implementation (figure 77).

When only non-human-induced habitats are considered, however, the trends in managed and unmanaged areas are clearly similar. Managed and unmanaged areas with increasing habitat diversity had an equal proportion of non-human-induced habitat (4 of 12, 2 of 6, respectively). At areas where habitat diversity decreased after implementation, one of three managed and two of three unmanaged areas were affected by non-human-induced habitats.

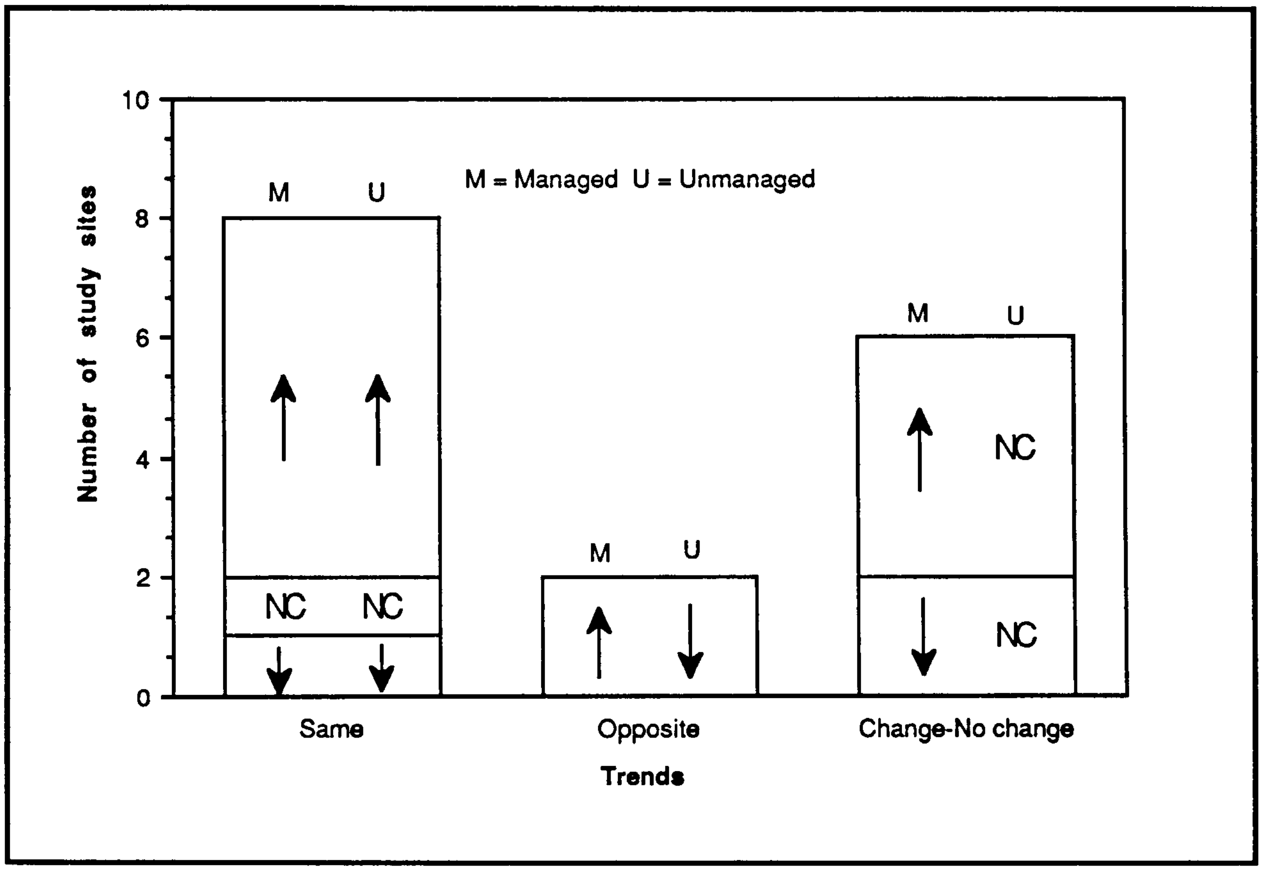

Figure 77. Trends in habitat diversity changes at the 16 sites since implementation.

Marsh-to-Water Ratios and Marsh Loss

Patterns of change in marsh-to-water ratios were similar to those of change in marsh type. More specifically, marsh-to-water ratios declined significantly at both the managed and unmanaged areas during 1956-1978, and then noticeably less during the next 10 yr. This sharp coastwide decline in marsh-to-water ratios occurred regardless of physiographic setting or management practices. Five plans were implemented for at least 11 yr of 1956-1978. Management plans at three of these five sites (Rockefeller Refuge, Marsh Island Refuge, and Louisiana Land and Exploration Company) were implemented for nearly the entire 22 yr. Before management implementation, only at the McIlhenny Company site did the managed and unmanaged marshes change differently (figure 60).

The effect of management on marsh-to-water ratios was unclear. Patterns of change were similar at managed and unmanaged areas after management implementation at 8 of 16 sites (figure 78). This suggests inconsistent management effects. Many of the existing differences were small and might have been related to factors such as photograph characteristics, environmental conditions at the time photographs were taken, or duration of implementation (e.g., Amoco West Black Lake). Of the five sites where opposing trends of marsh-to-water ratios developed after management implementation, three of the managed areas had increased ratios of marsh to water and two decreased. The most frequent pattern of marsh-to-water ratios after management implementation (six sites) was declining ratios at both managed and unmanaged areas. Where management did produce improvement (six sites), marsh-to-water ratios declined at three companion unmanaged areas, increased at unmanaged and managed marsh at two sites, and remained unchanged at one. Marsh-to-water ratios increased at four unmanaged areas while management was implemented at their corresponding managed areas. At two of these sites, the managed area marsh-to-water ratio declined, whereas the marsh-to-water ratio increased at the remaining two managed areas.

Management sometimes did not change marsh-to-water ratios. At 2 of the 16 sites (Amoco West Black Lake and Fina-Falgout Canal), pre-implementation trends of virtually no change continued after management implementation. This may be an indication of no positive management influence or a consequence of the short duration of management at these sites. The influence of management on marsh-to-water ratios may be apparent within just a few years. In those areas where management had been in effect more than 5 yr, the last interval examined (1985-1988 or last two where possible, 1983-1985 and 1985-1988) indicated improved marsh-to-water ratios at three of eight sites.

Overall Habitat Changes Since Management Implementation

Management had mixed influences on marsh gain (figure 79; table 49). From implementation to 1988, two managed and no unmanaged areas gained marsh. Although lost water habitat may reappear as habitats other than marsh, loss of water habitat consistent with management goals is generally considered a desirable outcome. Data analysis indicates that six managed and three unmanaged areas lost water while habitat management was in effect. Overall, eight managed areas and five unmanaged areas performed better than their

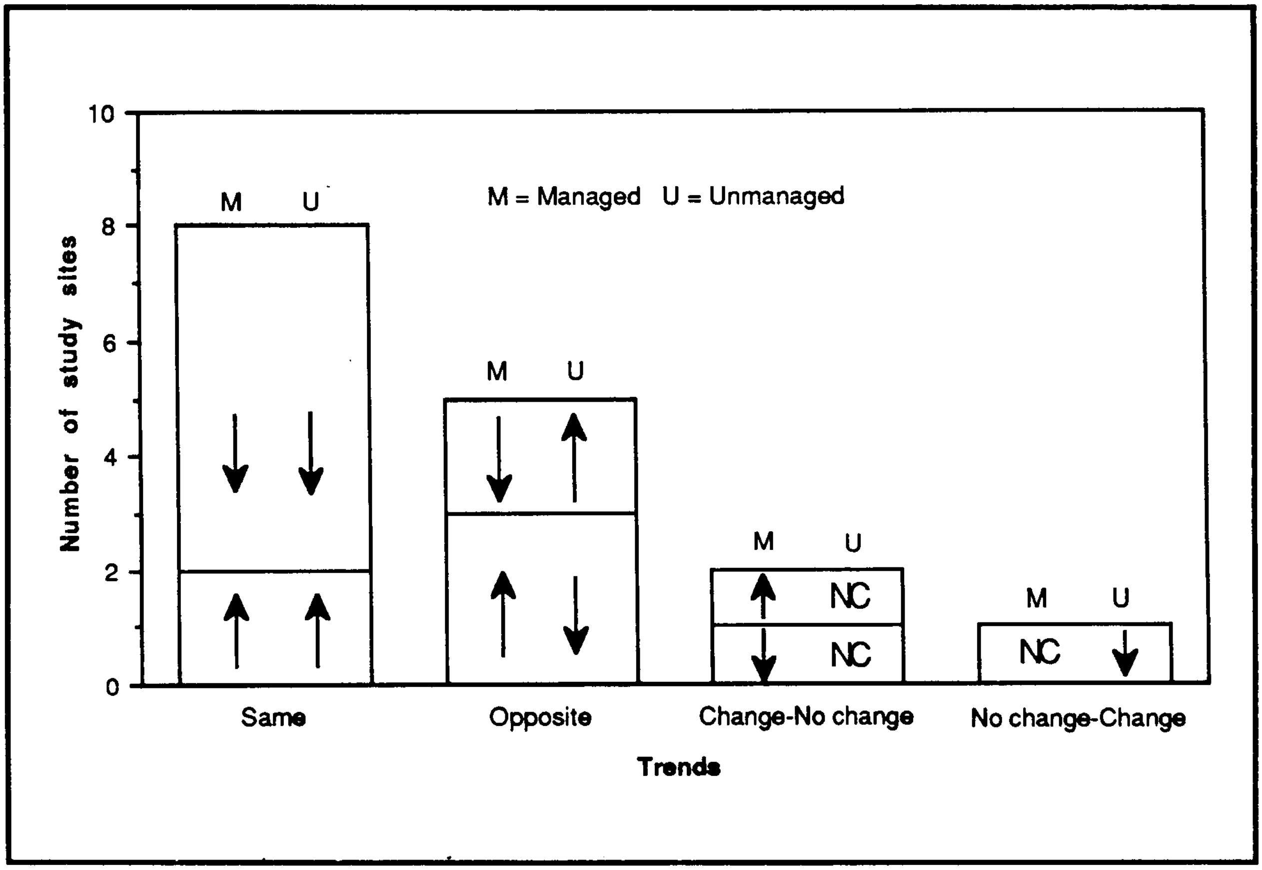

Figure 78. Trends in marsh-to-water ratio changes at the 16 sites since implementation.

comparison marshes, while at three sites the areas could not be clearly differentiated (table 49). Interpretation at several sites (Avoca Bayou Lawrence, Vermilion Bay Land) could be affected by the importance of particular habitats to the interpreter.

Analysis of 1985-1988 Marsh and Water Changes

A fundamental factor in evaluations of marsh loss and marsh-to-water ratios is the rate at which marsh changes to water and water changes to marsh. Many other habitat change possibilities enter into the synthesis of final marsh-to-water ratios (e.g., water to land, marsh to land, land to marsh). As an example of this type of analysis, 1985-1988 marsh-to-water and water-to-marsh change data were evaluated for comparison between managed and unmanaged areas. Because this analysis covers only a small interval of the total duration of many of the management plans, it is not meant to be a definitive evaluation of marsh management plans examined in this study. By agreement among project participants, a difference ($|d|$) of 5% between managed and unmanaged areas has been designated as indicating a noteworthy difference. Differences between sites of less than this amount should be interpreted with caution.

The first method used to compare marsh change in managed and unmanaged areas during 1985-1988 focused on change that involved water. Figure 80 shows the amount of water changing to marsh, less the amount of marsh changing to water. The net amount is expressed as a percentage. Managed areas had significantly greater net changes from water to marsh than the unmanaged areas (randomization test, one-tail, $p = .0062$). Five managed areas fared appreciably better than the unmanaged areas (net differences expressed as percentages): Fina-Bayou Chauvin (15.85%), Rockefeller Wildlife Refuge (14.3%), Avoca Bayou Lawrence (7.2%), Creole Canal (6.5%), and L.H. Ryan (5.4%). The Vermilion Corporation (3.1%) unmanaged area showed the greatest marsh expansion at the expense of water when compared to its respective managed area. The remaining eight plans differed little ($|d| < 5\%$) from their unmanaged areas in the water analysis: Fina-Falgout Canal (3.7%), Vermilion Bay Land (2.1%), Little Pecan Island Unit 9 (1.6%), Little Pecan Unit 6 (1.6%), Lafourche Realty (1%), McIlhenny Company (0.7%), Louisiana Land and Exploration Company (0.4%), State Wildlife Refuge (0.3%), Amoco West Black Lake (.25%), and Marsh Island Refuge (0.2%).

We also quantified marsh change by comparing the percentage of marsh gain or loss at managed and unmanaged areas during 1985-1988. The amount of marsh in 1988 less the amount of marsh in 1985 is expressed as a percentage. The results of this analysis are presented in figure 81. As a group, the managed marshes (mean difference = -1.4%) had significantly less reduction in marsh area from 1985 to 1988 than the unmanaged areas (mean difference = -4.5%, randomization test, $p = .0143$). This result is consistent with the objectives of marsh management. Five managed areas fared better than the site's unmanaged areas: Fina-Bayou Chauvin (net difference = 17.8%), Rockefeller Wildlife Refuge (13.9%), Avoca Bayou Lawrence (6.5%), Creole Canal (6.5%), and L.H. Ryan (5.3%). One of the unmanaged areas outperformed the plans by an appreciable difference, namely Little Pecan Unit 6 (2.5%, net difference is negative; more marsh went to water). The remaining plans

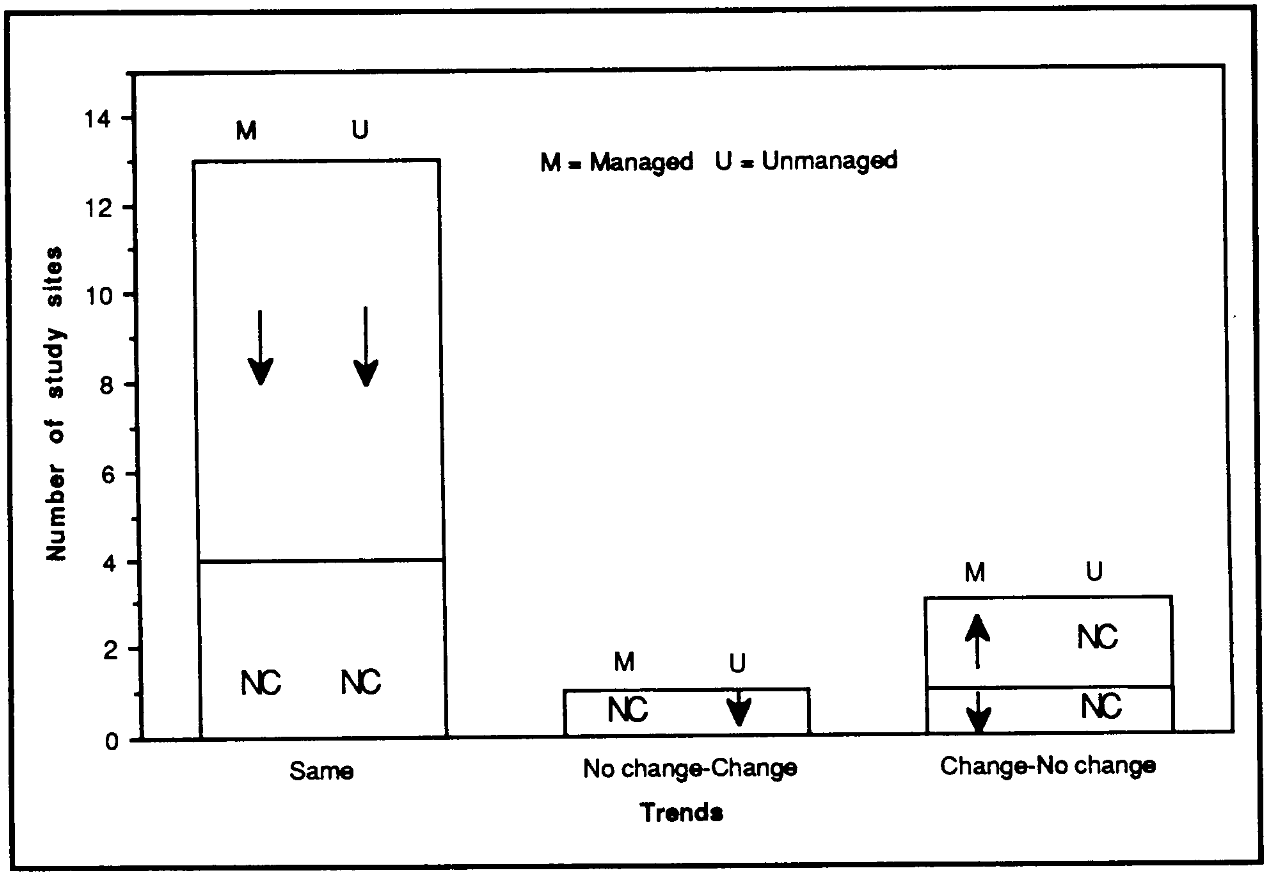

Figure 79. Trends in net marsh changes at the 16 sites since implementation.

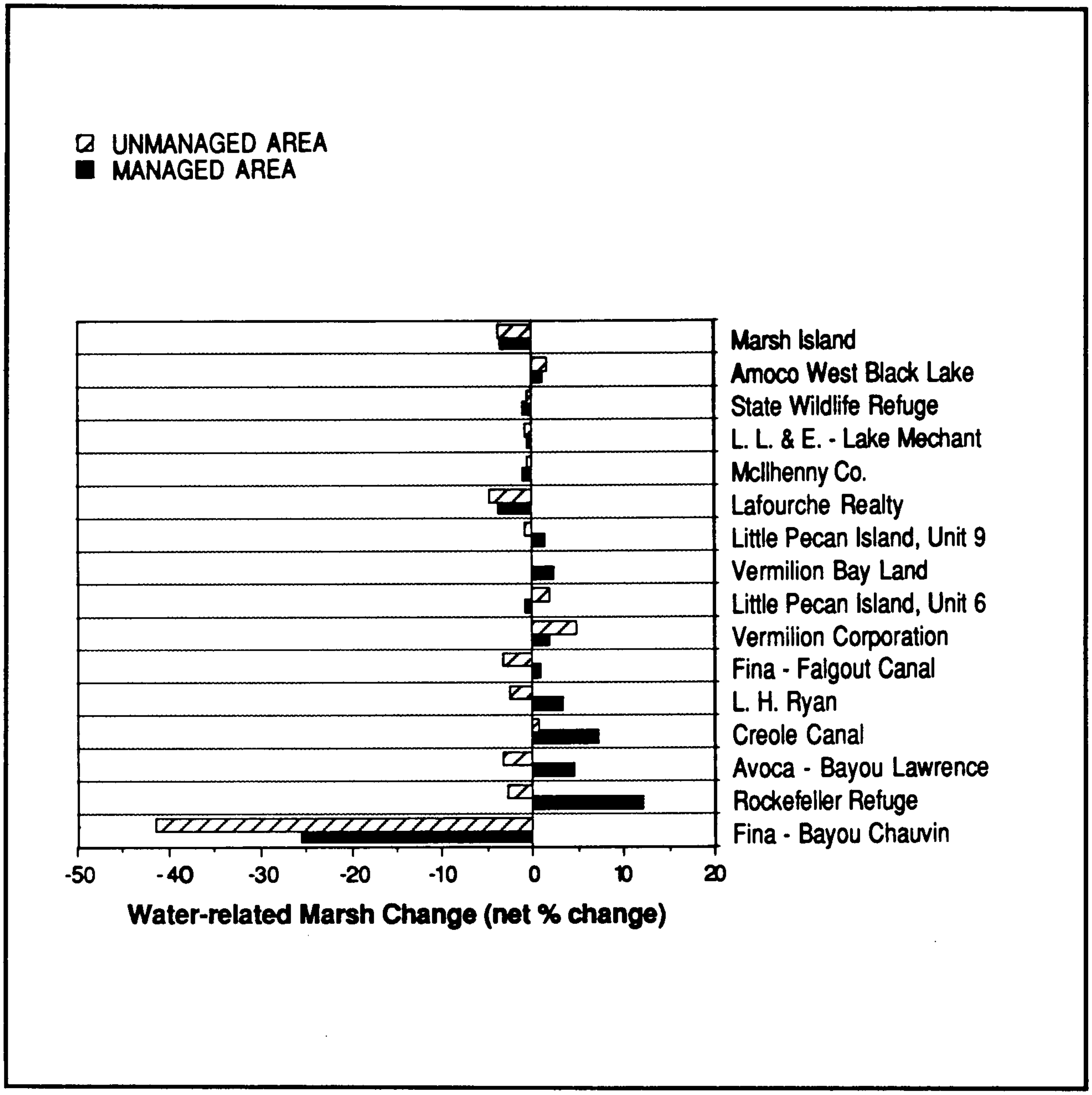

Figure 80. Net changes of water to marsh at all sites, 1985-1988. Sites are sorted by degree of divergence between managed and unmanaged areas.

differed little ($|d| < 5\%$) from their unmanaged areas in the general analysis: Vermilion Corporation (3.0%), Fina-Falgout Canal (1.5%), Vermilion Bay Land (1.2%), State Wildlife Refuge (1%), McIlhenny Company (0.9%), Marsh Island Refuge (0.75%), Amoco West Black Lake (0.6%), Louisiana Land and Exploration Company (0.1%), Little Pecan Unit 9 (0.1%), and Lafourche Realty (0.0%).

The results of these two analyses of the most recent interval were generally quite similar, with some exceptions. The managed areas at Amoco and Vermilion Corporation fared better than the unmanaged areas in terms of marsh areas but worse in the marsh/water analysis. The principal reason is that the unmanaged areas of both sites lost marsh to land (mud flats) during 1985-1988, and change of this sort was ignored in the marsh/water analysis. The Vermilion Bay Land managed area fared worse than its unmanaged area in the marsh analysis, but did better than the unmanaged area in the marsh/water analysis. Considerable amounts of marsh in this area changed to land (mud flats) during 1985-1988. The managed areas of Little Pecan Island Unit 9 and Fina-Falgout Canal did poorer in the marsh analysis than in the marsh/water analysis, but the relationship between the managed and unmanaged areas remained constant. The main reason for the better result in the marsh/water analysis is that some of the marsh in the managed areas changed to land (shrub/scrub) during 1985-1988.

Active Versus Passive Management

Areas without means to implement management decisions via water-level manipulations (passive management) did not show as much improvement in marsh gain/loss factors as did actively managed areas. No passively managed areas produced net gains in marsh area or net water-to-marsh gains in 1985-1988. No passively managed areas produced net gains in marsh after implementation. Marsh-to-water ratios improved at one passively managed area (McIlhenny Company). Passive management has often been used exclusively to enhance waterfowl habitat. However, three of the six passively managed areas in this study included land loss control and mitigation as management goals. Active management did result in increases of net marsh area at some managed areas (2 of 10 sites) and improved marsh-to-water ratios (5 of 10 sites). Some actively managed areas (4 of 10 sites) had a net change of water to marsh in 1985-1988.

Summary of Management Influences

The influences of management on marsh type, habitat diversity, and marsh-to-water ratios and marsh loss are summarized in the following list.

Impacts on Marsh Type

Trends in 1956-1978:

- 9 of 16 managed and unmanaged areas changed from lower-salinity habitats to higher-salinity habitats

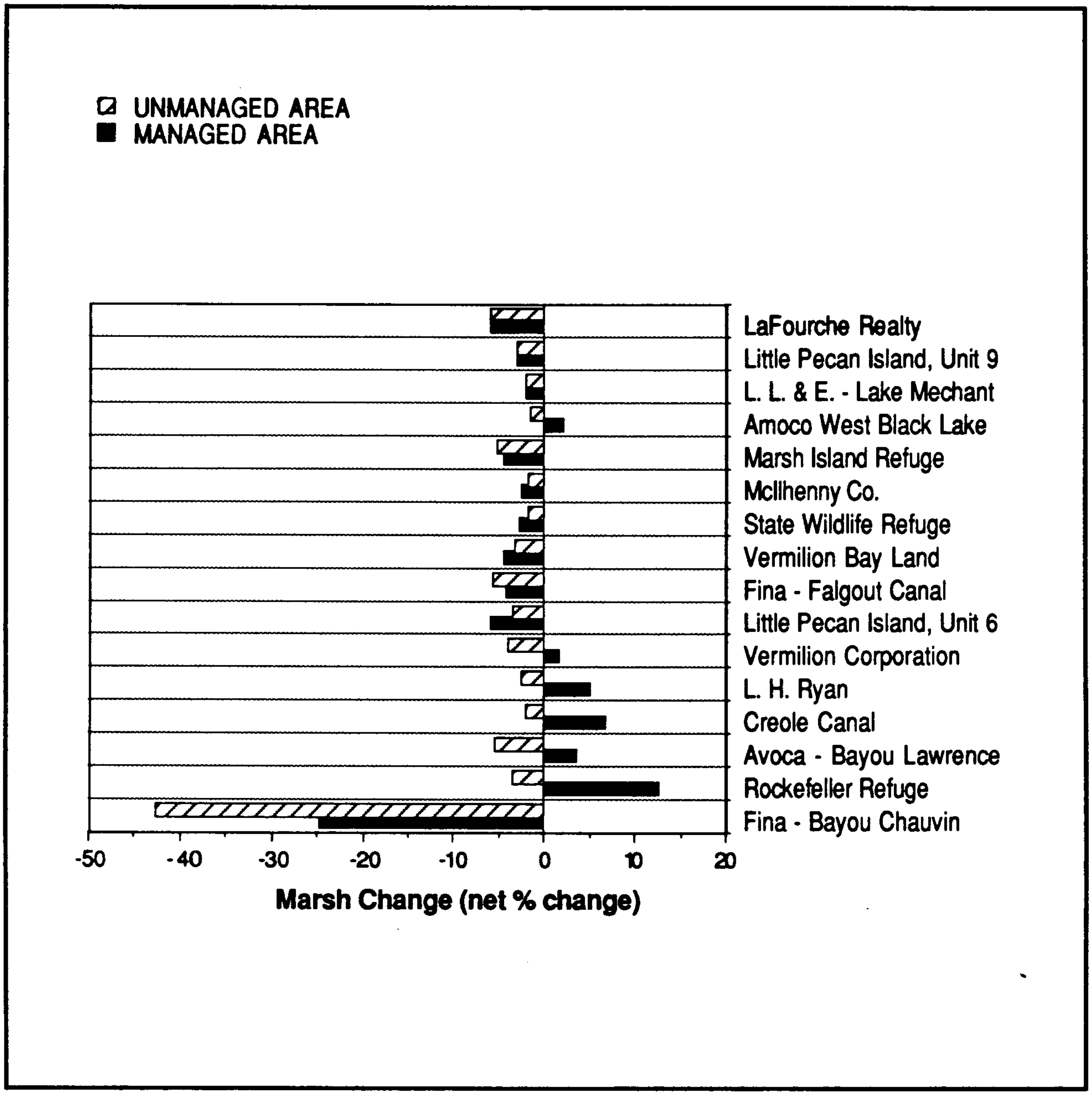

Figure 81. Net changes of areal marsh at all sites. Sites are sorted by degree of divergence between managed and unmanaged areas.

- 4 sites did not change

- at 13 of 16 sites, managed and unmanaged areas exhibited the same trend

Post-implementation trends:

- 50% of the sites (managed/unmanaged pairs) did not have substantial changes in marsh type

- 11 of 16 sites exhibited similar tendencies at the managed and unmanaged areas

Impacts on Habitat Diversity

Post-implementation trends:

- 12 of 16 managed and 6 of 16 unmanaged areas increased in habitat diversity, including both non-human-induced and human-induced habitat changes

- 3 managed and 2 unmanaged areas increased in habitat diversity solely by the addition of "inert" habitat (flats)

- inert habitats (flats) contributed to increased diversity in 8 of 16 managed and 5 of 16 unmanaged areas

- 3 managed and 2 unmanaged areas had habitat gains from non-human-induced habitats

- 1 managed and 5 unmanaged areas had habitat losses from non-human-induced habitats

Impacts on Marsh-to-Water Ratios

Trends in 1956-1978:

- marsh-to-water ratios declined at 13 managed and 12 unmanaged areas

- 12 managed/unmanaged pairs exhibited the same trend

Post-implementation trends:

- 8 sites exhibited the same pattern at both managed and unmanaged areas

- marsh-to-water ratios declined at 9 managed and 10 unmanaged areas

- 2 managed and no unmanaged areas gained marsh

- 6 managed and 3 unmanaged areas lost water area
- of the 6 managed areas to increase marsh-to-water ratios after management, 1 was passively managed
- the 2 managed areas that had net gains in marsh both were actively managed

Trends in 1985-1988:

- 8 managed areas established more marsh or lost less marsh than their unmanaged areas
- 7 managed areas had more water change to marsh than marsh change to water compared to their unmanaged areas

CONCLUSIONS

1. Marsh management is not consistently effective at increasing marsh acreage, reversing salinity influence on habitat composition, or improving marsh-to-water ratios. When examining these indicator parameters and comparing managed to unmanaged areas, some managed areas performed better than their unmanaged area and some unmanaged areas performed better than their managed area. However, in at least 50% of the comparisons, there was no difference between the changes occurring at the managed area and those occurring at the unmanaged area.

2. Compared to unmanaged marsh, actively managed marsh sometimes produced improved marsh-to-water ratios (5 of 10 sites), net gains in marsh (2 of 10 sites), and a net change of water to marsh between 1985 and 1988 (4 of 10 sites).

3. Passive management, with very few exceptions, produced no gains in marsh-to-water ratios or marsh acreage.

4. During 1956-1978, a decline in marsh-to-water ratios often approaching at least one order of magnitude affected all sites except McIlhenny Company and three others to a lesser degree. Although only five areas were managed, this was true regardless of whether or not a management plan was in effect except at the Vermilion Corporation site.

5. During 1956-1978, there was a general movement from fresh marsh to non-fresh marsh.

6. The magnitude of change in marsh-to-water ratios was greatly reduced and remained comparatively steady for most managed and unmanaged marsh areas after 1978.

7. The magnitude of salinity changes as reflected by changes in marsh type was greatly reduced at a majority of both managed and unmanaged areas after 1978.

ANSWERS TO QUESTIONS

The following questions from table 47, chapter 9, were addressed by the research reported in this chapter.

What are the differences in the loss of emergent vegetated wetlands and aquatic vegetation between areas with and those without structural marsh management (question I.A.1)?

A substantial majority of sites lost marsh in both areas during the intervals in question (implementation through 1988, figure 79). A total of 12 managed and 15 unmanaged areas had marsh loss after management implementation (table 49). The average loss was similar at both managed and unmanaged areas (10% vs. 9%). In seven managed areas, the magnitude of marsh loss was greater than that in the companion unmanaged area, while six unmanaged areas had marsh losses greater than those in their associated managed areas. Several managed areas gained marsh (4, mean = 3%), and one unmanaged area gained marsh (1%). Overall, differences between managed and unmanaged marsh losses were small. Aquatic vegetation was not present at many sites. This may be an artifact of the aerial imagery methods employed in the study. Of the areas studied that had aquatic vegetation immediately before implementation and at the end of the study (1988), three of six managed areas and three of three unmanaged areas had gains. The acreages involved were small at most areas.

How does marsh management affect habitat diversity within the enclosed area (question IV.A.2)?

The most apparent finding of this analysis is the dominance of human-induced habitat gains. These gains are predominantly derived from activities (such as dredging associated with levee and canal building) that are more prevalent in managed areas. Where habitat diversity changed as a result of non-human-induced habitats, no trends were apparent. Habitat diversity changed because of non-human-induced changes in more managed (4) than unmanaged (2) areas. Habitat diversity increased, however, in 12 managed areas and 6 unmanaged areas when all sources were considered (figure 77). In considering both human-induced and non-human-induced changes, twice as many managed areas showed increases in habitat diversity. Equal numbers of managed and unmanaged areas (3) had overall decreases in habitat diversity.

Chapter 12

FIELD MONITORING OF STRUCTURAL MARSH MANAGEMENT

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INTRODUCTION

Because the marsh management monitoring data base is small and of limited usefulness (chapters 7 and 10), two of the sixteen management areas (with associated unmanaged reference area) described in chapter 11 were selected for intense field monitoring. The two areas selected were the Fina LaTerre Mitigation Bank site in the delta plain and Rockefeller State Wildlife Refuge and Game Preserve in the chenier plain (figure 82). These two areas were selected for study because they represent the two main physiographic provinces

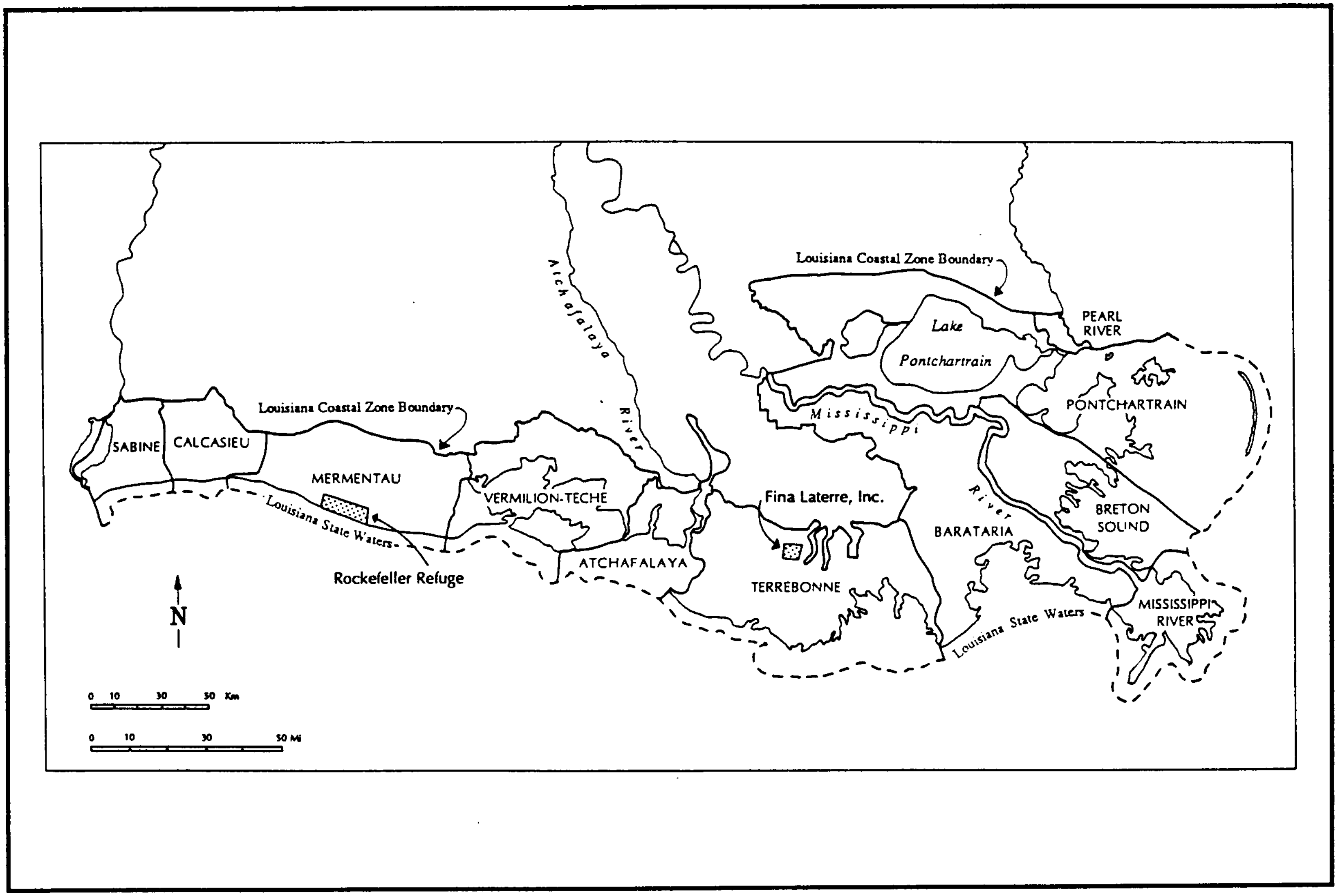

Figure 82. The Fina LaTerre Mitigation Bank site and the Rockefeller Refuge site monitored to evaluate the influence of structural management of water levels.

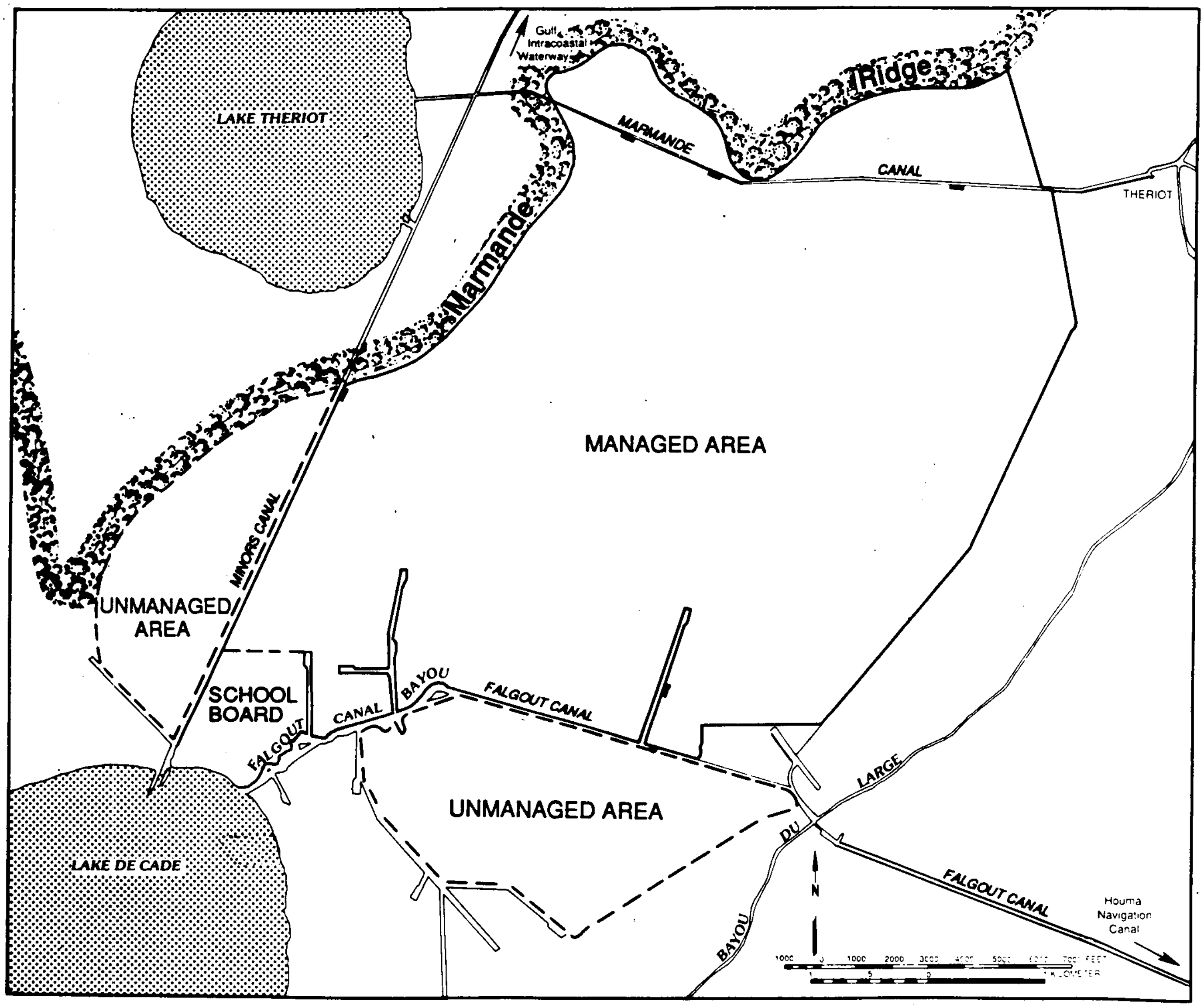

Figure 83. The Fina LaTerre Mitigation Bank site, Terrebonne Parish, Louisiana.

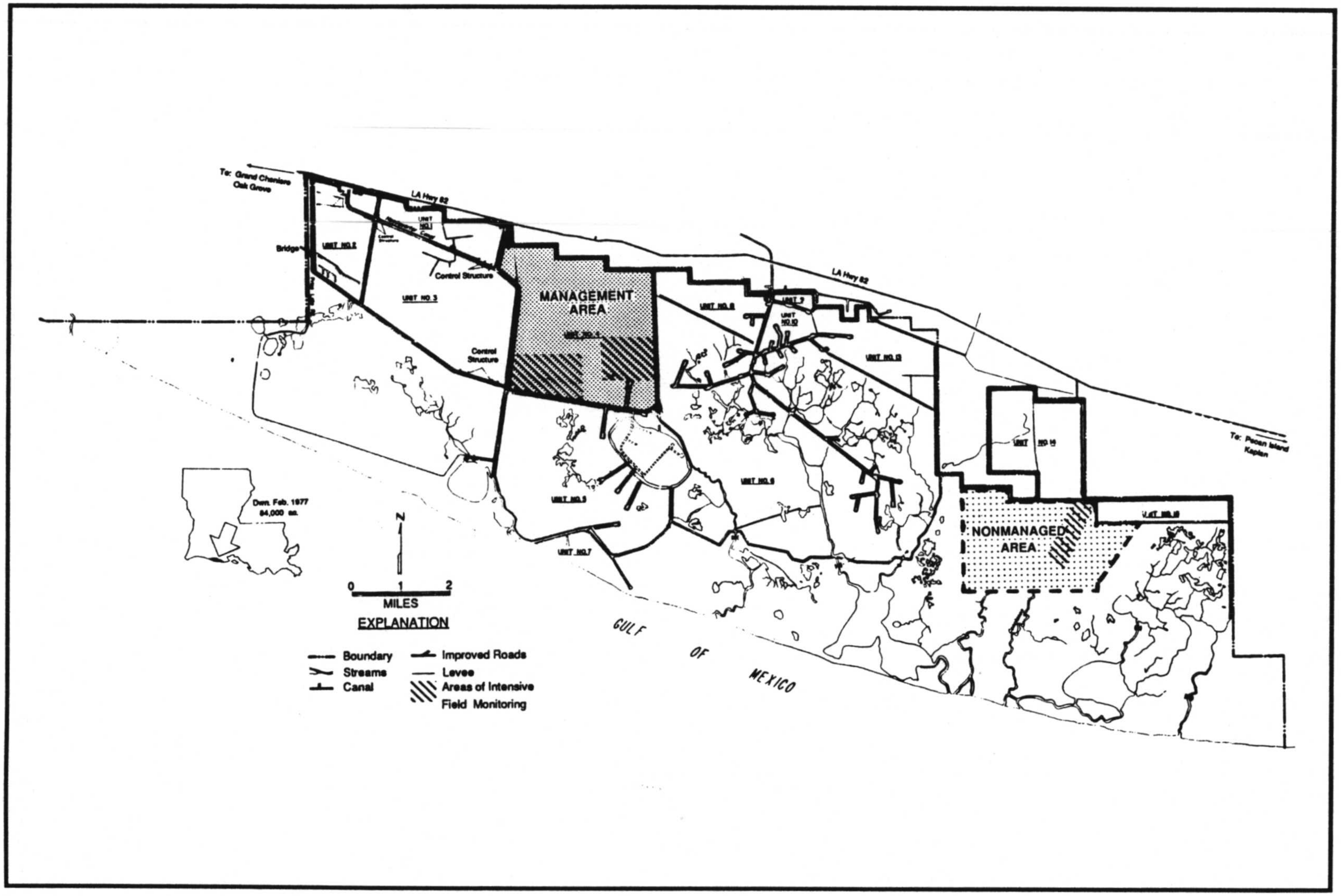

Figure 84. Rockefeller State Wildlife Refuge and Game Preserve, Louisiana.

Management Goals and Operation Schedule

Fina LaTerre Site

The management objectives for the Fina LaTerre site are to reverse the evolution of marsh to open water, reverse the trend toward increased salinity, increase freshwater and sediment inflow, improve water circulation, stabilize water levels, enhance productivity of the marsh, and accommodate fisheries use of the marsh (Kerr and Associates 1987; Memorandum of Agreement cited in Soileau 1989).

> The basic strategy is to bring fresh water from the northern part of the managed area, and from the freshwater canals to the west and north of the managed area, into the brackish and intermediate marshes in the southern section, and to manage the water levels inside the management area. The objective is to encourage regrowth of freshwater plants in the currently saline areas, and revegetation of plants in the areas which have become open water in order to recapture those areas as marshland. The underlying thesis is that the southern part of the management area "is experiencing rapid marsh loss from saltwater intrusion." (Kerr and Associates 1987:16)

It was projected that the freshening effect of management would result in the conversion of all brackish marsh (e.g., *Spartina patens*-dominated) to intermediate marsh (e.g., bulltongue- and cattail-dominated) within the first five years of management (Soileau 1984). It was also assumed that aquatic vegetation cover would increase by 150% within one year and that scrub/shrub habitat would remain essentially unchanged (Soileau 1984).

To this end, a two-phase water management scheme (drawdown/flood) was implemented (see chapter 5 for a description of water management technique) coupled with measures to allow exchange of fresh water and sediment in the northern portion of the managed area. Four fixed-crest weirs were installed, three along Marmande Canal and one on Minors Canal (figure 83). Water-level drawdowns have been attempted every spring at Fina LaTerre by means of a variable-crest flap-gated structure (with two gates) constructed on the southern side of the managed area. During the drawdown phase, all stoplogs were removed (sill level is 24" below the marsh surface), and the gates were in the down position and flapping out. In 1989, drawdown began in mid-February and continued until mid-July. The flooding phase was begun in mid-July by placing stoplogs in the structure to a level 6" below the marsh surface with gate in the up position. The structure was operated in this fashion until the next drawdown phase began in February 1990. During the flooding phase, the gate was lowered to the down position during high-salinity events to prevent salt water from entering the managed area. Such an event occurred in October when a hurricane entered the Gulf of Mexico. When the salinity event was over, the gate was returned to the up position.

Rockefeller Refuge

Water levels are managed in unit 4 of Rockefeller Refuge to reduce salinities, increase marsh-to-water ratios, and enhance production of aquatic vegetation to improve waterfowl habitat while accommodating production of shrimp and other fishery resources. The long-range goal of management is to restore vegetative and habitat diversity to the conditions present before navigation canals caused major hydrologic changes in the region.

A two-phase water-level management scheme (drawdown/flood) is implemented every third or fourth year. Water-level drawdown is achieved at Rockefeller Refuge (unit 4) by means of a variable-crest flap-gated structure with seven gates. A drawdown was conducted in 1989 from mid-February to mid-June. During the drawdown phase, the stoplogs were set at 18" below the marsh surface, and the gates were in the down position and flapping out. Exceptions to this operation schedule were made to allow post-larval shrimp into the management area. Two gates were opened on May 17-18, May 22-26, and June 2, and three gates were opened on June 15-19 to allow for the ingress of post-larval shrimp. From mid-June to early July, hydrologic and meteorologic conditions were favorable for introducing fresh water into the area. Hence, all gates were opened with the stoplogs set at 18" to allow fresh water into the management unit. From early July to mid-February, the stoplogs were set at 6" below the marsh surface with all gates flapping out for the flooding or ponding stage of the annual water-level cycle.

During nondrawdown years, water levels are maintained at or near marsh level, or what is called "pool stage." The purpose of pool stage is to encourage the growth of aquatic plant species while maintaining or improving the marsh-to-water ratios. Pool stage is maintained by setting stoplogs at 6" below the marsh surface with all gates flapping out. The flap gates prevent water from entering the marsh during high-water or high-salinity events. When hydrologic conditions permit, the ingress/egress of aquatic organisms (e.g., post-larval shrimp) is accommodated by allowing three of the gates to flap in while the remaining gates flap out. This operation schedule can also be used to allow fresh water into the managed area. Hence, the structure is not operated on a fixed schedule but rather in response to changes in local hydrologic conditions and the life cycle of aquatic organisms.

Experimental Approach

Field plots were selected and data collected within managed marsh and nearby unmanaged marsh so that the influence of management on basic ecological processes could be evaluated. All plots were located in brackish marsh areas dominated by *Spartina patens*. Slightly different experimental designs were employed at the two sites because of differences in the environmental setting. Both areas underwent a drawdown in the spring of 1989 during this study.

Fina LaTerre Site

There is a distinct vegetation gradient within the managed area at Fina LaTerre. The northern region of the managed area is dominated by a mixture of fresh plant species, while the southern portion is dominated by brackish species, mainly Spartina patens. Consequently, two reference unmanaged areas were selected for comparison to the managed area (see figure 83). The unmanaged area west of Minors Canal, which is dominated by fresh plant species, was selected as a reference area for the northern portion of the managed area; the unmanaged area south of Falgout Canal, which is dominated by Spartina patens, was selected as a reference area for the southern portion of the managed area. Due to the large size of the managed and unmanaged areas (approximately 10,000 acres total area) and funding constraints, our field effort could be implemented in only one of the two major vegetation zones. The Spartina patens-dominated managed and unmanaged areas were selected in consultation with the Technical Steering Committee to enable general comparisons with Rockefeller Refuge, and because the brackish unmanaged area had fewer potential confounding effects than the fresh unmanaged area. Hence, the results and conclusions presented in this chapter pertain to the southern portion of the management area only. Additional research needs to be conducted in the northern portion and its reference area west of Minors Canal to determine management effects in the fresh marsh zone. Funding has been provided by the U.S. Environmental Protection Agency to conduct a preliminary follow-up evaluation of water and sediment flux and accretionary processes in the northern portion of the managed site. This investigation will commence during fall 1990.

Figure 85 shows the layout of field plots and sampling sites. The Spartina patens-dominated brackish marsh in the southern portion of the managed area north of Falgout Canal was selected for comparison to the Spartina patens-dominated brackish marsh area immediately south of Falgout Canal. Additional sampling plots were established on the parish school board's property along the shore of Lake DeCade. The school board's property is in the southwestern corner of the management area and is not bordered by levees. Small streams that drain the managed area through the school board's property into Lake DeCade have been dammed on Fina LaTerre property to reduce channel water exchange into the managed area, but there are no levees to impede exchange of surface waters across the marsh.

Forty vegetation-sedimentation plots were established in the brackish marsh in five groups of eight (figure 85). Two groups were located in the managed area in brackish marsh selected for uniformity; one group was located near the water control structure and another farther away. Similarly, two groups of plots were located in the unmanaged area, one near the main point of water exchange and one farther away. Although a water exchange point lies approximately 0.5 km due east of the far plots in the unmanaged area (figure 85) flow through this 2-m-wide point is restricted by a fixed-crest weir set 15 cm below marsh elevation and represents 3.7% ± 1.5% of the total flow into the unmanaged area (flow through the main point of water exchange makes up > 50% of the total flow). Water flow through this weir empties into a borrow ditch with spoil banks. This ditch empties into an open water area southeast of the far plots. Consequently, the distance that this small volume of water and sediment must travel to reach the far plots is comparable to that from the main point of water exchange. The results of the vertical accretion measurements in the soil accretion section of this chapter indicate the limited nature of the hydrologic link between this small exchange point and the far plots.

A single group of eight plots was located on the school board's property. Because of the unique position of the school board's property at the juncture

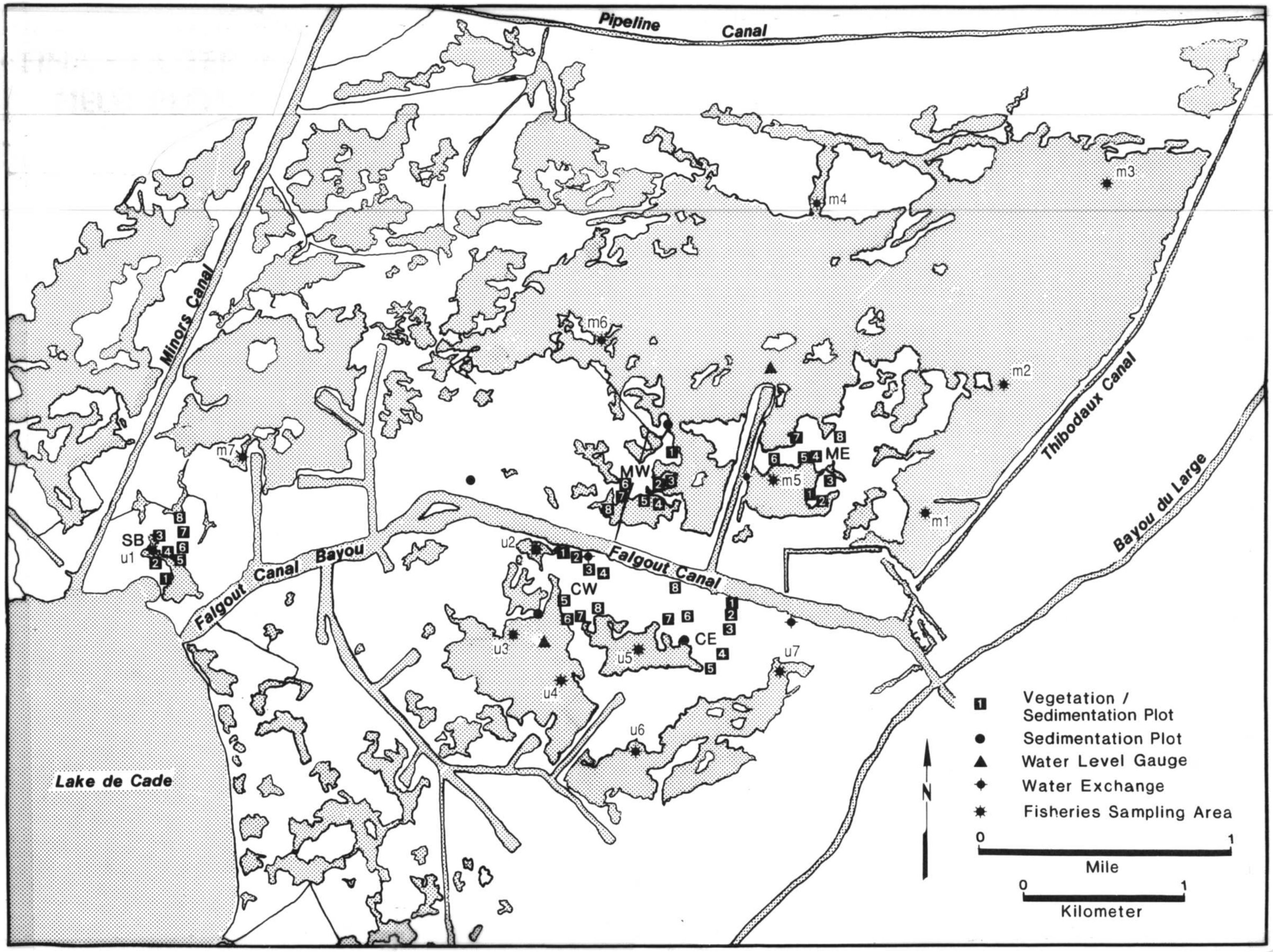

Figure 85. Field plots and sampling stations at the Fina LaTerre site.

of Minors Canal, Lake DeCade, Falgout Canal, and the boundary of the management area, this site provides an opportunity to compare an area receiving high inputs of sediment and fresh water to the managed and unmanaged sites. The locations of field plots within each group were selected randomly from a 500-by-500-m grid. All plots were established in the marsh 5 m in from the water's edge.

A water-level gauge was established in the managed and unmanaged areas approximately 0.5 km from the main point of water exchange. The flux of water and sediment was measured at the drawdown structure on the southern edge of the managed area (figure 85) and at the main point of water exchange in the unmanaged area (in the vicinity of CW field plots, figure 85) and at several smaller water exchange sites on the bank of Falgout Canal east of fishery sampling station U7. Fishery sampling stations were also established at the locations indicated in figure 85.

Rockefeller Refuge

The areas of marsh in which fieldwork occurred are shown in figure 84, and the locations of field plots in figures 86 and 87. The managed and unmanaged s*ites were selected for uniformity of vegetation type (e.g., Spartina patens), distance from the coast, and presence or absence of burning of the vegetation. Unit 4, the managed site, lies in the northern part of the refuge and has extensive areas of Spartina patens-dominated brackish marsh and areas of burned and unburned vegetation. Water exchange occurs through two water control structures in the southwestern and southeastern corners of the unit. Because structural management of wetlands is prevalent throughout much of the refuge, the nearest unmanaged area of Spartina patens-dominated marsh lying a similar distance from the coast is at East Little Constance Bayou (figure 84). Marsh on one side of the bayou had been burned shortly before we began our investigation. Water is exchanged in this area through the bayou, which is directly connected to the Gulf of Mexico, and through a structure in the bayou on the northern boundary of the refuge that regulates freshwater inputs from fresh marshes north of the refuge. Canal and levee impacts are less numerous in the unmanaged area than in the managed area.

We established 40 vegetation-sedimentation plots in the refuge, 20 each in the managed (unit 4) and unmanaged (East Little Constance Bayou) areas (figures 86, 87). Within each area, 10 plots were established in burned marsh, and 10 in unburned marsh. In the management unit, 10 plots were established near each water control structure, 5 burned and 5 unburned. The locations of the field plots within each area were randomly selected along the marsh-water interface. In East Little Constance Bayou, 10 plots were located near the source of fresh water, 5 burned and 5 unburned, and 10 plots were located farther downstream immediately north of East Constance Lake, 5 burned and 5 unburned. The locations of field plots were randomly selected along the length of each section of the waterway. A typical streamside effect was evident near the bayou; slightly higher elevations and different plant species occurred immediately adjacent to its banks. Consequently, all field plots were established 10 m beyond the inland edge of streamside vegetation. For the sake of consistency, all plots in the managed unit also were placed 10 m in from the marsh-water interface or the Spartina patens-Spartina alterniflora interface, even though the marsh in the managed area did not exhibit a typical streamside effect. In

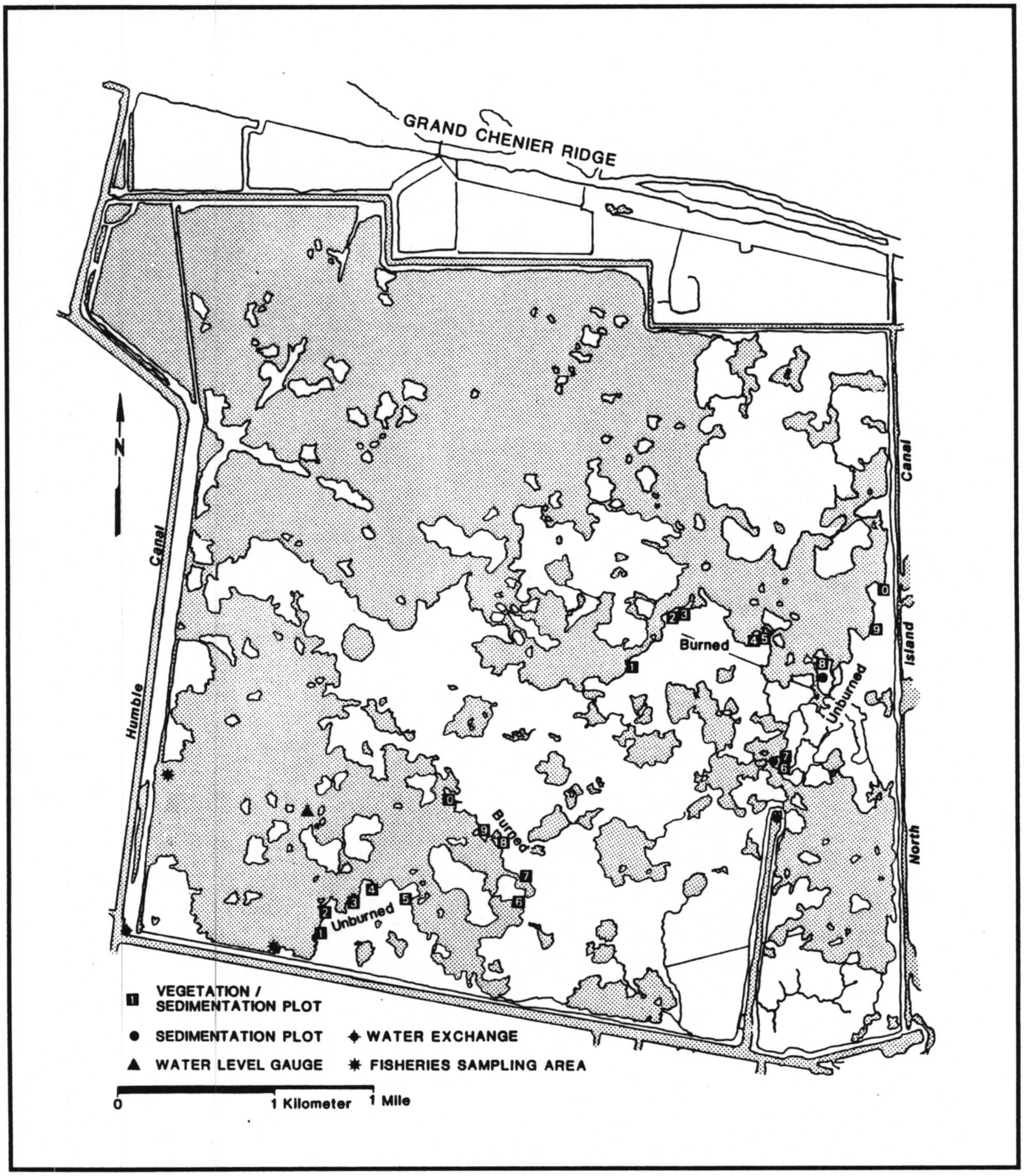

Figure 86. The managed study area and field plots at Rockefeller Refuge.

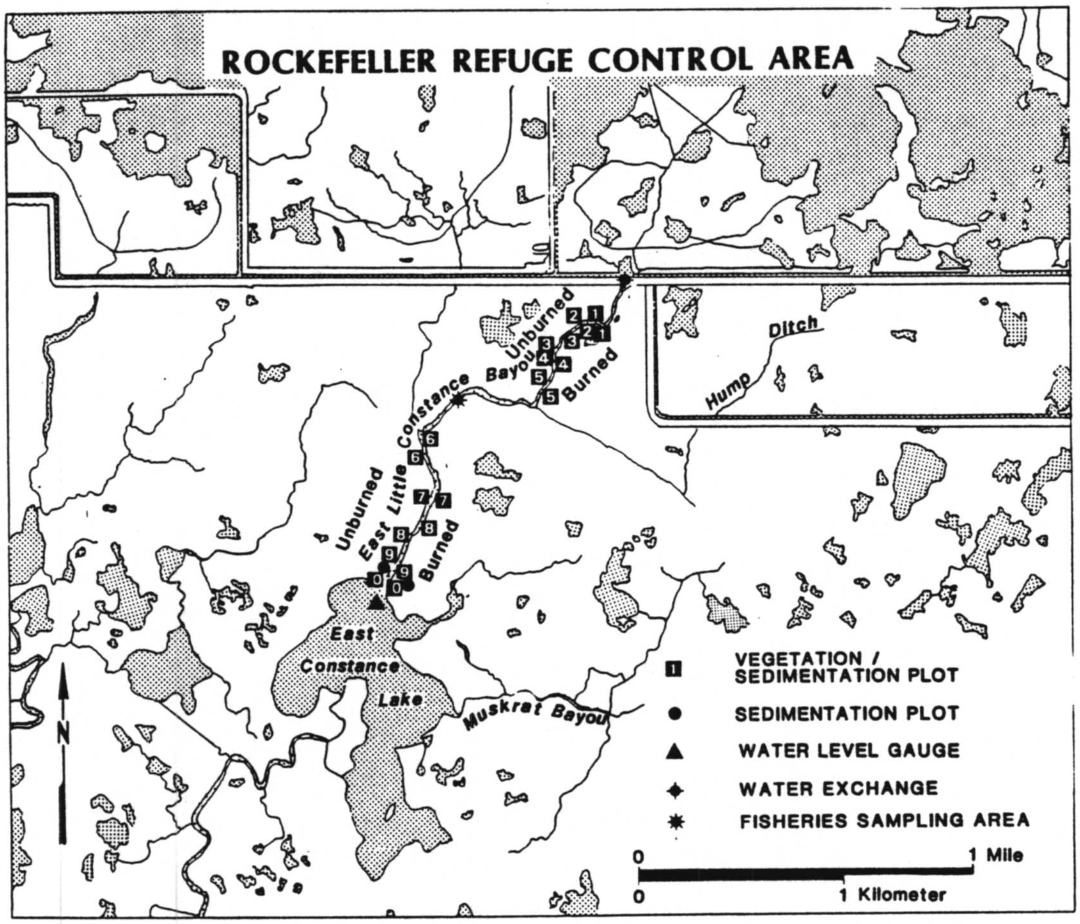

Figure 87. The unmanaged study area and field plots at Rockefeller Refuge.

some portions of the management unit, S. alterniflora has recently colonized open-water areas adjacent to the S. patens zone.

A water-level gauge was established in the managed unit approximately 0.5 km from the southwestern structure and in East Constance Lake immediately south of the sampling area. Flux measurements were made at the southwestern structure in unit 4 and in the bayou at the unmanaged area. Fishery sampling occurred in the levee borrow canals near the southwestern structure in unit 4 and in East Little Constance Bayou. (Fishery sampling at Rockefeller Refuge was performed by Drs. Hoese and Konikoff, University of Southwestern Louisiana, under separate contract to the Department of Natural Resources. The results of this investigation are presented in a report submitted to the department [Hoese et al. 1989].)

WATER LEVELS IN MANAGED AND UNMANAGED MARSHES

Joann Mossa
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Methods

Water levels were measured at the managed and unmanaged areas of the Fina LaTerre and Rockefeller Refuge study sites. At each of the four locations, the gages were situated on wooden platforms sunk in large water bodies so that representative water-level conditions could be measured. The locations of these gages are shown on figures 85, 86, and 87.

The gages used from February to May, 1989, were float-type digital recorders manufactured by Leupold and Stevens of Beaverton, Oregon (Leupold and Stevens, undated). The Stevens Model 7000 Series was driven by a marine battery, which was replaced periodically. Instrumentation used throughout the remainder of the project was also a float-type recorder, with a chart drive and ink record. The recorder used was made by Belfort Instrument Company of Baltimore, Maryland, and the model type is No. 5-FW-1 (Belfort Instrument Company 1976, 1986). The range on the gage could be set to measure a 1' or 5' water-level range. All instruments were set to measure a 5' range.

Each time the chart-type water-level gages were examined, the following procedures were conducted: (1) Two C-size batteries were removed and replaced. (2) Chart paper was removed and replaced. (3) The drum was rotated to the appropriate time on day 1. (4) The time, date, area name, and water level of the staff gage were written on the chart. (5) The ink well was filled about two-thirds to three-quarters full. (6) The ink arm was centered on the paper by readjusting the gage. (7) The ink arm was positioned to touch the paper.

Although sufficient data were collected to identify several types of short-term to annual changes in water levels, the data record was discontinuous because of problems with the recorders and logistics in transportation to the recorders. The digital recorders did not record several observations for certain periods, possibly because of problems with the marine battery, but also possibly for other reasons. Because of the many people involved in this component of the project, some of the digital data did not get returned to the Louisiana Geological Survey and could not be analyzed. None of the data collected at Rockefeller Refuge with the digital recorders was recoverable for inclusion in this report. Once the chart-type water-level gages were installed, however, there were fewer problems at both areas.

At Fina LaTerre problems were less significant than at Rockefeller Refuge because of the nearer location and the periodic biweekly sampling associated with fisheries sampling. Once it was determined that the rechargeable batteries were functioning poorly, problems with the data were greatly reduced. Even with the frequent visitation and biweekly replacement of the batteries, however, at one area little frogs had entered the recorder platform and casing box. They caused ink spillage, footprints on the chart, and sometimes loss of data. In addition, the metal tape occasionally became displaced from the studs on the cylinder between the float and counterweight, which also caused problems with the data. The cause of the displacement was unknown, but displacement was more common in the late fall and winter than in the spring and summer, and may have been influenced by winter storms.

Data collected with the ink-chart recorders at Rockefeller Refuge was also very erratic because of several problems. Initially, rechargeable batteries were used to reduce costs, but they proved to have short or no longevity out in the field. These areas could not be visited frequently because of travel distance and costs, so the gages were examined in conjunction with other sites visited for sedimentation or 48-h monitoring studies. On some visits, it was not possible to visit the gage more than once, and therefore it was not possible to determine whether the gage was functioning and whether the chart was being marked properly with ink. At such times, no data, or only a small amount of data, was collected from these locations.

The Mitron Reader at the Department of Wildlife and Fisheries in Baton Rouge was used to convert the digital data to tabular form, which provided a listing of hourly measurements. The foil backing caused problems with some of the tapes because these did not easily slide through the reader. Both the digital data and the strip chart data were transferred onto grid paper to show the variations in water levels during the study period and checked for correspondence with field staff readings.

Results and Discussion

The types of influences on water-level changes differed in the unmanaged and managed areas (figures 88-90). In unmanaged areas, they included diurnal tidal variations, long-term seasonal changes, winter storms, tropical storms, and lunar tidal effects. In the two managed areas, changes in water level were related to combined structural and seasonal changes, and tropical storms; diurnal tidal variations, winter storms, and lunar tidal cycles were not of sufficient magnitude or duration to cause appreciable changes in water level in the managed areas. These findings indicate that management has been successful at isolating the managed marsh from local hydrologic influences and controlling water levels.

The effects of management on diurnal tides were quite apparent (figures 88-90). Both unmanaged areas showed appreciable tidal influence, whereas the managed areas did not show noticeable diurnal variations. Tidal range at the Fina LaTerre unmanaged area was typically less than 0.5′ in a given day. At the Rockefeller Refuge unmanaged area, a 1.0′ diurnal tidal range was not uncommon. These differences in tidal range are related to distance from the Gulf of Mexico,

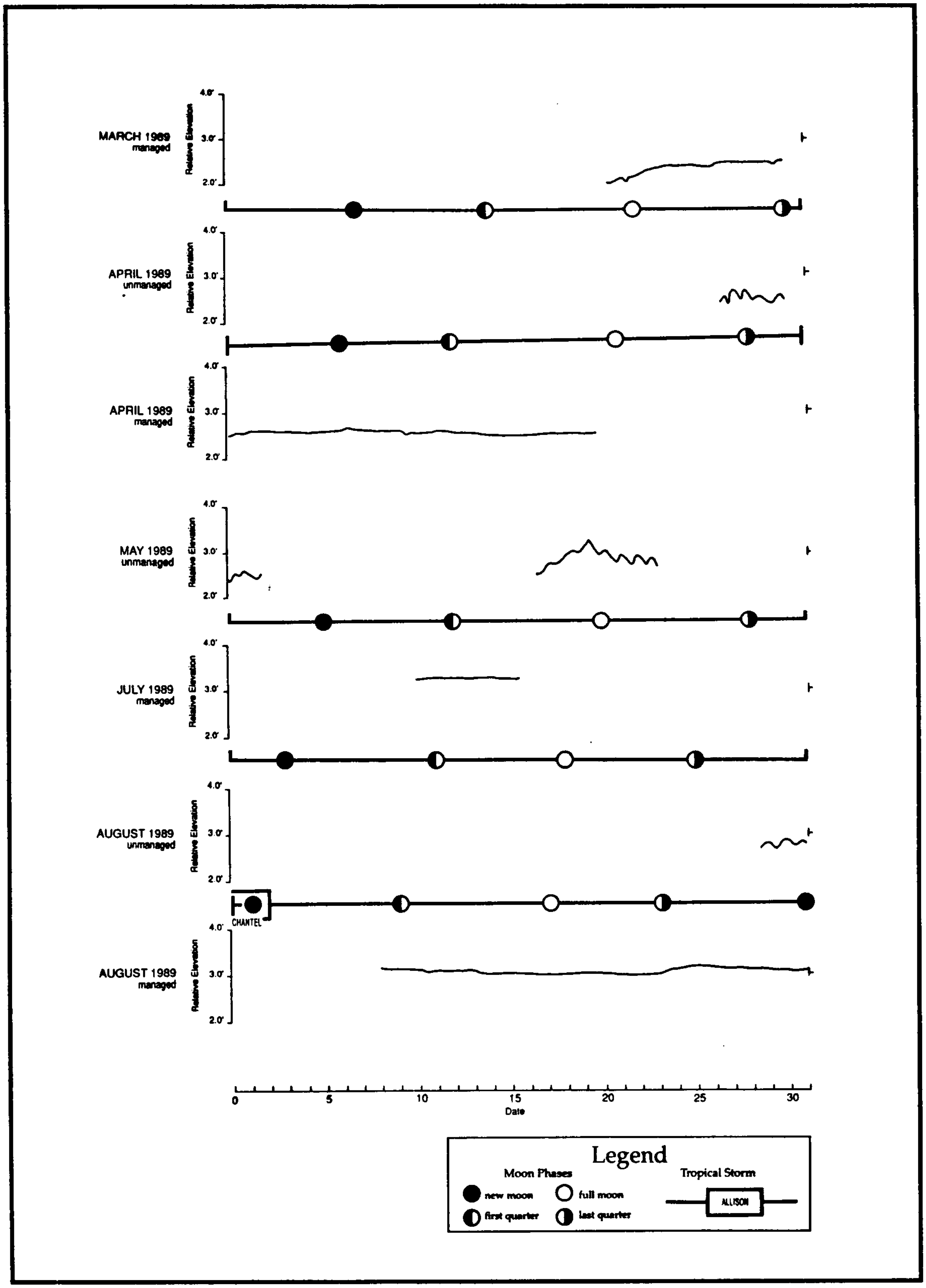

Figure 88. Water levels at the Fina LaTerre managed and unmanaged areas from March through August 1989.

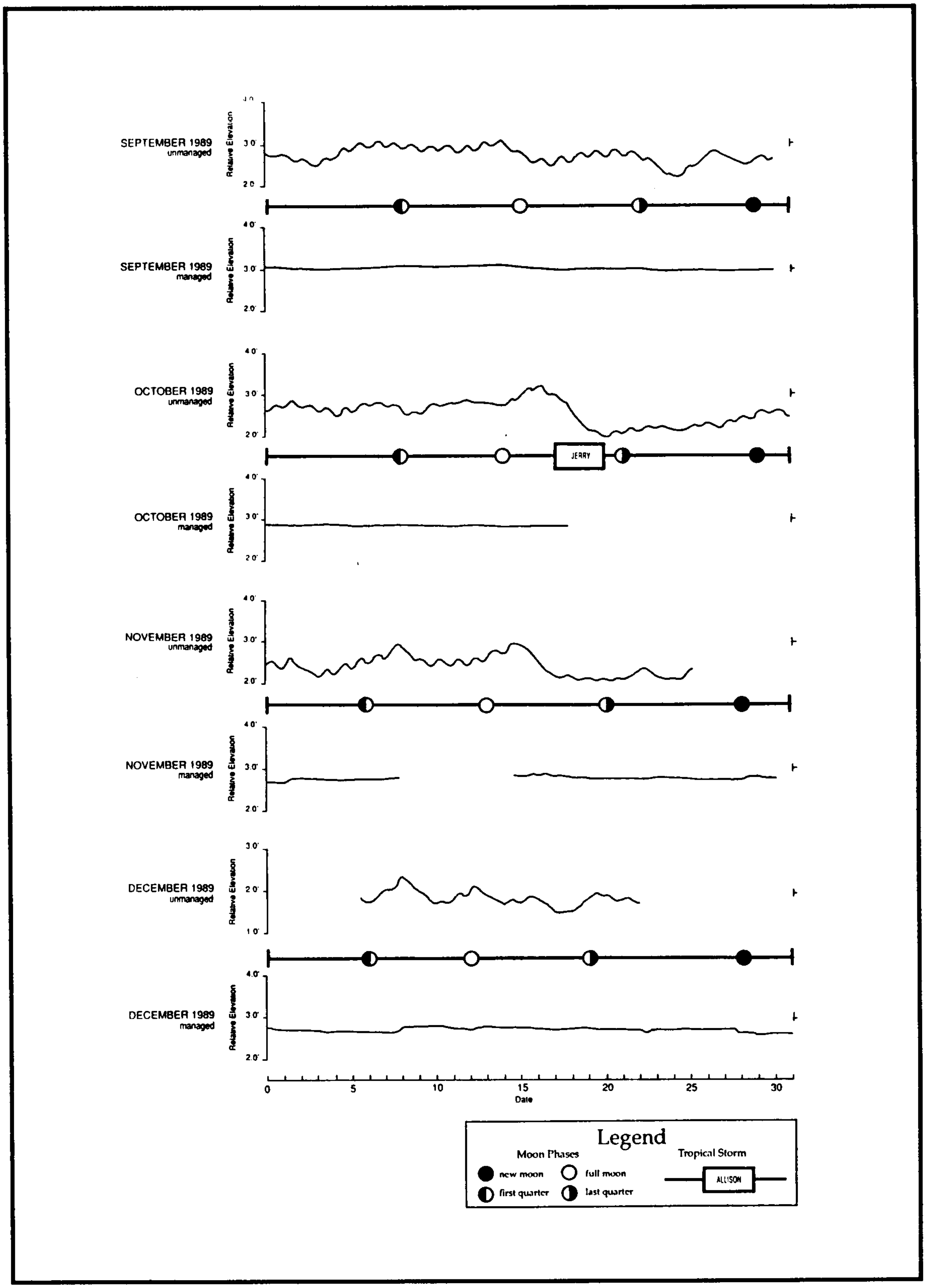

Figure 89. Water levels at the Fina LaTerre managed and unmanaged areas from September through December 1989.

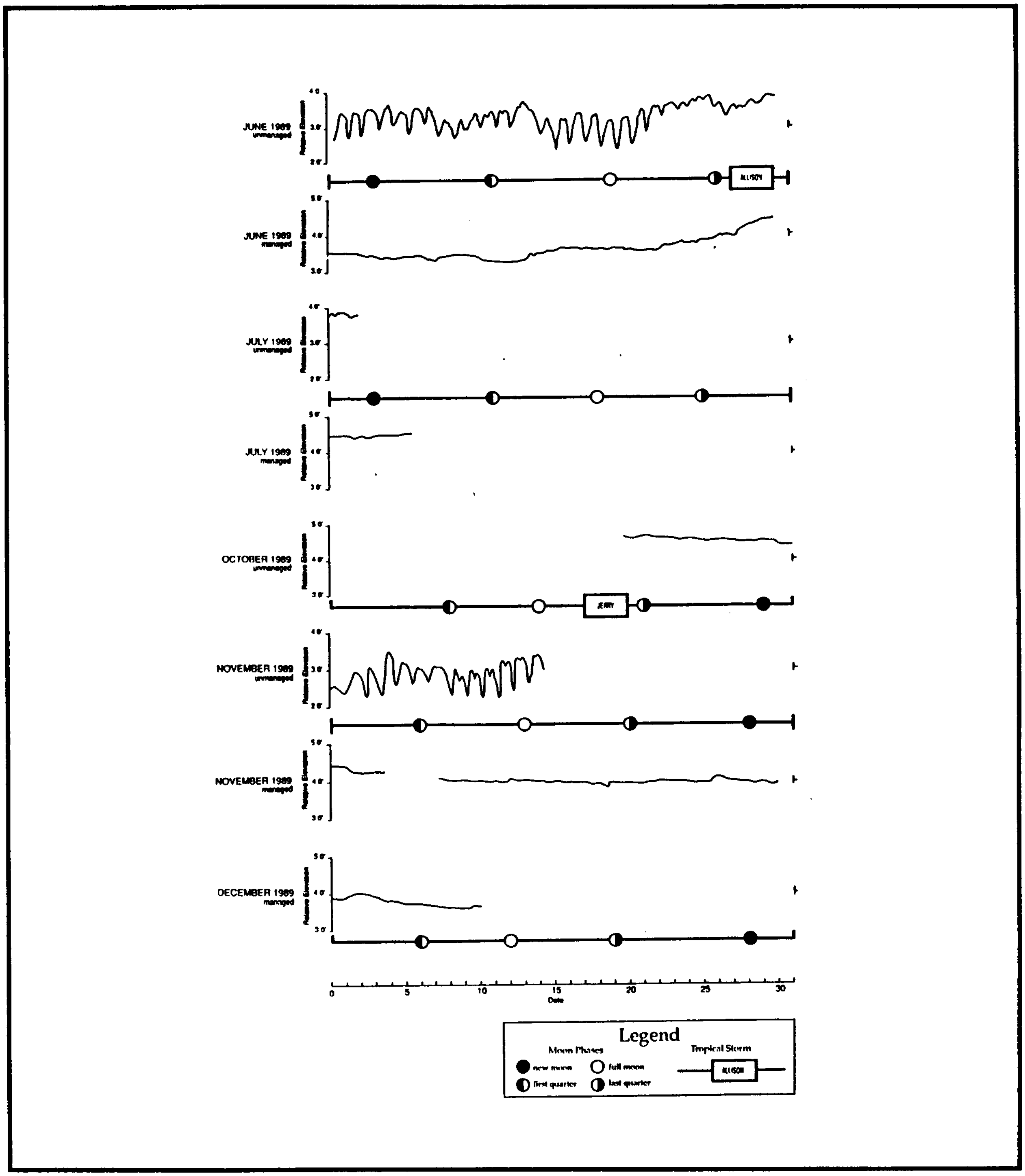

Figure 90. Water levels at the Rockefeller Refuge managed and unmanaged areas from June through December 1989.

such that tidal effects are much smaller inland at the Fina LaTerre unmanaged site than closer to the coast at the Rockefeller unmanaged site.

Seasonal changes, incorporating operation of structures, were apparent in both managed and unmanaged areas (figures 88-90). Water levels at the managed area of Fina LaTerre increased from a low at the beginning of the period of record in March to the highest levels in midsummer (July), and generally decreased through the end of the period of record in December. The seasonal changes at the Fina LaTerre water-level gage in the managed area correspond well with the staff gage readings collected inside and outside the variable-crest flap-gated structure (figure 91). Water levels also increased at the unmanaged area of Fina LaTerre through midsummer, then decreased through the end of the period of record in December. At both locations, the difference between the lows in winter and highs in summer was approximately 1.0'. Seasonal effects could not be determined at the Rockefeller managed and unmanaged areas because data are spotty.

Changes in water level over several days due to cold-front passages were apparent in the late fall and winter (figures 89-90). Before frontal passages, winds blow from a southerly direction toward the advancing front and cause water-level setup against the coast as well as high wave energy because of the long fetch. If the front moves slowly and winds blow for a long time, elevated water levels may persist for several days. Immediately after the frontal passage, winds change direction and blow strongly from the northern quadrant, causing set-down by forcing waters offshore. The water-level changes associated with frontal passages were apparent at the unmanaged areas, but were not obvious at the managed areas, although there were slight changes on corresponding dates. Some of the stronger frontal passages during November and December of 1989 illustrate this well. Fronts crossed Louisiana on November 2, 9, 16, 23, and 28, and on December 3, 8, 12, 16, 19, 22, and 31 (National Oceanic and Atmospheric Administration 1989). These events resulted in water-level setup and set-down varying from 0.5' to 1.0' at both unmanaged areas, particularly at Fina LaTerre (figure 89). Events of such magnitude may be important in the movement of sediment and nutrients in the project area. Diurnal variations in the unmanaged areas were much less pronounced during winter storms than during non-storm conditions (figures 89, 90).

Three tropical storms that made landfall in western Louisiana or eastern Texas influenced water levels in coastal Louisiana in 1989 (figures 88-90). Because the storms made landfall west of the monitoring areas, they traveled from west to east and resulted in a succession of water-level setup and set-down similar to that caused by the winter storms. For two of these events, data were available from some of the water-level gages monitored. Tropical storm Allison (June 27-30) elevated water levels at Rockefeller Refuge in both the managed and unmanaged areas; levels rose nearly 1.0' beginning on June 25 and remained high for at least the first few days in July. Data from this event were not available for the Fina LaTerre managed and unmanaged areas. Tropical storm Chantel (July 31 to August 2) occurred when water-level data were not available from any of the sites. Tropical storm Jerry (October 15-17) caused a marked rise in water levels of almost 1.0' from October 15 to 18, which was followed by a marked drop of nearly 1.5' from October 18 to 20, at the unmanaged area in Fina LaTerre. Such events are clearly important for the movement of sediment and nutrients in the project area. Data for the Fina LaTerre managed area did not reveal any changes for the period that data were available because the structure was closed

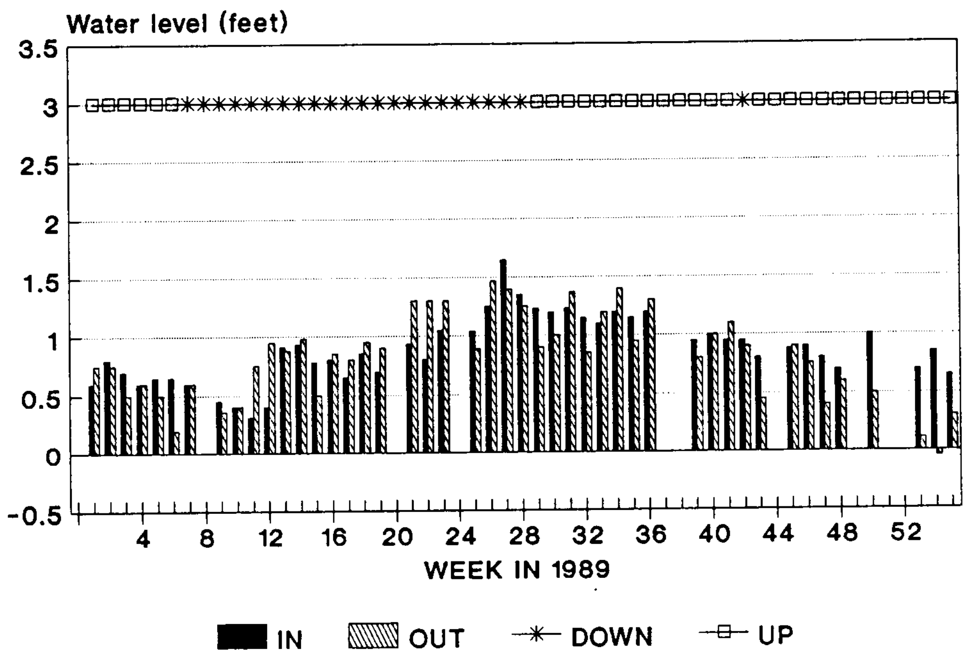

Figure 91. Weekly averages of Fina LaTerre staff gage readings inside and outside the variable-crest, flap-gated structure, 1989.

during the storm. Data were not available for this event from the Rockefeller Refuge water-level gages. Diurnal variations are much less pronounced during tropical storms than during non-storm conditions (figures 88-90).

Lunar effects on the tides influenced water levels somewhat, but not as much as the local storms did (figures 88-90). Spring tides, which are coincident with the new moon and full moon, had somewhat greater tidal ranges than neap tides associated with the first quarter and last quarter of the lunar cycle. These effects were most pronounced at the unmanaged area; data from Rockefeller Refuge for June 1989 showed the effects of lunar cycles clearly (figure 90). Tidal amplitude was greater around the full moon on June 19 and much lower on June 11 and 26. Spring tides were approximately 0.2′ greater in amplitude than neap tides at Rockefeller. It was difficult to assess whether lunar cycles affected tidal amplitude at Fina LaTerre because the range was generally much smaller.

Summary

Measurements with digital and ink-chart recorders at the managed and unmanaged areas of Fina LaTerre and Rockefeller Refuge showed several types of influences on water levels in 1989, though the record was discontinuous because of problems with recorders and logistics. The types of influences on water-level changes differed in the unmanaged and managed areas. In unmanaged areas, they included diurnal tidal variations, long-term seasonal changes, winter storms, tropical storms, and lunar tidal effects. In the two managed areas, changes in water level were related to combined structural and seasonal changes, and tropical storms; diurnal tidal variations, winter storms, and lunar tidal cycles were not of sufficient magnitude or duration to cause appreciable changes in water level in the managed areas. These findings indicate that management has been successful at isolating the managed marsh from local hydrologic influences and controlling water levels.

WATER BUDGET ANALYSIS

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Coastal Ecology Institute, Center for Wetland Resources, Louisiana State University

This part of the project analyzed the water budgets of the Fina LaTerre and Rockefeller sites to determine possible impacts of evaporation and precipitation on water levels and water salinities.

Methods

Daily and monthly water budgets were analyzed using the Thornthwaite continuous water budget program (for details on this method, see Thornthwaite and Mather 1957, and Muller and Thompson 1985). Water budget analysis uses precipitation (P) and potential evaporation (PE) to determine whether a surplus ($P > PE$) or deficit ($P < PE$) occurred during a given period. Soil moisture is often included in water budget analysis so that cumulative P-PE (precipitation minus potential evaporation) values can be calculated.

We used data from the nearest weather stations to conduct monthly water budget analysis for the two sites. Data beginning with 1965 are available for the Rockefeller Wildlife Refuge, and a monthly water budget was calculated for 1965-1989. The Fina LaTerre site has no weather station, so we used data from Houma (the nearest station) to run a 30-yr budget covering 1960-1989. Since a long-term data set was available from Houma, the water budget for that station was begun with data from 1959 to permit the water balance and soil moisture storage values to reach "equilibrium" by January 1960. Daily water budgets were run for 1988-1989 to cover the study period. Data from 1987 were used to allow for "equilibrium" to be reached by January 1988.

For the monthly analysis, soil moisture storage was set at 0 storage capacity to reflect conditions in the wetlands where hydrologic influences generally keep the soils completely saturated. For the daily water budgets, we made the same general assumption regarding soil moisture storage. We calculated the daily water budgets, however, using a two-layer soil; the upper layer had a total capacity equivalent to 2.5 cm, and the lower layer a 13-cm capacity.

In runs with no storage capacity, P-PE (or EP-PE in the daily analysis; EP is estimated precipitation) is likely to be the most useful variable. If we assume that wetland soils are saturated, then actual evaporation (AE) = PE (i.e., there is never a shortage of water to evaporate). Thus P-PE (EP-PE) can be used to assess the amount of PE fulfilled by P when P-PE is positive. Conversely, a negative P-PE could reflect the amount of evaporation (PE) being fulfilled by tidal or other hydrologic inputs.

Results

Monthly Water Budgets

Fina LaTerre. Based on the 30-yr data set, average annual precipitation at Houma was 160 cm (table 50). Rainfall was quite variable and ranged from a low of 103 cm in 1962 to a high of 208 cm in 1966. Rainfall in 1988 was 17 cm above average, whereas in 1989 it was 25 cm below average. Late summer (July, August, September) is normally the wettest time of the year at Houma, and October is generally the driest month (figure 92A). For the 30-yr average, precipitation exceeds potential evaporation except for a slight deficit in June. The two study years (1988-1989) had very different rainfall patterns. During 1988, February through April and July through August were periods of heavy rainfall, whereas May through June and September through December were dry (figure 92B). In 1989, precipitation was concentrated mainly from May through August, and during a three month period beginning in August, potential evaporation exceeded rainfall (figure 92C).

Rockefeller Refuge. At Rockefeller Wildlife Refuge, average precipitation for the period of record was 151 cm (table 51); a low of 107 cm occurred in 1969, and a high of 190 cm in 1973. Average monthly precipitation was very similar to that for Houma, except that slightly lower rainfall in late spring led to a more pronounced period of deficit from May through June (figure 93A). July is, on average, the wettest month, and November is normally the driest. During

Table 50. Average monthly water budget values for Houma, Louisiana. All values are in centimeters.

Year	PE[a]	P	P-PE	AE	DEF	SUR	RO
1960	109.70	142.82	33.12	80.87	28.83	61.95	60.43
1961	107.47	186.31	78.84	97.10	10.36	89.20	88.06
1962	115.42	102.59	-12.83	77.01	38.40	25.58	29.64
1963	111.40	176.00	64.59	74.24	37.19	101.75	91.34
1964	111.86	183.31	71.45	99.01	12.83	84.30	91.80
1965	114.63	153.82	39.19	88.54	26.09	65.28	61.09
1966	107.11	207.92	100.81	94.31	12.80	113.61	115.77
1967	108.94	165.94	57.00	94.08	14.86	71.86	65.94
1968	106.45	128.91	22.45	77.29	29.16	51.61	53.72
1969	104.44	144.42	39.98	82.07	22.38	62.36	70.66
1970	102.84	141.53	38.68	87.35	15.52	54.18	54.51
1971	105.54	151.00	45.47	82.88	22.66	68.12	65.46
1972	110.72	157.94	47.22	84.71	26.01	73.23	64.90
1973	108.28	197.79	89.51	78.97	29.31	118.82	120.75
1974	109.73	142.85	33.12	86.11	23.60	56.74	60.76
1975	105.69	181.25	75.57	104.19	1.50	77.06	79.20
1976	97.59	121.26	23.67	75.21	22.38	46.05	38.58
1977	109.60	162.20	52.60	91.01	18.57	71.20	74.19
1978	108.61	165.25	56.64	88.95	19.66	76.30	77.88
1979	103.91	184.99	81.08	97.61	6.30	87.38	91.03
1980	108.43	195.10	86.66	85.06	23.39	110.03	110.16
1981	110.19	128.83	18.64	91.16	19.02	37.67	37.52
1982	112.17	170.26	58.09	102.79	9.37	67.46	60.02
1983	100.86	156.90	56.03	74.75	26.11	82.14	86.41
1984	107.80	156.87	49.07	95.17	12.62	61.70	66.45
1985	111.99	173.86	61.87	90.58	21.44	83.29	81.94
1986	112.34	125.53	13.18	90.25	22.10	35.28	31.95
1987	101.22	178.00	76.78	90.60	10.62	87.40	91.49
1988	102.72	176.89	74.17	84.40	18.29	92.48	93.62
1989	104.14	135.18	31.04	91.72	12.42	43.46	41.22
Average	107.73	159.85	52.12	87.93	19.79	71.92	71.88
Standard deviation	4.22	25.16	25.71	8.20	8.58	23.04	23.75

[a]PE = potential evaporation; P = precipitation; P-PE = precipitation minus potential evaporation; AE = actual evaporation; DEF = deficit (precipitation less than potential evaporation); SUR = surplus (precipitation greater than potential evaporation); RO = runoff.

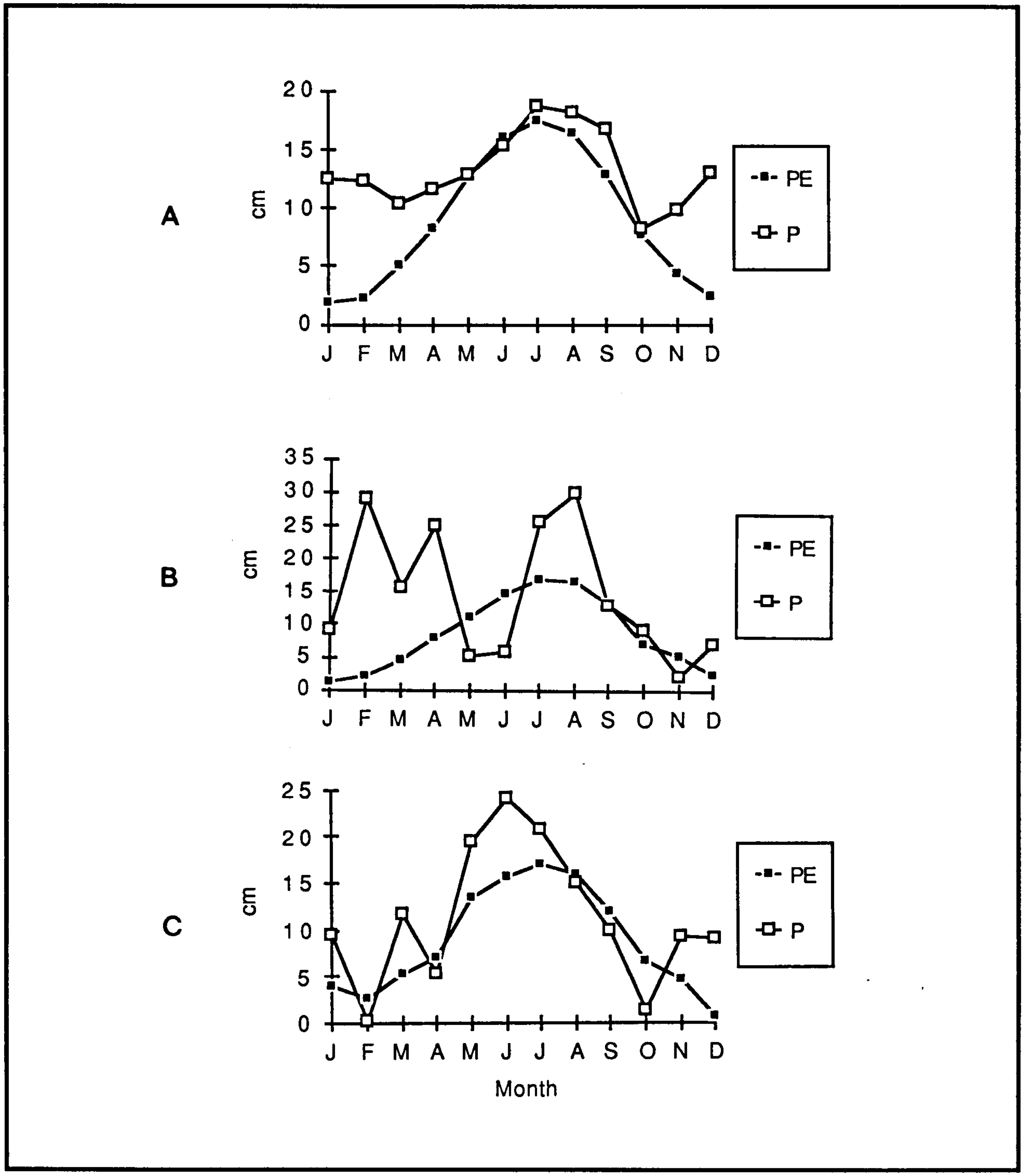

Figure 92. Water budgets for Houma, Louisiana, showing (A) the 30-yr average, (B) 1988, and (C) 1989.

Table 51. Average monthly water budget values for Rockefeller Wildlife Refuge, Louisiana. All values are in centimeters.

Year	PE[a]	P	P-PE	AE	DEF	SUR	RO
1965	109.14	109.17	0.03	82.04	27.10	27.13	19.30
1966	102.34	178.82	76.48	94.28	8.05	84.53	87.50
1967	107.42	144.30	36.88	83.46	23.95	60.83	55.50
1968	102.79	129.97	27.18	73.38	29.41	56.59	55.52
1969	108.05	106.65	-1.40	66.19	41.83	40.46	47.47
1970	104.24	143.13	38.89	81.00	23.24	62.13	61.42
1971	108.61	149.61	41.00	82.96	25.63	66.65	51.82
1972	110.64	160.40	49.76	90.20	20.47	70.21	78.84
1973	109.73	189.74	80.01	94.41	15.32	95.33	99.77
1974	109.25	169.34	60.10	92.84	16.38	76.50	73.33
1975	107.59	168.50	60.91	96.39	11.20	72.11	74.35
1976	98.76	121.41	22.66	68.86	29.92	52.55	45.01
1977	110.19	177.39	67.21	87.07	23.11	90.32	97.43
1978	107.21	134.19	26.97	74.07	33.15	60.12	61.54
1979	105.36	171.53	66.17	87.30	18.03	84.23	85.34
1980	110.52	157.12	46.61	88.32	22.20	68.81	67.89
1981	111.56	128.98	17.42	80.65	30.94	48.34	46.69
1982	113.46	146.71	33.25	96.98	16.46	49.73	43.74
1983	101.98	168.15	66.17	82.27	19.71	85.88	94.31
1984	109.98	146.94	36.96	72.34	37.62	74.60	74.57
1985	113.87	164.52	50.65	78.05	35.81	86.46	81.48
1986	113.89	141.22	27.33	91.19	22.71	50.04	49.12
1987	106.55	153.14	46.58	90.78	15.77	62.36	67.54
1988	102.64	163.37	60.73	86.66	15.98	76.71	77.22
1989	103.94	147.96	44.02	83.95	19.99	64.01	60.22
Average	107.59	150.89	43.30	84.23	23.36	66.66	66.28
Standard deviation	4.01	21.26	21.44	8.55	8.34	16.65	19.48

[a]PE = potential evaporation; P = precipitation; P-PE = precipitation minus potential evaporation; AE = actual evaporation; DEF = deficit (precipitation less than potential evaporation); SUR = surplus (precipitation greater than potential evaporation); RO = runoff.

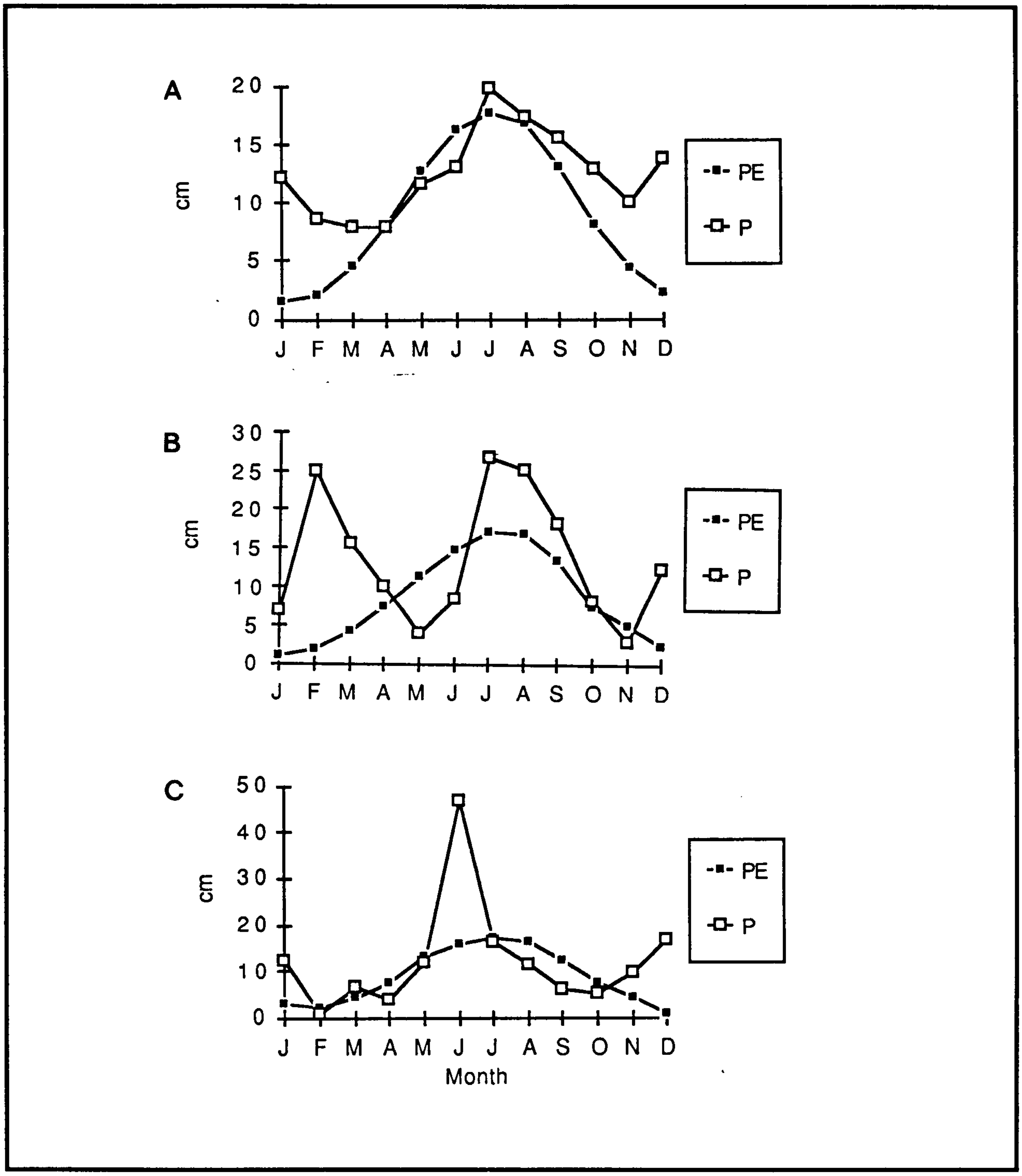

Figure 93. Water budgets for Rockefeller Wildlife Refuge, Louisiana, showing (A) 25-yr average, (B) 1988, and (C) 1989.

1988, rainfall patterns at Rockefeller were generally similar to those at Houma (figures 92B, 93B), but in 1989 they were very different. In 1989 most of the summertime rainfall at Rockefeller occurred in June (figure 93C), whereas at Houma rainfall occurred more evenly throughout the summer. At Rockefeller potential evaporation exceeded precipitation for a much longer period (beginning in June and ending in October).

Daily Water Budget

A more detailed analysis of the water balance showing the daily cumulative P-PE values for September 1988 through December 1989 for both areas is presented in figures 94 and 95. It was much drier during the early part of the study at Houma. Potential evaporation was greater than precipitation at Houma from mid-October 1988 to mid-January 1989 and again from October through November 1989. At Rockefeller potential evaporation was greater than precipitation during only two short periods (mid-November to mid-December 1988 and October 1989).

Management Considerations

This analysis has several management implications. Periods of low rainfall are not uncommon. When these periods occur during the warmer part of the year, PE may exceed P for extended times. These periods are characterized by low freshwater surplus or a freshwater deficit. The fall is often a period of low surplus or deficit because of the high evapotranspiration during the summer. This was the case in 1988 and 1989 at both Fina LaTerre and Rockefeller (figures 94, 95).

Prolonged periods of low freshwater surplus or deficit may accompany extended periods of low rainfall, as happened at Fina LaTerre in the fall of 1988 and the spring of 1989. Rainfall was below normal at Fina LaTerre from September 1988 into April 1989 (figure 92). Salinities were higher than average at Fina LaTerre from September into December (figure 94). This was perhaps partially due to the freshwater deficit. In shallow ponds about 25 cm deep or less, evaporation alone could increase salinity by several parts per thousand during extended periods of low rainfall. This points to the importance of introducing fresh water into management areas. The analysis indicates that during periods of normal rainfall, salinity increases are not a serious problem.

Finally, the results of the analysis suggest, at least for Fina LaTerre, that hurricanes can significantly raise salinity. Two hurricanes affected the study area during the period of the daily water budget analysis: hurricane Gilbert in September 1988 and hurricane Jerry in September 1989. After both hurricanes, salinities were high at Fina LaTerre (figure 94). Any rainfall associated with these storms seems minimal at Fina LaTerre in terms of both the water budget analysis and salinities. This may be because little fresh water is being introduced at Fina LaTerre. If the high freshwater runoff generated by hurricanes could be used in the management area, the effects of high salinity could be reduced.

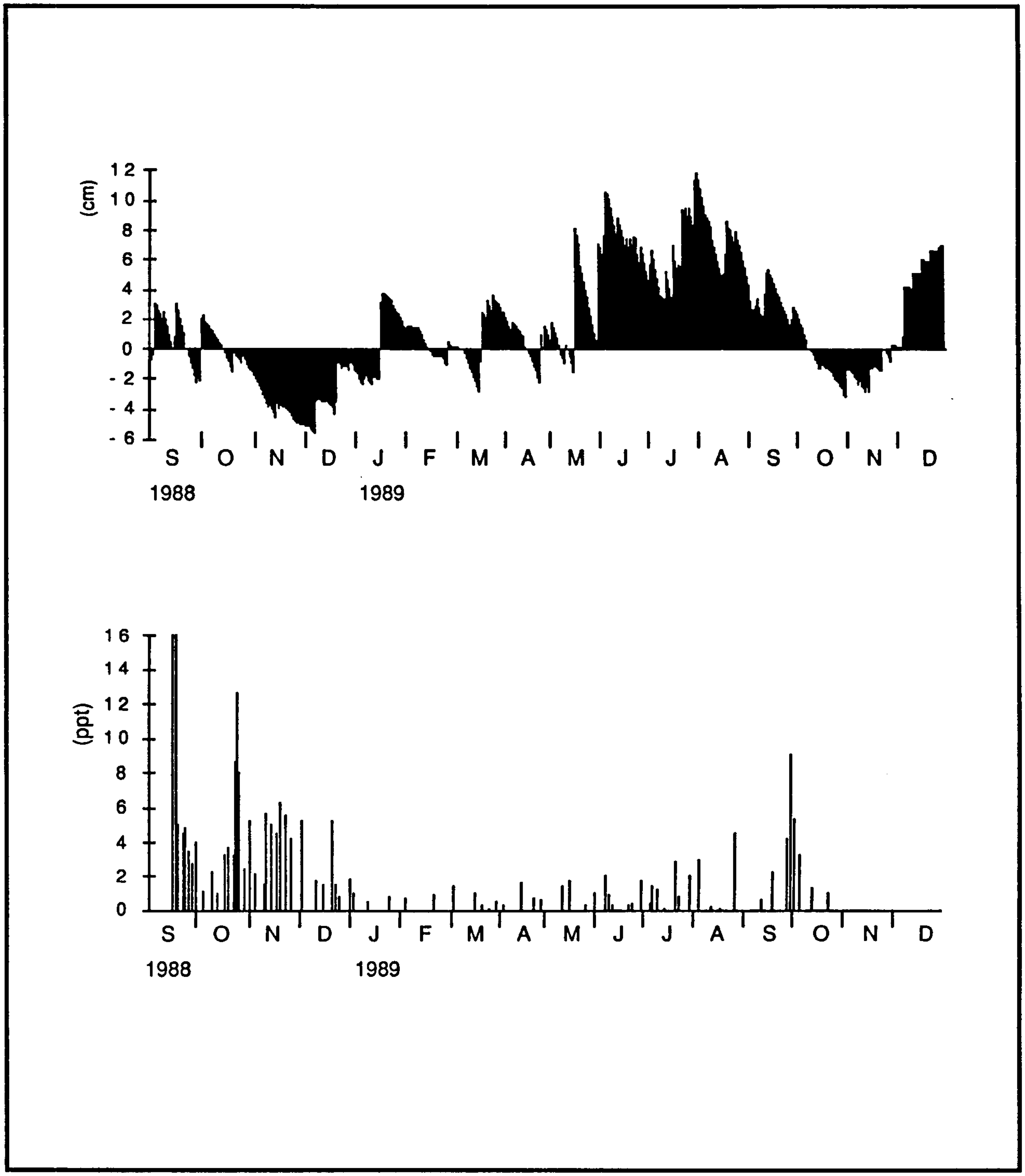

Figure 94. Cumulative P-PE (precipitation minus potential evaporation) for Houma, Louisiana, from September 1, 1988, through December 31, 1989 (top), and salinity levels for the Fina LaTerre site (bottom).

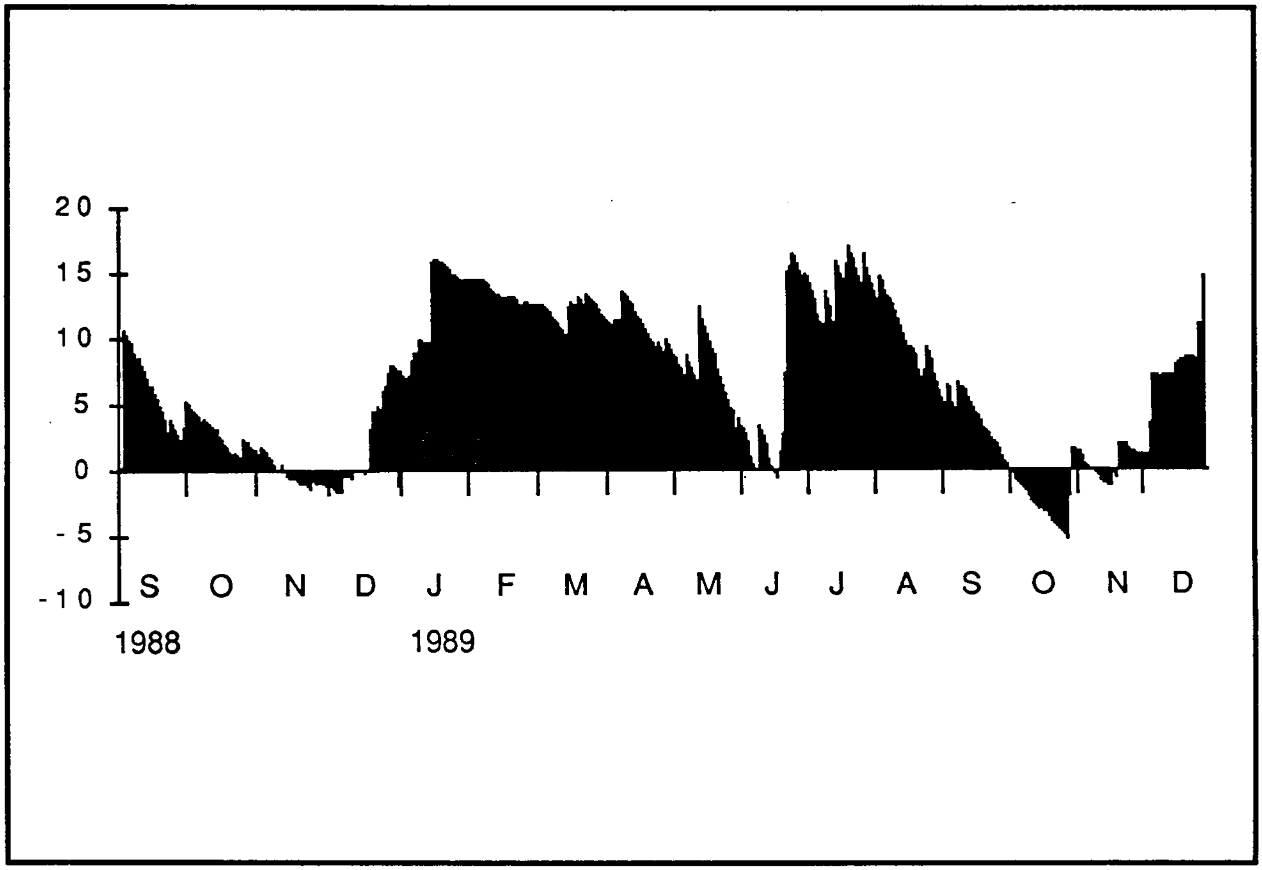

Figure 95. Cumulative P-PE (precipitation minus potential evaporation) for Rockefeller Wildlife Refuge from September 1, 1988, through December 31, 1989.

SHORT-TERM SEDIMENTATION AND WATER AND MATERIALS FLUX

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Objectives

The analysis of short-term sedimentation and water materials flux had two objectives:

1. to measure short-term sedimentation patterns during two- to four-week intervals in managed and unmanaged areas

2. to measure water and materials fluxes in managed and unmanaged areas under different climatic and operational conditions.

Methods

Flux Studies

We examined material flux at the two study areas in 1989. Field trips for the flux studies were spaced to account for seasonal variations in climate, mean sea level, and operation of the structures. We made trips to Rockefeller on May 31 through June 2, September 21-23, and November 2-4; to Fina-LaTerre on May 22-24, September 28-30, and October 26-28. At Rockefeller, measurements were made at the large structure at the southwestern corner of management unit 4 and in East Little Constance Bayou just above Little Constance Lake (figures 86, 87). At Fina LaTerre, measurements were made at the main control structure on the canal on the northern side of Falgout Canal and at several inlets in the unmanaged area south of the Falgout Canal (figures 83, 85). The largest channel into the unmanaged areas was monitored every two hours for the duration of each field trip. At four smaller channels, water flux was measured approximately every two hours during daylight hours to estimate total water exchange between the unmanaged area and Falgout Canal. The cross-sectional area of the channels and control structures was measured. During each trip, we noted weather conditions, structure operation, and other factors that might prove useful in analyzing and interpreting the data. Because of logistic limitations, no measurements of water fluxes were made at the four fixed-crest weirs in the northern part of the Fina LaTerre area, nor have earlier monitoring efforts provided information on water fluxes at these sites from which conclusions could be drawn. The results of the flux measurements are for tidally driven exchange with Falgout Canal.

During each trip, we measured water level and current velocity and direction, and took samples to determine material concentrations over a period of 48-50 h (two tidal cycles). On all trips, measurements were made every 2 h. At the unmanaged areas, we collected samples in the center of the channel at depths of 30-40 cm. In an earlier study of flux in a similar channel in coastal Louisiana, Stern et al. (1986) found that a single sample was sufficient to characterize flux in such channels. At Fina LaTerre all water samples were taken at the main unmanaged channel. Water samples were also collected with an autosampler at one additional channel (the box weir) for the analysis of total suspended solids only. At the managed areas, we measured currents and collected water samples in the bays of the structure. At Fina LaTerre we made routine measurements in the south bay of the structure. Several times during each trip additional current measurements were made in the north bay as well as in front of the structure to ensure that measurements in the south bay were sufficient to characterize water flux. At Rockefeller, the structure contained seven bays. We took routine measurements in the centers of bays 2, 4, and 6. Several times during each trip we took three current measurements in each of the seven bays so that total water flux could be calculated.

Water samples were collected for analysis of nitrate plus nitrite (NO_3), ammonium (NH_4), soluble reactive phosphate, total suspended solids, and salinity. Samples for NO_3, phosphate, and NH_4 were filtered through GF/C filters and frozen on dry ice in the field in plastic autoanalyzer vials. We used the Environmental Protection Agency's (1979) methods to identify all nutrient concentrations with a Technion Autoanalyzer II. Total suspended solids were determined gravimetrically (Banse et al. 1963), and salinity was measured with a chloridity meter.

Current velocity was measured using a Montedoro Whitney model PVM-2A current meter. Water levels were read from staff gages. We placed the staffs in the channels at the unmanaged areas and inside and outside of the structures at the managed areas. The existing staff gauge at the Fina LaTerre structure was used. Fluxes were calculated from each velocity, water-level, and concentration value. We accounted for changes in cross-sectional area due to changes in water level (Stern et al. 1986). The net fluxes reported are the average of algebraic sums of the instantaneous fluxes recorded during a trip (Spurrier and Kjerfve 1988). The term "ebb-directed flux" (indicated by "-") refers to transport out of the study area; "flood-directed flux" (indicated by "+") refers to upstream transport into the study area. Material concentrations and fluxes from unmanaged and managed areas were compared to identify possible effects of management.

<u>Short-term Sedimentation</u>

We measured short-term sedimentation every two to four weeks between August 1989 and January 1990 as deposition on petri dishes placed in the marsh at the managed and unmanaged sites. The petri dishes were placed as follows. A hole was drilled in a 25-x-25-cm cedar board slightly larger than a 98-mm-diameter glass petri dish. The board was placed on the marsh such that the top of the board was level with the surface of the marsh. Four galvanized wires about 35 cm long were then pushed through small holes drilled in each corner of the board and into the marsh soil to anchor the board in place. The petri dish was then placed in the hole in the center of the board over an aluminum wire bent to hold the dish in place as well as to help remove the dish for sampling. At sampling sites 10 boards with petri dishes were set out in 2 transects of 5 dishes each for a total of 40 dishes (see locations, figures 85, 86). Each transect consisted of dishes in the managed and unmanaged areas of Fina LaTerre and Rockefeller set 5, 10, 15, 20, and 25 m from the marsh edge. In each area, one transect was placed on the edge of a large pond, and a second was placed in a more protected area. At East Little Constance Bayou, transects were set out on each side of the bayou. The petri-dish technique is a modification of a technique Reed (1989) used to measure short-term sedimentation with glass-fiber filters wired to the top of plastic petri dishes. We tried this technique, but found that the length of the sampling interval made it impractical; most of the filter papers were either missing or partially destroyed by the time they were collected.

Samples were collected as follows. We gathered all material that had collected on the tops of the petri dishes and placed it in a plastic bag. Grass stems and other larger material were picked up by hand. We used a razor knife to cut grass pieces so that only material over the petri dishes was sampled. The petri dishes were then carefully removed and placed over a funnel. Fine-grained material that had accumulated on the dish was scraped off with the razor knife and washed into the plastic bag, which was then placed on ice and returned to the lab. In the laboratory, water and the materials collected in plastic bags were placed in a crucible, and the water was evaporated at 60°C. The crucible was then weighed, fired at 400°C for 16 hours, and then reweighed. The weight of the material after firing was mineral matter; that lost on ignition was organic matter. The data were calculated on a g m^{-2} d^{-1} basis.

Statistical tests on the sedimentation data were conducted using the Statistical Analysis System (SAS Institute 1985). Statistically significant differences between sites and sampling times for total sedimentation, mineral sedimentation, organic sedimentation, and percentage organic matter were determined with Duncan's multiple range test (analysis of variance, ANOVA), and also by using split-plot analysis of variance with treatment, in the main plot and sampling time in the subplot.

<u>Soil Analysis</u>

Sediment samples were taken from each of the permanent stations with a 2.5-cm stainless steel cover. The upper 6" (15 cm) of the samples from each area were homogenized for analysis (see also the section of this chapter by Flynn et al. for more detail on the sampling procedure). Parameters measured included:

1. total phosphorus

2. Na^{+}

3. percentage organic matter

Elemental analyses were done using an Applied Research Laboratory inductively coupled Argon plasma quantometer (ICP). Results are reported as the average of duplicate analyses that are within a 10% confidence interval. The results are based on weight after oven drying (Soil Survey Staff 1972).

Results and Discussion

Water-Level Variations During Flux Studies

The water-level variations show a number of interesting results. Clear tidal signals existed outside the control structure of the managed areas and at the unmanaged areas at both the Rockefeller and Fina LaTerre sites, whereas inside the managed areas water level changed less during the 48 h of the flux studies, especially at Rockefeller (table 52; figures 96, 97). The tides showed the signals typical for the northern Gulf. At Rockefeller, for example, there was a mixed tide that had both diurnal and semidiurnal components on September 21-23, 1989, and a diurnal tide on November 2-4, 1989. The tide range at the two unmanaged sites was also typical for the region; it varied from 16 to 38 cm at Rockefeller and from 12 to 14 cm at Fina LaTerre (see also figures 89 and 90). This is the expected pattern of a decrease in tidal range with distance inland from the coast (Baumann 1987).

The tidal range in the canal outside of unit 4 at Rockefeller was amplified because the water was not able to spread out over the marsh (figure 96). Most of the area in the western part of the refuge is managed and surrounded by spoil banks, whereas the water is not restricted in the unmanaged area. The tidal range in the canal during the three tidal-cycle studies ranged from 74 to 79 cm, compared to 16-38 cm in the unmanaged area (table 53). At the Fina LaTerre site, we did not measure any such amplification of the tidal range (figure 97; table 53), probably because this area has lower tidal ranges and a much larger tidal plain than in the western part of Rockefeller. Floodwater entering the Fina LaTerre area can come from the east via Falgout Canal or west via Lake de Cade.

The increased tidal range at Rockefeller reduces the amount of time that the main control structure can drain unit 4. Normally, the tide level would be below the marsh surface for more than half of the time. But because the water level in the Humble and Union canals is more often higher than the water level in unit 4, the structure would be more effective in allowing water into the area than in draining it out if it were left open at all times. When the water level outside the structure is below the level inside, drainage is slow because of the limiting size of the structure openings. In other words, unit 4 would drain more efficiently with a larger structure. This is addressed in more detail in the following section. Management at Rockefeller was implemented partially to deal with problems caused by canals and management has stabilized water levels. The amplification of water-level variation in the canals is also an example of cumulative impact in the sense that an increasingly dense network of canals and spoil banks leads to amplification of water levels and the need for more intensive management.

Instantaneous Water Fluxes

The water-flux measurements reveal that considerably less water is exchanged through the control structures than in the unmanaged channels (figures 98, 99). Instantaneous water flux at the unmanaged sites followed the tidal signal, with considerable inflows and outflows.

At the Rockefeller site, peak fluxes ranged between 4 and 6 m^3 s^{-1} at the unmanaged area and between 1 and 2 m^3 s^{-1} at the managed area (figure 98). Because the May/June tidal-cycle measurements occurred during a period of low

Table 52. Results of the soil analysis.

Study Area	Unmanaged Mean		Unmanaged Std. Error	Managed Mean		Managed Std. Error	t-test
Rockefeller							
Phosphorus (mg/kg soil)	232	±	10	111	±	9	* *
Sodium (g/kg soil)	9	±	0.2	7.6	±	3.4	N.S.
Organic matter (%)	5.8	±	0.7	5.6	±	0.7	N.S.
Fina LaTerre							
Phosphorus (mg/kg soil)	118	±	7	101	±	5	*
Sodium (g/kg soil)	6.5	±	0.04	8.6	±	0.03	**
Organic matter (%)	7.1	±	0.3	8.6	±	0.1	**

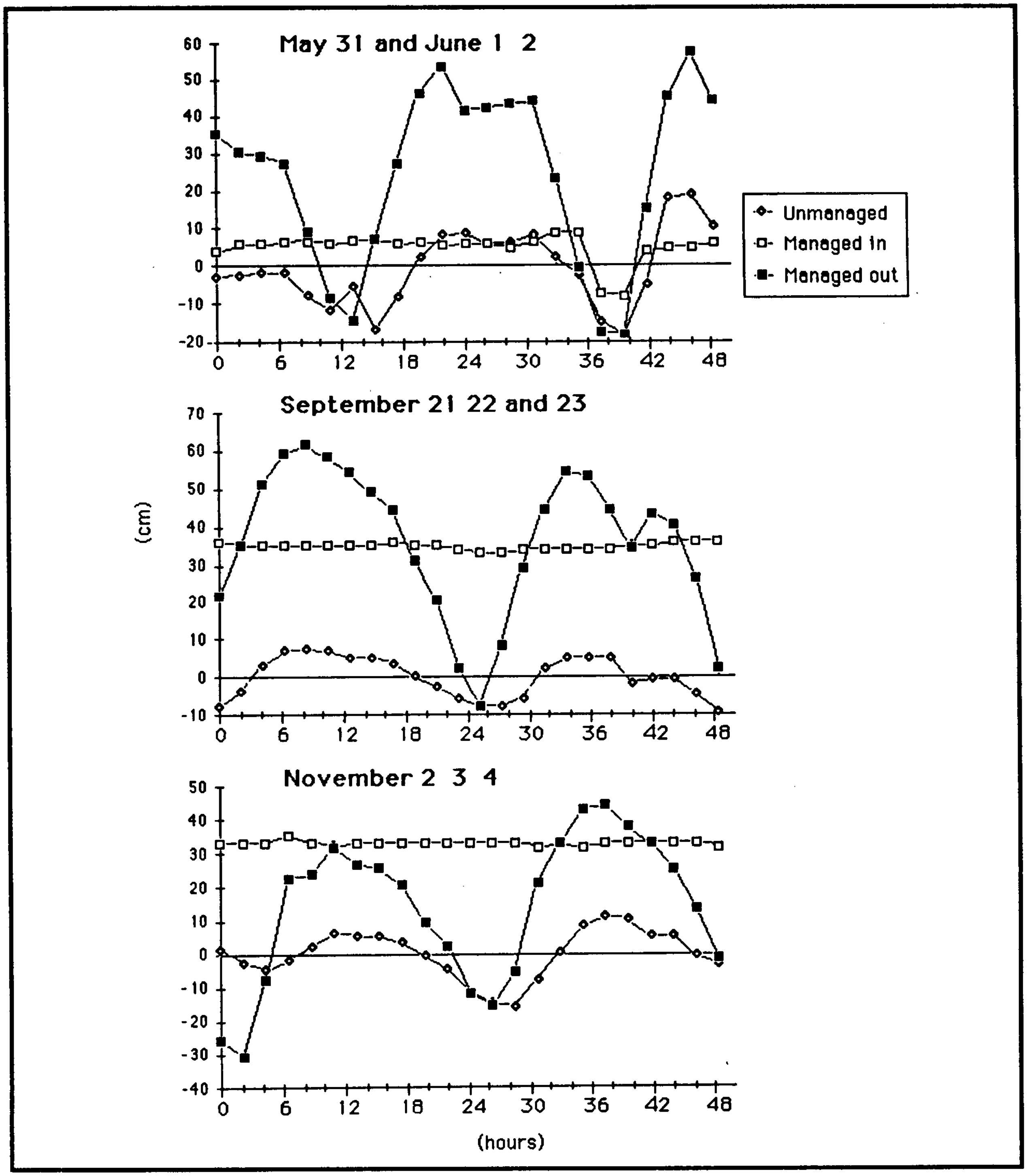

Figure 96. Water levels measured at the unmanaged and managed areas during the three tidal exchange studies at Rockefeller Refuge in 1989. "Managed out" refers to water levels in the canal outside of the water control structure. The water-level scale is relative, but water levels in and out of the managed area are absolute to each other. The curve for the unmanaged area is plotted such that low water coincides with low water for the "managed out" site.

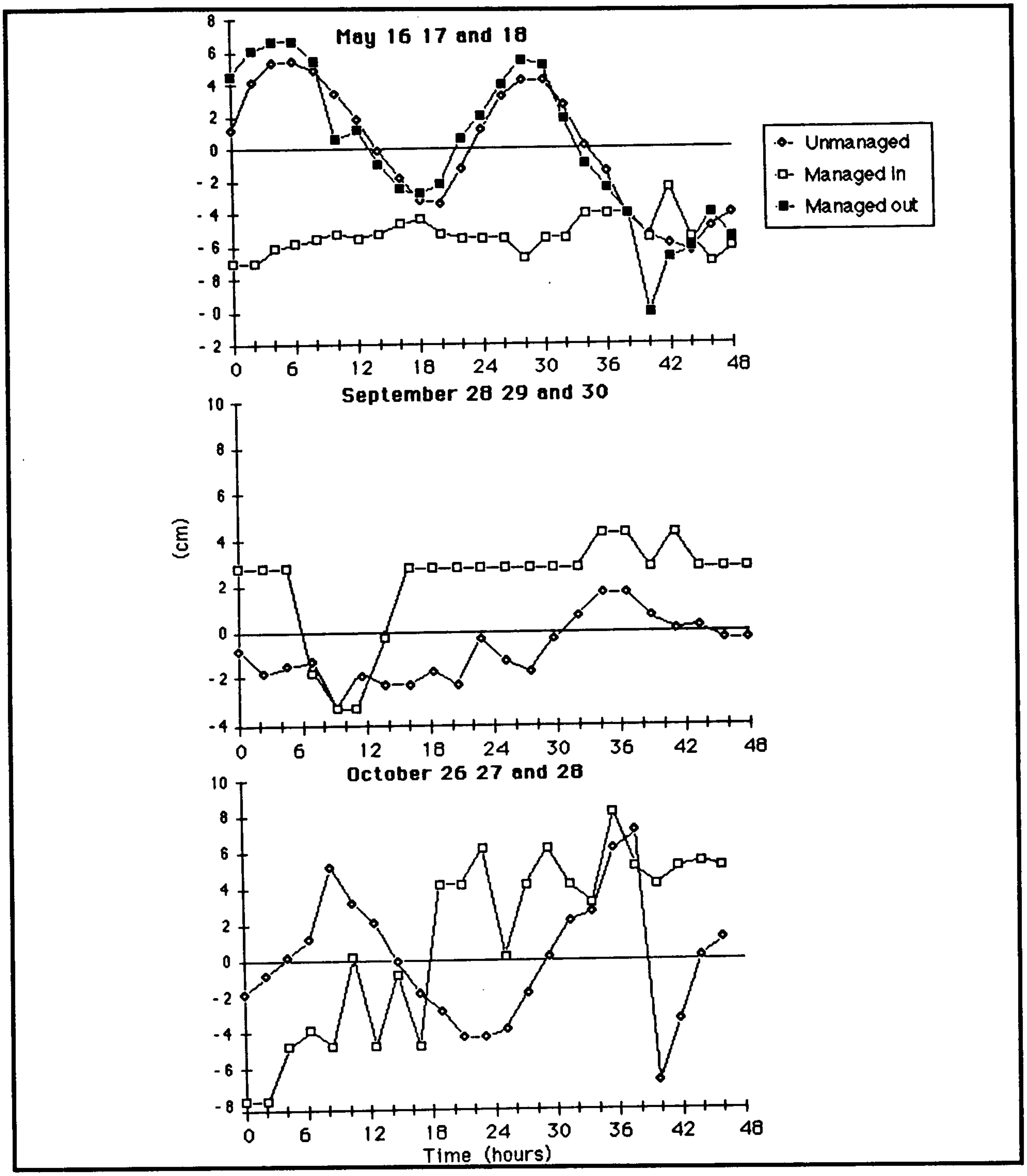

Figure 97. Water levels measured at the unmanaged and managed areas during the three tidal exchange studies at Fina LaTerre in 1989. During the May 16-18 study, water levels were measured both inside ("managed in") and outside ("managed out") of the water control structure. During the September and October studies, the control structure was open, and water levels inside and outside were the same. The water-level scale is relative, but the different curves are absolute to one another.

Table 53. Tidal range during flux studies for each of the study sites.

Study Site	Tidal Range (cm)		
	May	Sept.	Oct.
Fina LaTerre			
Managed, in[a]	5	8	13
Managed, out[b]	17		
Unmanaged	12	12	14
	May	Sept.	Nov.
Rockefeller			
Managed, in	17	5	3
Managed, out	76	79	74
Unmanaged	38	16	27

[a]"Managed in" refers to measurements taken within the water control structure.
[b]"Managed out" levels were measured outside of the water control structure.

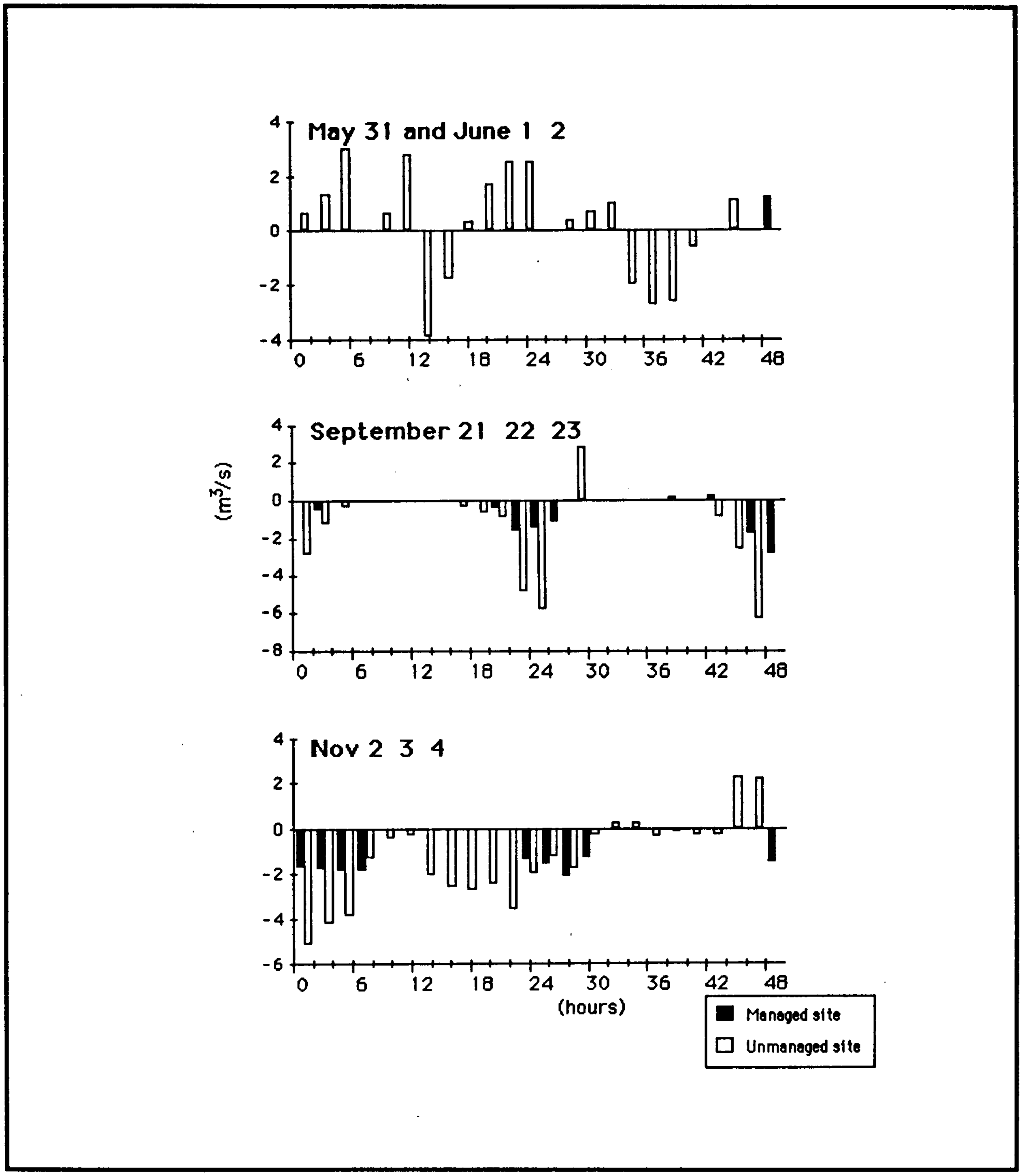

Figure 98. Instantaneous water fluxes measured every 2 h during the three tidal flux studies at Rockefeller Refuge in 1989. The water flux for the managed area was measured at the control structure in the southwestern corner of unit 4. The water flux for the unmanaged area is for water exchange in East Little Constance Bayou north of East Constance Lake. Positive values indicate flux into the area, and negative values flux out of the area.

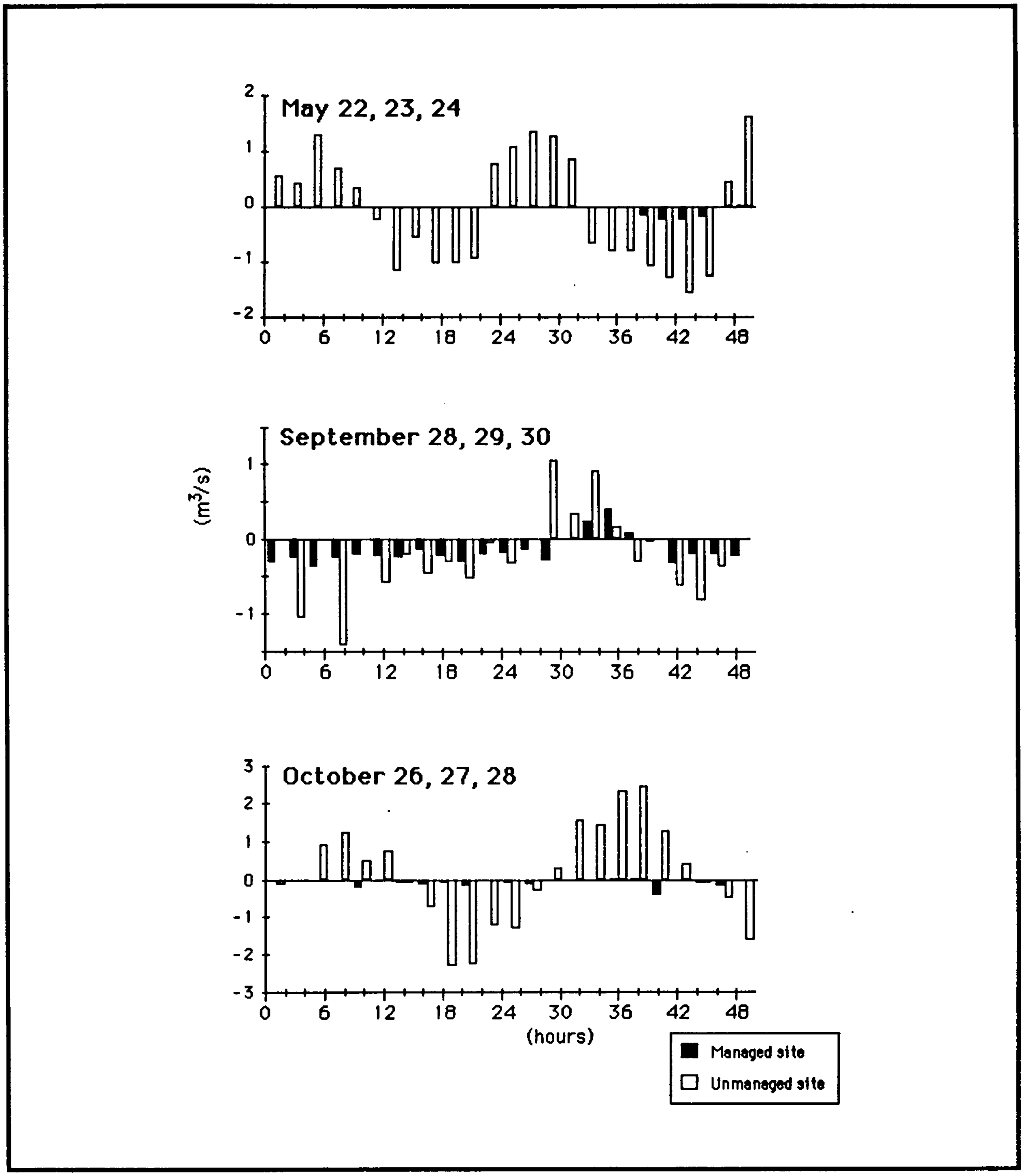

Figure 99. Instantaneous water fluxes measured every 2 h during the three tidal flux studies at Fina LaTerre in 1989. The water flux for the managed area was measured at the control structure north of Falgout canal. The water flux for the unmanaged area is for water exchange with Falgout canal. Positive values indicate flux into the area, and negative values flux out of the area.

winds, water fluxes were mainly tidally driven. At the unmanaged site, the water-flux pattern reflected the mixed tide. There was considerable flow in and out, but the net flow was relatively low. At the managed site the structure was closed most of time but was opened briefly at the end of the measurement period to allow post-larval shrimp to enter the management unit. This resulted in the strong pulse of inflow at about 5 p.m. on June 2, 1989. The September measurements were taken during a period of brisk north winds and low tidal range (16 cm). At the unmanaged site this resulted in a net flow out of Little Constance Bayou; the flow was out for 22 h and in for 8 h. In comparison, at the managed area the outflow lasted 14 h. The November samples were also taken during a period of strong north winds. At the unmanaged area, there was again a strong net outflow; water flowed out of the bayou for 38 h and in for 8 h. At the managed site, there was outflow for 18 hours. For both September and November, the flap gates were down and flapping out. These results reveal that the increased tidal range outside the managed site gives that area less time to drain than the unmanaged site.

The water fluxes at the Fina LaTerre unmanaged site showed the effects of the ebb and flood of the tide, but the peak fluxes were smaller than at Rockefeller (figure 99). Peak fluxes in the unmanaged area were between 1.5 and 2.5 m^3 s^{-1}. In comparison, peak fluxes at the managed site were less than 0.5 m^3 s^{-1}. In May, when there were no strong winds and the tidal range was 12 cm, the pattern of flood and ebb was fairly normal. The flux data for the unmanaged site, with a regular pattern of inflow and outflow, reflect the tidal signal. There was outflow from the managed area for only 8 h and no inflow because the flap gates were down. In September, the tidal range was again 12 cm, but variable and shifting winds resulted in a somewhat irregular pattern of water flux. Inflow or outflow occurred at both managed (where the flap gate was up) and unmanaged sites, but the flows were generally higher at the unmanaged site when compared to flow through the main structure at the managed site. In October, a more typical tidal signal resulted in a regular pattern of water flux at the unmanaged site. Water fluxes through the main control structure at the managed area were low. Overall, there was a net inflow at the unmanaged site on each of the three sampling trips.

<u>Net Material Fluxes</u>

The data on instantaneous water fluxes and materials concentrations were used to calculate net fluxes of each material measured for each tidal-cycle study. The net fluxes of each material in the unmanaged and managed areas were plotted against each other to compare the behavior of each area during the same time. These comparisons are made for total fluxes for each trip (figure 100) and per square meter of drainage area (figure 101). In general, the magnitudes of the fluxes were much greater in the unmanaged areas, primarily because of the greater water transport. This is especially evident when the fluxes are expressed per square meter of the drainage area. In unmanaged areas, both import and export of materials were strong on different trips. In the managed areas, there was import at Rockefeller in May; the rest of the fluxes were generally very small or exports.

Water fluxes varied between the Rockefeller and Fina LaTerre sites and on the different sampling dates. In the Rockefeller unmanaged area a strong net export of water occurred during the September and November trips and a slight

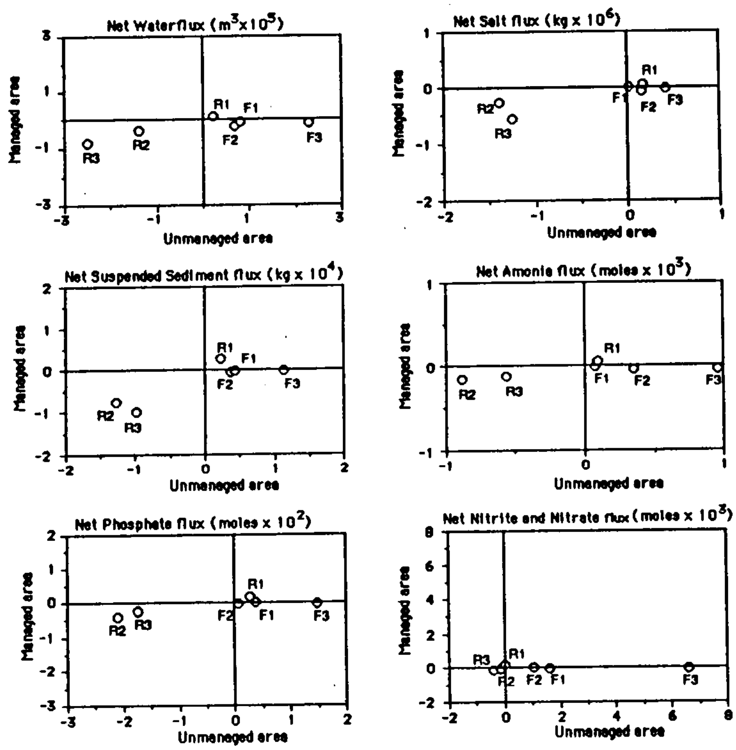

Figure 100. A comparison of total net material fluxes for the managed and unmanaged areas for each 48-h sampling period. The net fluxes for the unmanaged areas are on the horizontal axis and for the managed areas are on the vertical axis. Each circle compares the net flux between managed and unmanaged areas for a particular constituent (water, salt, suspended sediments, ammonia, phosphate, and nitrate plus nitrite) for an individual sampling trip. Positive values indicate flux into the area and negative values flux out of the area. "R" and "F" stand for Rockefeller and Fina LaTerre, respectively, and 1, 2, and 3 are for the first, second, and third trips.

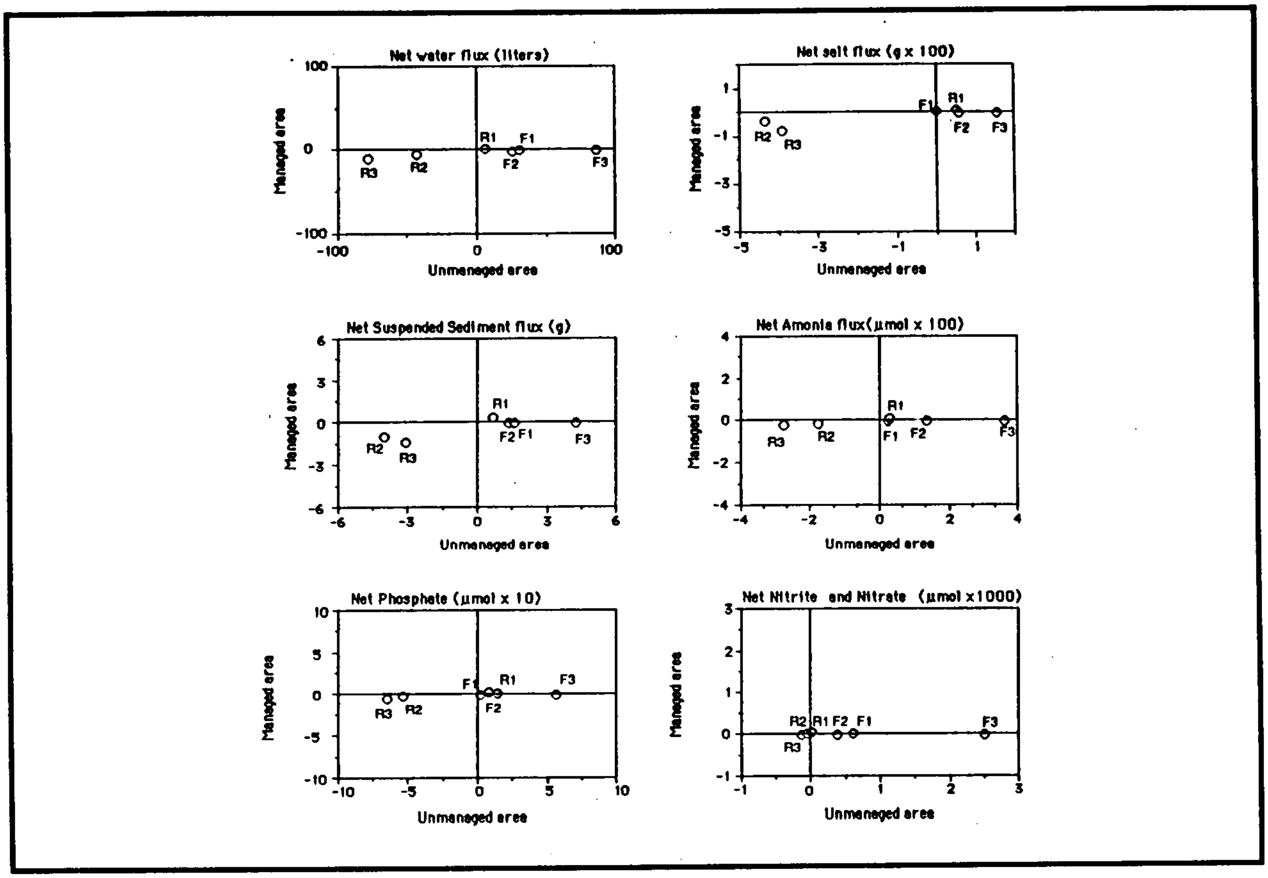

Figure 101. A comparison of net material fluxes per square meter of the study area for the managed and unmanaged areas for each 48-h sampling period. The net fluxes for the unmanaged areas are on the horizontal axis, and those for the managed areas are on the vertical axis. Each circle compares the net flux between managed and unmanaged areas for a particular constituent (water, salt, suspended sediments, ammonia, phosphate, and nitrate plus nitrite) for an individual sampling trip. Positive values indicate flux into the area, and negative values flux out of the area. "R" and "F" stand for Rockefeller and Fina LaTerre, respectively, and 1, 2, and 3 are for the first, second, and third trips.

net import during the May trip. At the Fina LaTerre unmanaged area, a net import of water occurred on all three trips. At the Rockefeller managed area, a strong net export of water in September and November reflected the north winds during the sampling trips; in May a small net water import occurred. At the Fina LaTerre managed area, a small net export of water occurred during each of the trips. These net water transport patterns are the main driving forces affecting materials export.

It must be remembered that water fluxes for the Fina LaTerre managed area are for the main control structure only and do not include the fixed-crest weirs in the northern part of the managed area. Thus, the results for net water fluxes for the Fina LaTerre management area are low. Table 54 presents data on the net water fluxes in liters per m^2 for the main control structure and the unmanaged area for the three Fina LaTerre trips.

These data show that if the water flux at the fixed-crest weir were 10 times higher than at the main control structure, the total water flux per m^2 would be considerably less for trips 1 and 3 and approximately equal for trip 2 when compared to the unmanaged area. These data indicate that water fluxes at the fixed-crest weirs would have to be very high before approximating that at the central area. The fluxes at the fixed-crest weirs should be measured so that an accurate estimate of their importance can be obtained.

For suspended solids transport, there was a strong net export from both the managed and unmanaged areas at Rockefeller during September and November. At the Fina LaTerre unmanaged area, a net import of suspended solids occurred during all three trips, and there was essentially no net exchange for the managed area. These results suggest that drawdown by draining during northerly winds may result in considerable sediment export from a managed area with considerable areas of open water.

The pattern of net flux of dissolved solids (salinity) closely resembled that of the net water flux. This was expected because salinity behaves conservatively and can be used as a tracer of water masses as long as there is no water mass change (Day et al. 1989). Conservative behavior means that the concentration is changed only by dilution. There was a considerable net export of salt from both the Rockefeller managed and unmanaged areas in September and November, a net import of salt to the Fina LaTerre unmanaged area in September and October, and to the Rockefeller unmanaged area in late May. On other trips, the net flux of salt was close to zero.

A net import of NH_4 and NO_3 to the Fina LaTerre unmanaged area occurred on all three trips. The Fina LaTerre managed areas had very small net fluxes of these materials. The net fluxes of NO_3 at both the Rockefeller unmanaged and managed sites were small on all three trips, reflecting the low NO_3 concentrations during these periods. An export of NH_4 from the unmanaged and managed areas at Rockefeller occurred, however, during September and November. When expressed on a per-square-meter basis, the fluxes at the managed areas of both sites are close to zero. The net flux patterns for PO_4 are similar to those of nitrogen. A net import to the Fina LaTerre unmanaged area occurred on all three trips, but there was almost no net flux in the managed area. Considerable net export of PO_4 occurred at both the Rockefeller managed and unmanaged areas in September and November, reflecting the net water export. Per square meter, the net fluxes for the managed areas were near zero.

Table 54. Net water fluxes (l/m^2) at Fina LaTerre.

	Managed Area	Unmanaged Area
Trip 1	-0.69	31
Trip 2	-2.7	26
Trip 3	-1.28	86

General Discussion of Net Flux Studies

The use of tidal flux studies to measure interactions between coastal marshes and water bodies has a long history. Numerous studies have addressed the importance of coastal marshes in estuarine nutrient cycling, sediment dynamics, and export of organic matter (Axelrad et al. 1976; Bowden 1986; Chalmers et al. 1985; Childers 1989; Chrzanowski et al. 1982a,b, 1983; Daly and Mathieson 1981; Dame et al. 1986; Dankers et al. 1984; Heinle and Flemer 1976; Jordan et al. 1983; Kjerfve and McKellar 1980; Lee 1979; McIvor and Odum 1986; Nixon 1980; Odum and de la Cruz 1967; Odum et al. 1979; Reimold 1972; Rublee et al. 1983a,b; Simpson et al. 1983; Stern et al. 1986; Valiela et al. 1978; Welsch 1980; Woodwell et al. 1977, 1979; Whiting et al. 1987; Wolaver and Zieman 1983a,b; Wolaver et al. 1980; Wolaver et al. 1985). These researchers took measurements in tidal creeks, in flumes built on the marsh surface, and in different types of structures. The measurements made in our study were designed on the basis of the literature on materials fluxes.

Some general conclusions have emerged from flux studies. First, coastal marshes are highly interactive with coastal waters. Coastal marshes can be sinks, sources, and transformers of many materials. For example, Childers (1989) found a net uptake of inorganic nitrogen during high flow of the Atchafalaya River and a net release during low river flow in marshes surrounding Four League Bay, Louisiana. In general, coastal marshes export organic carbon to estuarine waters (Day et al. 1989; Nixon 1980). The results from the unmanaged sites at Fina LaTerre and Rockefeller showing a strong interaction between the marshes and adjacent waters are consistent with earlier transport studies of coastal marshes. In the managed sites, these interactions were greatly reduced.

The net flux of a material during a specific period often depends on local climatic and hydrologic conditions. Thus, during the September and November trips at Rockefeller, there was considerable net export of water and total suspended solids from both the managed and unmanaged sites. We suspect that the loss of total suspended solids resulted from resuspension of bottom sediments in shallow ponds and waterways and subsequent export with water flowing out of the areas. Export of suspended solids has also been related to strong rainstorms at low tide (Childers 1989; Settlemyre and Gardner 1975; Ward 1981). Net gain of suspended solids, such as we measured at the unmanaged area at Fina LaTerre on all three trips, has also been reported (Wolaver et al. 1988).

We believe that the results from the flux studies have implications for marsh management. Drawdown is most effective when carried out during north winds when coastal water levels are depressed. The second and third trips at Rockefeller were made under these conditions. During both trips, a brisk north wind was accompanied by strong net water export. This drove net exports of total suspended solids, salt, ammonia, and phosphate. These results suggest that drawdowns can effectively remove salt from a managed area. The results also suggest that drawdowns lead to a net loss of sediments and nutrients. In managed areas where flooding is mainly due to rain water, drawdown can lead to freshening and a progressive sediment deficit. It is not known whether these conditions would be reversed during non-drawdown years.

Weekly water turbidity data measured with a secchi disk inside and outside the managed marsh by Fina LaTerre personnel in 1989 indicated a high suspended sediment load in the spring in the waterways bordering the managed area and the potential for this material to enter the managed marsh over the fixed-crest weirs on the north side. These data also corroborate the flux study finding that there is very little net transport of matter into the southern portion of the managed area.

There was a seasonal trend in 1989 in water turbidity in the waterways bordering the managed area (the access canal off of Falgout Canal with the variable-crest structure, Minors Canal, Marmande Canal, Lake DeCade, and Falgout Canal [stations 1, 2, 3, 12, and 13, figure 102). Turbidity was measured at least once a week with a secchi disk by personnel from Fina LaTerre, Inc. Secchi depth readings for these locations during the first six months of 1989 averaged 25-36 cm, but during the last six months, they averaged 43-66 cm (table 55). The shallower readings during the first six months indicate the presence of sediment-laden spring floodwaters plus the influence of winds on suspended sediment. As the spring floods receded and cold fronts became less frequent, the water turbidity decreased and remained lower during the latter part of the year.

Turbidity measurements taken immediately inside and outside the fixed-crest weir on Minors Canal and Marmande Canal were nearly always identical throughout 1989. These data indicate that turbid water was entering or leaving the managed marsh over the fixed-crest weirs during high tides or high water levels. However, the direction and magnitude of the net flux of sediment is not known because the direction of water flow was not recorded, and the amounts of water and sediment moving over the weir were not measured. Consequently, though it is clear that sediment-laden spring floodwaters were present in the waterways, we cannot say how much is entering through these structures or how much is staying, if any, in the managed marsh. This is an important area for future monitoring.

During 1989, water turbidity was measured at least once a week by personnel from Fina LaTerre at seven stations in the managed area (stations 4, 5, 6, 8, 9, 10, and 11, figure 102) and three stations in the unmanaged area (stations 15, 16, and 17, figure 102) in shallow-water areas away from the points of water exchange and near the fisheries sampling stations. Because of shallow water depths at these interior stations, the secchi disk was visible when resting on the bottom at 88% of all the readings in the managed area and 80% of all the readings in the unmanaged area. At three of the stations in the managed area (9, 10, and 11), 100% of the readings were on the bottom, and at stations 5, 6, and 8, at least 92% of the readings were on the bottom. Only station 4 had less than half of its readings on the bottom (38%) because it was apparently located near a channel with a depth of approximately 102 cm. At the three stations in the unmanaged area, 67%-87% of the readings were on the bottom. Consequently, water turbidity could not be accurately measured in either area except perhaps at station 4. In shallow-water environments such as these, the transparency of the water column should be measured with a submersible light sensor or estimated by measuring the concentration of suspended solids.

Station 4 is directly opposite the drawdown structure (station 1). A comparison of the readings from station 4 and station 1 (outside) during the first six months of 1989 (i.e., during the drawdown) suggests that little suspended sediment is getting into the interior portions of the marsh near this structure. A similar comparison for the unmanaged area is not possible because of the high percentage of bottom readings at those stations. These data are consistent with the flux study showing almost no net movement of material into the southern portion of the managed marsh.

Table 54. Secchi depth readings in the waterways bordering the managed marsh at the Fina LaTerre Mitigation Bank Site during 1989. Values are means ± 1 SE. See figure 102 for station locations.

Station Number	January-June (cm)	July-December (cm)
1, outside	36 ± 23	56 ± 18
2, outside	28 ± 13	53 ± 23
3, outside	33 ± 10	66 ± 20
12	30 ± 13	53 ± 20
13	25 ± 8	43 ± 13

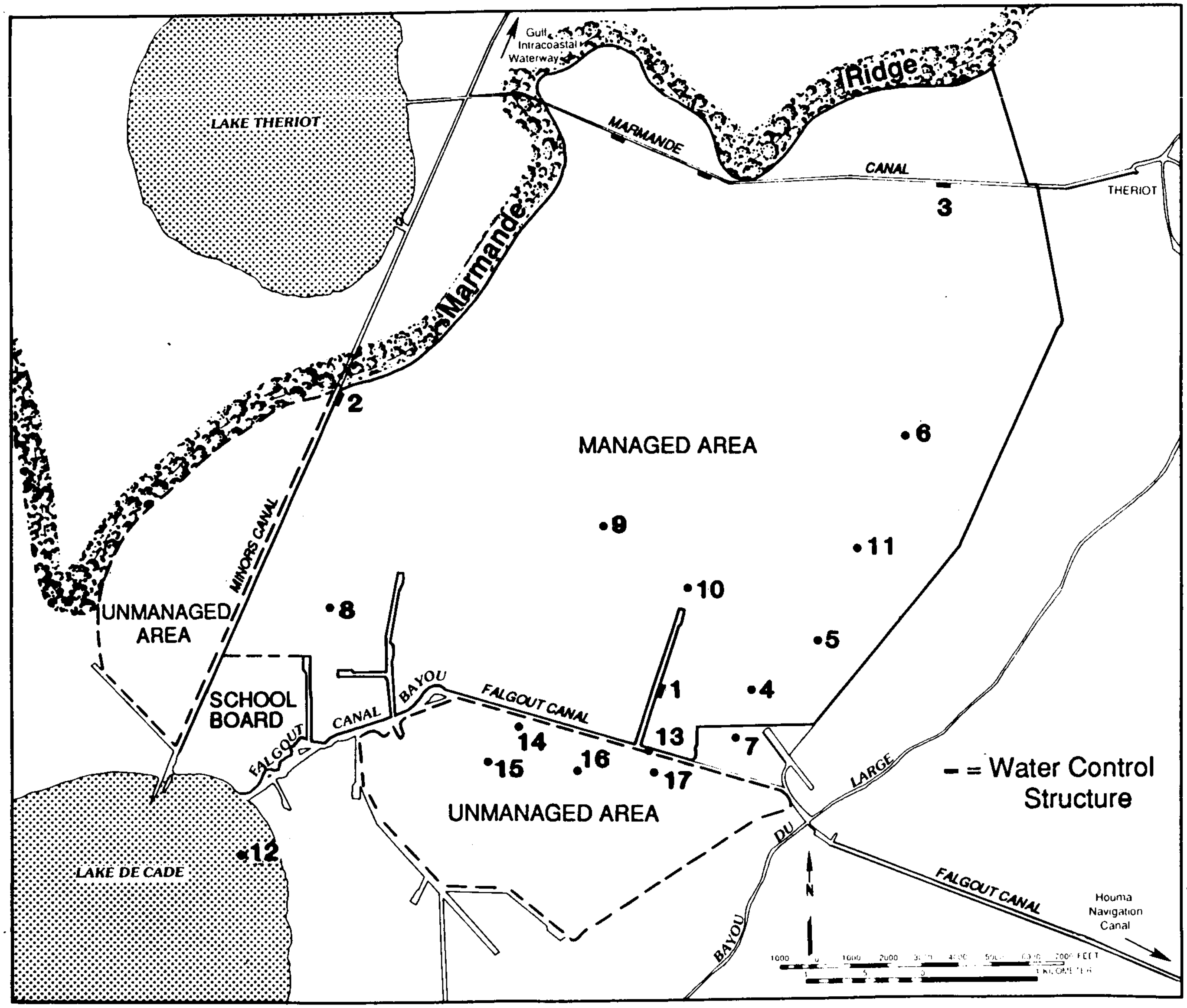

Figure 102. Water-quality sampling stations at the Fina LaTerre site.

Short-term Sedimentation Studies

Overall, sedimentation rates were higher at Rockefeller than at Fina LaTerre (figures 103, 104). Mineral sedimentation was significantly higher at the Rockefeller unmanaged area than at the other areas. Streamside sedimentation was significantly higher than that inland only at the Rockefeller unmanaged site. Sedimentation rates significantly decreased over time at all sites. Sedimentation was high, however, after the passage of hurricane Gilbert (September 26, 1989) in all areas except for the Rockefeller managed area.

At Fina LaTerre, short-term sedimentation rates in the managed and unmanaged areas were not significantly different, nor was a streamside effect measured. The longer term sedimentation measured by Cahoon at Fina LaTerre showed significantly higher rates in the unmanaged area. This different result is probably due to high variability (Reed 1989) of short-term measurements as well as mineralization of organic matter over time. The significant differences measured in the longer term marker horizon studies indicate that variability diminishes as the interval increases between measurement because of the decreasing importance of specific sedimentation events. Percentage organic matter was significantly higher in December than in the other months, probably because of lower decomposition rates at lower temperatures.

Total sediment deposition at Fina LaTerre ranged from 0 to 2.3 g m^{-2} d^{-1} and 0 to 1.32 g m^{-2} d^{-1}. Mineral sediments ranged from 0 to 0.26 g m^{-2} d^{-1} at the unmanaged area and from 0 to 0.38 g m^{-2} d^{-1} at the managed area. The organic fraction ranged from 26% to 100% at the unmanaged area and from 55% to 100% at the managed area.

At the Rockefeller site, the mineral sedimentation rate was significantly higher in the unmanaged area ($p < 0.05$). Probably as a result of this, the percentage organic matter was significantly higher in the managed area ($p < 0.05$) (figure 105). Overall, the percentage organic matter and the rate of sedimentation (total, organic, and mineral) were significantly higher near the streamside. This difference was probably mainly due to the great differences at the unmanaged area. Total, organic, and mineral sedimentation significantly decreased, and percentage organic matter significantly increased during the study period.

The total sedimentation at Rockefeller ranged from 0 to 11.9 g m^{-2} d^{-1} at the unmanaged area and from 0 to 3.6 g m^{-2} d^{-1} at the managed area. Mineral deposition ranged from 0 to 4.22 g m^{-2} d^{-1} at the unmanaged and from 0 to 1.08 m^{-2} d^{-1} at the managed area. The organic fraction values ranged from 9% to 74% at the unmanaged and from 15% to 100% at the managed area.

Reed (1989) measured short-term sedimentation in two salt marsh sites in the Terrebonne marshes. She reported total mean sedimentation rates of 0-20 g m^{-2} d^{-1}, almost all of which occurred during winter frontal passages. When taken together, our data and Reed's show the expected trend of high sedimentation rates in marshes near the coast.

The importance of the influence of storms, especially hurricanes, on depositional patterns in Louisiana and other coastal areas has been reported. For example, Baumann et al. (1984) used clay feldspar marker horizons to measure sedimentation rates in the salt marshes of the Barataria basin estuary. In Barataria basin, 36%-40% of all sedimentation in the years studied (1975-1979) was related to one hurricane and one tropical storm. In years without hurricanes, 70%-80% of total annual sediment deposition occurred during winter

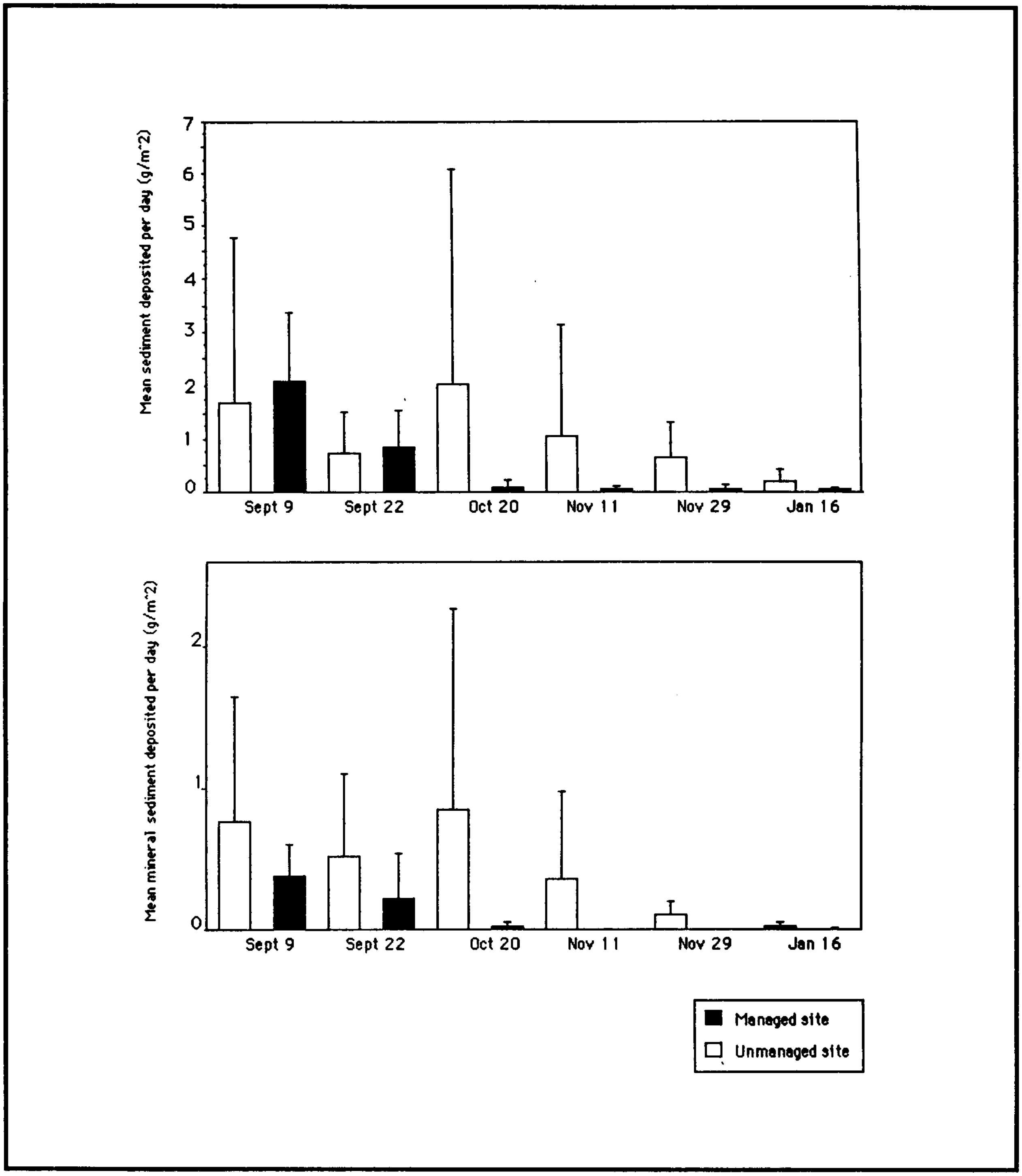

Figure 103. Short-term sedimentation patterns for total (top) and mineral (bottom) sediments for the Rockefeller area. Dates indicate the time of collection. Vertical bars are standard deviation.

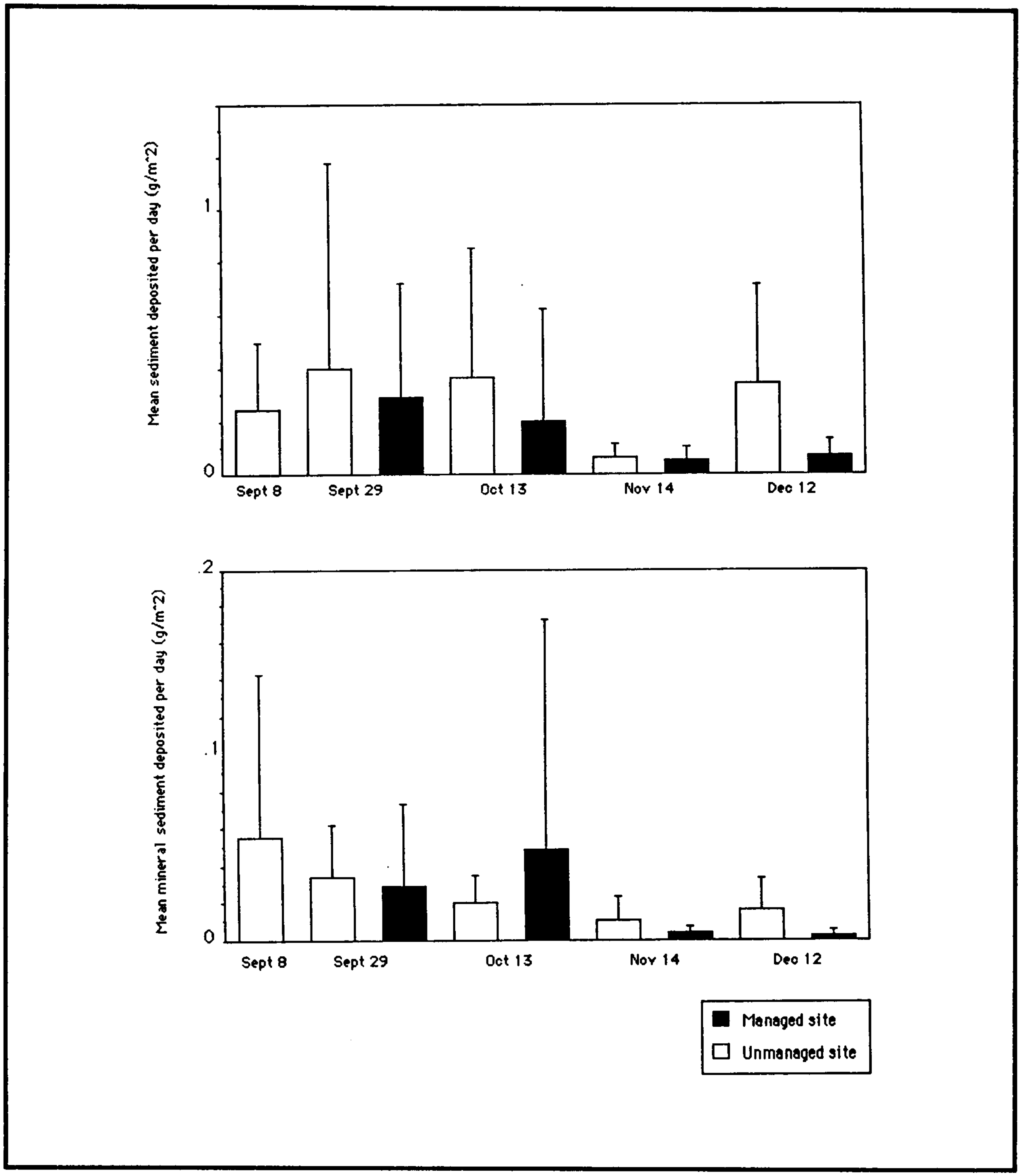

Figure 104. Short-term sedimentation patterns for total (top) and mineral (bottom) sediments for the Fina LaTerre area. Dates indicate the time of collection. Vertical bars are standard deviation.

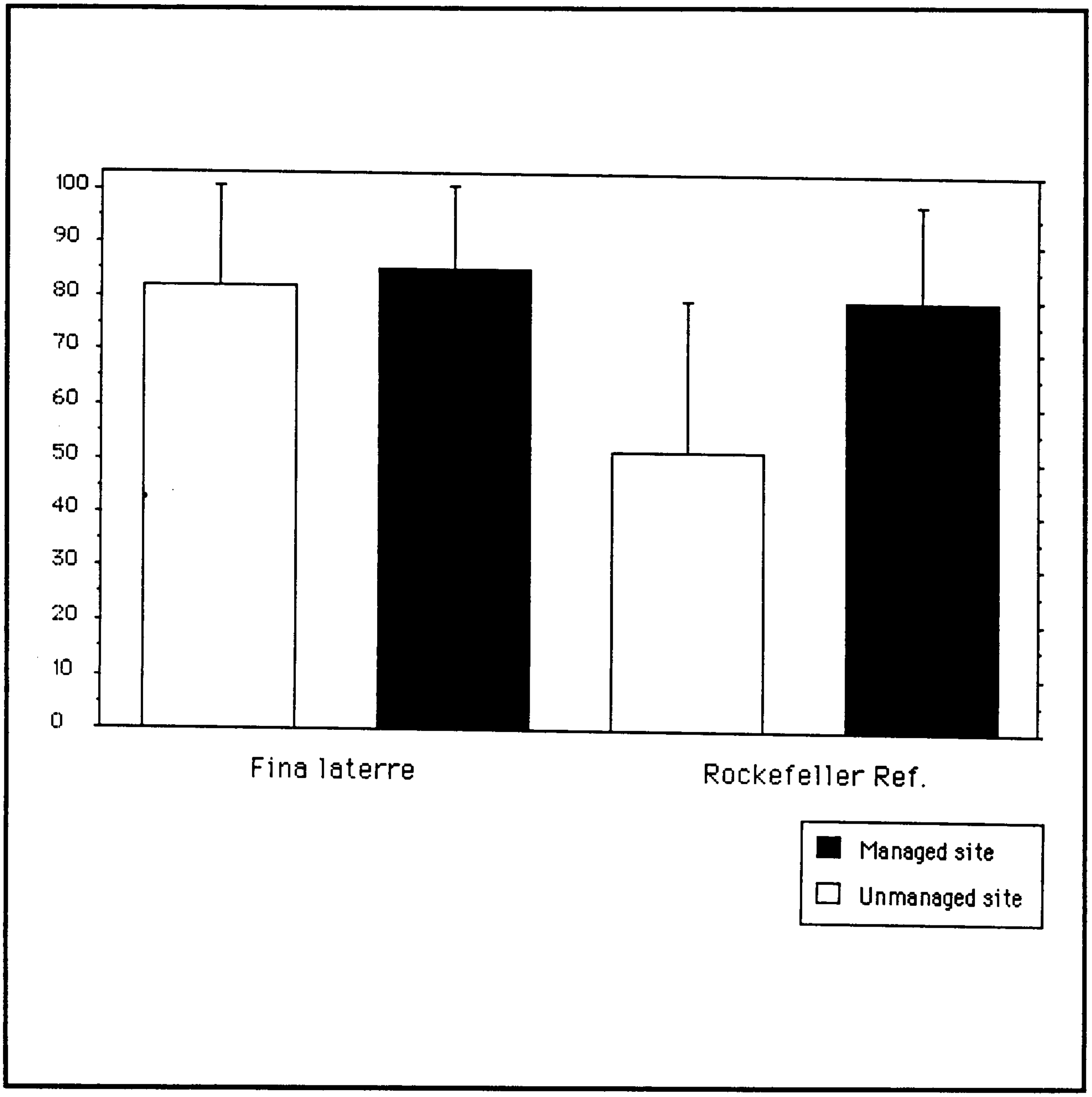

Figure 105. Percentage organic matter from all samples of material deposited during short-term sedimentation studies at Fina LaTerre and Rockefeller Refuge. Vertical bars are standard deviation.

frontal passages. Rejmanek et al. (1988) reported that a minor hurricane resuspended bottom sediments from shallow bays in the Atchafalaya delta region and deposited up to 2.2 cm of sediments in *Phragmites australis* marshes as far as 7 km from the bay shore. They concluded that hurricane-induced sedimentation at least partly compensated for marsh subsidence in coastal Louisiana. Their results indicate that hurricanes can be an important force leading to sedimentation in fresh marshes far inland from the Gulf of Mexico. Meedor (1987) reported that a hurricane led to substantial sediment deposition in the Rainey Refuge west of Vermilion Bay. For both tropical storms and frontal passages, resuspension of bottom sediments in shallow water bodies appeared to supply most of the deposited sediment. Stumpf (1983) documented a similar storm-dominated accretionary process for microtidal Delaware marshes. Conner and Day (1989) reviewed the literature on the influence of hurricanes along the northern Gulf of Mexico. They reported that hurricanes generally enhance sediment deposition in wetlands and lead to increased productivity. The results suggest that management may decrease sedimentation associated with hurricanes.

The results of the soil analysis (table 52) show that the amount of organic matter in the soil is about 10% of the organic level in recently deposited material. The average fraction of organic matter at the Fina LaTerre unmanaged site was 7.1%, and at the managed site, 8.6%. The average percentage of organic matter at the Rockefeller unmanaged site was 5.8%, and at the managed site, 5.6%. These data suggest that recently deposited organic matter is mostly lost through decomposition. The results of the soil analysis showed that phosphorus was significantly higher in the unmanaged areas at both the Rockefeller ($p < .01$) and Fina LaTerre ($p < .05$) sites. Sodium was significantly higher in the soils of the Fina LaTerre managed area ($p < .01$), but levels in the managed and unmanaged sites at Rockefeller were not significantly different.

We converted the average daily sedimentation rates for each site to a yearly basis to estimate annual sedimentation. Because the daily rates were collected for only about half a year, the annual values should be considered general estimates. In the Fina LaTerre unmanaged area, organic sedimentation was 84.9 g m^{-2} yr^{-1}, and mineral sedimentation was 9.4 g m^{-2} yr^{-1}; in the managed area, the average values were 46.5 g m^{-2} yr^{-1} for organics and 7.8 g m^{-2} yr^{-1} for minerals. In the Rockefeller unmanaged area, organic sedimentation was 210.0 g m^{-2} yr^{-1}, and mineral sedimentation was 144.4 g m^{-2} yr^{-1}; in the managed area, the average values were 122.6 g m^{-2} yr^{-1} for organics and 32.3 g m^{-2} yr^{-1} for minerals. Templet and Meyer-Arendt (1988) reported that 1,450 g m^{-2} yr^{-1} of sediments are needed to prevent submergence of vegetation in the Louisiana coastal marshes. The values calculated for Fina LaTerre and Rockefeller are lower than this, but our results do not take into consideration any belowground production.

Conclusions

The following conclusions are based on data collected during a drawdown year only. Drawdowns have occurred usually every fourth year at Rockefeller Refuge, while at Fina LaTerre a drawdown has been implemented every year since management began in 1985. For the Fina LaTerre site, the conclusions pertain only to the southern portion of the managed area and the unmanaged reference area south of Falgout Canal.

Water-level Variations

1. The tidal amplitudes at the Rockefeller unmanaged area were larger than those at Fina LaTerre because of Rockefeller's closer proximity to the coast.

2. Tidal amplitudes outside unit 4 at Rockefeller were amplified because of the restriction of the tidal-plain area. This was not the case at Fina LaTerre.

3. In the managed areas there was little short-term water-level variation.

Fluxes

1. A sharp reduction in water exchange in the managed areas led to a reduced exchange of both dissolved and particulate materials.

2. The second and third flux studies at Rockefeller were conducted during periods of north winds. There was a strong net export of water, salt, suspended sediments, ammonia, and phosphate during these trips. Material export was generally proportional to water flow.

3. The reduction of interaction between the managed areas and the larger estuarine system during drawdown due to reduced water exchange and the net export of material from the managed areas suggests that (a) drawdowns may lead to a gradual loss of fertility in managed areas if rainwater is the only freshwater input to managed areas, and (b) marsh management accomplished through water-level manipulation may result in net loss of sediments from managed areas during drawdown. These results are for a drawdown period. There is no data at this time about material fluxes during non-drawdown periods.

Short-term Sedimentation

1. Deposition of mineral deposits was relatively low, except at the Rockefeller unmanaged area.

2. More mineral sediments were deposited at the Rockefeller unmanaged area. In some cases the rates on individual sampling trips were significantly different. Overall, mineral deposition in the Rockefeller unmanaged area was significantly greater than in the managed area.

3. The highest average rate of mineral deposition occurred at the Rockefeller unmanaged area during a hurricane passage, when deposition at the managed area was low.

4. The low levels of organic matter in the soils relative to the amounts of recently deposited material suggest that most organic matter deposited on the surface of the marsh during a drawdown is lost through decomposition.

5. Soil phosphorus levels were significantly higher in the unmanaged areas of both Rockefeller and Fina LaTerre.

SOIL ACCRETION IN MANAGED AND UNMANAGED MARSHES

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The main objective of this part of the study was to measure recent accumulation (≤ 1 yr) of matter on the marsh surface and soil properties (e.g., bulk density and organic matter content) in managed and nearby unmanaged marshes.

Methods

We established a feldspar marker horizon plot at each of the vegetation-sedimentation plots. Feldspar was laid in an even layer between the clumps of Spartina patens stems covering a 50-by-50 cm area of marsh. A large stake marked the location of each plot, and two 3-mm-diameter rods placed nearby marked each plot's boundaries. Accretion cores were collected from the plots 6 and 12 months after establishment of the marker horizon. The 0-6-month interval corresponded to the drawdown phase (February to June/July), and the 6-12-month interval corresponded to the flooding phase (June/July to February) of the water-level management schedule.

The procedures used to collect and process accretion cores and bulk-density samples are described in detail in Cahoon and Turner (1989). A single core 5-10 cm long was collected from each marker plot 6 and 12 months after marking with a thin-walled aluminum beverage can (6 cm in diameter). Cores were taken from previously unsampled areas of the plot until the marker horizon was visible in the borehole. A sampled hole was filled with exogenous mud to prevent it from trapping sediments. Bulk density of the top 2 cm of soil was measured (at the same time accretion was measured) from cores collected in the immediate vicinity of the marker horizon plots. We calculated the percentage mineral and organic matter content of the bulk density cores by determining loss to ignition at 375°C after 16 h (Cahoon and Turner 1989). We calculated the rate of accumulation of organic and mineral matter by multiplying the rate of vertical accretion by the soil bulk density value and the percentage soil organic/mineral content.

We used SAS GLM statistical programs to conduct analysis of variance and tested at the 5% level. When interactions were significant, means were compared by the SAS least square means procedure. Means from the school board's property were compared to those from the near managed and near unmanaged areas by linear contrasts.

Results and Discussion

Fina LaTerre

Analysis of the main treatment effect (i.e., managed vs. unmanaged), averaged over time and distance to the point of water exchange, reveals that, during a drawdown/flooding water management cycle, the unmanaged marsh south of the Fina LaTerre managed area had a significantly higher vertical accretion rate, higher soil bulk density and soil mineral matter content, lower soil organic matter content, and higher rate of organic matter accumulation than the southern portion of the managed marsh. The rate of mineral matter accumulation was the same for both areas. A detailed description of the responses of each variable to management, sampling time, distance, and interaction effects is presented below.

Vertical accretion. Management significantly affects the accretion of matter at Fina LaTerre. When averaged over time and distance, the vertical accretion of matter (cm) deposited atop the feldspar marker was greater in the unmanaged than in the managed marsh (0.30 ± 0.09 vs. 0.07 ± 0.01 [mean $\pm$ 1 SE], $p = .02$, $n = 31$). Averaged over treatment and distance, vertical accretion varied significantly between samplings; more matter was measured above the marker after 12 months than after 6 months (0.30 ± 0.08 vs. 0.08 ± 0.04 [mean $\pm$ 1 SE], $p = .0001$, $n = 31$). This difference is due to a significant increase in accretion from 6 to 12 months in the unmanaged area, but not in the managed area ($p = .004$, see figure 106). There was no management effect after 6 months of accretion, but there was a significant management effect after 12 months.

When averaged over time and treatment (i.e., managed and unmanaged), the main effect of distance on vertical accretion was not significant ($p = .07$), but the interaction of management × distance was significant at $p = .0556$ (figure 107). Analysis by least square means reveals a significant decrease in accretion in the unmanaged area as distance from the source of matter increases, but no effect of distance in the managed area. Accretion was the same far from the source of matter in both the managed and unmanaged areas.

These data indicate that vertical accretion was not only slight but uniformly slight throughout the southern portion of the management area. This finding is consistent with the results of the flux studies showing that very little matter is entering through the water control structure. The accreted matter is probably resuspended from pond bottoms and deposited on the marsh surface during periods of high water fluctuation. On the other hand, the unmanaged marsh apparently receives allochthonous matter through the channel openings that settles out in a distinct spatial pattern as the water loses velocity. Vertical accretion did not differ between the managed and unmanaged areas after 6 months (the drawdown phase), but did differ after 12 months (the drawdown + flooding phase). These data indicate that vertical accretion in the managed marsh during the flood phase (when the gates are open) did not keep pace with vertical accretion in the unmanaged marsh during the same interval.

Bulk density. Averaged over time and distance, the bulk density (g/cm^3) of the marsh soil was significantly greater in the unmanaged than in the managed marsh (0.13 ± 0.01 vs. 0.06 ± 0.004 [mean $\pm$ 1 SE], $p = .0008$, $n = 32$). Averaged over treatment and distance, the soil bulk density decreased significantly between 6 and 12 months (0.11 ± 0.01 vs. 0.08 ± 0.01 [mean $\pm$ 1 SE], $p = .0001$, $n = 32$). The lack of significance of the management × time interaction indicates that soil bulk density decreased at both the managed and unmanaged areas. Soil bulk density did not vary with distance (when averaged over treatment and time) in either the managed or unmanaged area. The management × time × distance interaction was nearly significant ($p = .06$), and comparison of the means suggests that soil bulk density did not decrease with time at the nearby unmanaged marsh (figure 108).

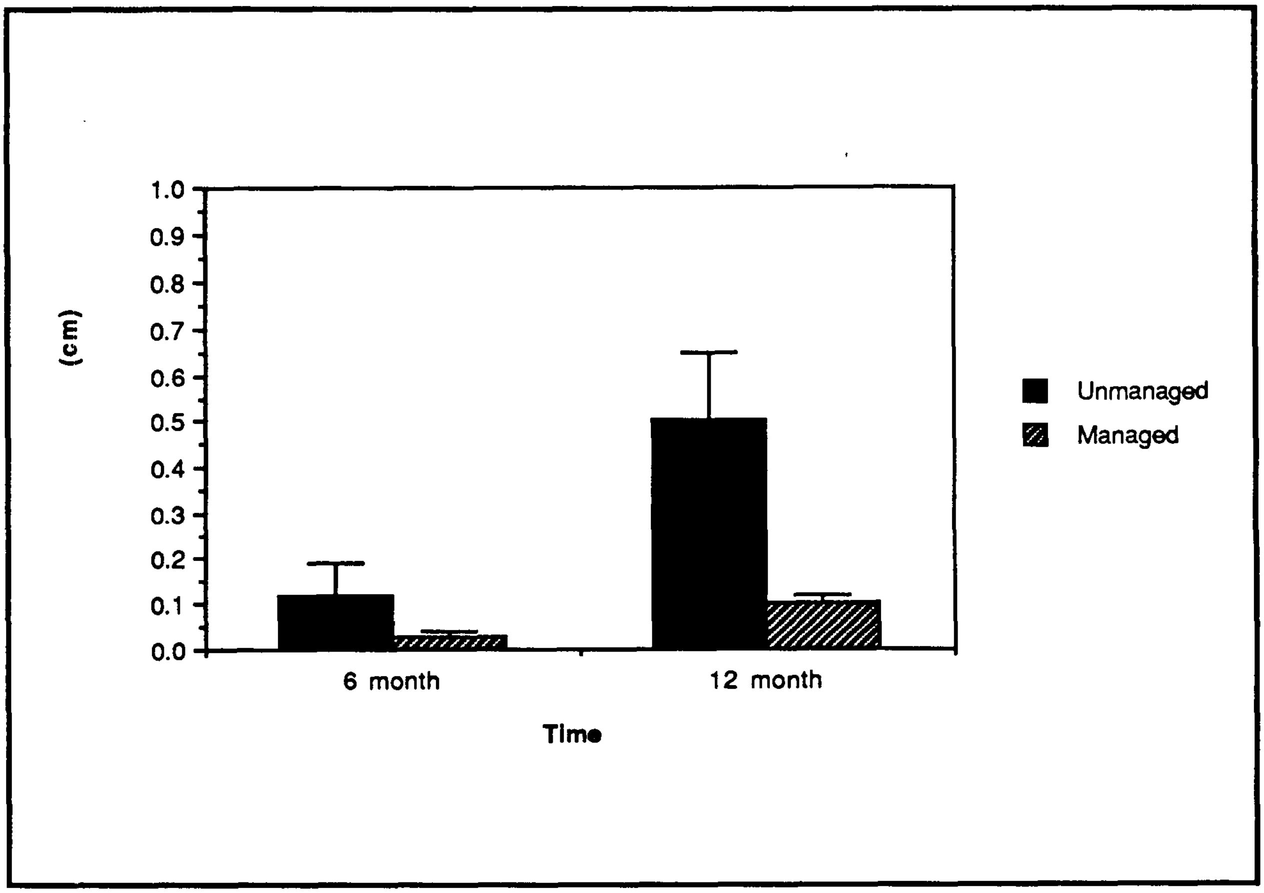

Figure 106. The effect of management and sampling time on marsh vertical accretion at Fina LaTerre (means ± 1 SE).

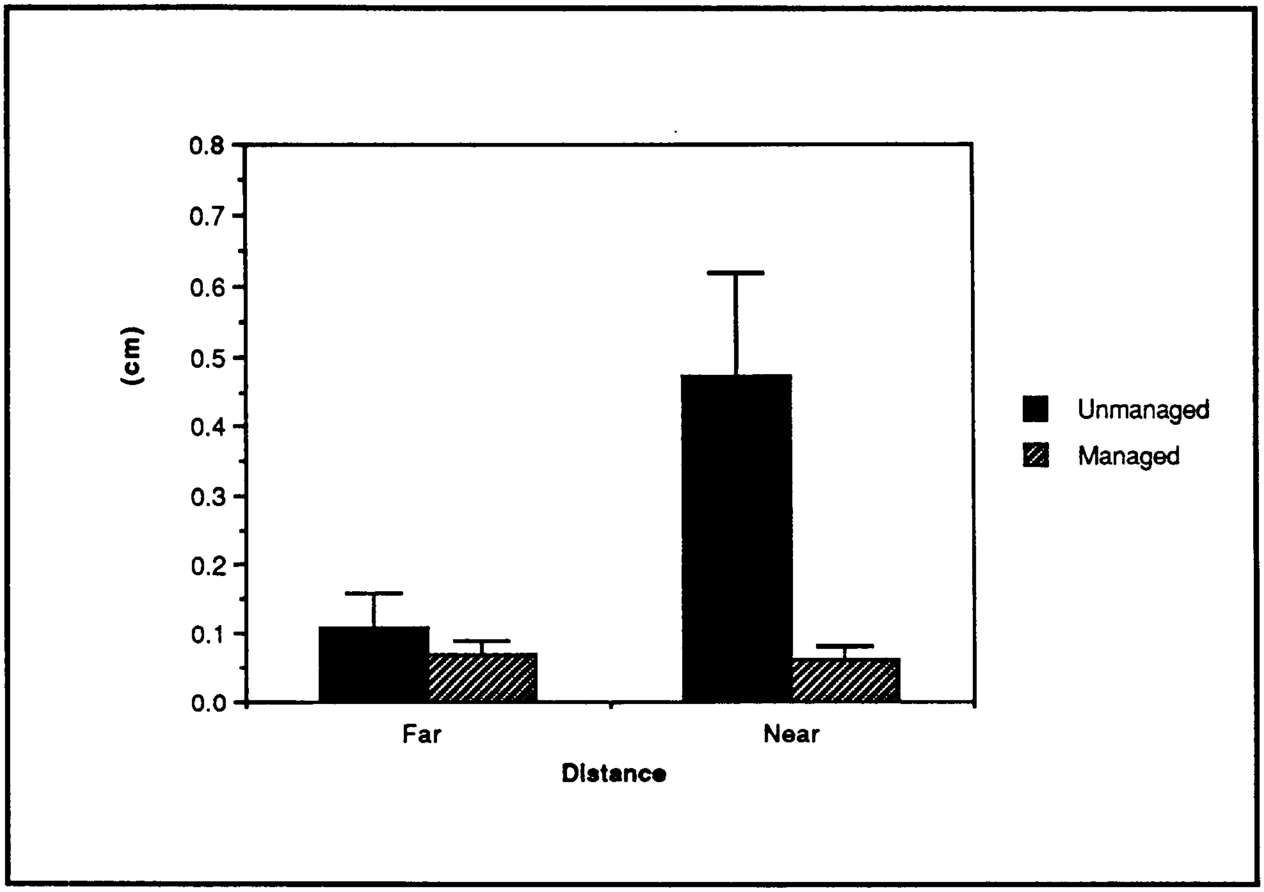

Figure 107. The effect of management and distance from source of water exchange on marsh vertical accretion at Fina LaTerre (means ± 1 SE).

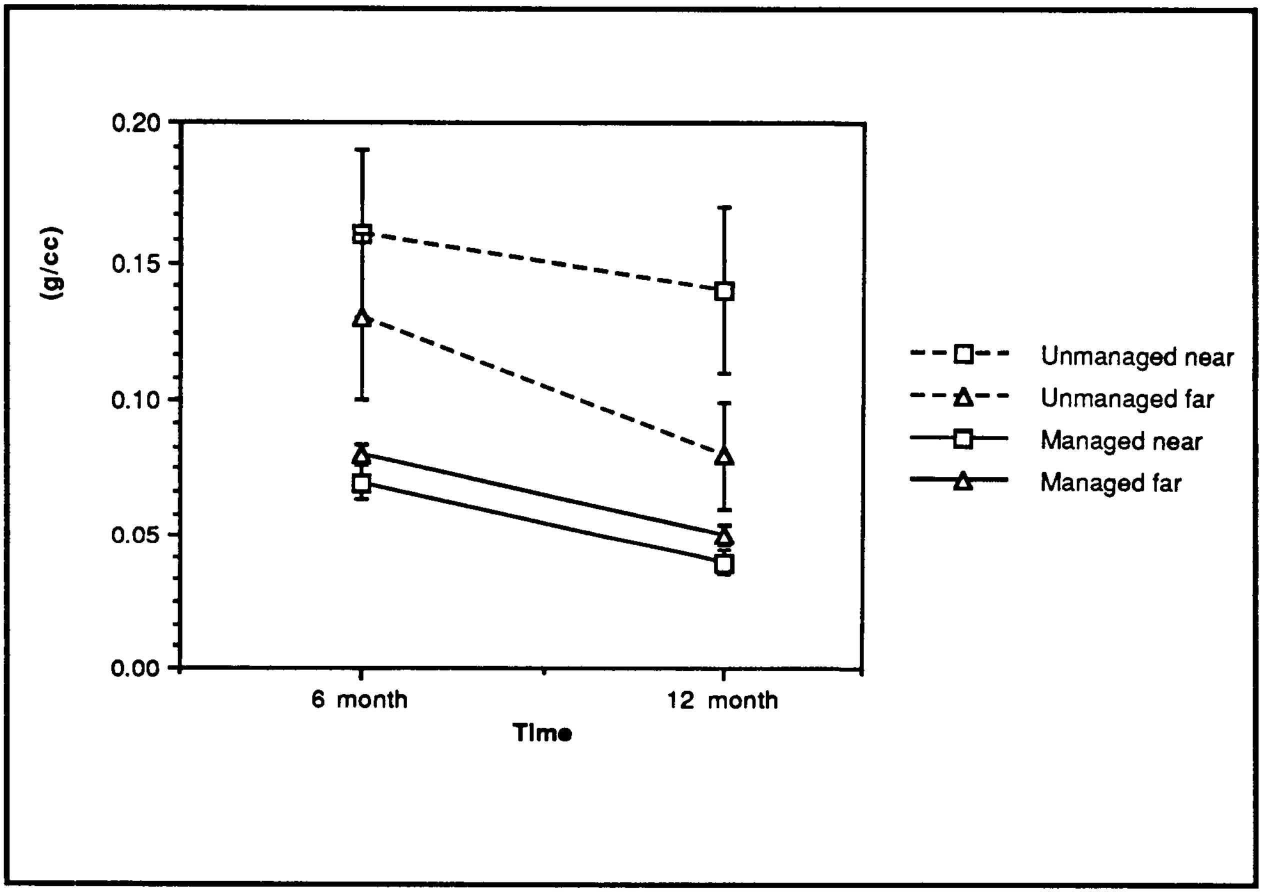

Figure 108. The effect of management, sampling time, and distance from source of water exchange on soil bulk density at Fina LaTerre (means ± 1 SE).

These data indicate that soil bulk density is greater in the unmanaged marsh and this likely reflects the differences in vertical accretion. It is possible but not probable that the differences in bulk density are due to different soils present in the two areas. Analysis of habitat types at Fina LaTerre (chapter 11) indicates that the marsh type in both the southern portion of the managed area and the unmanaged reference area was the same over the past 30 years. Both areas were one contiguous expanse of marsh before construction of the Falgout Canal. Both areas were fresh marsh in 1956 and both changed to *Spartina patens*-dominated brackish marsh by the 1980s. However, if the soil type in the two areas was different when management was implemented, the differences in soil bulk density and soil organic matter content would not be entirely related to the influence of management because of the low rate of vertical accretion in the managed area.

Why the soil bulk density decreased with time at both locations is unclear. Perhaps the soil is denser during a drawdown, when it probably becomes more compact, and less dense during flood conditions, when soil air spaces are flooded. But a similar water-level pattern would have to occur at the unmanaged site if this were true. A comparison of water levels between the two times of year in the unmanaged area would help clarify this issue. Or, perhaps the difference is due to seasonal changes in below-ground productivity.

Soil organic matter content. Averaged over time and distance, the percentage of organic matter in the soils of the unmanaged marsh was significantly lower than that in the soils in the managed marsh (52 ± 4 vs. 75 ± 2 [mean ± 1 SE], p = .0001, n = 32). All other main effects (time and distance) and all of the interactions were nonsignificant, indicating that soil organic matter content responded the same way in the managed and unmanaged areas to all the sources of variation. This difference in soil organic matter content may indicate a slower decomposition rate in the managed marsh soils or a higher rate of belowground organic matter production. The latter is unlikely because of the lower CO_2 exchange rates and aboveground productivity of the managed marsh (see the section on plant growth). Investigations of *Spartina alterniflora* response to flooded (i.e., reduced) soil conditions show reduced belowground biomass as well as aboveground biomass (Linthurst 1979; Mendelsson and Seneca 1980).

Organic matter accumulation. The accumulation of organic matter (g/cm^2) was significantly influenced by management and differed significantly at the 6- and 12-month sampling intervals. Averaged over time and distance, the rate of organic matter accumulation was higher in the unmanaged than in the managed marsh (0.015 ± 0.004 vs. 0.002 ± 0.0006 [mean ± 1 SE], p = .02, n = 31). Averaged over treatment and distance, organic matter accumulation was greater after 12 months than after 6 months (0.013 ± 0.004 vs. 0.004 ± 0.002 [means ± 1 SE], p = .0003, n = 31). The management × time interaction was significant (p = .002) because organic accumulation increased between samplings in the unmanaged area, but not in the managed area (figure 109). Averaged over treatment and time, distance had no effect on organic matter accumulation, but the management × distance and time × distance interactions were significant (p = .04 and p = .047, respectively). Organic accumulation decreased with distance in the unmanaged marsh, but not in the managed marsh (figure 110), so that there was no difference at the far locations in both the managed and unmanaged areas. Accumulation of organic matter increased between samplings at the near locations, but not at the far locations so that after 12 months the accumulation at the near sites was

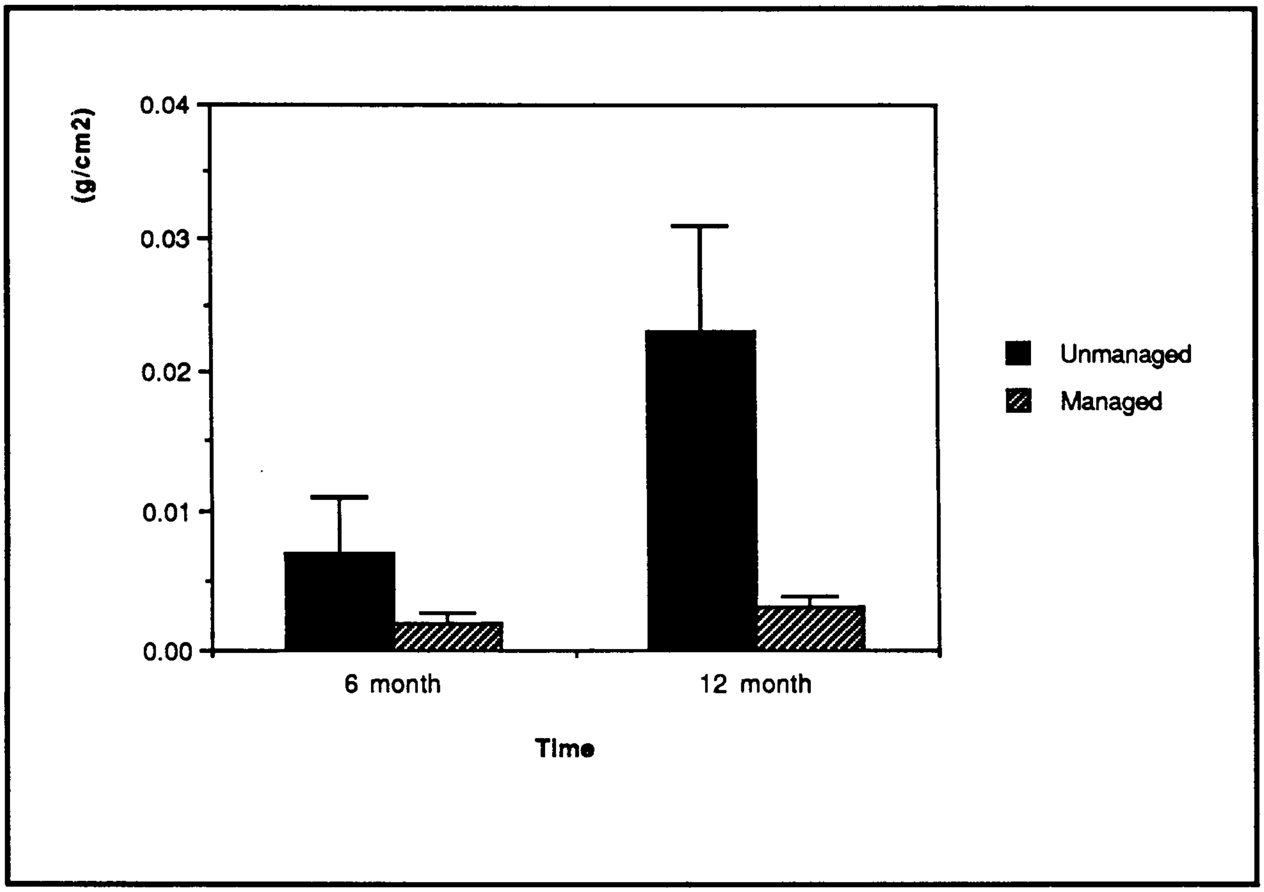

Figure 109. The effect of management and sampling time on organic matter accumulation at Fina LaTerre (means ± 1 SE).

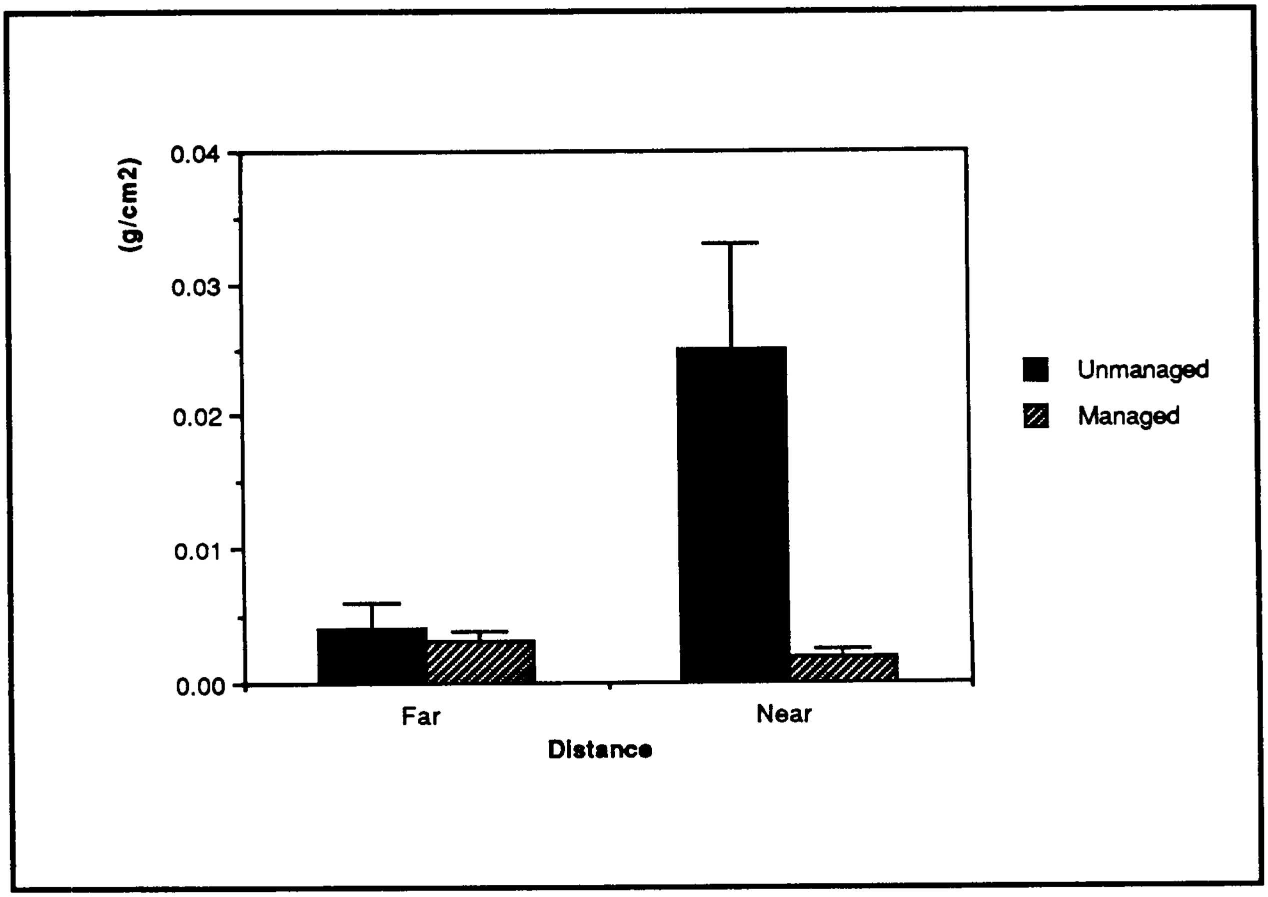

Figure 110. The effect of management and distance from source of water exchange on organic matter accumulation at Fina LaTerre (means ± 1 SE).

greater than that at the far sites (figure 111). The interaction of management × time × distance was significant at $p = .0548$ (figure 112). Analysis by least square means indicates that organic accumulation differed (1) at near vs. far sites in the unmanaged marsh but not in the managed marsh, and (2) between samplings in the near unmanaged marsh but not in the far unmanaged marsh, while the near and far sites in the managed marsh did not differ between samplings.

These data indicate that organic matter accumulation (1) is higher in the unmanaged area, (2) occurs mostly near the source of water exchange in the unmanaged area, and (3) increases between samplings in the unmanaged area. By contrast, accumulation of organic matter is uniformly low throughout the management area during the entire year. Like the variable accretion, organic accumulation did not differ between the managed and unmanaged marshes after 6 months (the drawdown phase), but did differ after 12 months (the drawdown + flooding phase). These data indicate that accumulation of organic matter in the managed marsh during the flood phase (when the gates are open) is not keeping pace with accumulation in the unmanaged marsh during the same interval.

Mineral matter accumulation. None of the main effects (i.e, management, time, distance) or interactions were significant for mineral matter accumulation. The accumulation of matter was uniformly low throughout the managed marsh but not the unmanaged marsh. The average accumulation was one order of magnitude greater near the source of water exchange in the unmanaged marsh (0.091 ± 0.061 [near] vs. 0.009 ± 0.005 [far]), but the difference between the means was not significant because of a large coefficient of variation combined with small sample size.

Comparison with school board area. Comparison of the 12-month data from the school board property with that from the managed and unmanaged marsh (near locations only) revealed significant differences in vertical accretion ($p = .03$), bulk density ($p = .0006$), organic/mineral matter content ($p = .0067$), and organic matter accumulation ($p = .0051$) (table 56). The means from the school board property and the unmanaged marsh were not different for any of the variables, but the managed marsh had significantly lower values. The mean of mineral matter accumulation was greater at the unmanaged and school board marsh, but the differences were not significant because of high coefficients of variation and small sample sizes.

These data indicate that the accretionary environment of the unmanaged marsh near the point of water exchange with Falgout Canal is similar to that of the school board property at the juncture of Falgout Canal, Minors Canal, and Lake DeCade (see figure 83).

Rockefeller Refuge

Analysis of the main treatment effect (i.e., managed vs. unmanaged), when averaged over time and distance, reveals that, during a drawdown/flooding water management cycle, the unmanaged marsh near East Little Constance Bayou had a significantly higher vertical accretion rate, higher soil bulk density and soil mineral matter content, lower soil organic matter content, and higher rate of organic and mineral matter accumulation than the managed marsh. A detailed description is presented below of the responses of each variable to management, sampling time, burning, and interaction effects.

Vertical accretion. Management significantly affects the accretion of matter at Rockefeller Refuge. Averaged over time and burning effect, vertical

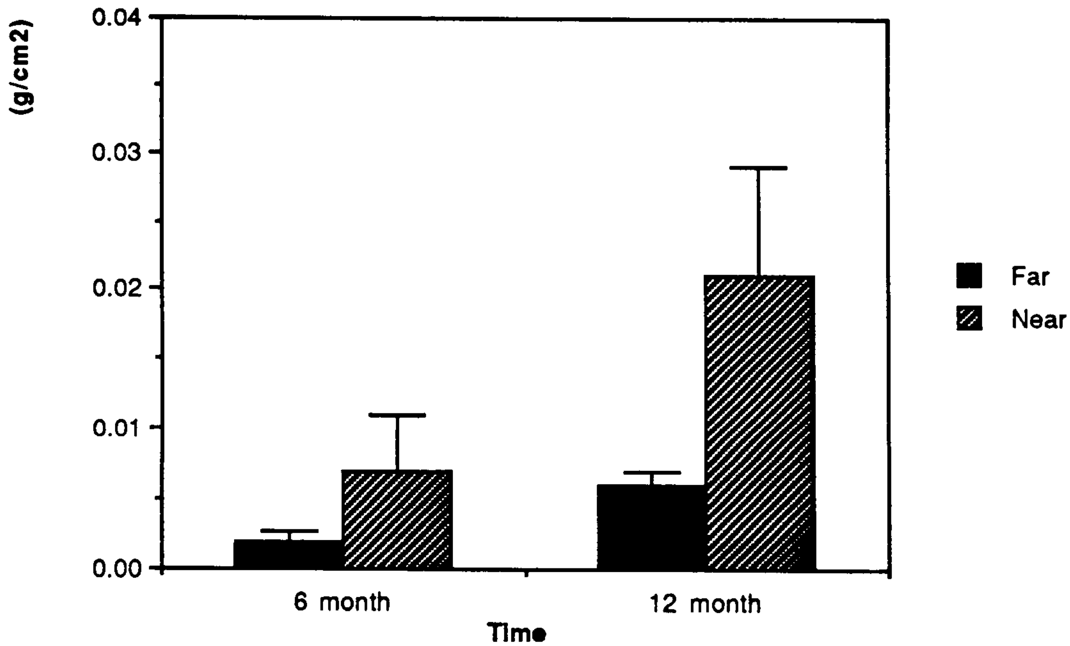

Figure 111. The effect of sampling time and distance from source of water exchange on organic matter accumulation at Fina LaTerre (means ± 1 SE).

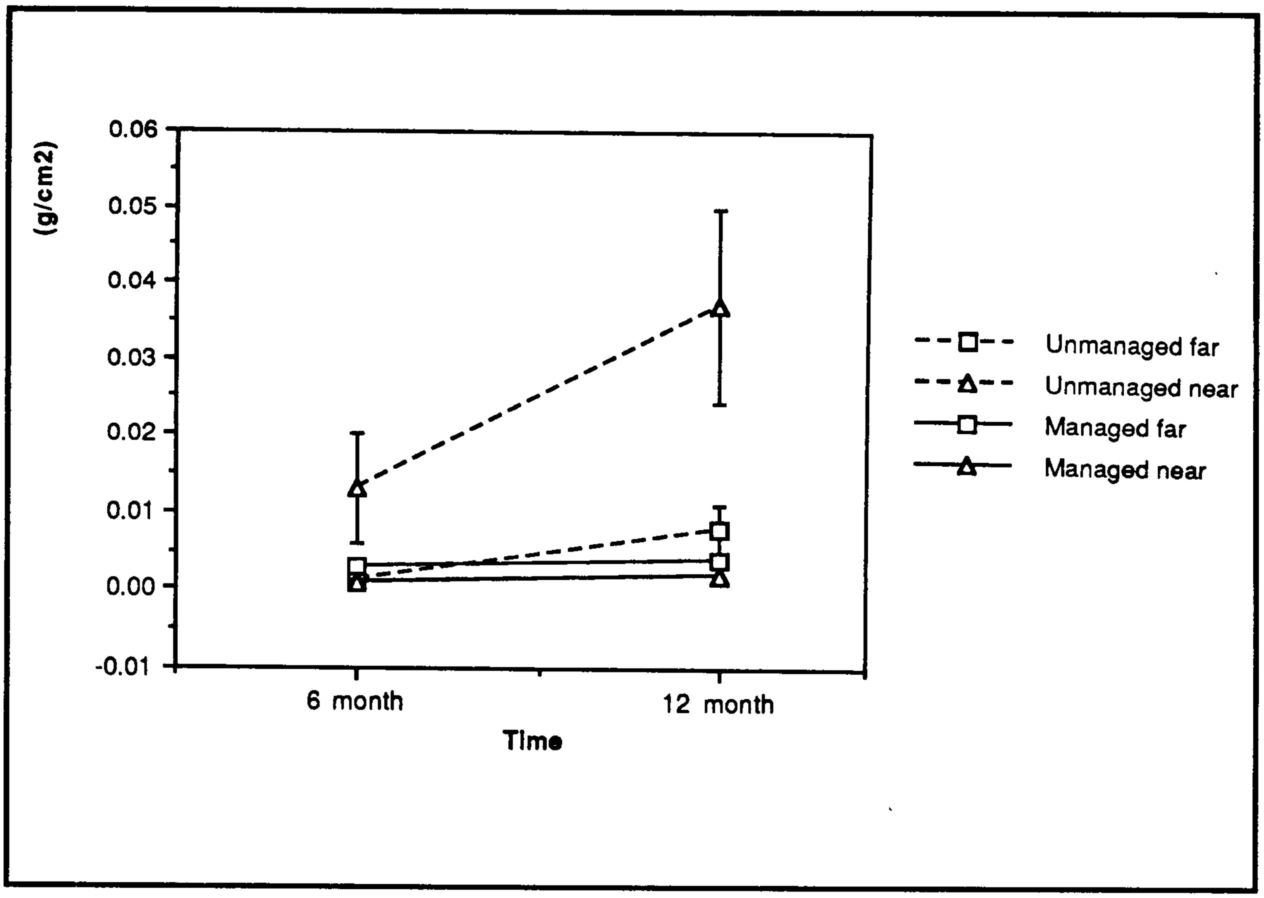

Figure 112. The effect of management, sampling time, and distance from source of water exchange on organic matter accumulation at Fina LaTerre (means ± 1 SE).

Table 56. Accumulation of organic and mineral matter ($g/cm^2/yr$) at the school board property, managed marsh, and unmanaged marsh at Fina LaTerre (means ± 1 SE).[1]

Water Level	Distance	n	Vertical Accretion (cm/yr)	Bulk Density (g/cm^3)	Organic/Mineral Content (%)	Accumulation ($g/cm^2/yr$)	
						Organic	Mineral
Managed	Near	7[*]	0.11 ± 0.03[a]	0.04 ± 0.004[a]	72/28 ± 5[a]	0.002 ± 0.0009[a]	0.001 ± 0.0007[a]
Unmanaged	Near	8	0.75 ± 0.24[b]	0.14 ± 0.03[b]	47/53 ± 8[b]	0.037 ± 0.013[b]	0.091 ± 0.061[a]
School Board		8	0.59 ± 0.20[b]	0.13 ± 0.01[b]	49/51 ± 2[b]	0.038 ± 0.012[b]	0.041 ± 0.013[a]

[1]Each mean is an average of seven or eight samples.
[2]n = 8 for bulk density and percentage organic/mineral matter.
Note: All means within a column followed by a different letter are significantly different at the 1% level except for vertical accretion means, which are significant at the 5% level.

accretion was significantly higher in the unmanaged marsh than in the managed marsh (0.98 ± 0.11 vs. 0.12 ± 0.04 [means ± 1 SE], $\underline{p}$ = .0001, n = 40). The main effect of sampling time was not significant, but the interaction of management × time was significant ($\underline{p}$ = .02) because accretion increased between samplings at the unmanaged site but not at the managed site (figure 113). Burning had no effect on vertical accretion.

These data indicate that accretion was high and increased between samplings in the unmanaged marsh, but was low throughout the year in the managed marsh.

<u>Bulk density</u>. The main effects of management and sampling time were significant, but the main effect of burning was not. Averaged over time and distance, soil bulk density (g/cm^3) was significantly higher in the unmanaged area than in the managed area (0. 27 ± 0.01 vs. 0.14 ± 0.01 [means ± 1 SE], $\underline{p}$ = .0001, n = 40) and decreased significantly between samplings (0.23 ± 0.02 vs. 0.18 ± 0.01 [means ± 1 SE], $\underline{p}$ = .0008, n = 40). The insignificance of the interaction of management × time indicates that bulk density decreased between samplings at both the managed and unmanaged marshes. The interaction of management × time × burning was significant at $\underline{p}$ = .0534 (figure 114). In the unmanaged marsh, bulk density decreased significantly in the burned but not the unburned marsh; the opposite was true in the managed marsh. Bulk density was greater in the burned unmanaged marsh than in the unburned unmanaged marsh after 6 months but not after 12 months.

As with Fina LaTerre, it is not clear why bulk density decreases with time at both areas. Perhaps the decrease is related to flooding effects on the soil, or perhaps there is a physical process that has yet to be evaluated that influences this soil property at management sites.

<u>Soil organic matter content</u>. The management and sampling time main effects on organic matter content were all significant, but the burning main effect was not. Averaged over time and distance, the percentage organic matter content in the soil was higher in the managed marsh than in the unmanaged marsh (59 ± 3 vs. 26 ± 1 [means ± 1 SE], $\underline{p}$ = .0001, n = 40) and increased between samplings (39 ± 2 vs. 45 ± 4 [means ± 1 SE], $\underline{p}$ = .03, n = 40). Organic matter content of the soil did not change significantly between 6- and 12-month samples in the unmanaged area, but did increase between samplings in the managed marsh (management × time interaction, $\underline{p}$ = .0001, see figure 115). The time × burn interaction also was significant ($\underline{p}$ = .02), indicating that organic matter content increased between samplings in the unburned area but not in the burned area. Thus, the organic matter content was greater in the unburned than in the burned area after 12 months (figure 116).

The greater and increasing organic matter content of the managed marsh soils may reflect a slower decomposition rate than in the unmanaged marsh or a higher rate of organic matter production.

<u>Organic matter accumulation</u>. Management significantly affected the accumulation of organic matter. The unmanaged marsh accumulated more organic matter (g/cm^2), averaged over time and distance, than did the managed marsh (0.067 ± 0.010 vs. 0.009 ± 0.004 [means ± 1 SE], $\underline{p}$ = .0002, n = 40). The interaction of management × time × burn was significant at $\underline{p}$ = .0582 (figure 117). In the managed marsh, organic matter accumulation was not different between samplings in burned or unburned areas. In the unmanaged marsh, however, organic matter accumulation was higher in the burned marsh after 6 months, but subsequently decreased significantly so that it was equal with the unburned marsh after 12 months.

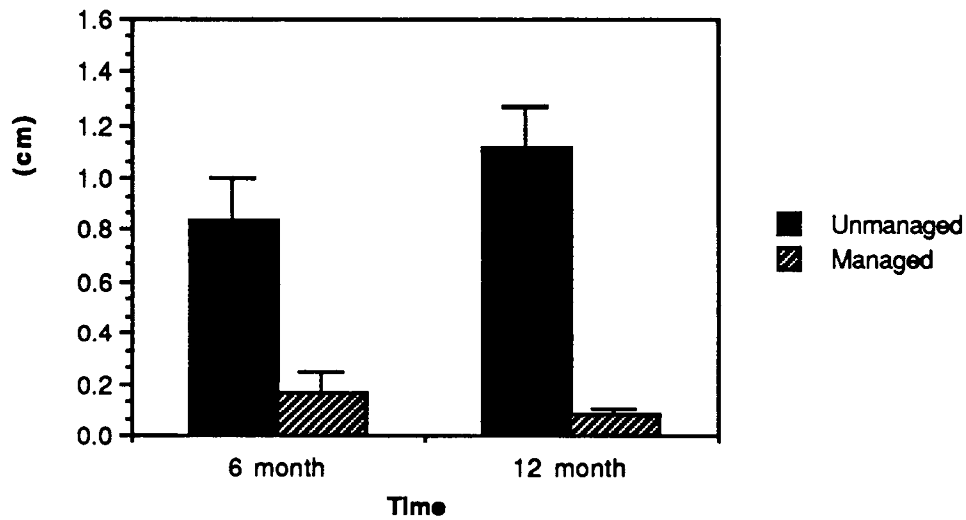

Figure 113. Marsh vertical accretion at Rockefeller Refuge (means ± 1 SE).

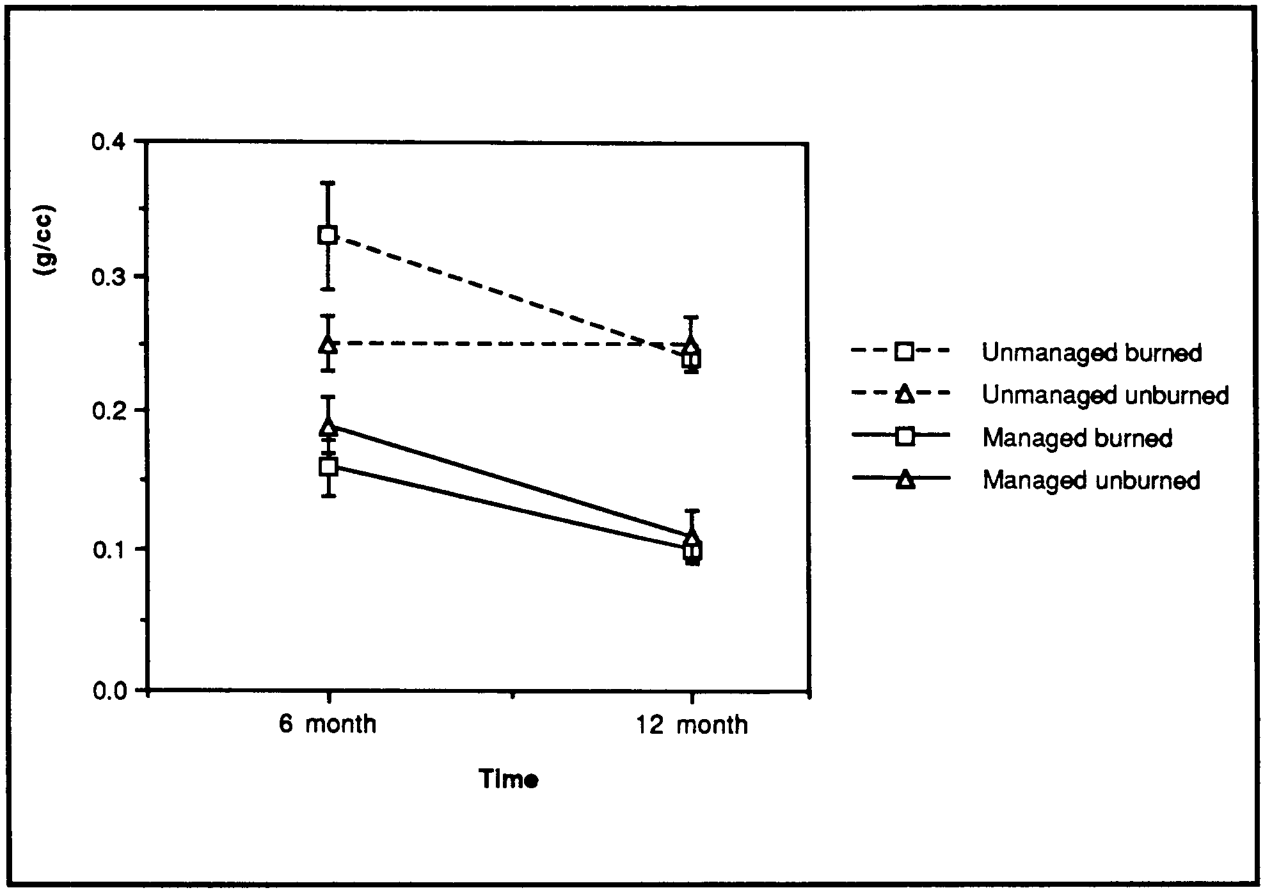

Figure 114. The effect of management, sampling time, and burning on soil bulk density at Rockefeller Refuge (means ± 1 SE).

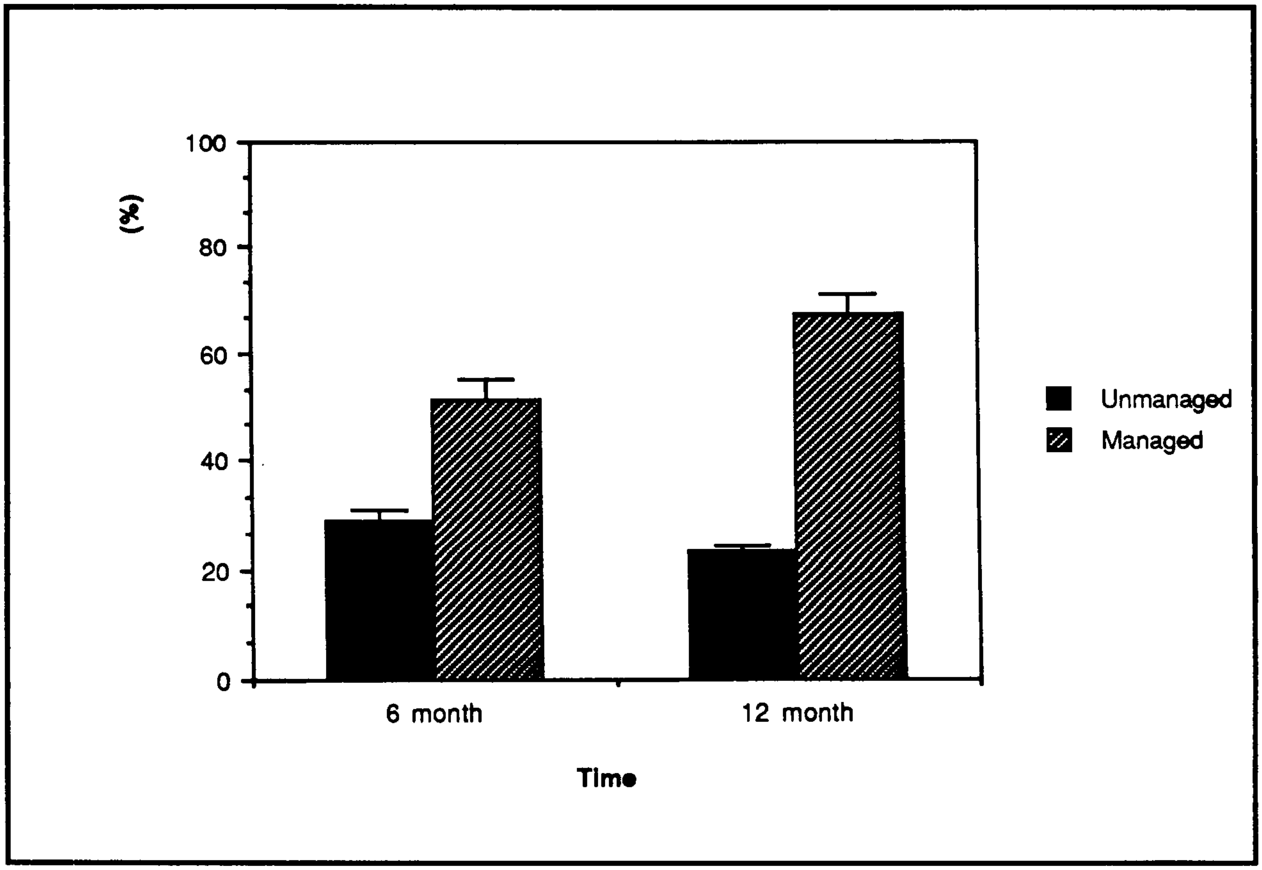

Figure 115. The effect of management and sampling time on soil organic matter content at Rockefeller Refuge (means ± 1 SE).

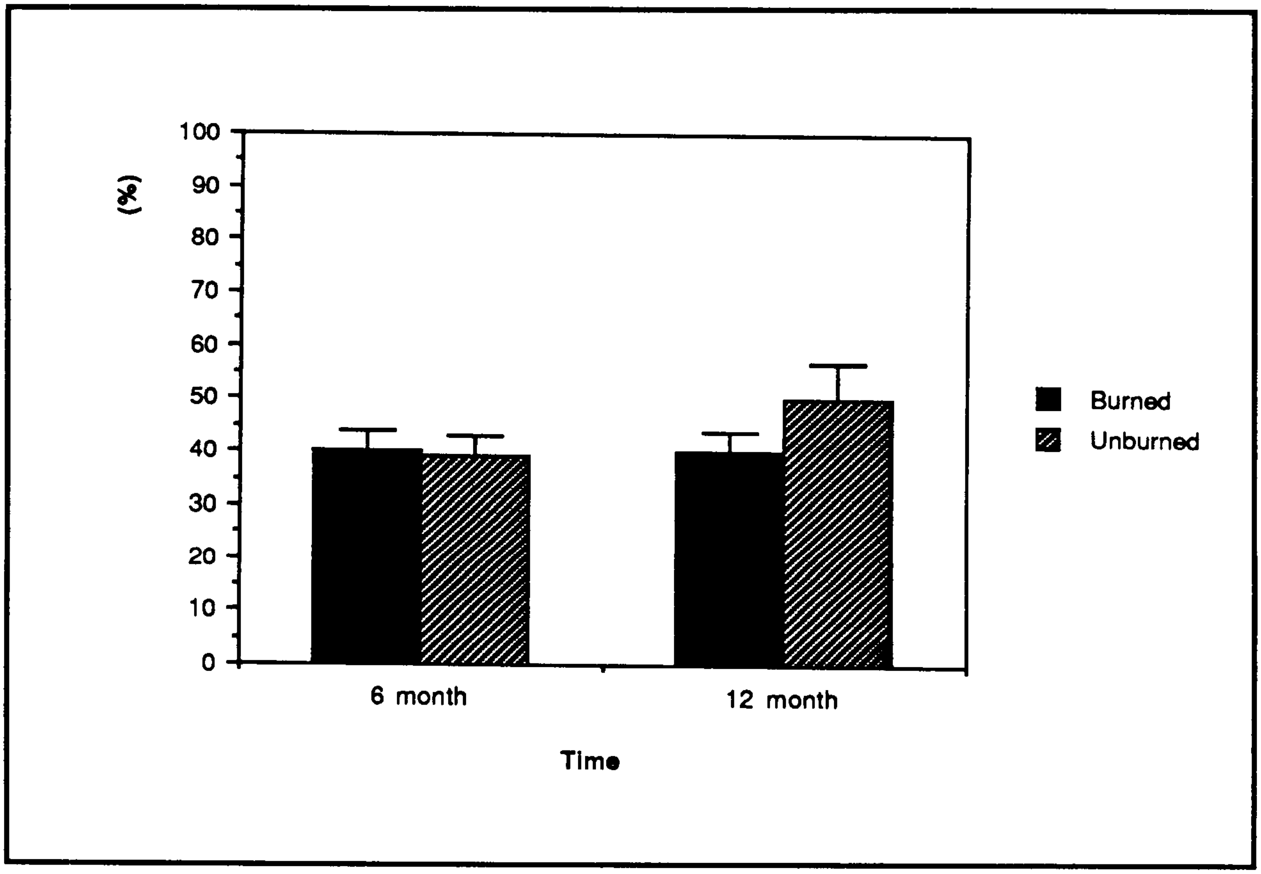

Figure 116. The effect of sampling time and burning on soil organic matter content at Rockefeller Refuge (means ± 1 SE).

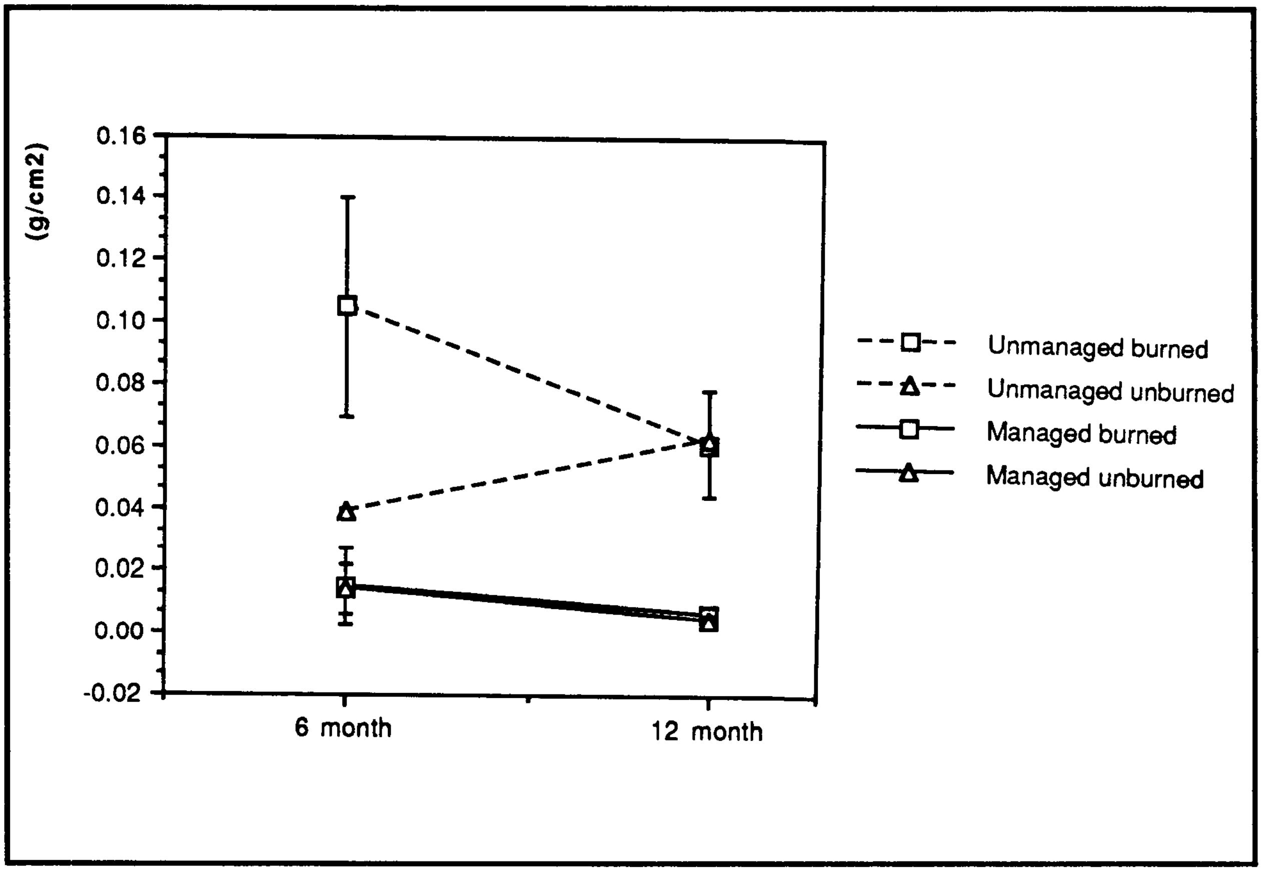

Figure 117. The effect of management, sampling time, and burning on organic matter accumulation at Rockefeller Refuge (means ± 1 SE).

These data indicate that management reduced the accumulation of organic matter. The fact that managed marshes also had a higher percentage of soil organic matter suggests that organic matter decomposes more slowly in managed marshes. Burning caused a dramatic increase in organic matter accumulation within the first 6 months after burning, but this effect was not apparent after 12 months.

Mineral matter accumulation. Management significantly affected the accumulation of mineral matter. The unmanaged marsh accumulated more mineral matter (g/cm^2), averaged over time and distance, than the managed marsh (0.202 $\pm$ 0.027 vs. 0.008 $\pm$ 0.004 [means $\pm$ 1 SE], *p* = .0001, n = 40). There was no significant effect of sampling time, burning, or any of the interactions on the accumulation of mineral matter. These results indicate that the rate of mineral matter accumulation responded the same way in the managed and unmanaged marshes to all the sources of variation.

SUMMARY

The following summary and conclusions are based on data collected during a drawdown year only. At Rockefeller Refuge, drawdowns have occurred usually every fourth year while at Fina LaTerre a drawdown has been implemented every year since management was implemented in 1985. For the Fina LaTerre site,the conclusions pertain only to the southern portion of the managed area and the unmanaged reference area south of Falgout Canal.

Fina LaTerre

1. The unmanaged marsh had a significantly higher vertical accretion rate, higher soil bulk density and soil mineral matter content, lower soil organic matter content, and higher rate of organic matter accumulation than the managed marsh. The mean rate of mineral matter accumulation was two orders of magnitude higher in the unmanaged area than in the managed area but was not statistically significantly different.

2. In the managed marsh, there was no significant difference in vertical accretion, bulk density, soil organic matter content, or organic and mineral matter accumulation rates between areas near and far from the point of water exchange. Rates or values for all of these variables were uniformly low at field plots in the southern portion of the management area in comparison to the unmanaged area.

3. In the unmanaged marsh, there was a significant difference in vertical accretion, bulk density, and organic matter accumulation between areas near and far from the main point of water exchange. Rates or values for all three variables were higher at the field plots near the point of water exchange than at the field plots farther away.

4. In the managed marsh, there was no significant difference in vertical accretion, soil organic matter content, or organic or

mineral matter accumulation between the six- and twelve-month means. These two time intervals coincide with the drawdown phase (0-6 months) and the drawdown plus flooding phase (0-12 months) of the annual water management cycle employed during 1989. However, there was a significant decrease in bulk density in the managed marsh between the six- and twelve-month means.

5. In the unmanaged marsh, there was a significant difference in vertical accretion, bulk density, and organic matter accumulation between the six- and twelve-month means. Vertical accretion and organic matter accumulation increased between the six- and twelve-month samplings while bulk density decreased.

6. The above conclusions indicate that vertical accretion and accumulation rates of organic and mineral matter in the managed marsh during the flood phase (months 6-12) are not keeping pace with vertical accretion and accumulation in the unmanaged marsh.

Rockefeller Refuge

1. The unmanaged marsh had a significantly higher vertical accretion rate, higher soil bulk density and soil mineral matter content, lower soil organic matter content, and higher rate of organic and mineral matter accumulation than the managed marsh.

2. Vertical accretion and organic matter accumulation were high and increased between the six- and twelve-month samplings in the unmanaged marsh, but were low throughout the year in the managed marsh. Bulk density decreased significantly between the six- and twelve-month samplings in both the managed and unmanaged areas.

3. Burning affected soil organic matter content and the rate of organic matter accumulation. Organic matter content increased between the six- and twelve-month samplings in the unburned areas but not in the burned areas. Thus, the organic matter content was greater in the unburned than in the burned areas after 12 months. Burning caused a dramatic increase in the rate of organic matter accumulation within the first six months after burning, but this effect was not apparent after twelve months.

General Conclusion

Management affected accretionary processes (e.g., vertical accretion and accumulation of organic matter) similarly at both Fina LaTerre and Rockefeller Refuge during a year of water-level drawdown management even though the two management areas lie in different sedimentologic and hydrologic regimes (i.e., near and far from the coast) and each site employs a different water management design and schedule of operation.

PLANT SPECIES COMPOSITION IN MANAGED AND UNMANAGED MARSHES

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The objective for this part of the study was to measure plant species composition in managed and nearby unmanaged marsh.

Methods

Emergent vegetation

Plant species composition and cover were determined in late spring (May-June) and fall (October) at Fina LaTerre and Rockefeller Refuge by methods currently being used by the landowners. At Fina LaTerre 50-m transects were established at two randomly selected vegetation-sedimentation sites in each of the five sampling areas. The directions of the transects were determined from randomly selected compass headings. In the fall, transects in the school board area were not sampled; instead, an additional transect was surveyed in the managed and unmanaged marsh. We surveyed vegetation in a 3.17-m^2 circular plot at 5-m intervals along each transect (10 sampling stations per transect). Within each plot we recorded the species present and visually estimated the percentage cover of each species. Frequency of occurrence was calculated for each species and open water as follows:

$$\text{Frequency} = \frac{\text{no. of plots where species occurred}}{\text{total no. of plots}} \times 100$$

Data on species richness and cover from Fina LaTerre were analyzed with SAS GLM statistical programs and tested at the 5% level (SAS Institute 1985). Each variable was analyzed separately with a split-plot analysis of variance with treatment effects in the main plot and time effects in the subplot. Variables were tested for normality with a W-test statistic and transformed with the square root of x + 0.5 transformation if they were not normal (Steel and Torrie 1980:235). Species that were exceedingly rare (frequency < 10%) or that could not be normalized through transformations were excluded from the model. Variances associated with interactions were pooled for analysis if the probability was greater than 0.3.

At Rockefeller Refuge, we established a single transect approximately 0.5 km long in each of the unburned sampling areas in unit 4 and in the burned and unburned sampling areas at the unmanaged marsh (East Little Constance Bayou). The species present were recorded and the portion of the line covered by plant stems visually estimated for a 1.5-m segment at 30-m intervals along each transect. Frequency was calculated for each species and open water.

Results and Discussion

Because management influenced species composition differently at the two study sites, we will present the results separately for each site.

Fina LaTerre

The managed and unmanaged marshes of Fina LaTerre each had 27 species present (table 57). Generally, differences in species presence between the managed and unmanaged marshes occurred only in rare species (frequency < 10%). The most frequently occurring species are listed in tables 58 and 59. The dominant emergent species (highest percentage cover and frequency) was *Spartina patens* in both the managed and unmanaged marsh. The percentage cover of this species was significantly greater, however, in the unmanaged area than in the managed. *Distichlis spicata* and *Bacopa monnieri* were the next most common species, but like all the remaining species, they were relatively unimportant compared to *S. patens*. The frequency of occurrence of open water was consistently higher in the managed marsh at both times of year.

Management had a significant influence on total vegetative cover (p = .0485) and cover of *S. patens* (p = .016), but not on species richness and extent of open water (p = .11) (table 60). Distance from the source of water exchange, however, did not influence any of these variables. Total vegetative cover and cover of *S. patens* were significantly lower in the managed marsh at both times of the year. Although the difference was not significant (p = .15), the average amount of open water was consistently greater in the managed marsh regardless of the operating schedule of the water control structure.

Plant species composition at the school board property was different from that at the managed and unmanaged marshes. The school board property had a similar number of species (28), but they tended to be more of a fresh marsh assemblage (table 61), with species such as *Sagittaria lancifolia* prominent in the landscape (table 62). Species found at the school board property but not at the managed or unmanaged marshes included *Baccharis halimifolia*, *Juncus* sp., *Colocasia esculenta*, and *Dichromena colorata*. Species not at the school board property that occurred in the other marsh sites included *Eleocharis* sp., *Carex* sp., *Cyperus* sp., *Kosteletzkya virginica*, and several submerged aquatic species (see table 57). The relative frequency and cover of *S. lancifolia* was comparable to that of *S. patens*. That other new species occur frequently but cover little area indicates that they are widely spaced individual plants.

Rockefeller Refuge

Plant species composition was more diverse in the managed than in the unmanaged marsh at Rockefeller Refuge (table 63). The managed marsh had 19 species, including the aquatic plant *Eleocharis parvula*. The unmanaged marsh had only eight species, and none of them were aquatic. The most common species at both marsh locations was *Spartina patens*, followed by *Distichlis spicata* (table 64). The next most common species were *Eleocharis parvula*, present only in the managed marsh, and *Scirpus olneyi*, present only in the unmanaged marsh.

Spartina patens was the dominant species in both the managed and unmanaged marsh (table 65). No trends were apparent in the data, however. The percentage cover of *S. patens* and the extent of open water do not appear to change with

Table 57. Aquatic and emergent plant species recorded during spring and fall surveys at Fina LaTerre, 1989.

	Managed	Unmanaged
Aquatic Species		
Algae	x	
Ceratophyllum demersum		x
Chara vulgaris	x	
Eleocharis parvula	x	x
Myriophyllum spicatum		x
Najas guadalupensis	x	x
Potamogeton berchtoldii	x	
Ruppia maritima	x	
Salvinia rotundifolia		x
Eichhornia crassipes		x
Emergent Species		
Alternanthera philoxeroides	x	x
Amaranthus cannabinus		x
Ammannia coccinea	x	x
Bacopa monnieri	x	x
Carex sp.	x	
Cyperus sp.	x	x
Distichlis spicata	x	x
Eleocharis sp. (med)		x
Eleocharis sp. (tall)	x	x
Galium tinctorium	x	x
Hibiscus lasiocarpus	x	x
Hydrocotyle sp.	x	x
Ipomoea sagittata	x	
Kosteletzkya virginica		x
Leptochloa fascicularis	x	
Lythrum lineare	x	x
Panicum sp.	x	
Phyla nodiflora	x	x
Pluchea camphorata	x	x
Polygonum punctatum	x	x
Sagittaria lancifolia		x
Scirpus olneyi	x	x
Solidago sp.	x	
Spartina patens	x	x
Thelypteris palustris		x
Vigna luteola	x	x
Total Number	27	27

Table 58. Frequency and percentage cover (expressed as a range) of open water and selected plant species at Fina LaTerre along transects T_1-T_4, June 1989.

	Unmanaged					Managed				
Species	T^1	T_2	T_3	T_4	Cover (%)	T_1	T_2	T_3	T_4	Cover (%)
Open water	70	0	70	0	0-100	50	100	60	80	0-100
Emergent Species										
Spartina patens	50	100	60	90	0-80	30	10	40	50	0-60
Alternanthera philoxeroides	0	40	10	20	0-10	10	0	0	0	0-T[a]
Bacopa monnieri	10	40	0	0	0-5	20	20	20	40	0-15
Distichlis spicata	30	10	10	0	0-3	0	0	30	0	0-5
Pluchea camphorata	0	10	20	20	0-10	10	0	10	20	0-T
Polygonum sp.	0	0	20	20	0-5	0	10	0	0	0-T
Aquatic Species										
Eleocharis parvula	10	30	10	20	0-5	0	0	40	10	0-25
Myriophyllum spicatum	0	0	50	0	0-20	0	0	0	0	0

[a]"T" indicates that the species was present in trace amounts.

Table 59. Frequency and percentage cover (expressed as a range) of open water and selected plant species along transects T_1 and T_4 at Fina LaTerre, October 1989.

	Unmanaged						Managed					
	T_1	T_2	T_3	T_4	T_5	Cover (%)	T_1	T_2	T_3	T_4	T_5	Cover (%)
Open water	50	0	0	30	60	0-100	100	50	30	80	50	0-100
Emergent Species												
Spartina patens	50	90	100	100	50	0-75	10	60	70	40	60	0-40
Alternanthera philoxeroides	0	0	0	0	10	0-T[a]	0	0	0	0	0	0
Bacopa monnieri	20	0	50	20	0	0-40	10	50	30	30	30	0-15
Distichlis spicata	50	10	20	10	30	0-10	10	50	30	10	50	0-10
Pluchea camphorata	0	20	50	0	10	0-5	0	0	20	0	10	0-T
Polygonum sp.	0	10	0	0	0	0-T	10	0	0	0	0	0-T
Aquatic Species												
Eleocharis parvula	10	20	10	20	0	0-25	0	0	0	10	10	0-5
Myriophyllum spicatum	0	0	0	0	0	0	0	0	0	0	0	0

[a]"T" indicates that the species was present in trace amounts.

Table 60. Species richness (number of species per plot), total vegetative cover, percentage open water, and *Spartina patens* cover at Fina LaTerre. Values are means ± 1 S.E.

	June				October			
	Managed		Unmanaged		Managed		Unmanaged	
	Near	Far	Near	Far	Near	Far	Near	Far
Water (%)	62 ±11	67 ± 10	34 ± 10	30 ± 10	64 ± 9	50 ± 11	30 ± 10	26 ± 8
Total vegetative cover (%)	24 ± 7[a]	8 ± 3[a]	44 ± 7[b]	40 ± 7b	9 ± 2[a]	15 ± 5[a]	41 ± 6[b]	30 ± 4b
Spartina patens cover (%)	10 ± 5[a]	5 ± 2[a]	42 ± 7[b]	40 ± 7[b]	7 ± 2[a]	5 ± 2[a]	39 ± 6[b]	26 ± 4[b]
Species richness (species/plot)	1.2 ± 0.4	2.6 ± 0.6	2.7 ± 0.5	1.9 ± 0.4	1.9 ± 0.5	3.2 ± 0.6	2.9 ± 0.5	2.5 ± 0.4

[a]Means within the same row followed by different letters are significantly different at the 5% level. Only total cover and *Spartina patens* means were significantly different.

Table 61. Aquatic and emergent plant species recorded during a spring 1989 survey of the school board property.

Aquatic Species	
Eichhornia crassipes	
Eleocharis parvula	
Myriophyllum spicatum	
Potamogeton berchtoldii	
Salvinia rotundifolia	
Emergent Species	
Alternanthera philoxeroides	
Amaranthus cannabinus	
Baccharis halimifolia	
Colocasia esculenta	
Dichromena colorata	
Distichlis spicata	
Galium tinctorium	
Hibiscus lasiocarpus	
Hydrocotyle sp.	
Ipomoea sagittata	
Juncus sp.	
Ludwigia leptocarpa	
Lythrum lineare	
Mikania scandens	
Panicum sp.	
Phyla nodiflora	
Pluchea camphorata	
Polygonum punctatum	
Sagittaria lancifolia	
Scirpus olneyi	
Solidago sp.	
Spartina patens	
Thelypteris palustris	
Vigna luteola	
Total	29

Table 62. Frequency and cover of the most common species and of open water recorded along transects T_1 and T_2 during the summer vegetation survey at the school board property.

Species	Relative Frequency(%) T_1	Relative Frequency(%) T_2	Cover (%) T_1	Cover (%) T_2
Aquatic species				
Eleocharis parvula	70	40	0-10	0-5
Myriophyllum spicatum	0	20	0	0-30
Emergent species				
Alternanthera philoxeroides	10	10	0-T	0-T
Baccharis halimifolia	60	20	0-10	0-2.5
Colocasia esculenta	20	0	0-5	0
Dichromena colorata	90	10	0-2.5	0-T
Hydrocotyle sp.	70	30	0-10	0-2.5
Ipomoea sagittata	10	60	0-T	0-15
Juncus sp.	10	20	0-T	0-5
Lythrum lineare	50	40	0-2.5	0-5
Mikania scandens	40	20	0-2.5	0-30
Polygonum punctatum	70	50	0-15	0-5
Sagittaria lancifolia	100	70	5-60	0-60
Solidago sp.	70	0	0-2.5	0
Spartina patens	60	80	0-30	0-25
Thelypteris palustris	70	20	0-10	0-2.5
Vigna luteoia	80	80	0-5	0-5
Open water	10	50	0-20	0-100

Table 63. Aquatic and emergent species recorded during spring and fall surveys at Rockefeller Refuge, 1989.

Species	Managed	Unmanaged
Aquatic Species		
Eleocharis parvula	x	
Emergent Species		
Amaranthus sp.	x	x
Baccharis halimifolia	x	
Bacopa monnieri	x	
Cyperus sp.	x	
Distichlis spicata	x	x
Ipomoea sagittata	x	
Leptochloa fascicularis	x	x
Mikania scandens	x	
Panicum sp.	x	
Paspalum sp.	x	
Pluchea camphorata	x	
Polygonum sp.	x	
Rumex sp.	x	
Scirpus olneyi		x
Scirpus robustus	x	x
Spartina alterniflora	x	x
Spartina patens	x	x
Typha latifolia	x	
Vigna luteola	x	x
Total number	19	8

Table 64. Frequency (%) and cover (expressed as a range) of selected plant species and open water at Rockefeller Refuge, 1989.

	May					October				
	Unmanaged		Managed		Cover (%)	Unmanaged		Managed		Cover (%)
	Burned	Unburned	Unburned	Unburned		Burned	Unburned	Unburned	Unburned	
Distichlis spicata	25	63	47	13	0-50	0	60	64	25	0-40
Eleocharis parvula	0	0	27	0	0-60	0	0	29	0	0-70
Scirpus olneyi	19	0	0	0	0-16	19	0	0	0	0-16
Spartina patens	81	88	67	80	0-70	88	87	71	81	0-50
Open water	13	50	20	7	0-100	13	40	27	7	0-100

Table 65. Percentage cover of selected species and of open water at Rockefeller Refuge, 1989.

	May				October			
	Unmanaged		Managed		Unmanaged		Managed	
	Burned	Unburned	Unburned	Unburned	Burned	Unburned	Unburned	Unburned
Distichlis spicata	1 ± 1	4 ± 1	14 ± 5	2 ± 1	0	5 ± 2	7 ± 3	2 ± 1
Eleocharis parvula	0	0	13 ± 6	0	0	0	16 ± 8	0
Scirpus olneyi	2 ± 1	0	0	0	1 ± 1	0	0	0
Spartina patens	30 ± 4	35 ± 6	19 ± 5	39 ± 6	36 ± 4	17 ± 3	18 ± 4	25 ± 4
Open water	13 ± 9	39 ± 10	11 ± 6	7 ± 7	13 ± 9	32 ± 11	6 ± 3	6 ± 6
Total cover	35 ± 4	39 ± 6	36 ± 6	48 ± 4	37 ± 5	22 ± 4	27 ± 5	36 ± 4

season or location. Management does not appear to affect total cover of all plant species.

Conclusions

The following conclusions are based on data collected during a drawdown year only. For the Fina LaTerre site, the conclusions pertain only to the southern portion of the managed area and the unmanaged reference area south of Falgout Canal.

Fina LaTerre

1. There was no substantial difference in species composition between managed and unmanaged brackish marsh zones at Fina LaTerre.

2. Total vegetative cover and cover of the dominant species, *Spartina patens*, were significantly lower in the managed marsh at Fina LaTerre.

Rockefeller Refuge

1. Species diversity was significantly greater in the managed than in the unmanaged marsh at Rockefeller Refuge.

VEGETATION AND SOIL RESPONSE TO MARSH MANAGEMENT

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Introduction

In southern Louisiana, marsh management is being used to address a diverse range of objectives, including increasing waterfowl and furbearer use (Craft and Kleinpeter 1986), excluding salt water and promoting freshwater species, and preventing marsh loss (Simmering et al. 1989). Until this study, little or no comprehensive, multiparameter information was available on the effects of marsh management on vegetation response and associated soil parameters in comparison to nearby unmanaged marshes. Previous reports describing the effects of marsh management on vegetation have relied on monthly salinity measurements, water depth measurements, and vegetation transects. The vegetation transects were used to estimate percentage cover, changes in vegetation, and species diversity, which in turn were used as the basis for reporting whether marsh management improved plant productivity (Craft and Kleinpeter 1986; Joanen and McNease 1987; Simmering et al. 1989). The objective of this component of the study was to directly determine (1) the effect of marsh management on the primary productivity and vigor of the dominant emergent marsh vegetation (Spartina patens) and (2) which soil variables may be controlling this vegetative response to marsh management.

We addressed several questions concerning the effects of marsh management on vegetation within two managed marshes. First, what effect does marsh management have on edaphic factors (i.e., soil oxidation state and interstitial concentration of nutrients, salinity, and sulfide) as compared to nearby unmanaged marshes? Second, what influence does marsh management have on the productivity of emergent vascular plant production as compared to nearby unmanaged marshes? And third, what conclusions can be made about the use of marsh management in light of the information this study has provided?

Materials and Methods

Sampling Schedule

Sampling at Fina LaTerre was conducted four times during the course of the investigation, on May 17-18, July 18-19, September 20-21, and November 14-15, 1989. The school board area was not sampled for vegetation and soil response because of time constraints. In May, September, and November we sampled all sites in the managed and unmanaged marshes. In July all sites near to and far from the water exchange point were sampled within the managed area. In the unmanaged area, all sites near the water exchange point were sampled, but only six sites far from the exchange point were measured because of instrumentation problems.

Sampling at Rockefeller Refuge was conducted four times during the investigation, on May 31 through June 1, August 21-22, October 4-6, and November 29 through December 1, 1989. Because of instrumentation problems at Rockefeller in May and August, and the shorter days in October and November, samples were not collected from every site during every sampling period. In May, nine burned and ten unburned sites were sampled in the managed marsh. However, only one burned and six unburned sites were sampled in the unmanaged marsh. In August, five sites within the burned and five sites within the unburned areas of both the managed and unmanaged marshes were sampled. In October and November, the shorter days prevented sampling at two of the burned sites in the managed marsh. However, all sites were sampled in the managed, unburned area and in the burned and unburned areas of the unmanaged marsh.

Analysis of Vegetation Response

Net leaf CO_2 exchange rates of S. patens, the dominant species at both Fina LaTerre and Rockefeller, were measured with a portable infrared CO_2 analyzer (LCA-2), an ADC air supply unit or ADC air supply unit with mass flow, and a Parkinson Leaf Chamber (Analytical Development Co., Ltd.). Two to four measurements (using an open gas exchange system) were made on mature, intact leaves at each sample site. We used a generator-powered 300W, 125V Sylvania Wide-Flood light when photosynthetically active radiation (PAR) was below 1,300 μmole m^{-2} s^{-1}. DeJong et al. (1982) and Pezeshki et al. (1987) reported that net photosynthesis of S. patens was light saturated at approximately 800 μmole m^{-2} s^{-1} under field conditions. This allowed measurement of light-saturated exchange rates, which were calculated using equations adapted from von Cammerer and Farquhar (1981). Net CO_2 exchange rates were expressed as μmoles of CO_2 exchanged per square meter of leaf surface per second. Total CO_2 exchange rates (per unit area of marsh) were determined by multiplying leaf CO_2 exchange with leaf area per square meter of marsh.

Clip plots (0.1 m^2) were sampled at each site adjacent to where CO_2 exchange rates were measured. All aboveground plant material was collected, transported to the lab, and separated by species into live and dead categories. Live stems of S. patens were counted to determine stem density. Samples were dried to constant weight at 65°C and weighed to the nearest 0.1 g. Plant data from clip plots were used to estimate net aboveground primary productivity (gm^{-2}) of S. patens with three different methods, those of (1) Smalley and (2) Milner and Hughes, and (3) the maximum-minimum method as described by Kirby and Gosselink (1976). Net primary productivity is "organic matter stored in plant tissue in excess of respiration during the period of measurement" (Odum 1963:39). The maximum-minimum method estimates productivity on the basis of the difference between the maximum and minimum live aboveground standing crop. Milner and Hughes' method takes into account only changes in live standing crop between frequent harvests during the growing season. Smalley's method estimates net primary productivity on the basis of changes in both live and dead standing crops over time. None of these methods accounts for losses due to decomposition between sampling intervals or losses due to herbivory, and they therefore underestimate productivity (Kirby and Gosselink 1976). We used all of these methods to determine whether trends in productivity calculated with different estimation techniques agreed.

We measured the leaf area of S. patens indirectly by calculating it on the basis of leaf weight. Leaf area of individual leaves (from Fina LaTerre samples collected May 17-18) was measured with a Licor LI-3000 leaf area meter; the leaves were weighed, and a linear regression ($y = 0.2264 + (31.27X)$, $r^2 = 0.93$) was generated relating leaf area (dependent variable) to leaf weight (independent variable). All subsequent measurements of leaf area were based on leaf weight using this equation. Leaf weights per 0.1-m^2 area in May samples were determined using the leaves from all stems in the plot; leaf weight for other months was computed by multiplying the leaf weight of 20 representative stems by the stem density in a plot. All weights and leaf surface areas are presented on the basis of square meter of marsh surface.

Soil Parameters

Duplicate, instantaneous Eh (redox potential) readings were made at the soil surface and at a depth of 15 cm at each site. Measurements were made using a calomel reference electrode, brightened platinum electrodes, and a portable digital pH-mV meter. So that we could base the readings on a standard hydrogen electrode, we added 244 mV to each reading (Faulkner et al. 1989). Soils were classified as aerated (>300 mV), moderately reduced (100 to 300 mV), reduced (-100 to 100 mV), and highly reduced (<-100mV [Patrick 1980]). Eh readings were not corrected for pH.

To determine water depth above or below the soil surface at each site, we installed shallow wells between S. patens hummocks. The wells consisted of 150-cm lengths of PVC pipe, which were buried to a depth of approximately 61 cm. Quarter-inch holes were drilled into the buried end of each pipe to allow free movement of water in and out. Each pipe was covered on top with a removable cap. We measured water depth at each site on all four sampling dates by removing the cap and dropping a float connected to a line into the pipe. Distance from the pipe top to the midpoint of the float was then measured. The height of each pipe was measured twice during the study. We calculated water depth above or below the soil surface by subtracting the distance from the top of the pipe from the pipe height.

Soil cores were collected to a depth of approximately 12 cm using an aluminum corer 6 cm in diameter. Soil was extruded into 500-ml centrifuge bottles and sealed. To ensure an anaerobic environment, we gassed the samples with nitrogen via a rubber septum in the bottle cap and placed them on ice for transport to the laboratory. The samples were centrifuged at 10,000 g at 4°C for 10 minutes. Immediately upon opening the bottles, an aliquot of the supernatant was added to an antioxidant solution (NaOH, ascorbic acid, sodium salicylate) for sulfide determination using a Lazar ISM-146 Micro Ion sensing electrode and a portable Cole-Parmer Model 5985-80 Digi-Sense mV meter (Lazar 1986).

Salinity of the interstitial water was measured using a Fisher Conductivity Meter Model 152, and pH was measured using an Altex Model 3560 Digital pH meter with a Corning General Purpose Combination Electrode. The water was filtered using a 0.45-micron millipore filter, and an aliquot was then removed and frozen for NH_4-N analysis (U.S. Environmental Protection Agency 1979). The remainder of the filtered water was acidified with concentrated nitric acid and analyzed for essential nutrients (P, K, Ca, Mg, Na, Fe, Mn, Cu, and Zn) using a Fisher inductively coupled plasma argon emission spectrometer (ICAP, Atom Comp Series 800).

Statistical Analyses

Statistical analyses were conducted with SAS software (SAS Institute 1985). The effects of treatments and month on soil and plant variables were analyzed with a split-plot analysis of variance, with treatment effects (at Fina LaTerre, management and proximity to a water exchange point; at Rockefeller, management and burning) in the main plot and month effects in the subplot. Pairwise comparisons between months were computed with least squares means when the overall month effect was significant. All hypotheses were tested at the .05 probability level unless otherwise indicated.

Results

Fina LaTerre

Soil Response. The effect of marsh management on water levels measured in the shallow wells varied with proximity to the water exchange point and with month (treatment × water × month interaction significant [p = .0289, figure 118A]). Water level was higher in the unmanaged marsh (near and far) than in the managed marsh (near and far) on all sampling dates except July, when no significant differences occurred. Water depth was not different between the near and far areas within the managed marsh on any sampling date. While no significant differences between the near and far unmanaged areas occurred in

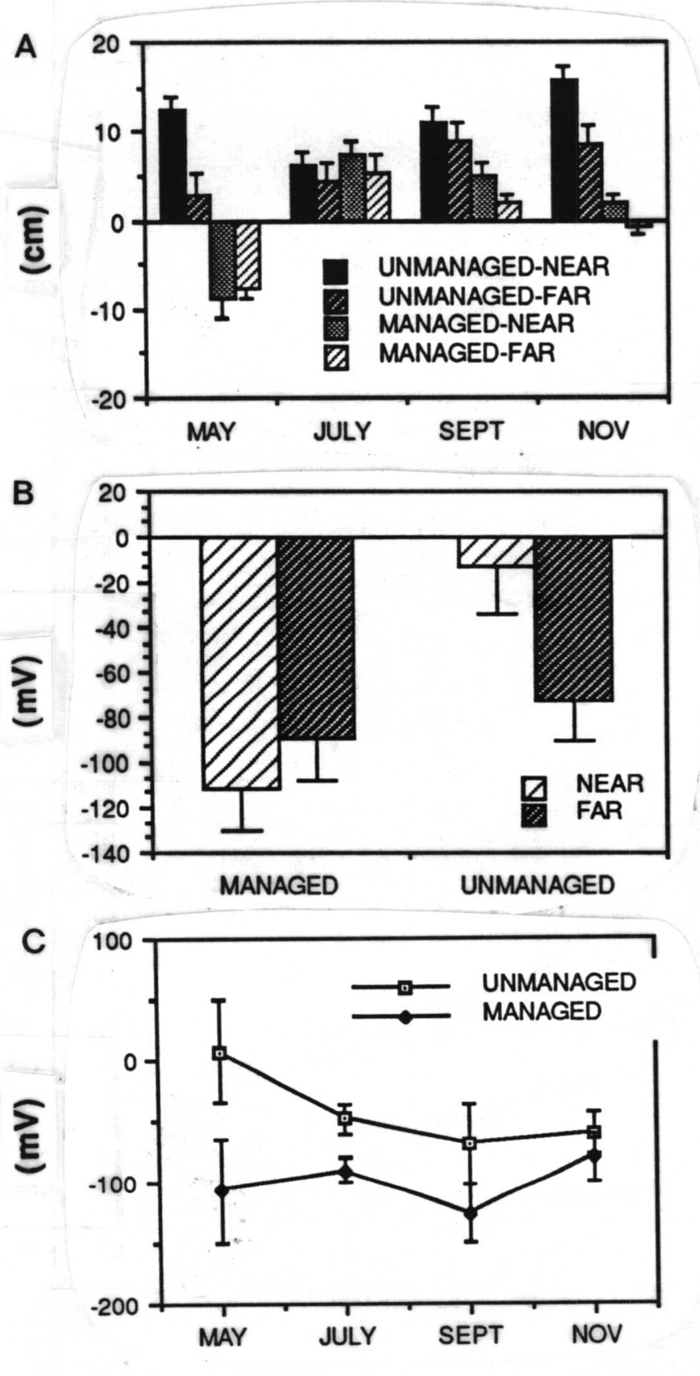

Figure 118. (a) Water depth, (b) surface Eh, and (c) surface Eh over time in an unmanaged and a managed marsh near and far from a water exchange point at Fina LaTerre, Terrebonne Parish, Louisiana, 1989 (± 1 S.E.).

July or September, the unmanaged near area had significantly greater water depth than the unmanaged far area in May and November (figure 118A). Water depth increased significantly in the managed marsh (near and far) from May to July, but decreased in the unmanaged near area. Water depth increased significantly from May to September in the unmanaged far area and in September and November in the unmanaged near area (figure 118A).

Although water depth was, on average, greater in the unmanaged marsh, surface soil conditions in the managed marsh (-101 ± 13 mV) were more reduced than in the unmanaged marsh (-43 ± 15 mV, [treatment significant p = .0033]). The effect of marsh management on surface Eh varied with proximity to the water exchange point (treatment × water interaction significant, p = .0573, figure 118B). In the unmanaged marsh, surface Eh, when averaged over time, was significantly higher nearer to the water exchange point than farther from it (figure 118B). However, in the managed marsh, surface Eh did not vary as a function of nearness to the water exchange point. In addition, the surface Eh in the unmanaged near marsh was significantly higher than that in the managed near marsh. In the managed marsh, the average surface Eh in the near area was not significantly different from that in the far (figure 118B). The greater soil reduction in the managed marsh, despite lower water depth, may have been in response to (1) the lower mineral content of the surface soils within the managed marsh and hence a lower ability to poise the Eh at higher redox potentials (Gambrell and Patrick 1978), (2) the presence of more labile organic matter, resulting from organic matter decomposition, in the managed marsh, which contained higher total organic matter than the unmanaged marsh and (3) marsh vegetation can affect soil Eh (Chen and Barko 1988; de la Cruz et al. 1989). The greater productivity of S.patens in the unmanaged marsh may have resulted in less-reduced soil conditions due to transport of oxygen vis shoots to the root zone. A readily usable carbon source can stimulate bacterial activity in saturated soils and cause development of more reduced conditions (Gambrell and Patrick 1978). Although surface Eh did not vary significantly with time within either marsh (p = .3614, figure 118C), the surface Eh of the unmanaged marsh was consistently higher than that of the managed marsh throughout the investigation (figure 118C).

Eh of soils 15 cm deep varied with month (month significant, p = .0001). However, neither management nor distance from the water exchange point had any significant effect on soil Eh at 15 cm deep (treatment, p = .3330; water, p = .3936). Eh at 15 cm deep was highly reduced in May (-192 ± 10 mV), reduced in July (-95 ± 8 mV), highly reduced in September (-145 ± 10 mV), and reduced in November (-103 ±10 mV).

Averaged over time and proximity to the water exchange point, the unmanaged marsh had a higher pH (6.92 ± 0.02) than the managed marsh (6.79 ± 0.03; treatment significant, p = .0004). The effect of marsh management on pH varied with proximity to the water exchange point (treatment × water interaction significant, p = .0316, figure 119A) and with month (treatment × month interaction significant, p = .0003, figure 119B). In the unmanaged marsh, pH did not significantly differ between the near and far areas. In the managed marsh, however, locations near the water exchange point had a significantly higher pH than the far locations (figure 119A). The far area in the unmanaged marsh had, on average, higher pH than did the far area in the managed marsh. Near the water exchange point, however, the managed and unmanaged locations were not significantly different. The pH of both the managed and unmanaged marshes

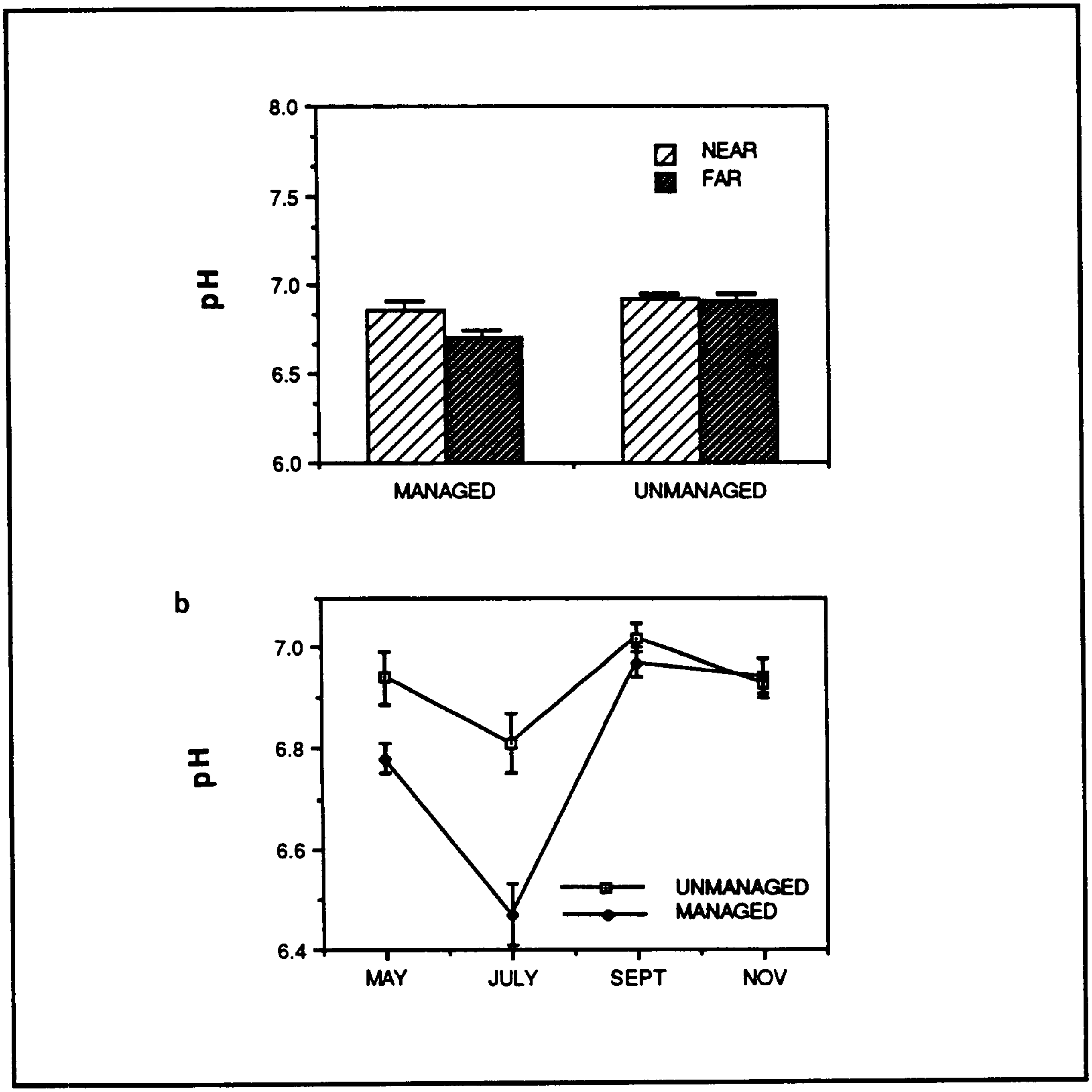

Figure 119. Interstitial water pH in (a) an unmanaged and a managed marsh near and far from a water exchange point, and (b) in an unmanaged and a managed marsh measured over time at Fina LaTerre, Terrebonne Parish, Louisiana, 1989 (± 1 S.E.).

decreased from May to July, and increased in September (figure 119B). The pH of the managed and unmanaged marshes was within the range expected for a flooded soil (Gambrell and Patrick 1978).

The effect of marsh management on interstitial sulfide concentration varied with proximity to the water exchange point (treatment × water interaction significant, $p = .0296$, figure 120A). Higher sulfide concentrations in the unmanaged area farthest from the point of water input, where Eh was lowest, indicated that at the time of sampling soil water drainage was impaired in the unmanaged far area. In addition, precipitation of sulfide with Fe in the managed marsh may have lowered sulfide concentrations and accounted for the lower Fe concentrations observed in the managed marsh. Sulfide concentrations were greater in the managed marsh than in the unmanaged marsh only at the near area. At the far area, the unmanaged marsh had higher sulfide concentrations than the managed marsh (figure 120A). Sulfide concentrations (figure 120A) and Eh values (figure 118B) in the managed marsh did not vary with distance from the water exchange point.

The effect of distance from the water exchange point on sulfide concentration varied with month (water × month interaction significant, $p = .0225$, figure 120B). When averaged over managed and unmanaged marshes, sulfide concentrations did not significantly differ on any of the four sampling dates at the marsh area located nearest the water exchange point. At the area located farthest from the water exchange point, sulfide concentration increased sevenfold from July to September (figure 120B). This was at a time when ambient surface water salinities increased and could have resulted in sulfate input to the marsh--especially in the unmanaged marsh. Sulfide concentrations, when averaged over managed and unmanaged marshes, were not significantly different between near and far marsh areas in May or July. In September and November, however, the area farthest from water input had significantly higher sulfide concentrations than the area near water input, indicating impaired soil-water drainage and poor circulation (figure 120B).

Ammonium concentration, averaged over all treatments, was 34% greater in the managed marsh (2.59 ± 0.14 mg l^{-1}), which had more reduced soil conditions (figure 118C) than the unmanaged marsh (1.70 ± 0.19 mg l^{-1}, treatment significant, $p = .0005$). Locations farther from the water exchange point had more reduced soil conditions (figure 118B), higher sulfide concentrations (figure 120A), and 27% more ammonium (2.50 ± 0.2 mg l^{-1}) than locations near the water exchange point (1.83 ± 0.14 mg l^{-1}, water significant, $p = .0090$). Ammonium concentrations also varied with month (month significant, $p = .0001$, figure 121). Averaged over all treatments, May (2.13 ± 0.36 mg l^{-1}) and July (2.14 ± 0.16 mg l^{-1}) concentrations were the same; concentrations peaked in September (2.90 ± 0.18 mg l^{-1}) and subsequently decreased in November (1.39 ± 0.14 mg l^{-1}). No significant differences in interstitial phosphorus were apparent during the investigation (treatment, $p = .7109$; water, $p = .8116$).

Nitrogen is considered to be the primary growth-limiting nutrient of saline marsh vegetation (Linthurst 1979; Mendelssohn 1979; Valiela and Teal 1974). In submerged soils, nitrate-nitrogen is rapidly denitrified (Patrick and Wyatt 1964). Because aerobic conditions are required for microbial oxidation of ammonium to nitrate, the breakdown of organic matter in anaerobic soils results in accumulation of ammonium-N (Redman and Patrick 1965). Even though organic matter breakdown is slow and incomplete in anaerobic soils, anaerobic microorganisms have a low requirement for N (Patrick and Mikkelsen 1971). As

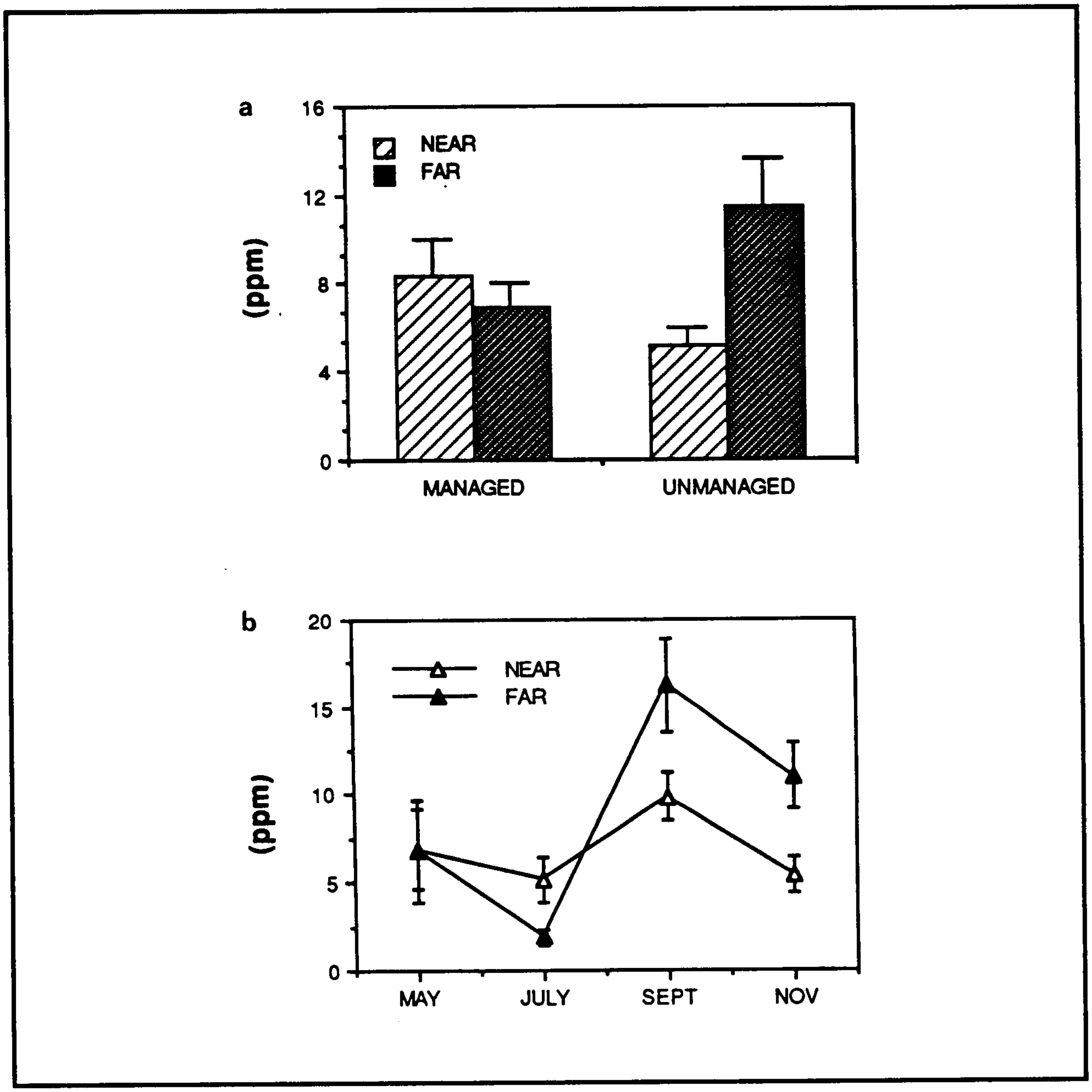

Figure 120. Interstitial water sulfide in (a) an unmanaged and a managed marsh near and far from a water exchange point, and (b) averaged over unmanaged and managed marshes near and far from a water exchange point at Fina LaTerre, Terrebonne Parish, Louisiana, 1989 (± 1 S.E.).

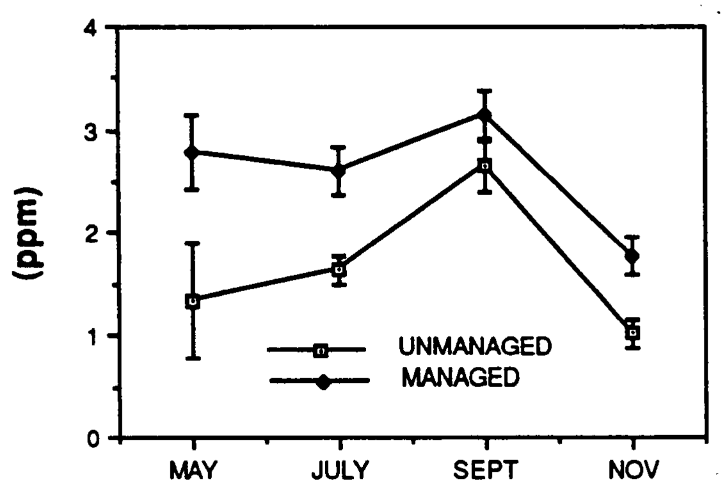

Figure 121. Interstitial water NH_4-N in an unmanaged and a managed marsh measured over time at Fina LaTerre, Terrebonne Parish, Louisiana, 1989 (± 1 S.E.).

a result, soils having a high percentage of organic matter will produce more ammonium (Redman and Patrick 1965). The higher interstitial ammonium concentrations in the managed marsh may have been due to higher organic matter and lower Eh in the managed marsh in conjunction with lower plant uptake (Koch and Mendelssohn 1989; Mendelssohn and McKee 1988).

Phosphorus availability is indirectly tied to Eh because of transformations of other elements with which it may precipitate. Under aerobic conditions, P exists as insoluble Fe-, Ca-, or Al-phosphate (Mahapatra and Patrick 1969). When anaerobic conditions develop (Eh $\leq$ 200 mV), Fe, Ca, and Al become more soluble, and P compounds hydrolyze (Redman and Patrick 1965). This usually results in an increase in extractable P upon submergence of soils due to its increased solubility (Patrick 1964). The lack of any significant difference in interstitial P between managed and unmanaged marshes may reflect the fact that P does not limit plant growth in these environments.

Averaged over time, interstitial salinity was higher in the managed marsh (3.3 ± 0.1) than in the unmanaged marsh (2.3 ± 0.1, treatment significant, $\underline{p}$ = .0001). In addition, the area farthest from the water exchange point had higher salinity (3.2 ± 0.1 ppt) than the area nearest the water exchange point (2.5 ± 0.1 ppt; water significant, $\underline{p}$ = .0045). The effect of marsh management on salinity varied with proximity to the water exchange point and month (treatment × water × month interaction significant, $\underline{p}$ = .0013, figure 122A). In the managed marsh, salinity in the far area was relatively high and constant throughout the study (figure 122A). However, although the managed near area had salinities equal to those of the managed far area in May, salinity declined significantly in July in the managed near area, which resulted in lower salinities in July, September, and November than occurred in the managed far area. Salinities at the near and far locations in the unmanaged marsh were different only in May and July (figure 122A). In the unmanaged marsh, salinities measured in May and July were lower than in the managed marsh, but over time salinities in the unmanaged marsh increased to the levels found in the managed marsh (figure 122A). The interstitial salinities in the unmanaged marsh tracked ambient surface salinities (see Rogers, this report) relatively closely, whereas salinities in the managed marsh did not.

Interstitial concentrations of the macronutrients Na, K, Mg, and Ca were measured in interstitial water samples from each site (figure 122B-E). Averaged over time, the managed marsh had greater concentrations of these four elements than the unmanaged marsh (treatment significant [Na, $\underline{p}$ = .0001; K, $\underline{p}$ = .0383; Mg, $\underline{p}$ = .0001; Ca, $\underline{p}$ = .0001], Na, managed: 1009 ± 36 ppm, unmanaged: 709 ± 54 ppm; K, managed: 30.46 ± 1.0 ppm, unmanaged: 25.89 ± 1.6 ppm; Mg, managed: 126.4 ± 4.4 ppm, unmanaged: 86.83 ± 6.7 ppm; Ca, managed: 59.15 ± 2.2 ppm, unmanaged: 39.25 ± 2.7 ppm). The effect of marsh management on Na, K, Mg, and Ca varied with proximity to the water exchange source and month (treatment × water × month interaction significant [Na, $\underline{p}$ = .0008; K, $\underline{p}$ = .0107; Mg, $\underline{p}$ = .0079; and Ca, $\underline{p}$ = .0014, figure 122B-E). Concentrations of Na, K, Mg, and Ca, which are the major cation components in seawater (Weyl 1970), exhibited the same pattern as described for salinity.

The micronutrients Fe, Zn, Mn, and Cu were also measured in interstitial water samples. Averaged over time and proximity to the water exchange point, the unmanaged marsh had approximately three times the level of Fe (0.1845 ± 0.0458 ppm) as the managed marsh (0.0685 ± 0.0030 ppm, treatment significant, $\underline{p}$ = .0385, figure 123A). There were no differences in Fe concentrations

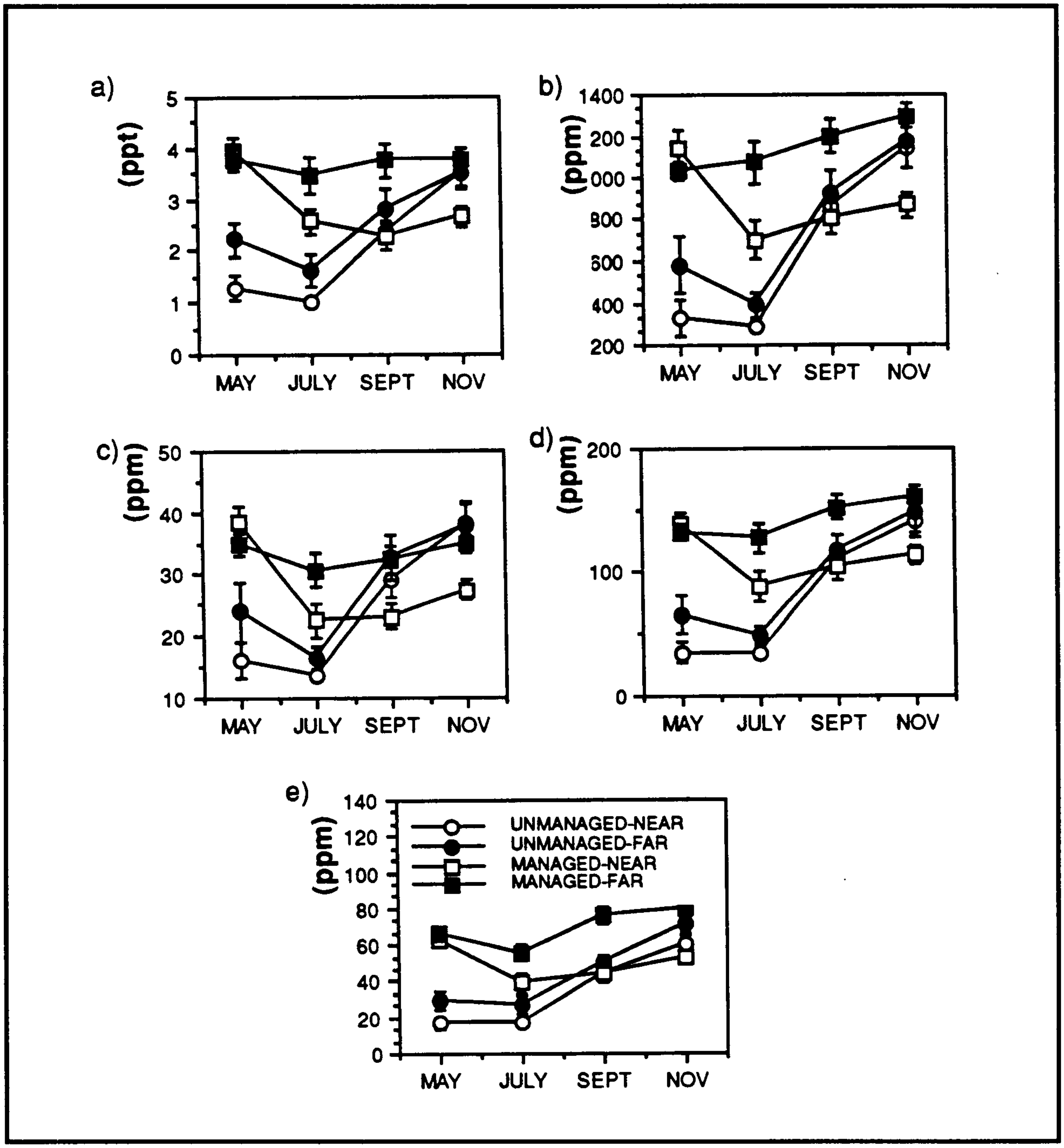

Figure 122. Interstitial water (a) salinity, (b) sodium, (c) potassium, (d) magnesium, and (e) calcium, measured over time in an unmanaged and a managed marsh near and far from a water exchange point at Fina LaTerre, Terrebonne Parish, Louisiana, 1989 (± 1 S.E.).

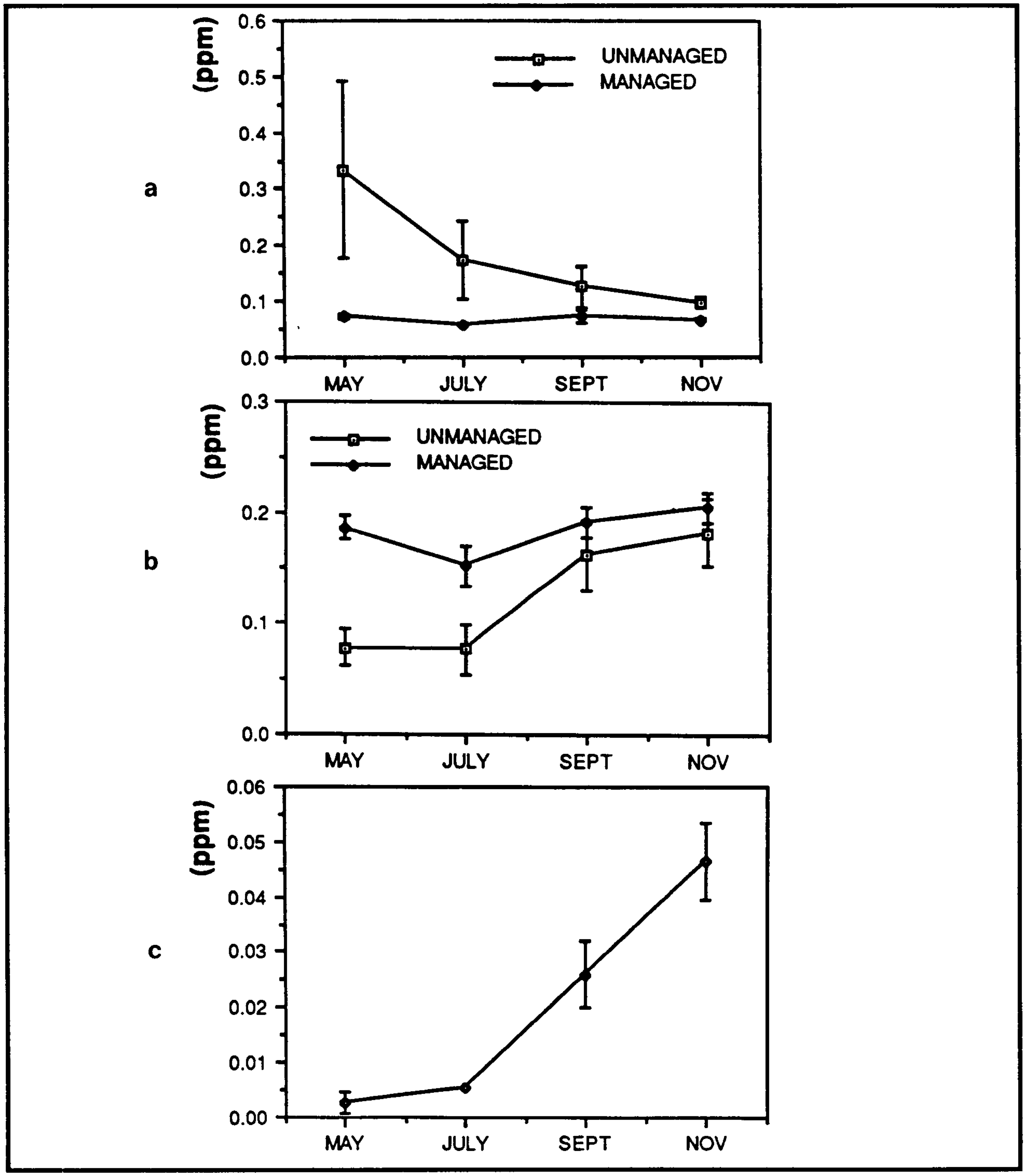

Figure 123. Interstitial water (a) iron, and (b) manganese, measured over time in an unmanaged and a managed marsh, and (c) zinc, averaged over managed and unmanaged marshes at Fina LaTerre, Terrebonne Parish, Louisiana, 1989 (± 1 S.E.).

associated with proximity to the water exchange point ($\underline{p}$ = .3873) or with sampling time ($\underline{p}$ = .1838). The lower concentration of soluble Fe in the managed marsh compared to the unmanaged marsh could be due to the formation and precipitation of FeS caused by the higher Eh (figure 118C), which would result in higher concentrations of soluble interstitial Fe and sulfide (Gambrell and Patrick 1978).

The effect of marsh management on Mn concentrations varied with month (treatment × month interaction significant, $\underline{p}$ = .0216, figure 123B). The managed marsh had greater concentrations of Mn than the unmanaged marsh in May and July. Concentrations of Mn were not significantly different in September and November. Although Mn concentrations in the managed marsh did not change over time, concentrations of interstitial Mn in the unmanaged marsh were significantly higher in September and November than in July. Distance from the water exchange point did not affect concentrations of Mn ($\underline{p}$ = .0926).

Zinc concentrations, which were the same in the unmanaged and managed marshes (treatment, $\underline{p}$ = .4688), varied with month (month significant, $\underline{p}$ = .0001). Zn levels were very low in May and July, but increased fivefold from July to November (figure 123C). Cu was not different between treatments ($\underline{p}$ = .4959) or with time ($\underline{p}$ = .2179).

<u>Vegetation Response</u>. Stem density and leaf area of <u>S</u>. <u>patens</u> were significantly greater (treatment significant; stem density, $\underline{p}$ = .0564; leaf area, $\underline{p}$ = .0512) in the unmanaged marsh (99 ± 6 stems m^{-2} marsh; leaf area, 0.75 ±0.06) than in the managed marsh (81 ± 4 stems m^{-2} marsh; leaf area, 0.56 ± 0.04). Stem density did not significantly change over time. Leaf area, averaged over treatments, exhibited a seasonal pattern; it increased from May (0.49 ± 0.06) to July (0.74 ± 0.10) and September (0.79 ± 0.07), and declined in November (0.56 ± 0.05) (month significant, $\underline{p}$ = .0034). The seasonal increase in leaf area, however, was more evident in the unmanaged marsh (figure 124A). The treatment effect upon stem density and leaf area did not differ with month (treatment × month interaction [stem density, $\underline{p}$ = .6178; leaf area, $\underline{p}$ = .0950]). Also, proximity to the water exchange point did not affect stem density ($\underline{p}$ = 0.6717) or leaf area ($\underline{p}$ = .3743).

Live aboveground biomass of <u>S</u>. <u>patens</u>, averaged over time and proximity to the water exchange point, was significantly greater in the unmanaged marsh (1,356.5 ± 97.2 g m^{-2}) than in the managed marsh (897.2 ± 63.7 g m^{-2}, treatment significant, $\underline{p}$ = .0068). Live biomass, averaged over treatments, varied with month (month significant, $\underline{p}$ = .0192), though the effect was more evident in the unmanaged marsh (figure 124B). The effect of marsh management on live biomass, however, did not differ with month (treatment × month interaction, $\underline{p}$ = .2579) or proximity to the water exchange point ($\underline{p}$ = .7225). <u>S</u>. <u>patens</u> made up 99-100% of the live vegetation in the unmanaged clip plots and 92-100% of the live vegetation in the managed clip plots at Fina LaTerre.

Both dead and total aboveground biomass varied with sampling date (month significant [dead, $\underline{p}$ = .0003; total, $\underline{p}$ = .0046]), but were not affected by treatment (dead, $\underline{p}$ = .2097; total, $\underline{p}$ = .8586). Dead biomass increased from May (1,757.7 ± 223.9 g m^{-2}) to July (2,188.5 ± 218.1 g m^{-2}). It decreased in September (1,649.2 ± 151.5 g m^{-2}), after which no significant change in dead biomass occurred (November, 1,234.7 ± 132.1 g m^{-2}). Total biomass exhibited the same pattern as leaf area--a low in May (2,648.9 ± 279.8 g m^{-2}) and an increase in July (3,316.3 ± 309.6 g m^{-2}). No significant differences in total biomass were measured in July (3,316.3 ± 309.6 g m^{-2}) and September (2,981.5 ± 211.3 g

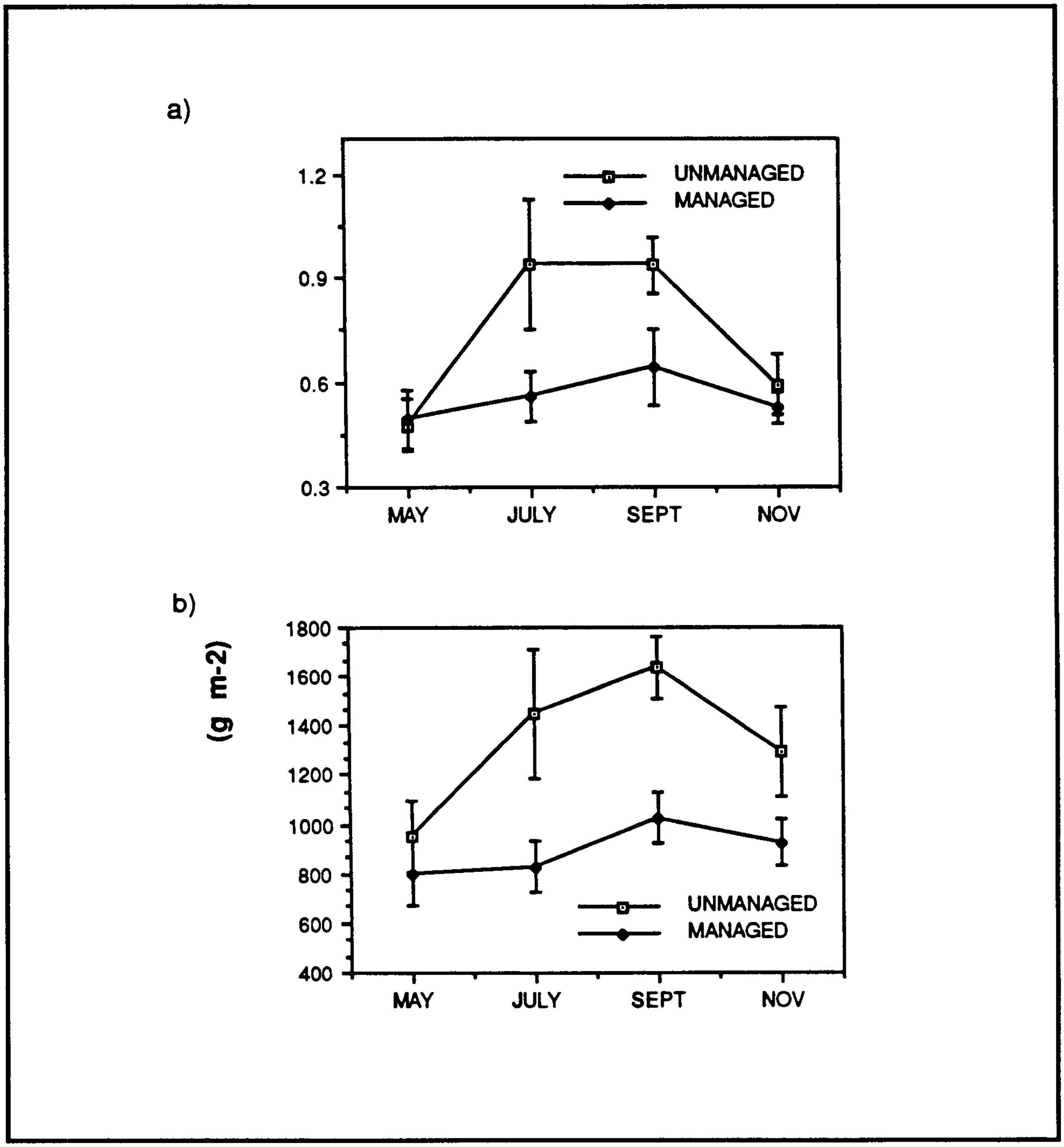

Figure 124. Spartina patens (a) leaf area and (b) live biomass measured over time in an unmanaged and a managed marsh at Fina LaTerre, Terrebonne Parish, Louisiana, 1989 (± 1 S.E.).

m^{-2}). Total biomass decreased to initial levels in November (2,345.4 ± 195.9 g m^{-2}). Proximity to the water source did not affect either dead (p = .3540) or total (p = .6459) biomass.

Regardless of the method used, estimates of net primary productivity of S. patens in the unmanaged marsh were always approximately twice as great as those for the managed marsh (treatment significant [maximum-minimum, p = .0289; Smalley, p = .0134; Milner and Hughes, p = .0495], table 66). The Smalley method, which accounts for plant mortality but not decomposition between sampling intervals (Kirby and Gosselink 1976; Shew et al. 1981), generated the highest estimate of net primary productivity, whereas the maximum-minimum and the Milner and Hughes methods, which do not account for either of these losses (Kirby and Gosselink 1976), gave much lower estimates. The greater net primary productivity of the unmanaged marsh compared to the managed marsh is consistent with differences between the two marshes in stem density, leaf area (figure 124A), and live biomass (figure 124B). Distance from the water exchange point did not significantly affect net primary productivity rates within the managed or unmanaged marsh (maximum-minimum, p = .6871; Smalley, p = .0881; Milner and Hughes, p = .2954).

Averaged over time and proximity to the water exchange point, the leaf CO_2 exchange rate of S. patens was higher in the unmanaged marsh (19.0 ± 1.15 μmole m^{-2} s^{-1}) than in the managed marsh (15.0 ± 1.06 μmole m^{-2} s^{-1}) (treatment significant, p = .0102). The effect of marsh management on leaf CO_2 exchange rate varied with month (treatment × month interaction significant, p = .0349, figure 125A). Since the time of day when samples were collected significantly affected the CO_2 exchange rate measured (p = .0002, hour accounted for 7.4% of the overall variation in CO_2 exchange rate, table 67), the CO_2 exchange rates were adjusted for hour. Leaf CO_2 exchange rate was greater in the unmanaged marsh than in the managed marsh in May (figure 125A). Although leaf CO_2 exchange rate was not significantly different between the two marshes on any other sample date, values tended to be higher in the unmanaged marsh than in the managed marsh (figure 125A). The rate of CO_2 exchange did not significantly differ with month in the managed marsh. In the unmanaged marsh, the leaf CO_2 exchange rate was significantly lower in November than in May (figure 125A). Although the effect of marsh management on the leaf CO_2 exchange rate varied with month and proximity to the water exchange point (treatment × water × month interaction significant, p = .0462), the trends were not consistent with respect to proximity to the water exchange point.

Total CO_2 exchange rate was also adjusted for hour because of the significant effect of time on total CO_2 exchange rate (hour significant, p = .0297; hour accounted for 3.2% of the overall variation in CO_2 exchange rates, table 68). Averaged over the four sample dates and proximity to the water exchange point, total CO_2 exchange rate of S. patens was 125% higher in the unmanaged marsh (15.1 ± 2.1 μmole m^{-2} marsh s^{-1}) than in the managed marsh (6.7 ± 0.19 μmole m^{-2} marsh s^{-1}) (treatment significant, p = .0020). The average total CO_2 exchange rate also varied with month (month significant, p = .0012). In the unmanaged marsh, the total CO_2 exchange rate, which was low in May, increased significantly in July (figure 125B). No significant difference in total CO_2 exchange rate occurred between July and September, but a significant decrease occurred from July to November in the unmanaged marsh (figure 125B). No differences in the rate of total CO_2 exchange occurred in the managed marsh

Table 66. Estimates of net primary productivity of *Spartina patens* in managed and unmanaged marshes at Fina LaTerre, Louisiana, during the 1989 growing season (n = number of sites within each marsh for which biomass data were obtained on all sampling dates).

Site	n	Net Primary Productivity ($g\ m^{-2}$)		
		Max-min	Smalley	Milner-Hughes
Managed	15	945.0 ± 143.4[a]	1,486.6 ± 285.9[a]	860.0 ± 142.3[a]
Unmanaged	10	1,541.4 ±213.7[b]	3,036.2 ± 662.0[b]	1,424.1 ± 270.5[b]

[a]Means with different letters are significantly different from each other ($p < .05$).

Table 67. *Spartina patens* leaf CO_2 exchange rates (adjusted and not adjusted for time of day) in a managed and an unmanaged marsh, near and far from a water exchange point, at Fina LaTerre, Louisiana, 1989.

Sampling	n	Leaf CO^2 Exchange Rates (μmole m^{-2} leaf area) Adjusted	Not Adjusted
Managed, near			
May	8	16.4 ± 1.6	17.6 ± 1.8
July	8	13.2 ± 1.8	14.1 ± 1.0
September	8	14.8 ± 1.5	15.8 ± 2.2
November	8	15.9 ± 2.3	16.1 ± 1.1
Managed, far			
May	8	12.1 ± 2.4	12.2 ± 1.8
July	8	15.3 ± 2.8	14.6 ± 1.7
September	8	17.9 ± 2.2	17.3 ± 1.3
November	8	14.3 ± 2.2	14.6 ± 1.5
Unmanaged, near			
May	8	19.9 ± 1.5	21.3 ± 2.5
July	8	16.2 ± 1.5	17.7 ± 0.6
September	8	19.8 ± 2.3	19.9 ± 1.5
November	8	16.9 ± 2.0	17.1 ± 0.7
Unmanaged, far			
May	8	22.8 ± 2.4	22.6 ± 2.2
July	6	21.8 ± 2.4	21.0 ± 2.0
September	8	18.8 ± 3.2	15.0 ± 2.0
November	8	16.0 ± 2.3	15.0 ± 1.2

Table 68. *Spartina patens* total CO_2 exchange rates (adjusted and not adjusted for time of day) in a managed and an unmanaged marsh, near and far from a water exchange point, at Fina LaTerre, Louisiana, 1989.

		Leaf CO_2 Exchange Rates (μmole m^{-2} leaf area)	
Sampling	n	Adjusted	Not Adjusted
Managed, near			
May	8	3.6 ± 2.8	5.9 ± 1.1
July	8	5.3 ± 3.2	7.9 ± 1.8
September	8	11.9 ± 2.6	12.7 ± 3.7
November	8	6.2 ± 4.1	9.1 ± 1.4
Managed, far			
May	8	5.7± 4.4	8.9 ± 2.2
July	8	5.0 ± 5.0	7.8 ± 1.5
September	8	11.8 ± 4.0	8.7 ± 1.6
November	8	4.4 ± 4.0	7.3 ± 1.2
Unmanaged, near			
May	8	4.0 ± 3.9	7.9 ± 1.7
July	8	5.3 ± 3.2	14.9 ± 4.8
September	8	12.4 ± 4.1	15.2 ± 2.4
November	8	13.6 ± 3.6	11.8 ± 2.7
Unmanaged, far			
May	8	15.3 ± 4.3	11.6 ± 3.2
July	6	26.1 ± 4.3	23.6 ± 4.2
September	8	24.8 ± 5.7	16.9 ± 3.0
November	8	11.0 ± 4.1	7.4 ± 1.3

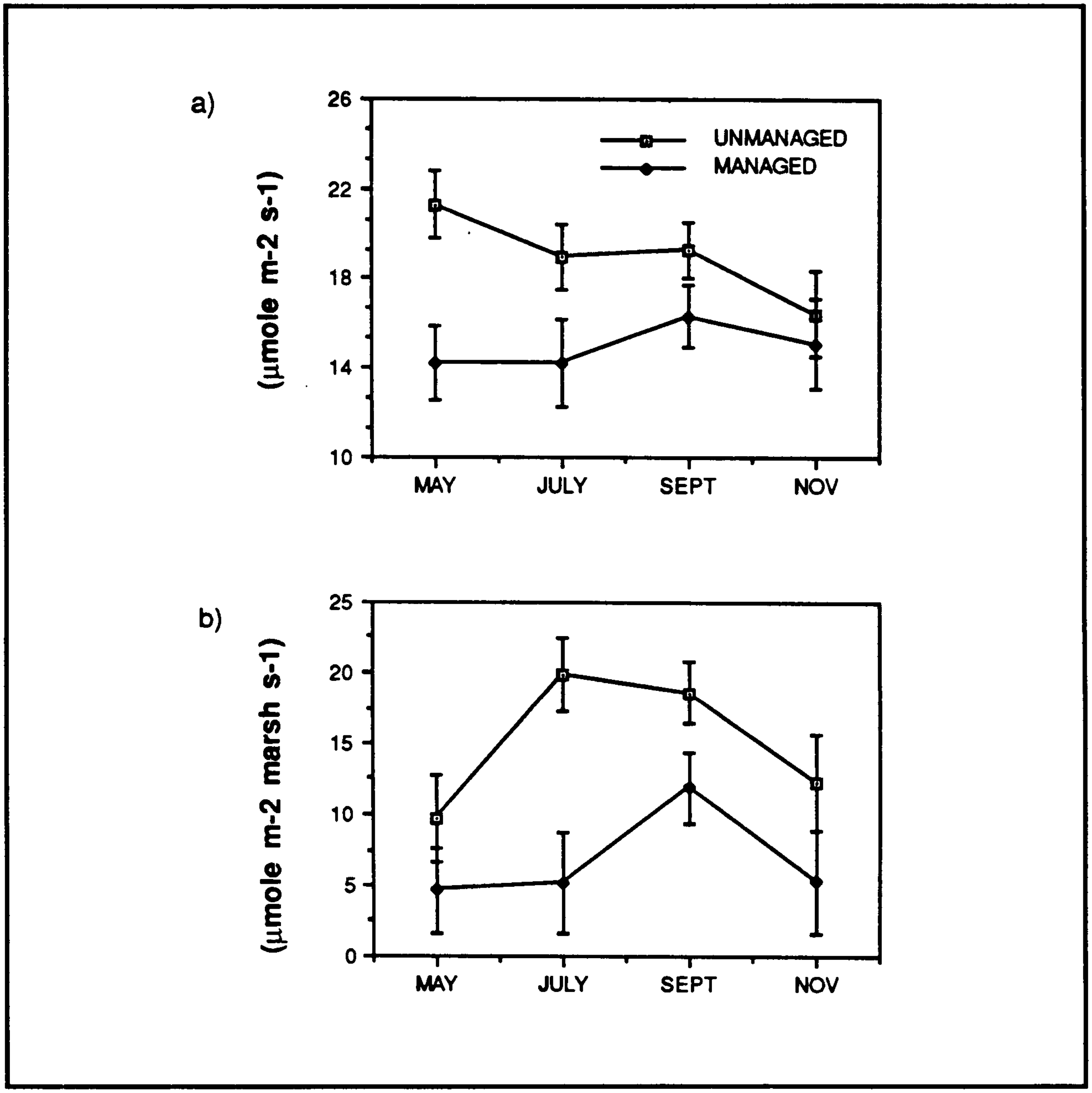

Figure 125. (a) Leaf CO_2 exchange rates and (b) total CO_2 exchange rates of Spartina patens in a managed and an unmanaged marsh at Fina LaTerre, Terrebonne Parish, Louisiana, 1989 (± 1 S.E.).

on any of the four sampling periods. Proximity to the water exchange point did not affect the total CO_2 exchange rate (p = .9578).

The growth response of S. patens within the managed marsh at Fina LaTerre was consistently poorer than that of S. patens in the unmanaged marsh. Stem density, leaf area, live biomass, and net aboveground primary productivity, as well as the leaf and total CO_2 exchange rates, were all greater in the unmanaged marsh. Apparently, the more reduced soil conditions in the managed marsh (figure 118C) were responsible for decreased growth. Anaerobic soil conditions have been demonstrated to cause reduced plant nitrogen uptake and reduced growth in Spartina alterniflora (Koch et al. in press; Morris and Dacey 1984). The higher concentrations of interstitial ammonium in the managed marsh compared to the unmanaged (figure 121) suggest that nitrogen uptake may be lower in the managed marsh. Koch and Mendelssohn (1989), in a greenhouse experiment, and Mendelssohn and McKee (1988), under field conditions, found that interstitial ammonium can accumulate when S. alterniflora is exposed to more anaerobic conditions, especially in the presence of sulfide. Since nitrogen is important for photosynthesis (Sage and Pearcy 1987), reduced ammonium uptake may play a role in the lower leaf and total CO_2 exchange rates (figures 125A-B) observed in the managed marsh. Lower net photosynthesis rates measured in S. alterniflora under extremely anaerobic conditions have been attributed to the potential for inadequate aeration of the root rhizosphere via aerenchyma (Pezeshki et al. 1989).

Rockefeller Refuge

Soil response. Averaged over time and burning, both surface Eh and 15-cm Eh were less reduced in the managed marsh (surface = 69 ± 24 mV, 15-cm Eh = -5 ± 16 mV) than in the unmanaged marsh (surface = -92 ± 23 mV, 15-cm Eh = -162 ± 9 mV) (treatment significant [surface Eh, p = .0030; 15-cm Eh, p = .0001]), and water level was higher in the unmanaged marsh (treatment significant, p = .0208). The effect of marsh management on water level, surface Eh, and 15-cm Eh varied with month (treatment × month interaction significant [water level, p = .0001; surface Eh, p = .0001; and 15-cm Eh, p = .0023], figure 126A-C). Although the effect of burning on water level varied with month (burn × month interaction significant, p = .0006), this difference may be due more to possible elevational differences between the burned and unburned areas than to any real effect of burning on water level.

In May, when the water level was 22 ± 1.2 cm below the surface of the managed marsh (figure 126A), surface soils were aerobic (figure 126B), and soils 15 cm deep were moderately reduced (figure 126C). Soils in the unmanaged marsh, however, where the water level was only -0.2 ± 1.4 cm from the surface, had highly reduced conditions at the surface and at a depth of 15 cm. Since flooding reduces the rate of gas exchange between the atmosphere and soil by a factor of 10,000 (Greenwood 1961), the respiration of vegetation and soil microorganisms quickly results in the development of reduced soil conditions (Ponnamperuma 1972).

In August, water levels in the managed marsh had risen to an average depth of 5 ± 1.1 cm above the soil surface (figure 126A). This resulted in the development of moderately reduced conditions at the surface and at a depth of 15 cm (figure 126B-C). Although Eh was not significantly different in the managed and unmanaged surface soils in August, the unmanaged soils were

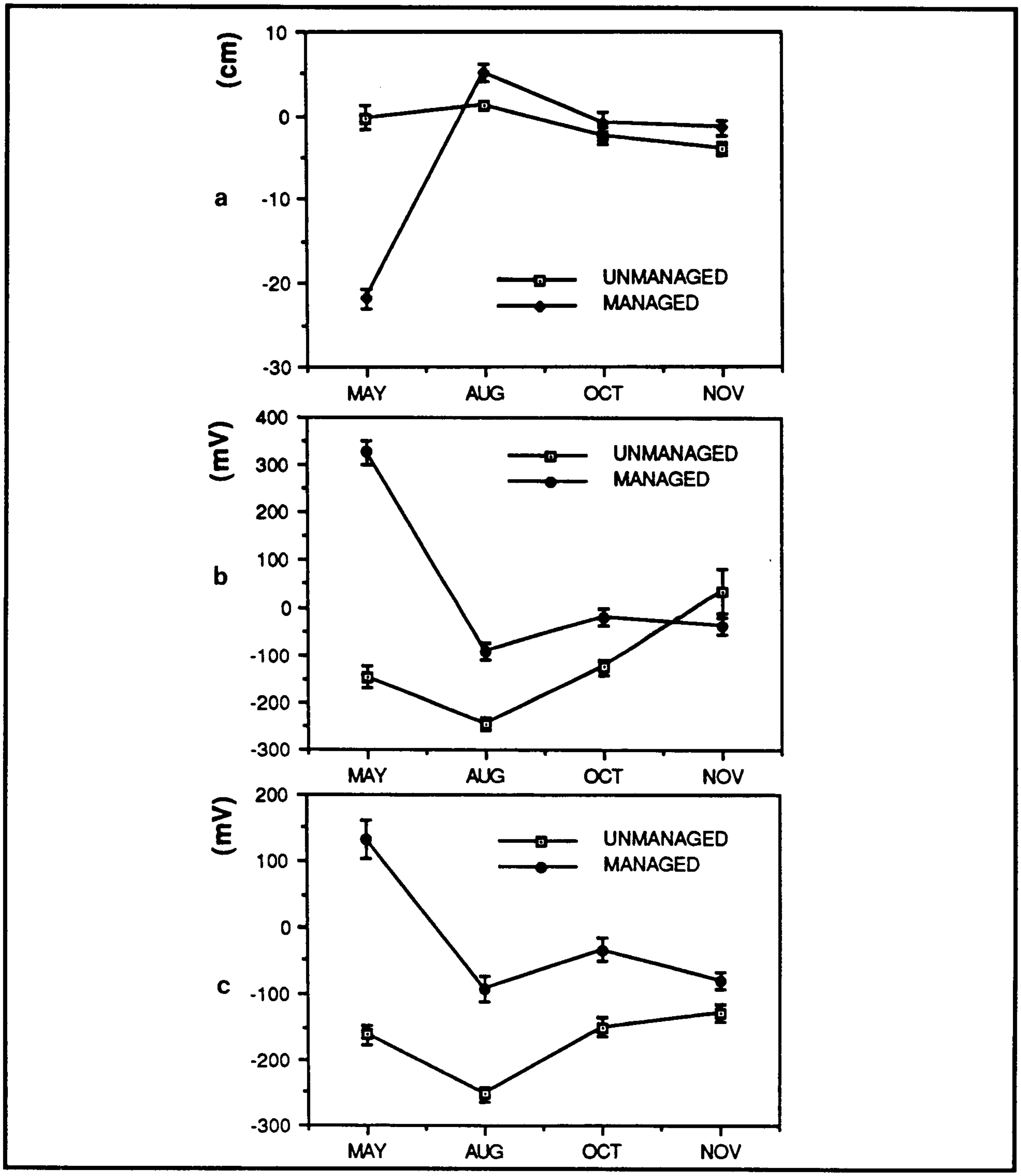

Figure 126. (a) Water depth, (b) surface Eh, and (c) Eh at 15 cm depth in an unmanaged and a managed marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, 1989 (± 1 S.E.).

classified as highly reduced. Eh at 15 cm was significantly lower in the unmanaged marsh than in the managed marsh in August and October. Water level dropped slightly below the soil surface in both the managed and unmanaged marshes in October; however, soil conditions remained significantly more reduced in the unmanaged marsh than in the managed marsh. Water level, which remained below the soil surface in November, was similar in the managed and unmanaged marshes. Even so, surface soil conditions were significantly less reduced in the unmanaged marsh (35 ± 47 mV) than in the managed marsh (-38 ± 18 mV). There were no differences in 15-cm Eh between the managed and unmanaged marshes in November.

Averaged over all treatments, interstitial water pH of the managed marsh was significantly lower than that of the unmanaged marsh (treatment significant, $\underline{p} = .0001$). The effect of marsh management on interstitial water pH varied with month (month × treatment interaction significant, $\underline{p} = .0001$, figure 127). The pH of the unmanaged marsh remained between 6.5 and 6.9 on all four sampling dates. In the managed marsh, however, the pH in May (5.1 ± 0.1) was significantly lower than in the other months (figure 127). This low pH during drawdown was probably a result of the oxidation of sulfide, Fe, and/or Mn, which can increase soil acidity (Ponnamperuma 1972). The increase in water level and subsequent development of reduced soil conditions caused the increase in pH in the managed marsh in August. When acidic soils are flooded, a series of reduction reactions that require H^+ occur and result in a trend towards neutral pH (Ponnamperuma 1972). Burning did not affect pH ($\underline{p} = .8308$).

Interstitial sulfide concentration, averaged over all treatments, was 25 times greater in the unmanaged marsh (11.7 ± 1.7 ppm) than in the managed marsh (0.5 ± 0.1 ppm, treatment significant, $\underline{p} = .0001$) and was consistently higher in the unmanaged marsh (figure 128). No differences in sulfide concentration were found with respect to burning ($\underline{p} = .0685$). Sulfide concentrations are so much lower in the managed marsh for several reasons--lower water levels, more soil oxidation, and lower input of sulfate. Flap gates are used to reduce the tidal inflow into the managed marsh that regularly occurs in the unmanaged marsh. This restriction of saline Gulf water from the managed marsh means that sulfate, which is present at high levels in seawater (Weyl 1970), is not readily available for reduction to sulfide when anaerobic soil conditions develop. Unless the flap gates are opened and tidal waters allowed into the managed marsh, the only way for reduced soil conditions (Eh) to develop is via precipitation. In addition, Connell and Patrick (1968) have reported that Eh must be at or below -150 mV, and pH must be between 6.5 and 8.5, for sulfate to be reduced to sulfide. These conditions were present in soils of the unmanaged marsh on all sample dates at the 15-cm depth, but were not present in the managed marsh. Sulfide, which can be toxic to vegetation at high concentrations (Ponnamperuma 1972), has been shown to reduce plant growth (Koch and Mendelssohn 1989; Linthurst 1979; Mendelssohn and McKee 1988). The susceptibility of vegetation to sulfide toxicity has been shown to vary with species. The biomass production of Panicum hemitomon, a dominant fresh marsh species in Louisiana, was affected by addition of sulfide to hydroponic culture more than was S. alterniflora, a dominant saline marsh species (Koch and Mendelssohn 1989). Mendelssohn and McKee (1989) found reduced aboveground growth of S. patens with sulfide accumulation of 85 ppm.

Ammonium concentration, averaged over all treatments, was greater in the unmanaged marsh (2.22 ± 0.23 ppm) than in the managed marsh (0.56 ± 0.08 ppm,

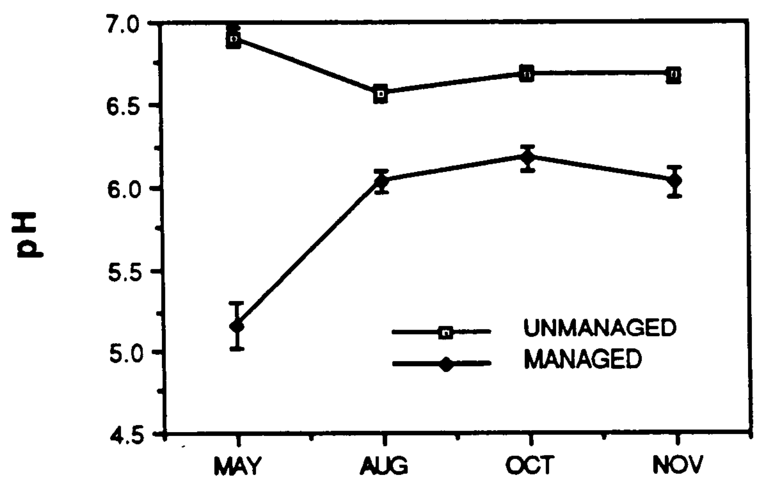

Figure 127. Interstitial water pH in an unmanaged and a managed marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

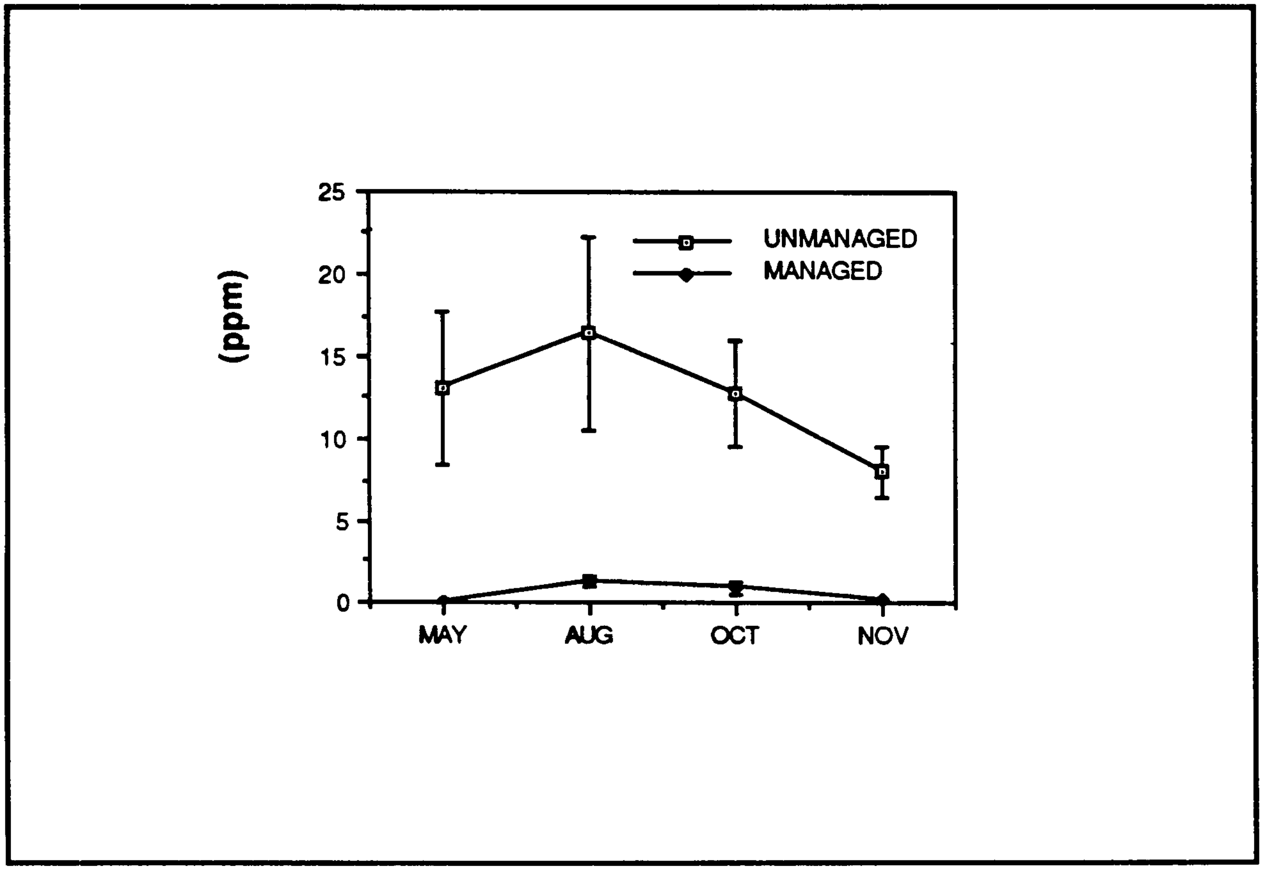

Figure 128. Interstitial water sulfide concentrations over time in an unmanaged and a managed marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

treatment significant, $p = .0001$). The effect of marsh management on ammonium concentration, however, varied with month and with burning (treatment × burn × month interaction significant, $p = .0486$, figure 129). In the unmanaged marsh, ammonium concentrations were highest with burning during all four sampling periods. In the managed marsh, ammonium concentration was not significantly affected by burning except in May, though levels tended to be higher in the unburned area. In May, the managed unburned marsh had a higher ammonium concentration than the unmanaged unburned marsh, but concentrations were not significantly different in August. In October and November, however, the unmanaged unburned marsh had a higher concentration of ammonium (figure 129). The unmanaged marsh (burned and unburned) had a seasonal pattern of low ammonium concentration in May and November, and a peak in October (figure 129). Ammonium concentrations decreased in the managed unburned marsh from May to November (figure 129).

Phosphorus concentrations, averaged over time and burning, were greater in the unmanaged marsh (2.24 ± 0.3 ppm) than in the managed marsh (0.71 ± 0.2 ppm, treatment significant, $p = .0016$). Phosphorus concentrations were not significantly affected by burning ($p = .1075$) or month ($p = .1486$). In addition, the effect of marsh management on interstitial P concentrations did not vary with burning (treatment × burn, $p = .0723$), or with month (treatment × month $p = .9867$).

Nitrogen is considered to be the primary growth-limiting nutrient in saline marshes (Linthurst 1979; Mendelssohn 1979; Valiela and Teal 1974). Ammonium accumulates in soils at an Eh of approximately 220 mV or less (Mitsch and Gosselink 1986). Soil conditions at the surface and 15 cm deep were within this range on all sample dates in the unmanaged marsh, as were conditions in the 15-cm-deep soils in the managed marsh (figure 126B-C). The surface soils of the managed marsh were also at or below 220 mV in August, October, and November. Koch and Mendelssohn (1989) reported increased interstitial ammonium in sods of S. alterniflora with the addition of sulfides and attributed the increase to reduced plant uptake. Higher P concentrations may be attributed to the increased solubility of P under anaerobic conditions (Redman and Patrick 1965) and low concentrations of iron for precipitation of P in the unmanaged marsh. Our data support these conclusions since we observed lower ammonium (figure 129) and P in the managed marsh, which had less-reduced conditions, virtually no sulfide, and greater biomass production.

Averaged over all treatments, interstitial water in the unmanaged marsh was more saline than that in the managed marsh (treatment significant, $p = .0001$). The effect of marsh management on interstitial water salinity varied with month (treatment × month interaction significant, $p = .0001$, figure 130A) and with burning (burn × month interaction significant, $p = .0041$, figure 131A). The highest salinities detected in either marsh were measured in May (managed, 5 ± 0.5 ppt; unmanaged, 10 ± 1.0 ppt). Salinities decreased significantly in August in both marshes (figure 130A). Although salinity remained unchanged in the managed marsh on the last two sample dates, it increased in October in the unmanaged marsh. Burned areas had significantly higher salinities than unburned areas in August and October, but did not significantly differ in May and November (figure 131A). Salinity levels were lowest in the unburned areas in August. Salinity levels were not significantly different in the unburned areas in May, October, and November. Salinity levels did not differ significantly within the burned areas on any of the sampling dates.

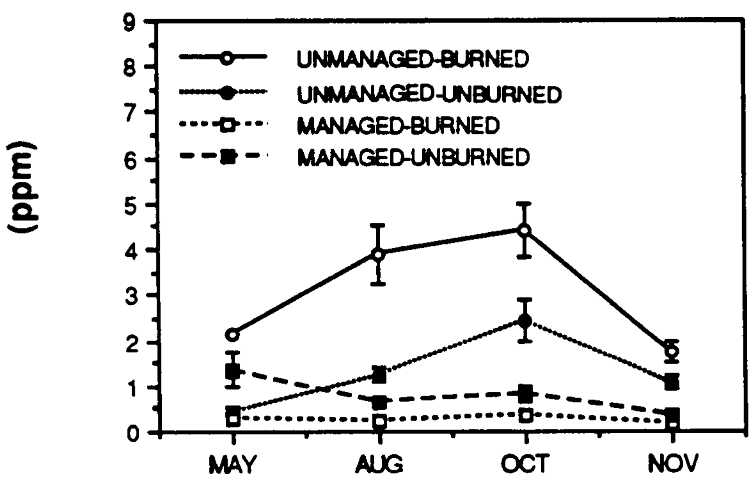

Figure 129. Interstitial water NH_4-N in an unmanaged (burned and unburned) and a managed (burned and unburned) marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

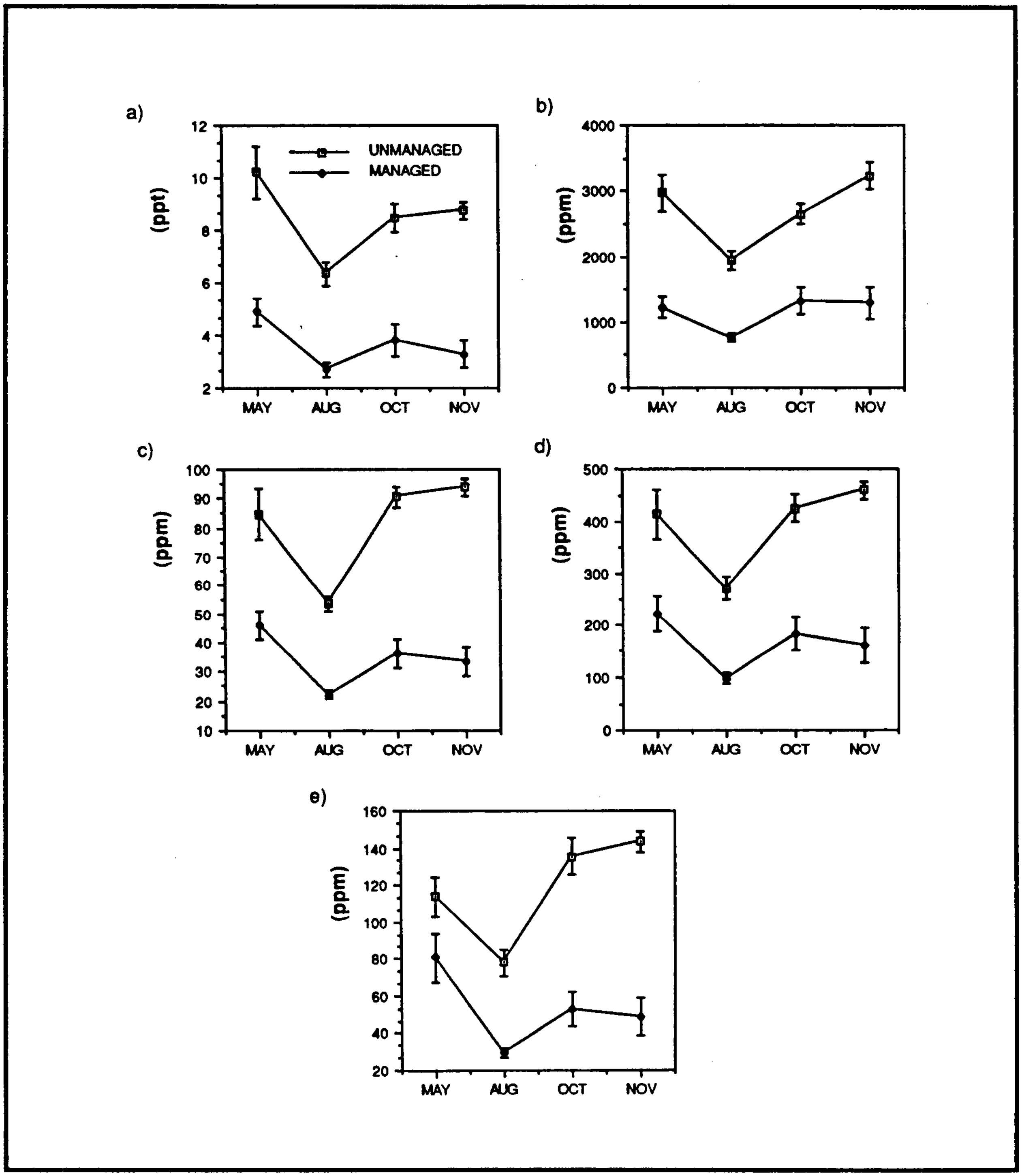

Figure 130. Interstitial water (a) salinity, (b) sodium, (c) potassium, (d) magnesium, and (e) calcium, measured over time in an unmanaged and a managed marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

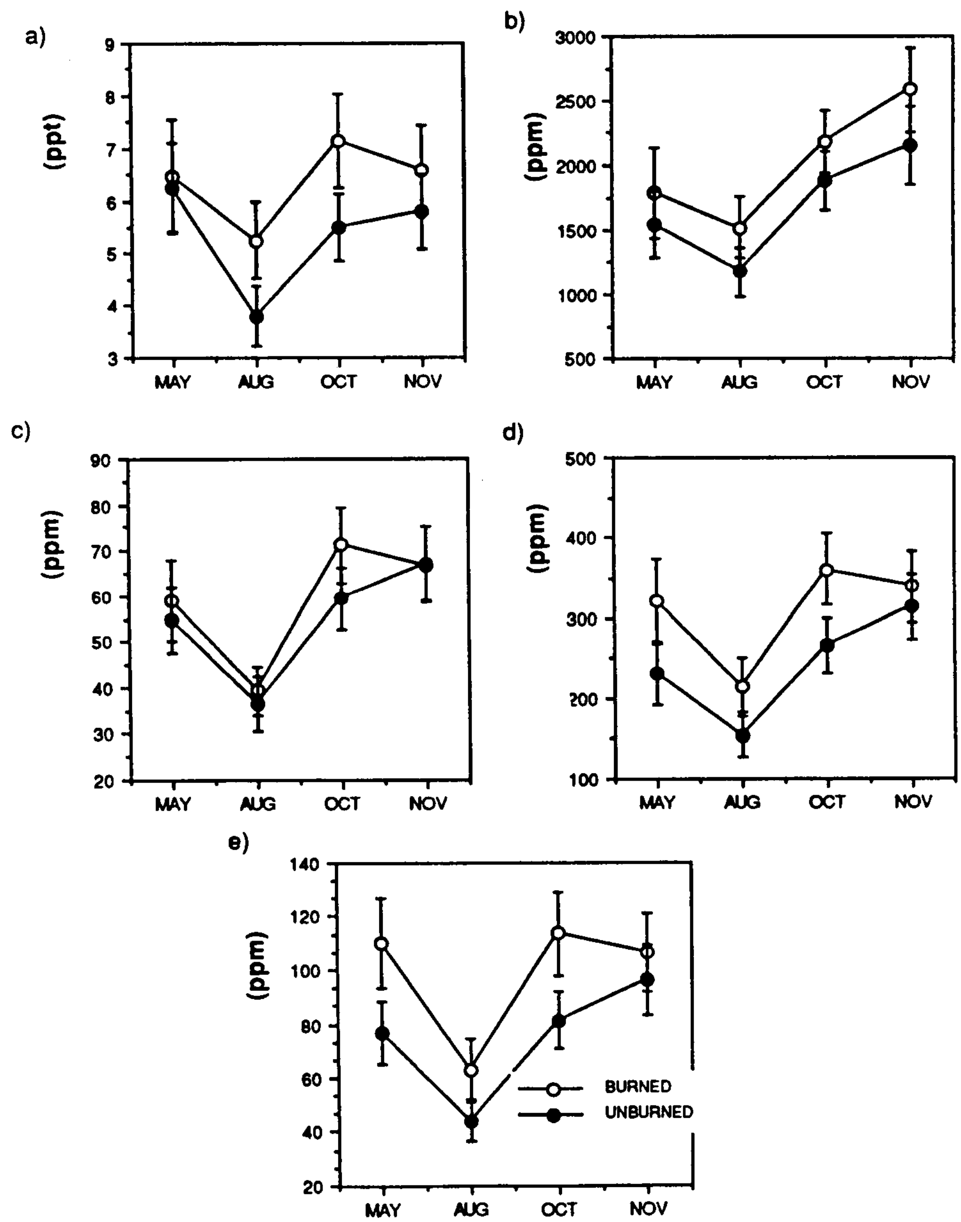

Figure 131. Interstitial water (a) salinity, (b) sodium, (c) potassium, (d) magnesium, and (e) calcium, measured over time in burned and unburned marshes at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

The primary cations (Na, K, Ca, Mg) of seawater exhibited similar responses to the treatments as salinity (figures 130A-E, 131A-E). Averaged over time, the unmanaged marsh had higher concentrations of K, Na, Ca, and Mg (treatment significant, p = .0001 for all four macronutrients). The effect of marsh management on K, Na, Ca, and Mg varied with month (treatment × month interaction significant, p = .0001 for all four macronutrients, figures 130B-E) and with burning (burn × month interaction significant, [K, p = .0008; Na, p = .0281; Ca, p = .0001; Mg, p =.0001], figure 131B-E). On average, burned areas had higher concentrations of Na, P, Ca, and Mg than unburned areas.

Salinity, Na, K, Mg, and Ca behave similarly within the managed and unmanaged marshes (figures 130, 131). Restricting tidal waters from the managed marsh resulted in a less saline environment. The decrease in the concentration of all five of these variables in both the managed and unmanaged marshes in August was related to the heavy precipitation prior to the August sampling period (Richard 1990). Subsequent increases in salinity, Na, K, Mg, and Ca in the unmanaged marsh were probably due to tidal inundation with more saline water. Salinity increases in the managed marsh were due to a decrease in water level (figure 126A) via drainage through opened flap gates and evapotranspiration. Sodium, K, Mg, and Ca are all components of seawater and, as such, were more highly concentrated in the tidally influenced unmanaged marsh than in the more tidally restricted managed marsh. Differences in Na, Mg, and Ca associated with burning (figure 131B-E) may be due to the release of these elements from burned plant tissue.

Averaged over all treatments, the managed marsh had higher concentrations of Fe (9.386 ± 1.57 ppm) than did the unmanaged marsh (0.5022 ± 0.0731 ppm), (treatment significant, p = .0001). The effect of marsh management on Fe concentration varied with month (month × treatment interaction significant [P=0.0006], figure 132A) and with burning (treatment × burn interaction significant, p = .0506, figure 132B). Iron concentrations were low in both the managed and unmanaged marshes in May. While no significant changes in Fe concentrations occurred in the unmanaged marsh during the investigation, concentrations of Fe increased twelvefold in the managed marsh from May to August. No significant differences in Fe concentrations were detected between August and October in the managed marsh; however, Fe concentrations decreased by 64% from October to November. Iron concentrations were not different between the burned and unburned areas in the unmanaged marsh. However, in the managed marsh, Fe concentrations were greater in the burned area than in the unburned area (figure 132B).

Iron is reduced from the ferric to the ferrous form at an Eh of approximately 120 mV or less. At this level of soil reduction, both Fe and Mn act as electron acceptors. Soils that initially have lower pH, such as those in the managed marshes, tend to have a greater release of ferrous Fe when flooded than do soils with higher initial pH (Redman and Patrick 1965). When redox potentials are low enough for sulfide to form, reducible Fe compounds in the soil will precipitate with sulfide to form insoluble ferrous sulfide (FeS) (Gambrell and Patrick 1978; Patrick and Mikkelsen 1971). In the unmanaged marsh, soil conditions are reduced enough for the formation of ferrous Fe and sulfide. However, while sulfide concentrations are, on average, 11.7 ppm in the unmanaged marsh, the scarcity of Fe indicates that Fe was precipitated from solution as insoluble FeS. Ferrous sulfide gives soils a gray or black color (Ponnamperuma 1972), such as was observed in the unmanaged marsh. In the

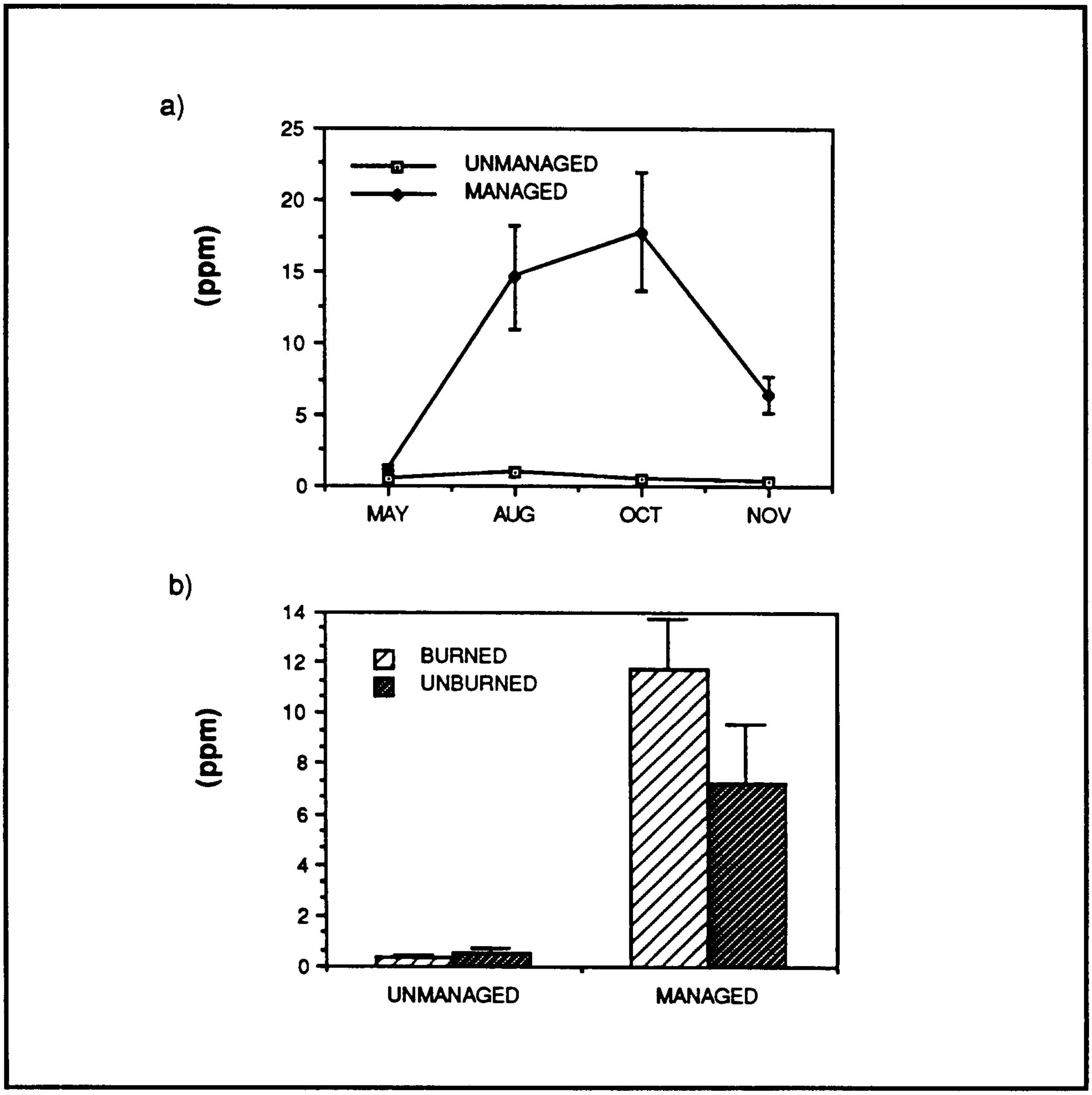

Figure 132. (a) Interstitial water iron in an unmanaged and a managed marsh over time and (b) in an unmanaged (burned and unburned) and a managed (burned and unburned) marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

managed marsh, there was virtually no sulfide even though soil conditions were reduced enough for sulfide formation. As a result, iron levels were relatively high (figure 132B).

The effect of marsh management on Mn varied with month (treatment × month interaction significant, $p = .0232$, figure 133). Whereas the managed marsh had higher concentrations of Mn than the unmanaged marsh in May, the reverse was true in August, October, and November. Concentrations of Mn in both marshes decreased in November. Burning did not affect Mn ($p = .7452$). Manganese can, in the presence of sulfide under anaerobic conditions, precipitate as insoluble MnS (Engler and Patrick 1975).

The managed marsh had greater concentrations of Zn (0.0642 ± 0.0093 ppm) than the unmanaged (0.0223 ± 0.0055 ppm) marsh (treatment significant, $p = .0054$), and this response did not differ with month. Overall, significant differences in Zn concentrations occurred with month (month significant, $p = .0022$). The highest concentrations of Zn were detected in May, and these steadily decreased through October (figure 133B). Burned and unburned areas had similar Zn concentrations ($p = .2451$). Concentrations of Cu ($p = .1075$) were not different between the managed and unmanaged marsh. The overall effect of flooding upon Zn and Cu is a decrease in solubility (Ponnamperuma 1972). The presence of sulfide could have affected Zn and Cu concentrations through formation of ZnS and CuS (Engler and Patrick 1975).

Vegetation response. The effect of marsh management on stem density varied with month (month × treatment interaction significant, $p = .0006$). Stem density was significantly greater in the unmanaged marsh in May, but no significant differences between marshes occurred in the other months (table 69). Burning did not affect stem density ($p = .2180$). Leaf area was greater in the managed marsh (1.33 ± 0.08) than in the unmanaged marsh (0.33 ±0.03) throughout the investigation (treatment significant, $p = .0001$, figure 134A). No significant differences in leaf area occurred with time in either marsh during the investigation ($p = .6086$), and burning had no effect on leaf area ($p = .7809$).

When averaged over all treatments, live aboveground biomass was three times greater in the managed marsh (2040.0 ± 135.4 g m^{-2}) than in the unmanaged marsh (687.7 ± 56.3 g m^{-2}) (treatment significant, $p = .0001$). The effect of marsh management on live biomass, however, varied with month and burning (month × treatment × burn interaction significant, $p = .0298$, figure 134B). In May, live biomass was similar in all areas except in the unmanaged burned marsh. However, this point was based on only one sample (see methods). Live biomass increased in the managed marsh from May to August in both the burned and unburned areas. Live biomass decreased from October to November in the managed burned marsh, and biomass in the unburned area was therefore significantly greater in November. Live biomass did not significantly differ over time or between burned and unburned areas in the unmanaged marsh. *S. patens* made up 82-99% of the live vegetation in the unmanaged clip plots and 92-97% of the live vegetation in the managed clip plots at Rockefeller.

More dead aboveground biomass was present in the managed marsh (1325.6 ± 178.6 g m^{-2}) than in the unmanaged marsh (590.2 ± 68.1 g m^{-2}) (treatment significant, $p = .0348$). Dead biomass was significantly greater in November than in May (month significant, $p = .0348$) and was greater when burning did not occur (burn significant, $p = .0001$, figure 135A-B). The unburned managed marsh

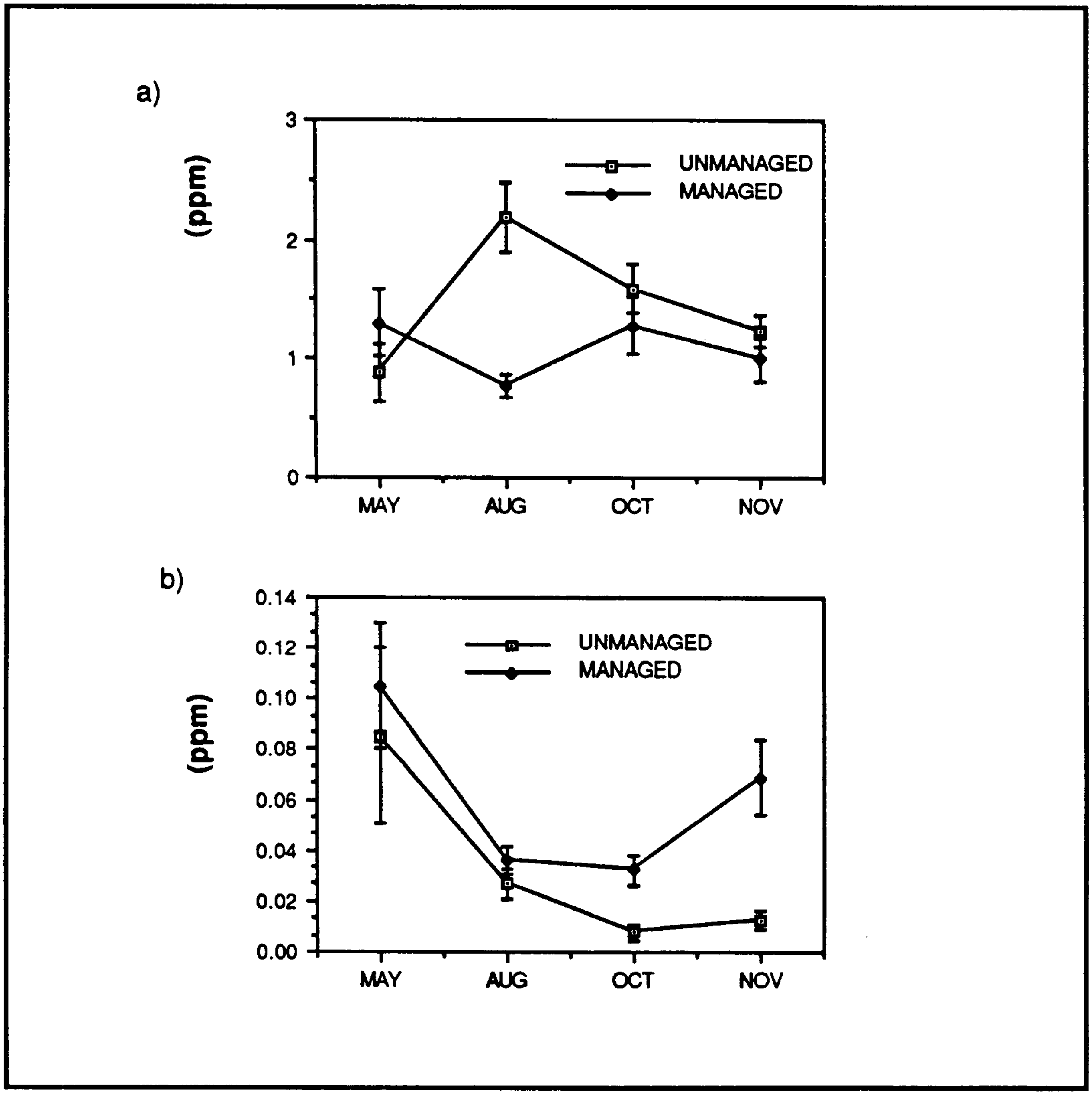

Figure 133. Interstitial water (a) manganese and (b) zinc measured over time in an unmanaged and a managed marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

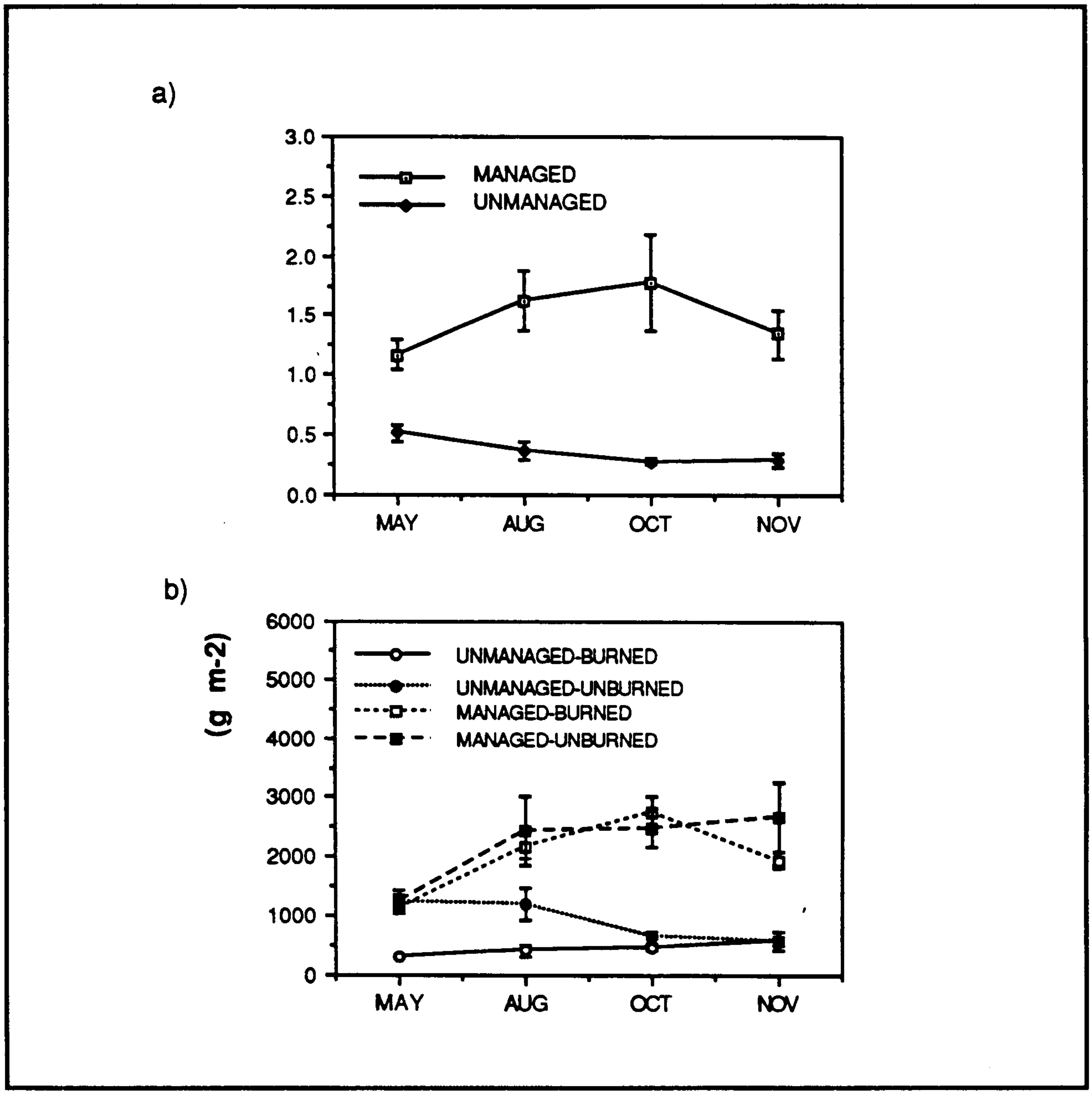

Figure 134. Spartina patens (a) leaf area measured over time in an unmanaged and a managed marsh and (b) live biomass measured over time in an unmanaged (burned and unburned) and a managed marsh (burned and unburned) at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

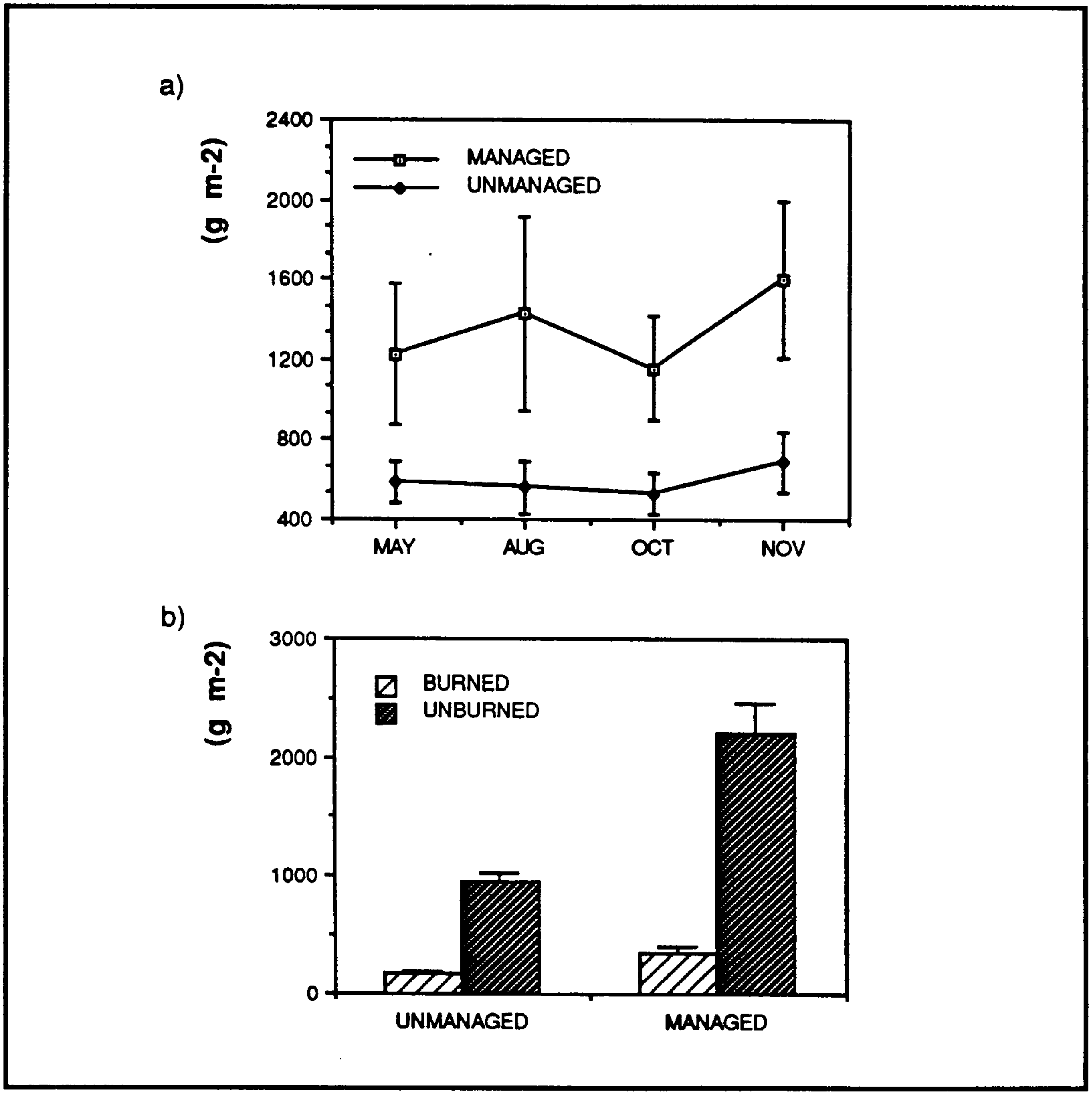

Figure 135. Spartina patens dead aboveground biomass measured in (a) an unmanaged and a managed marsh over time and (b) in an unmanaged (burned and unburned) and a managed (burned and unburned) marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

Table 69. Stem densities of *Spartina patens* in the managed and unmanaged marshes at Rockefeller Refuge, Cameron-Vermilion parishes, Louisiana, during 1989.

Month	Stem Densities ($g\ m^{-2}$)	
	Unmanaged	Managed
May	187 ± 34	105 ± 10
August	107 ± 18	94 ± 11
October	111 ± 7	128 ± 10
November	117 ± 14	136 ± 12

had greater dead biomass than the burned managed marsh or the unmanaged marsh (burned and unburned, treatment × burn significant, p = .0485, figure 135B).

Total aboveground biomass, when averaged over all sample dates and burning, was 2.5 times greater in the managed marsh than in the unmanaged marsh (treatment significant, p =.0001). Burning resulted in an average of 51% less total biomass (burn significant, p = .0002), primarily because of its effect on the dead component. Total biomass exhibited a seasonal trend; the lowest amounts occurred at the beginning and end of the growing season (month significant, p = .0094, figure 136).

The managed marsh had greater net primary productivity than the unmanaged marsh (treatment significant [maximum-minimum, p = 0.0053; Smalley, p = .0422; Milner and Hughes, p = .0049, table 70). Estimates of total net primary production differed with the method used. The Smalley method, which accounts for plant mortality between sampling intervals, yielded a higher estimate than the maximum-minimum method or the Milner and Hughes method, which do not account for plant mortality between sampling intervals. No significant differences in productivity were associated with burning (maximum-minimum, p = .2145; Smalley, p = .4060; Milner and Hughes, p = .6708).

The effect of marsh management on leaf CO_2 exchange rates varied with month (month × treatment interaction significant, p = .0005, figure 137A). Since the covariable, hour, did not significantly affect leaf CO_2 exchange rates (p = .1515), values are not adjusted for the time of day when measurements were made. The relatively high leaf CO_2 exchange rates measured in both the managed and unmanaged marshes in May were not significantly different. In August, the rate of leaf CO_2 exchange in the managed marsh was less than the rate in the unmanaged marsh. In October, however, the exchange rate was greater in the managed marsh. Both marshes had the same rate of leaf CO_2 exchange in November (figure 137A). Whereas leaf CO_2 exchange rates in the unmanaged marsh decreased steadily from May to November, the leaf CO_2 exchange rates measured in the managed marsh fluctuated from month to month and decreased significantly overall. Burning had no significant effect on leaf CO_2 exchange rates in either the managed or unmanaged marsh (p = .9704).

Total CO^2 exchange rates, when averaged over all sampling dates, were significantly higher in the managed marsh than in the unmanaged marsh (treatment significant, p = .0001, figure 137B). Since the covariable, hour, did not significantly affect total CO^2 exchange rates (p = .9133), we did not adjust values for the variation associated with time of day. Total CO^2 exchange rates decreased over time in both the managed and unmanaged marshes (treatment × month interaction significant, p = .0018). As with leaf CO_2 exchange rates, this decline was steady in the unmanaged marsh but fluctuated in the managed marsh (figure 137B). In the managed marsh, the highest total CO^2 exchange rates were measured in May and October, and the lowest were measured in November. Burning did not affect total CO^2 exchange rates (p = .2800).

The observed differences in total CO_2 exchange rate were due not to higher rates of CO^2 exchange per unit area of leaf, but to the greater leaf area in the managed marsh as compared to the unmanaged marsh (figure 134A). Interestingly, burning the marsh did not result in differences in total CO^2 exchange rate or leaf area between the burned and unburned areas in either the managed or unmanaged marshes. The 50% decline in leaf (figure 137A) and total (figure 137B) CO^2 exchange rates in the managed marsh from May to August may have been the result of the large increase in water level (figure 126A) and the associated

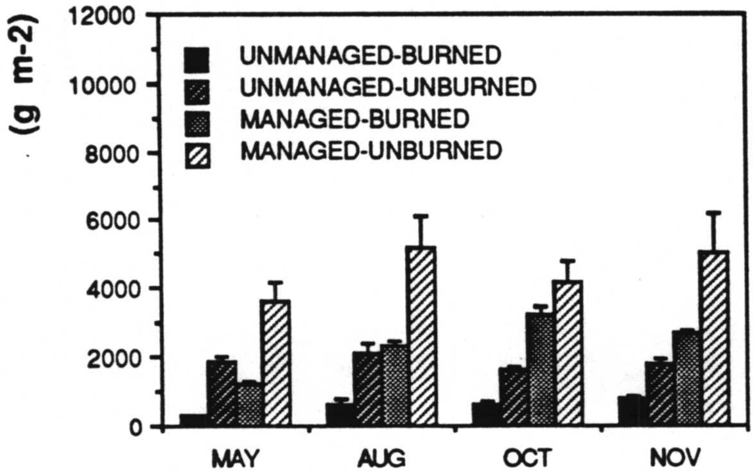

Figure 136. Spartina patens total aboveground biomass in an unmanaged (burned and unburned) and in a managed (burned and unburned) marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

Table 70. Estimates of net primary productivity (g m^{-2}) of *Spartina patens* in managed and unmanaged marshes at Rockefeller Refuge, Cameron-Vermilion parishes, Louisiana, during the 1989 growing season.

Site	n	Net Primary Productivity (g m^{-2})		
		Max-Min	Smalley	Milner-Hughes
Managed	8	2,373.5 ± 319.7[a]	4,252.7 ± 1,135.1[a]	2,414.7 ± 310.4[a]
Unmanaged	6	905.9 ± 158.3[b]	921.5 ± 355.9[b]	403.7 ± 284.7[b]

[a]Means with different letters are significantly different from each other ($p < .05$).

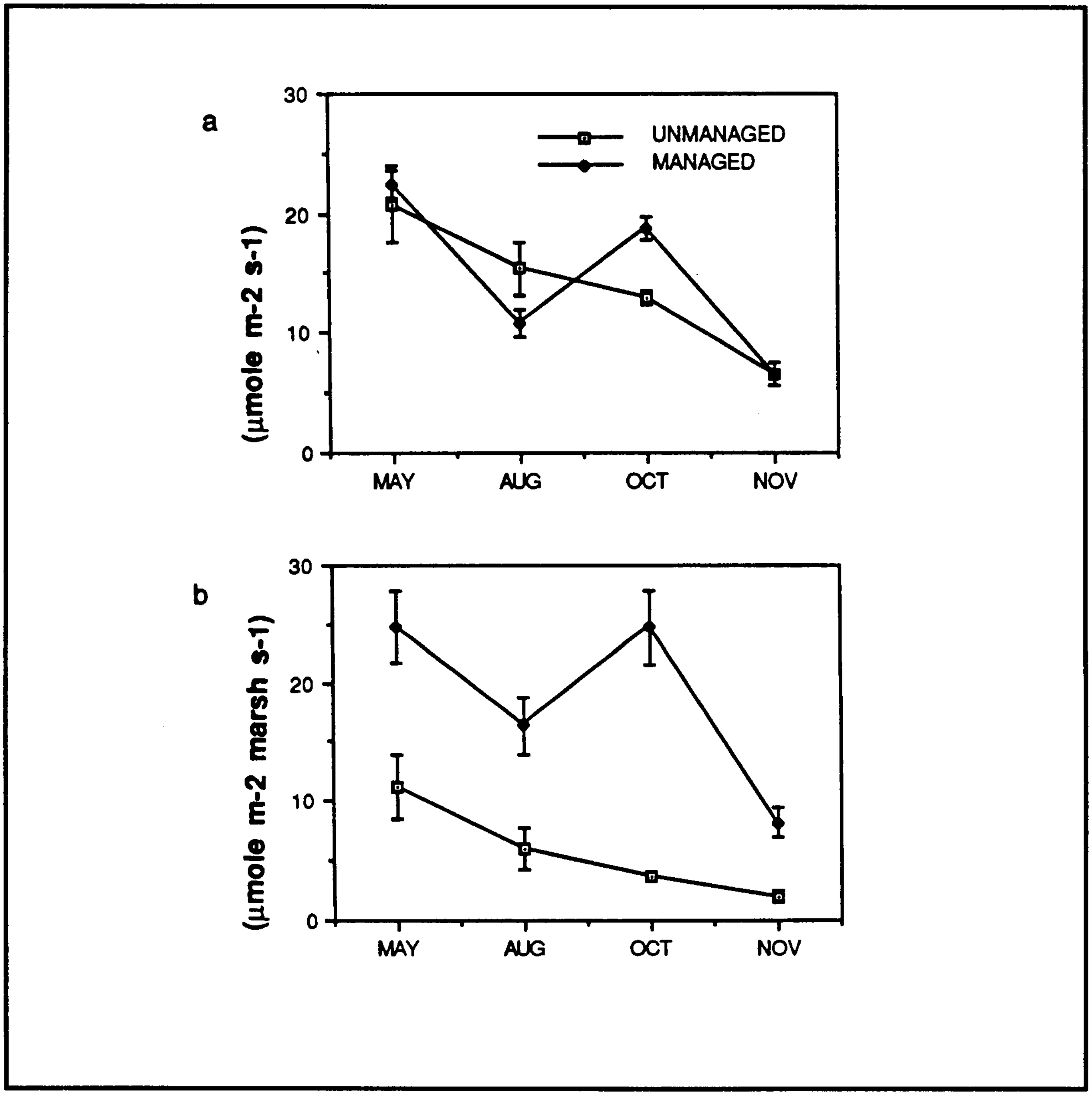

Figure 137. (a) Leaf CO_2 exchange rates and (b) total CO_2 exchange rates for Spartina patens in a managed and an unmanaged marsh at Rockefeller Refuge in Cameron-Vermilion parishes, Louisiana, in 1989 (± 1 S.E.).

decrease in surface and 15-cm Eh between May and August (figure 126B-C). Pezeshki et al. (1989) reported a temporary decrease in photosynthesis of Spartina alterniflora with development of reduced soil conditions.

Turitzan and Drake (1981) reported a seasonal decline in the photosynthetic efficiency of S. patens and Distichlis spicata in a Chesapeake Bay saline marsh. They attributed part of this decline to natural seasonal changes in the canopy structure. As fall approached, the canopy changed from an erect to a horizontal orientation, which resulted in a change in light distribution within the canopy. De Jong et al. (1982) also observed a seasonal decline in the photosynthesis of S. patens. They reported a stronger seasonal decline in S. patens than in either Scirpus olneyi or D. spicata, though all three species had similar in situ CO_2 exchange rates on a leaf area basis.

The soil parameters monitored during this investigation (Eh, interstitial water salinity, sulfide concentrations, and water level) indicate that soil conditions were more favorable for vegetation in the managed marsh than in the unmanaged marsh. Water levels were lower and conditions less reduced at the surface and at 15 cm deep in the managed marsh than in the unmanaged marsh (figure 126A-C). Because of the more aerobic soil conditions in the managed marsh, plant roots should have sufficient oxygen for aerobic respiration. However, the more reduced conditions in the unmanaged marsh could result in root oxygen deficiencies, as demonstrated by Burdick et al. (1989) for S. patens. Root oxygen deficiencies result in alcoholic fermentation, which is less energy efficient than aerobic respiration as the primary pathway for carbon metabolism.

Salinity (figure 130A) and sulfide concentrations (figure 128) were lower in the managed marsh than in the unmanaged marsh. This was due to the unrestricted tidal flooding of Gulf waters into the unmanaged marsh, which introduced both salt and sulfate into the marsh. The management plan used at unit 4 reduces this free influx of Gulf waters. In addition, precipitation can be retained within unit 4 and dilutes Gulf waters intruding when the management area is flooded. The reduced conditions in the unmanaged marsh allow the reduction of sulfate to hydrogen sulfide. Although sulfide concentration in the unmanaged marsh was not exceptionally high, a potential for sulfide toxicity in the unmanaged marsh compared to the managed marsh cannot be completely ruled out.

High interstitial salinity has been associated with decreases in net photosynthesis and productivity in S. patens (Pezeshki et al. 1988a). In addition, sulfide has been linked to decreased rates of photosynthesis in S. alterniflora (Pezeshki et al. 1988b) as well as decreased growth in this species (King et al. 1982; Koch and Mendelssohn 1989; Mendelssohn and McKee 1988). Sulfide-induced inhibition of photosynthesis and reduced growth are related to decreased nitrogen uptake (King et al. 1982; Koch and Mendelssohn 1989; Mendelssohn et al. 1982). The higher interstitial ammonium and sulfide concentrations along with the lower leaf and total CO_2 exchange rates measured in the unmanaged marsh as compared to the managed marsh agree with these conclusions. In addition, Koch et al. (in press) reported that sulfide inhibited the activity of alcohol dehydrogenase, an enzyme important in alcoholic fermentation, in S. alterniflora and P. hemitomon, which resulted in a reduced capacity for the anaerobic generation of energy needed for nutrient uptake under reduced soil conditions.

The management regime at unit 4 of Rockefeller Refuge has produced an environment more favorable to emergent vegetation than that of the unmanaged marsh bordering Little Constance Bayou. Results reported herein support this conclusion on several levels--total CO_2 exchange rates, leaf area m^{-2} marsh, biomass measurements (live, dead, and total biomass), and three methods of estimating net primary productivity. The favorable environment is apparently the result of the interaction of several edaphic factors ultimately controlled by water level: soil Eh, interstitial sulfide concentration, and salinity.

Summary

The following is based on data collected during a drawdown year only. Drawdowns have occurred usually every fourth year at Rockefeller Refuge, while at Fina LaTerre a drawdown has been implemented every year since management began in 1985. For the Fina LaTerre site, the conclusions pertain only to the southern portion of the managed area and the unmanaged reference area south of Falgout Canal.

Fina LaTerre

1. At Fina LaTerre the managed marsh had more organic soils, more reduced soil conditions, and higher interstitial salinities than in the adjacent unmanaged marsh in the 1989 growing season.

2. Net aboveground primary productivity of Spartina patens at Fina LaTerre was lower in the managed marsh, which had more reduced soil conditions and higher salinities, than in the adjacent unmanaged marsh during the 1989 growing season. In addition, stem density, leaf area, and live biomass of S. patens were greater in the unmanaged marsh during the 1989 growing season.

3. Leaf CO_2 exchange rate (per unit area of leaf surface) and total CO_2 exchange rate (per unit area of marsh surface) of S. patens were greater in the unmanaged marsh than in the managed marsh at Fina LaTerre during the 1989 growing season.

4. Although we cannot unequivocally state the reason for the lower primary productivity in the managed marsh compared to the unmanaged marsh, the more reduced soil conditions in the managed marsh is a likely factor. Although interstitial salinity levels were, on average, statistically significantly higher in the managed marsh, the difference was not great enough to be ecologically significant.

Rockefeller Refuge

1. The managed marsh at Rockefeller had less reduced soil conditions, lower interstitial salinity, and lower interstitial sulfide concentrations than did the unmanaged marsh during the growing season of 1989.

2. Net aboveground primary productivity of Spartina patens was three times greater in the managed area at Rockefeller than in the unmanaged area, probably because of the more favorable edaphic factors in the managed area during the 1989 growing season. In addition, leaf area and live biomass of S. patens were greater in the managed marsh than in the unmanaged marsh at Rockefeller during the 1989 growing season.

3. Total CO_2 exchange rates of S. patens were higher in the managed marsh than in the unmanaged marsh at Rockefeller Refuge during the 1989 growing season.

Conclusion

Water level marsh management, based on the two management areas investigated in this study, can either have a positive or negative effect on the productivity of Spartina patens. The cause or causes for this differential response cannot be stated unequivocally, but we hypothesize that the ability to create less biochemically reduced soil conditions during management, within a non-growth-limiting salinity range, is central to maintaining vigorous stands of Spartina patens within managed marshes.

EFFECTS OF THE FINA LATERRE MARSH MANAGEMENT PLAN ON FISHES AND MACROCRUSTACEANS

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Introduction

In Louisiana, several types of water control structures have been used in marsh management plans. The use of fixed-crest weirs has the longest history, and their effects on fisheries have been studied the most. The standard fixed-crest or Wakefield weir used extensively in Louisiana is a low-level dam, with the crest set approximately 15 cm below mean marsh soil level. These weirs have been used with and without levees and with partial levees. Herke (1971) used the term "semi-impounded" for an area under the influence of a fixed-crest weir because when the water level is above the weir crest, water exchange can occur into or out of the area. When the water drops to the level of the crest, such as at low tide, the area is impounded. To date, nearly 2,000 km^2 of Louisiana marsh are, or will soon be, semi-impounded (Knudsen et al. 1985).

Many studies have suggested or shown that fixed-crest weirs interfere with immigration and emigration of marine organisms. Burleigh (1966) used a trammel net to study the effects of Wakefield weirs on the distribution of fishes and the blue crab Callinectes sapidus in brackish marsh bordering Lake Borgne, Louisiana. He concluded that weirs affected distribution of some species, but apparently did not affect others.

Herke (1968), using small-mesh trawls to sample the distribution of fisheries species in an area east of Calcasieu Lake in Louisiana, found that weirs may be a behavioral barrier or may physically prevent movement of fish and crustaceans. He suggested that the effects of weirs may range from not measurable, to beneficial, to harmful, depending on the species.

In another study, Herke (1971) collected organisms by trawling in unimpounded and semi-impounded areas in the Biloxi Wildlife Management Area and the Marsh Island area in Louisiana. He found that semi-impoundment appeared to delay recruitment and emigration of organisms associated with the bottom, such as spot (Leiostomus xanthurus) and shrimp (Penaeus spp.), but not of surface-favoring organisms, such as anchovies (Anchoa spp.) and gulf menhaden (Brevoortia patronus). The submerged aquatic vegetation of semi-impoundments also appeared to affect organism distribution, favoring some and not others. He noted that the average weight of organisms from weired areas was equal to or greater than that of organisms from natural marshes.

Weaver and Holloway (1974) sampled with surface and otter trawls in semi-impounded and unimpounded marsh areas at Marsh Island. The average catch per trawl, by number, was greatest in the unimpounded areas by surface trawl and in the weired, vegetated areas by otter trawl. The average catch per trawl, by weight, was greatest in the unimpounded areas by both gears. They found that the numbers were probably greater in the weired vegetated areas because of the smaller sizes caught up in the vegetation that clogged the net. They suggested that habitat changes induced by weirs, such as the development of extensive submerged aquatic vegetation, may prevent maximum use of semi-impounded areas by commercial species such as gulf menhaden, Atlantic croaker (Micropogonias undulatus), spot, and white shrimp (Penaeus setiferus) that are more typical of open waters.

Bradshaw (1985) and Herke and Bradshaw (1985) compared relative abundances of post-larval and small juvenile brown shrimp (Penaeus aztecus) and white shrimp in semi-impounded and unimpounded areas at Sabine National Wildlife Refuge in southwestern Louisiana. Total and average post-larval shrimp catches were greatest in the unimpounded ponds during both years of the study. Differences between disparity of catches between the ponds in successive years suggested that variation in environmental conditions may mitigate weir effects.

Herke et al. (1987c) collected four times more brown shrimp in natural marsh areas than in semi-impoundments. The weirs apparently interfered with tidal processes that carry post-larval shrimp into the marsh. Recruitment of post-larval brown shrimp into the semi-impounded marsh was delayed; shrimp in the natural area were recruited primarily as postlarvae, whereas juveniles and subadults were generally recruited into weired areas. Emigration of shrimp from the semi-impounded area was delayed, and shrimp there grew larger before emigrating than shrimp in the natural marsh.

Herke et al. (1987a,b) conducted a two-year study of two nearly identical ponds east of Calcasieu Lake in Louisiana. They placed a fixed-crest weir in the opening of one pond and no structure in the opening of the other. They collected everything too large to pass through 5.2-mm^2 mesh openings that emigrated from both ponds for a year. The weir was then switched to the unweired pond, and the study was repeated for a second year to determine whether differences seen were due to the weir and not to minor differences between ponds. During both years, the fixed-crest weir severely reduced the number and total weight of emigrating estuarine-dependent species. The number of species collected in each area also varied. They collected 90 species from the unweired pond and 70 species from the weired pond during the first year of the study. Results were similar the second year; 92 species were collected from the unweired pond, and 69 from the weired pond. Because of a surveying error, the weir in this study was placed 15 cm lower than a standard fixed-crest weir; had the crest been set at normal level, the effects of the weir probably would have been much greater.

Chabreck and Hoffpauir (1965) suggested that ponds and lakes affected by weirs are ideal nursery grounds for penaeid shrimp and provide good fishing by concentrating fish. These conclusions, however, appear to be based on casual observations rather than scientific studies.

Perry (1981) studied distribution of brown and white shrimp in semi-impounded areas and concluded that the weir did not prohibit movements of shrimp. Wicker et al. (1983) found that trawl samples from a brackish-water impoundment at Rockefeller Wildlife Refuge indicated that the weired area allowed normal ingress of several estuarine-dependent species from the Gulf. Neither of these studies, however, included an unweired control area for comparison.

Herke (1971) and Weaver and Holloway (1974) found that species were generally not completely excluded from semi-impounded areas or completely prevented from emigrating unless the water levels did not exceed weir crest level for long periods. Fixed-crest weirs generally do not represent an absolute barrier, but delay immigration and emigration and reduce recruitment of many species.

One alternative to the fixed-crest weir is the slotted weir, which can be closed off using a gate or stoplogs. Rogers et al. (1987) compared an experimental passively operated slotted weir containing a 10-cm-wide vertical slot with a fixed-crest weir on the same paired ponds that Herke et al. (1987a,b) had studied. Trap catch of brown shrimp from the slotted weir was over 2.4 times greater than that from the identical pond with a fixed-crest weir. Rogers et al. (1987) reported that during a six-month period, 57 species emigrated from the slotted-weir pond, whereas 42 species emigrated from the pond with the fixed-crest weir. Equal trawling effort in these ponds and a nearby unweired control pond collected 46 species in the control pond, 29 species in the slotted-weir pond, and 27 species in the pond with the fixed-crest weir. This indicates that the slotted weir allowed more species to use the weired area than the area controlled by the fixed-crest weir, but the unweired pond allowed more species to use the area than either pond affected by a structure.

Rogers and Herke (1985) studied movements of fishes and crustaceans in canals at Sabine National Wildlife Refuge before the installation of slotted weirs with radial arm gates. Their goal was to determine how to manage these structures to least impede movements. They determined that closing the structures at any time of the year would interfere with the movements of some important estuarine-dependent species. Their primary recommendation was that the gates be left open as often as possible.

The rock weir, an alternative weir design, is currently being used in experimental management at the National Audubon Society's Paul J. Rainey

Wildlife Sanctuary in south central Louisiana. The riprap can be piled to give an effective height approximating that of a fixed-crest weir. The rock weir theoretically allows movement of organisms at all levels (through the spaces between the rocks and over the top), yet restricts water flow into and out of the area. The rock weir enables flexible management; rocks can be added or removed to control water movement. Rogers (1989) studied the effects of a rock weir, a standard fixed-crest weir, and no structure on fishery communities. Although the three areas had differences in elevation and submerged aquatic vegetation, she concluded that the rock weir was more effective than the fixed-crest weir in terms of hydrology and species composition, but more restrictive than no weir.

The variable-crest weir is another type of alternative structure. In Louisiana, the maximum height of a variable-crest weir is generally 15 cm below mean marsh soil level, making it effectively equivalent at that level to a fixed-crest weir.

Variable-crest weirs with flap gates are presently in limited use in Louisiana. Wicker et al. (1983) reported on a multi-use (estuarine fisheries and waterfowl) impoundment at Rockefeller State Wildlife Refuge and Game Preserve. A variable-crest, flap-gated structure was used to allow the ingress of post-larval brown shrimp and white shrimp into the impoundment. They reported that significant numbers of organisms could be introduced into the impoundment without greatly increasing water levels. The organisms were allowed to emigrate through the flap gates at low tide. They noted that fewer species were collected inside the impoundment (24) than outside (33).

Marsh management is currently leaning toward the use of more manageable water control structures such as variable-crest weirs, flap-gated structures, and slotted weirs.

Objectives

The Fina LaTerre marsh management plan utilizes a variable-crest, flap-gated structure and several fixed-crest weirs in an active management scheme. This study was designed to compare the fish and macrocrustacean community within the Fina LaTerre marsh management plan area with the community in the unmanaged marsh outside the plan area.

Methods and Procedures

The large amounts of submerged aquatic vegetation, shallow water depths, and the very soft bottom in much of the managed area created difficulties in sampling. Attempts at trawling were made with five or six different experimental trawl designs before a suitable trawl was found. The trawl, designed to be pulled alongside an airboat, was used to sample at all stations (figure 138). The trawl had an opening 0.43 m high and 1.5 m wide. The trawl frame was constructed of 1" PVC pipe, 3/4" x 3/4" x 1/8" angle iron, and 1" x 8" treated lumber for the frame skids. Three bars of 1" PVC pipe were spaced 10 cm apart across the mouth of the trawl to keep rooted aquatic vegetation from being pulled up and into the trawl. The trawl net had 9.5-mm (3/8") knotless

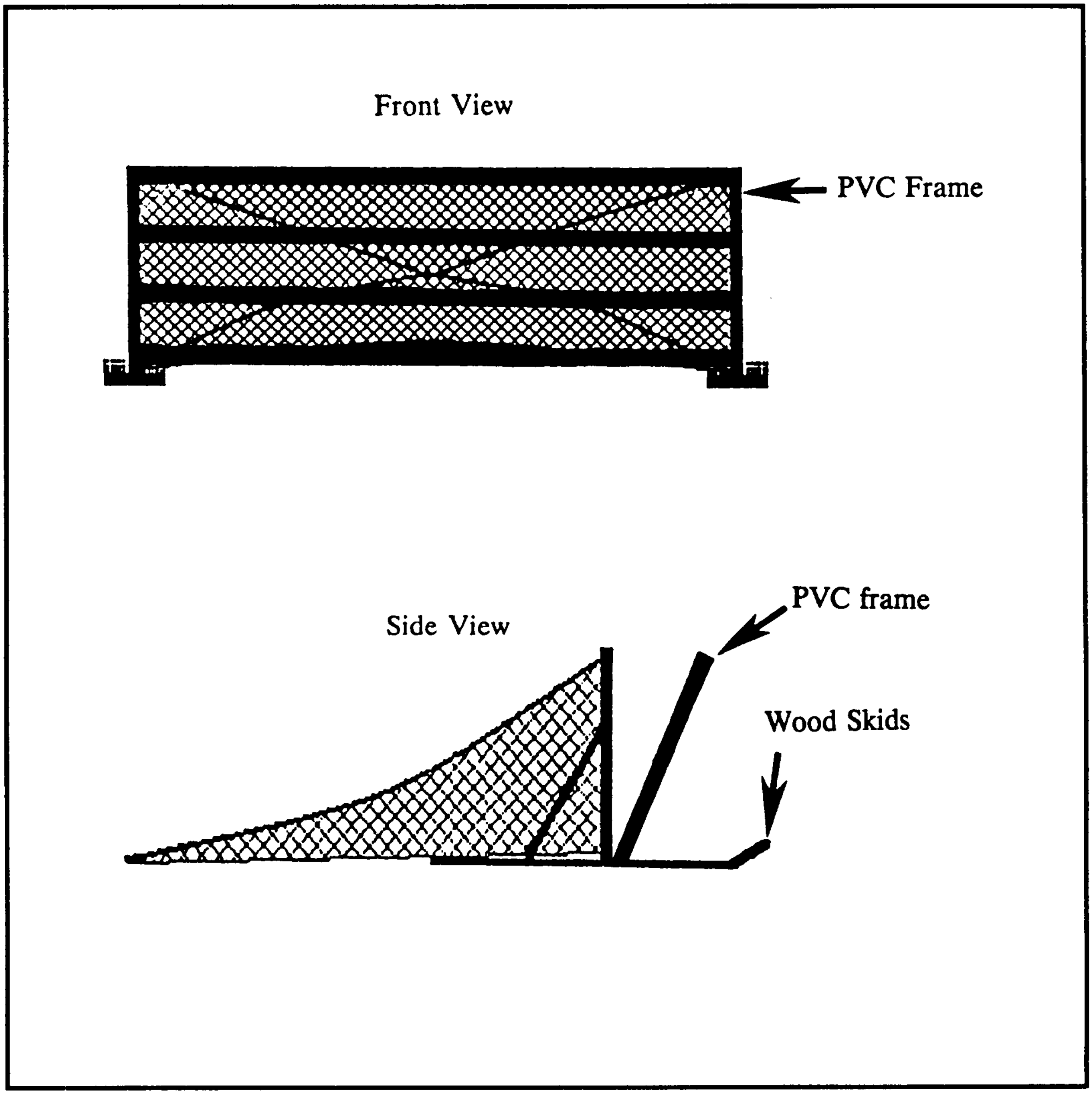

Figure 138. The trawl used in the study.

nylon mesh in the body and 6.4-mm (1/4") knotless nylon mesh in the cod end, and extended 2.6 m behind the mouth.

The stations in both areas were selected to be representative of as much of both areas as was possible. The managed area stations were placed below the pipeline canal (figure 138), as most of the water (and fishery organisms) was located in this area. The trawl was used to sample at seven stations inside the managed area and seven stations outside the managed area (figure 85). Stations within the managed area were designated M1-M7, and stations in the unmanaged area were designated U1-U7. We collected samples once every two weeks from February 20, 1989, to February 19, 1990. The trawl was placed into the water off the side of an airboat and towed alongside the boat for 1 minute at a speed of approximately 3 knots. One minute was determined to be the maximum time at heavily vegetated stations that the trawl could be towed without the vegetation clogging the net so much that the speed of the airboat, and thus the distance travelled, was affected. The trawl was then retrieved, and the contents of the trawl emptied and placed in a labeled bag. Samples were placed in an ice-and-water mixture until processing.

We measured water temperature (to the nearest 0.1°C), and salinity (to the nearest 0.1 ppt) at each station using a Beckman Model RS5-3 Salinometer. Dissolved oxygen levels (to the nearest 0.1 ppm) were measured at each station using a Yellow Springs Instrument Co. Model 57 dissolved oxygen meter. We noted the types and relative amounts of floating and submerged aquatic vegetation at each station during the summer and fall. Water levels were recorded from staff gauges in the two areas, and relative water depths were recorded for each station.

We identified and counted fishes and macrocrustaceans in each sample. Because of their large numbers and the difficulties in readily identifying the species without a microscope, grass shrimp were not keyed out to species. A small percentage of the grass shrimp collected were identified, and all were found to be Palaemonetes pugio. Standard lengths of fishes were measured in 5-mm length increments; the length class was designated by the lower end of the class. Blue crab carapace width was measured from tip to tip of the lateral spines. Blue crabs measuring 25 mm or greater were grouped into male crabs, immature female crabs, and mature female crabs. Xanthid crabs were measured laterally at the widest portion of the carapace. Total lengths of crawfish were measured from the tip of the rostrum to the end of the uropods. Total lengths of penaeid shrimp were measured from the tip of the rostrum to the end of the telson. Palaemonid shrimps were not measured because of the large numbers collected.

Very large samples of a species were subsampled using the method described in Herke (1978). Individuals of each species in a sample were combined and spun dry to remove excess water (Herke 1973). Total weight for each species was determined to the nearest 0.1 g with a Mettler PE6000 balance. Biological data were entered directly onto a computer to facilitate analysis and reduce transcription errors.

Results

Biological Data

From February 20, 1989, through February 19, 1990, we collected 109,306 organisms representing at least 34 species of fishes and macrocrustaceans and 1 species each of reptiles and amphibians. Of these, 76,867 organisms were from the managed area, and 32,439 organisms from the unmanaged area. In the managed area, 27 taxa were collected, and in the unmanaged area 33 taxa were collected (table 71).

Grass shrimp were the most abundant species collected at all stations except U5, where the sheepshead minnow was the most common (tables 72, 73). The most species were collected in the managed area at stations M5 and M6, the stations nearest, by water, to the structure. The unmanaged area stations with the most species were U2 and U7, shallow stations near the openings into the area; the station with the fewest number of species was U5, the station farthest, by water, from the openings into the area. Catches of the species collected in the two areas are presented by sampling date in table 74.

The total biomasses of all species combined were similar for the two areas (table 75). Average weights for species were compared if the number of organisms collected in each area was greater than 10. The average weights of the sheepshead minnow, bay anchovy, grass shrimp, bluegill, inland silverside, mosquitofish, and least killifish were greater in the unmanaged area. Average weights of rainwater killifish, sailfin molly, redear sunfish, and small blue crab were greater in the managed area.

The species collected can be grouped into two major categories, marine transient species that spend part of their lives in the estuary, and freshwater and estuarine resident species that spend their entire lives in the estuary and fresh water.

<u>Marine transient species</u>. Except for the bay anchovy, very few marine transient species were collected in the managed area (table 71). In fact, nearly seven times more marine transient species were collected in the unmanaged area than in the managed area. The disparity between the two areas was most obvious for the gulf menhaden and the blue crab. The marine transient organisms collected in the managed area were taken primarily at station M5, the one nearest the structure, but also at stations M6 and M7, which were those nearest the openings into the area. During several sampling trips, the structure was blocked open by debris, and water was leaking into the area, probably resulting in the entry of many of the transient organisms. We collected marine transient species at all stations in the unmanaged area, though most frequently at stations U2 and U7, shallow openings into the area.

<u>Freshwater and estuarine resident species</u>. Freshwater and estuarine resident species were collected at all stations in both areas (tables 72, 73). More than twice as many estuarine and freshwater resident organisms were collected in the managed area as in the unmanaged area. Grass shrimp, sheepshead minnow, and least killifish composed 82% of the managed area organisms, whereas these three species accounted for 64% of the organisms collected in the unmanaged area.

<u>Catch and water level</u>. Water levels (and consequently water depths) in the managed area were generally less variable than in the unmanaged area (figure 139). Throughout much of the year, the number of organisms collected appeared

Table 71. Number of organisms, by species, collected in both areas.

Species		Catch		
Common Name	Latin Name	Managed	Unmanaged	Total
Marine transient species				
Gulf menhaden	Brevoortia patronus	6	996	1,002
Blue crab (small; <25 mm)	Callinectes sapidus	20	231	251
Bay anchovy	Anchoa mitchilli	131	94	225
Striped mullet	Mugil cephalus	5	67	72
Blue crab (immature female)	Callinectes sapidus	6	22	28
Blue crab (male)	Callinectes sapidus	4	22	26
Atlantic needlefish	Strongylura marina	.	10	10
Atlantic croaker	Micropogonias undulatus	.	7	7
White shrimp	Penaeus setiferus	3	4	7
Ladyfish	Elops saurus	3	1	4
Spot	Leiostomus xanthurus	3	.	3
Spotted seatrout	Cynoscion nebulosus	.	1	1
Sheepshead	Archosargus probatocephalus	.	1	1
Subtotal		181	1,456	1,637
Estuarine and freshwater resident species				
Grass shrimp	Palaemonetes sp.	48,088	14,115	62,203
Sheepshead minnow	Cyprinodon variegatus	7,713	6,481	14,194
Rainwater killifish	Lucania parva	4,770	5,766	10,536
Least killifish	Heterandria formosa	7,322	225	7,547
Inland silverside	Menidia beryllina	3,261	2,826	6,087
Sailfin molly	Poecilia latipinna	2,601	1,006	3,607
Mosquitofish	Gambusia affinis	2,450	267	2,717
Bluegill	Lepomis macrochirus	215	96	311
Redear sunfish	Lepomis microlophus	82	49	131
Golden topminnow	Fundulus chrysotus	84	1	85
Gulf pipefish	Syngnathus scovelli	13	67	80
Dwarf crawfish	Cambarellus sp.	62	1	63
Gulf killifish	Fundulus grandis	8	19	27
Bayou killifish	Fundulus pulvereus	2	20	22
Tadpole	Hyla sp.	7	10	17
Naked goby	Gobiosoma bosci	2	9	11
Xanthid crab	Rhithropanopeus harrisii	.	9	9
Clown goby	Microgobius gulosus	1	5	6
Yellow bullhead	Ictalurus natalis	.	4	4

Table 71. Number of organisms, by species, collected in both areas (continued).

Species		Catch		
Common Name	Latin Name	Managed	Unmanaged	Total
Spotted gar	Lepisosteus oculatus	1	2	3
Largemouth bass	Micropterus salmoides	.	3	3
Red swamp crawfish	Procambaris clarkii	2	.	2
Diamond killifish	Adinia xenica	.	1	1
Pirate perch	Aphredoderus sayanus	.	1	1
Sunfish/bream	Lepomis sp.	1	.	1
Southern water snake	Nerodia fasciata	1	.	1
Subtotal		76,686	30,983	107,669
TOTAL		76,867	32,439	109,306

Table 72. Numbers of organisms collected in the managed area at each station and the average water depth at each station.

Species	Station M1	M2	M3	M4	M5	M6	M7
Grass shrimp	7,565	3,597	13,054	10,716	5,673	4,210	3,273
Sheepshead minnow	2,531	533	44	863	3,039	672	31
Least killifish	1,215	824	2,867	1,872	46	428	70
Rainwater killifish	1,147	585	206	950	524	949	409
Inland silverside	814	848	30	244	430	432	463
Sailfin molly	1,581	83	15	276	85	475	86
Mosquitofish	394	170	900	704	12	71	199
Bluegill	4	139	61	11	.	.	.
Bay anchovy	.	.	.	.	129	2	.
Golden topminnow	3	8	40	32	.	1	.
Redear sunfish	8	61	5	5	2	.	1
Dwarf crawfish	.	.	8	50	.	3	1
Blue crab (<25mm)	.	.	.	.	19	.	1
Gulf pipefish	6	4	.	.	.	.	3
Gulf killifish	4	.	.	.	3	1	.
Tadpole	.	1	1	.	.	3	2
Gulf menhaden	.	.	.	.	6	.	.
Blue crab (immature female)	1	.	.	.	4	.	1
Blue crab (male)	.	.	.	.	.	1	3
Striped mullet	.	.	.	.	4	1	.
Ladyfish	.	.	.	.	3	.	.
Spot	.	.	.	.	3	.	.
White shrimp	.	.	.	.	1	2	.
Bayou killifish	.	.	.	.	1	1	.
Naked goby	.	.	.	.	.	.	2
Red swamp crawfish	.	2	.	.	.	.	.
Clown goby	.	.	.	.	.	1	.
Southern water snake	.	1	.	.	.	.	.
Spotted gar	.	.	.	1	.	.	.
Sunfish/bream	.	1	.	.	.	.	.
Total	15,273	6,857	17,231	15,724	9,984	7,253	4,545
Average depth (cm)	29	40	46	54	31	58	72

Table 73. Numbers of organisms collected in the unmanaged area at each station and the average water depth at each station.

	Station						
	U1	U2	U3	U4	U5	U6	U7
Grass shrimp	669	4,762	1,690	1,264	1,050	1,020	3,660
Sheepshead minnow	7	1,394	728	57	2,713	14	1,568
Rainwater killifish	174	1,509	776	287	1,055	358	1,607
Inland silverside	83	546	278	461	203	383	872
Sailfin molly	141	161	320	23	70	26	265
Gulf menhaden	129	488	60	171	7	14	127
Mosquitofish	32	16	86	2	23	26	82
Blue crab (<25mm)	5	117	33	5	20	3	48
Least killifish	70	1	131	2	5	7	9
Bluegill	4	34	11	6	.	34	7
Bay anchovy	4	21	1	28	2	.	38
Striped mullet	9	22	5	1	2	1	27
Gulf pipefish	.	25	15	8	.	18	1
Redear sunfish	1	33	6	2	.	6	1
Blue crab (immature female)	4	8	2	2	1	.	5
Blue crab (male)	3	4	7	3	3	.	2
Bayou killifish	.	3	5	.	10	1	1
Gulf killifish	.	10	.	1	5	.	3
Tadpole	9	.	.	.	.	1	.
Atlantic needlefish	1	.	.	.	.	2	7
Xanthid crab	.	7	1	1	.	.	.
Naked goby	.	3	3	.	.	.	3
Atlantic croaker	.	4	.	1	.	.	2
Clown goby	.	5	.	.	.	.	.
Yellow bullhead	4	.	.	.	.	.	.
White shrimp	.	.	.	.	.	.	4
Largemouth bass	1	2	.	.	.	.	.
Spotted gar	1	.	.	.	.	.	1
Diamond killifish	.	.	.	.	1	.	.
Dwarf crawfish	.	1	.	.	.	.	.
Golden topminnow	1	.	.	.	.	.	.
Ladyfish	.	.	.	.	.	1	.
Pirate perch	.	.	1	.	.	.	.
Sheepshead	.	1	.	.	.	.	.
Spotted seatrout	.	1	.	.	.	.	.
Total	1,352	9,178	4,159	2,325	5,170	1,915	8,340
Average depth (cm)	76	28	53	71	35	71	43

Table 74. Total numbers of each species collected in each area, by month.

Species	(Structure closed)	FEB89	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB90
Gulf menhaden	M[a]	.	.	6	.	.	.	.	.	.	.	.	.	.
	U	27	22	316	398	3	.	.	.	.	4	3	.	223
Blue crab (<25mm)	M	.	5	1	6	1	.	.	1	1	2	2	.	1
	U	10	11	19	29	4	5	4	54	12	5	70	6	2
Bay anchovy	M	.	.	.	.	.	.	.	.	44	87	.	.	.
	U	1	6	4	2	1	32	12	8	21	5	2	.	.
Striped mullet	M	3	.	.	.	.	.	.	.	1	.	.	1	.
	U	3	11	1	19	7	3	1	1	2	.	7	10	2
Blue crab (immature female)	M	.	.	.	2	.	.	.	.	2	.	1	1	.
	U	.	1	2	4	2	4	1	2	4	.	2	.	.
Blue crab (male)	M	.	1	.	3	.	.	.	.	.	.	.	.	.
	U	.	.	3	6	1	6	.	.	1	.	5	.	.
Atlantic needlefish	M	.	.	.	.	.	.	.	.	.	.	.	.	.
	U	.	.	.	10	.	.	.	.	.	.	.	.	.
Atlantic croaker	M	.	.	.	.	.	.	.	.	.	.	.	.	.
	U	1	4	.	.	.	.	.	.	1	.	1	.	.
White shrimp	M	.	.	.	.	.	.	.	.	3	.	.	.	.
	U	.	.	.	.	.	.	.	1	.	.	3	.	.
Ladyfish	M	.	.	.	3	.	.	.	.	.	.	.	.	.
	U	.	.	.	1	.	.	.	.	.	.	.	.	.

Table 74. Total numbers of each species collected in each area, by month (continued).

Species (Structure closed)		FEB89	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB90
Bluegill	M	8	3	5	.	.	22	49	49	74	.	3	2	.
	U	1	3	.	8	.	15	16	4	5	1	36	5	2
Redear sunfish	M	3	1	1	1	.	.	9	21	19	3	1	18	5
	U	.	1	.	6	.	18	6	3	4	1	9	1	.
Golden topminnow	M	.	2	8	21	9	9	9	3	.	7	6	9	1
	U	.	.	.	.	.	.	.	.	.	.	1	.	.
Gulf pipefish	M	4	2	1	3	.	2	.	.	.	.	.	.	1
	U	1	1	15	31	.	2	5	3	1	2	6	.	.
Dwarf crawfish	M	4	11	5	1	10	12	2	3	6	5	1	2	.
	U	.	.	.	.	.	.	.	.	.	.	1	.	.
Gulf killifish	M	.	1	.	.	3	.	4	.	.	.	.	.	.
	U	.	1	1	.	.	.	2	.	.	.	7	6	2
Bayou killifish	M	.	2	.	.	.	.	.	.	.	.	.	.	.
	U	.	1	.	.	.	.	10	.	.	.	9	.	.
Tadpole	M	.	4	.	2	.	.	.	1	.	.	.	.	.
	U	.	.	.	9	.	.	1	.	.	.	.	.	.
Naked goby	M	.	2	.	.	.	.	.	.	.	.	.	.	.
	U	.	.	2	3	.	.	.	1	.	.	3	.	.
Xanthid crab	M	.	.	.	.	.	.	.	.	.	.	.	.	.
	U	.	3	2	3	.	.	.	.	.	.	1	.	.

Table 74. Total numbers of each species collected in each area, by month (continued).

Species		FEB89	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB90
(Structure closed)		___	___	___	___	___			___					___
Spot	M	.	.	3	.	.	.	.	.	.	.	.	.	.
	U	.	.	.	.	.	.	.	.	.	.	.	.	.
Spotted seatrout	M	.	.	.	.	.	.	.	.	.	.	.	.	.
	U	.	.	.	.	.	.	.	1	.	.	.	.	.
Sheepshead	M	.	.	.	.	.	.	.	.	.	.	.	.	.
	U	.	.	.	1	.	.	.	.	.	.	.	.	.
Grass shrimp	M	4,577	8,308	6,042	9,790	2,626	2,664	1,475	1,308	6,043	2,229	787	1,223	1,016
	U	654	894	1,453	2,674	402	3,009	929	413	377	116	2,885	207	102
Sheepshead minnow	M	175	567	154	1,922	363	510	396	717	1,219	972	494	202	22
	U	14	238	33	746	126	165	791	11	1	3	3,123	843	387
Rainwater killifish	M	572	676	135	715	129	175	203	391	1,134	144	159	240	97
	U	106	410	132	1,713	131	404	396	399	73	46	1,602	320	34
Least killifish	M	455	1,624	921	1,492	559	263	214	203	967	126	234	224	40
	U	.	.	.	57	.	5	4	1	2	3	153	.	.
Inland silverside	M	96	69	55	240	115	205	342	918	884	204	99	31	3
	U	409	197	94	409	110	225	209	256	209	54	369	191	94
Sailfin molly	M	29	306	73	258	84	185	416	209	624	325	11	72	9
	U	1	9	.	239	89	72	27	85	30	9	444	1	.
Mosquitofish	M	25	64	53	458	127	194	301	361	702	85	14	36	30
	U	.	4	.	21	10	31	21	42	16	2	116	4	.

Table 74. **Total numbers of each species collected in each area, by month (continued).**

Species (Structure closed)		FEB89	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB90
Clown goby	M	.	.	.	.	.	.	.	.	1	.	.	.	.
	U	.	.	.	3	.	.	.	.	.	.	2	.	.
Yellow bullhead	M	.	.	.	.	.	.	.	.	.	.	.	.	.
	U	.	.	.	4	.	.	.	.	.	.	.	.	.
Spotted gar	M	.	.	.	.	.	.	.	1	.	.	.	.	.
	U	.	.	.	2	.	.	.	.	.	.	.	.	.
Largemouth bass	M	.	.	.	.	.	.	.	.	.	.	.	.	.
	U	.	1	.	2	.	.	.	.	.	.	.	.	.
Red swamp crawfish	M	.	.	.	.	.	.	.	.	.	.	.	2	.
	U	.	.	.	.	.	.	.	.	.	.	.	.	.
Diamond killifish	M	.	.	.	.	.	.	.	.	.	.	.	.	.
	U	.	.	.	.	.	.	.	.	.	.	.	1	.
Pirate perch	M	.	.	.	.	.	.	.	.	.	.	.	.	.
	U	.	.	.	.	.	.	.	.	1	.	.	.	.
Sunfish/bream	M	.	.	.	.	.	1	.	.	.	.	.	.	.
	U	.	.	.	.	.	.	.	.	.	.	.	.	.
Southern water snake	M	.	.	.	.	.	.	.	1	.	.	.	.	.
	U	.	.	.	.	.	.	.	.	.	.	.	.	.

[a]"M" indicates the managed area; "U" indicates the unmanaged area.

Table 75. Biomass of organisms collected in both areas. Average weights for species are listed when the number of organisms collected in an area was greater than 10.

	Biomass (g)		Avg. Weight (g)	
	Managed	Unmanaged	Managed	Unmanaged
grass shrimp	4,923.4	1,783.3	0.1	0.13
sheepshead minnow	2,243.6	3,602.4	0.29	0.56
inland silverside	991.7	1,507.8	0.3	0.53
rainwater killifish	1,203.1	1,256.8	0.25	0.22
striped mullet	432.1	1,292.4		
sailfin molly	790.6	239.0	0.3	0.24
spotted gar	454.0	283.9		
bluegill	139.7	382.8	0.65	3.99
male blue crab	309.5	73.4		
redear sunfish	224.8	91.4	2.74	1.87
least killifish	279.3	15.8	0.04	0.07
mosquitofish	253.9	31.1	0.1	0.12
gulf menhaden	0.5	167.5		
immature female crab	13.0	100.0		
golden topminnow	78.6	0.5		
gulf killifish	16.6	50.8		
blue crab (<25mm)	6.0	48.4	0.3	0.21
bay anchovy	11.6	18.4	0.09	0.2
gulf pipefish	4.3	23.1	0.33	0.34
bayou killifish	2.7	12.4		
dwarf crawfish	13.5	0.1		
white shrimp	6.9	1.0		
tadpole	1.7	3.4		
naked goby	1.0	4.1		
clown goby	0.2	3.3		
lady fish	0.1	2.6		
Atlantic croaker		2.7		
spotted seatrout		1.8		
spot	0.8			
yellow bullhead		2.1		
xanthid crab		2.4		
southern water snake	87.7			
diamond killifish		0.5		
pirate perch		6.5		
sunfish/bream	0.1			
largemouth bass		285.2		
red swamp crawfish	1.9			
Atlantic needlefish		2.4		
sheepshead		0.1		
Total	12,492.9	11,299.4		

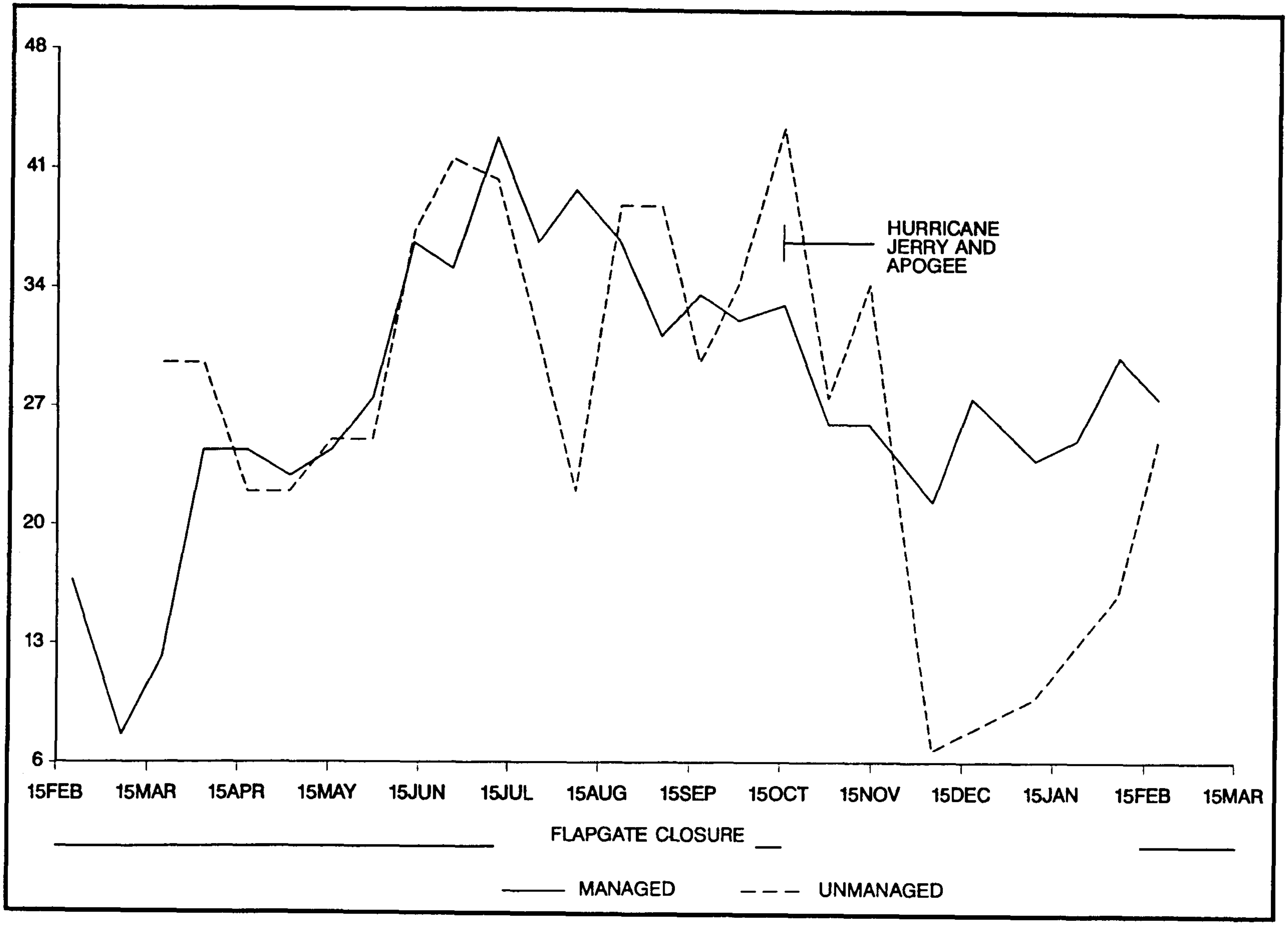

Figure 139. Average water level (cm) in each area, by month.

to be negatively related to water level (figures 140, 141). On the average, the unmanaged area stations were approximately 7 cm deeper than the managed area stations (tables 72, 73). As water depths increased, the numbers of organisms collected frequently decreased.

Differences between stations. Catches at the stations within an area were highly variable (tables 72, 73). Of the stations sampled in the managed area, the most organisms were collected at stations M1, M3, and M4, whereas the fewest organisms were collected at station M7, the deepest station in this area. In the unmanaged area, the most organisms were collected at stations U2 and U7, shallow openings into the area. The fewest organisms were collected at stations U1, U3, and U6, the deepest stations in this area. Thus, fewer organisms were collected at the deepest stations in both areas.

Length-frequency data. Length-frequency data for the most abundant species collected were examined. The length-frequency histograms for the small blue crab reveal that very few 5-14.9 mm blue crabs were collected in the managed area, whereas many were collected in the unmanaged area (figure 142). Very small redear sunfish were collected in May in the unmanaged area but not until August in the managed area (figure 143). Several species, including the rainwater killifish, inland silverside, and least killifish, appeared to have a slightly larger average size in the unmanaged area than in the managed area (figures 144-146).

Aquatic Vegetation

Submerged and floating aquatic vegetation were surveyed during the summer and fall months of the fisheries study. Table 76 summarizes the abundance of aquatic vegetation by station in each of the two areas sampled. Many of the stations in the managed area had abundant submerged aquatic vegetation. The stations in the unmanaged area had much sparser, but more varied, vegetation overall.

Environmental Data

Average salinities were low throughout the year, but were slightly greater in the managed area than in the unmanaged area during most of the drawdown. After July this trend was not apparent; the average salinity in the managed area during this non-drawdown phase varied less than in the unmanaged area (figure 147). Relatively high salinities were recorded at several stations in both areas after the storm surge of hurricane Jerry and apogee high tides in October. Salinities among the stations within the unmanaged area were generally less variable than those at the managed area stations (figures 148, 149).

Average water temperatures in the unmanaged area were slightly higher than those in the managed area (figure 150). Stations in both areas had minor differences in water temperatures (figures 151, 152). In late December, between sampling trips, very cold temperatures occurred in the area. Several weeks later, on the January 9, 1990, trip, hundreds of dead adult redfish (*Sciaenops ocellatus*) and several dead spotted seatrout and striped mullet were seen in Falgout Canal and in the unmanaged area; no dead fish were seen in the managed area.

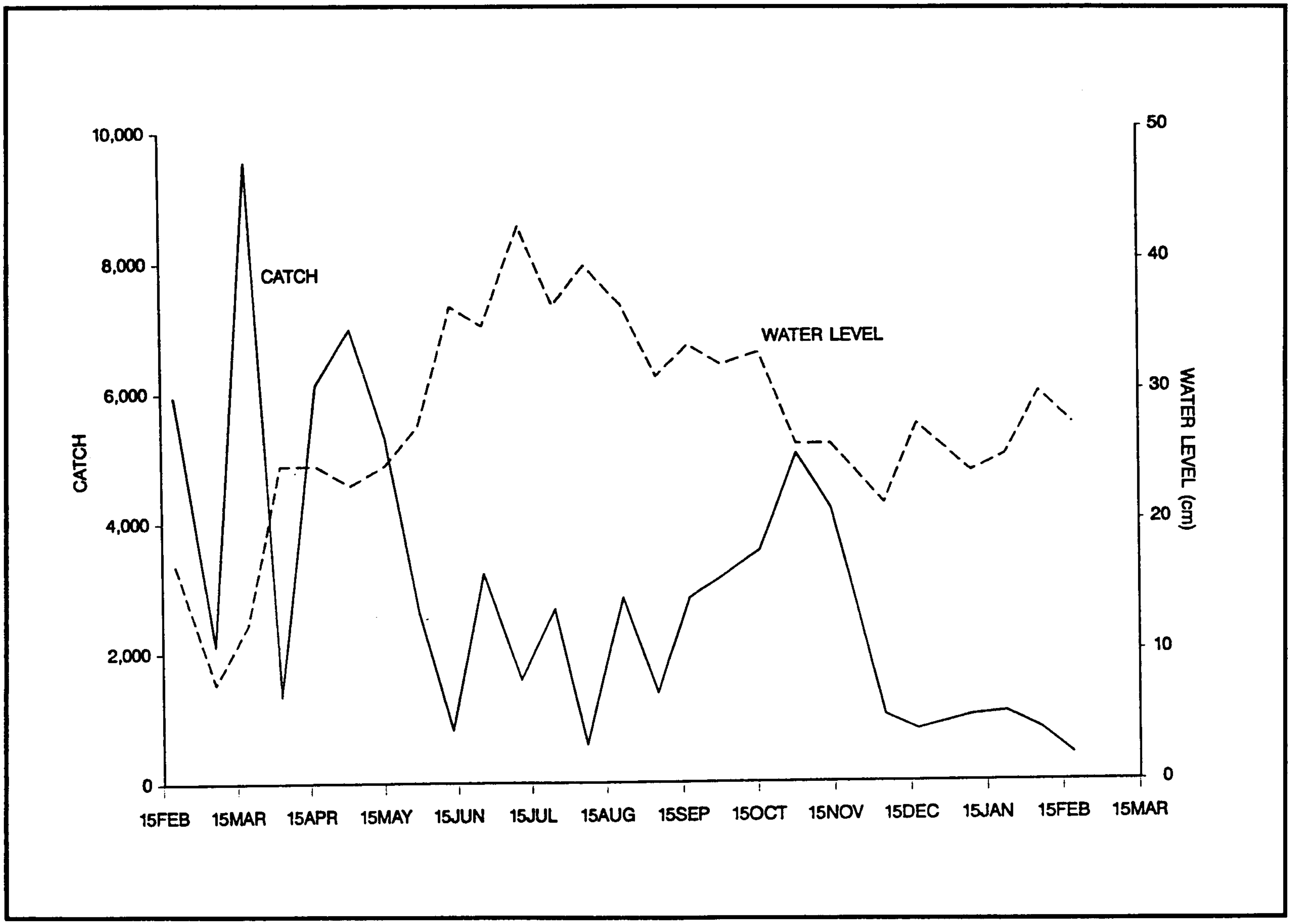

Figure 140. Average water level (cm) and total catch (all stations combined) for the managed area, by date.

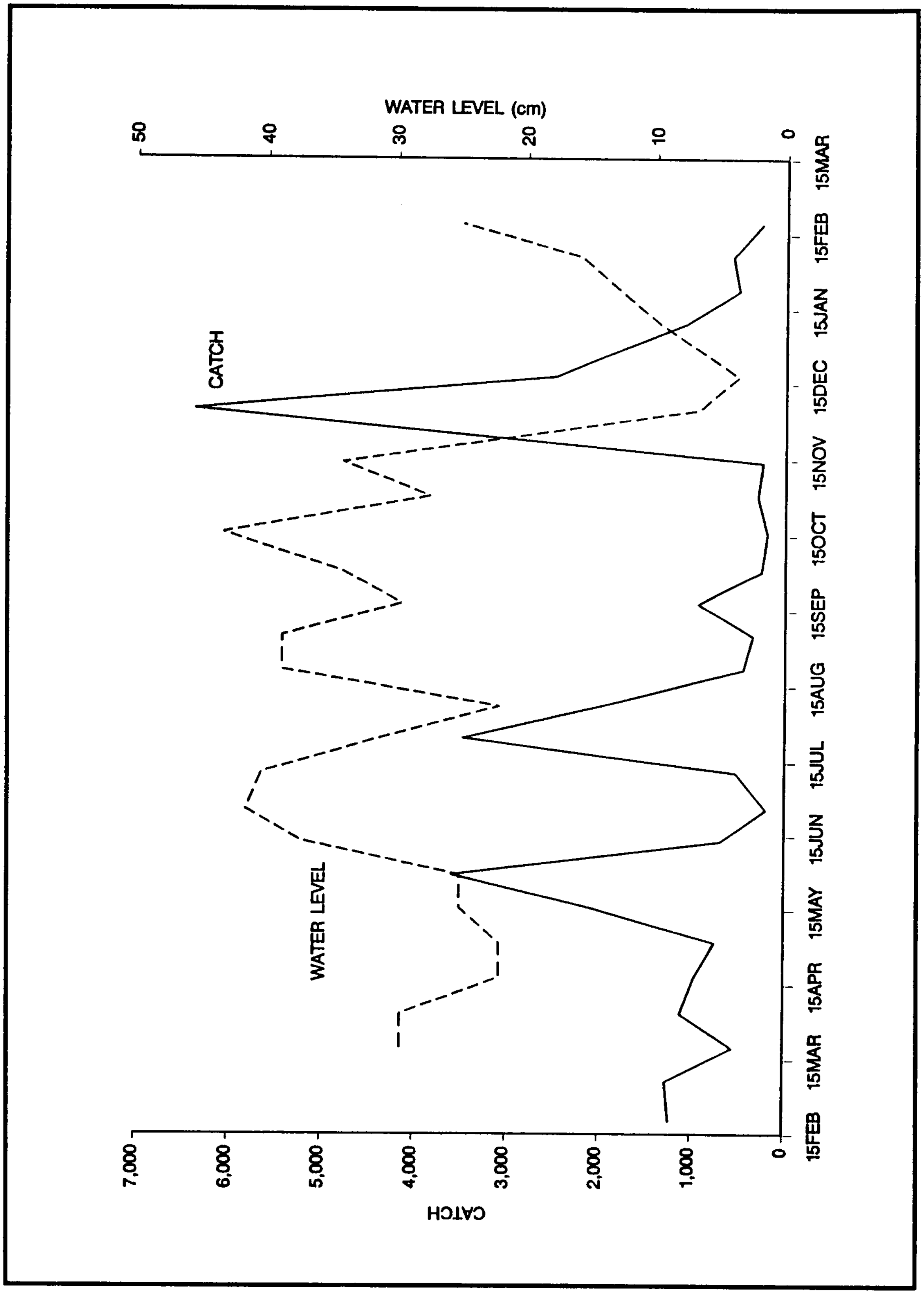

Figure 141. Average water level (cm) and total catch (all stations combined) for the unmanaged area, by date.

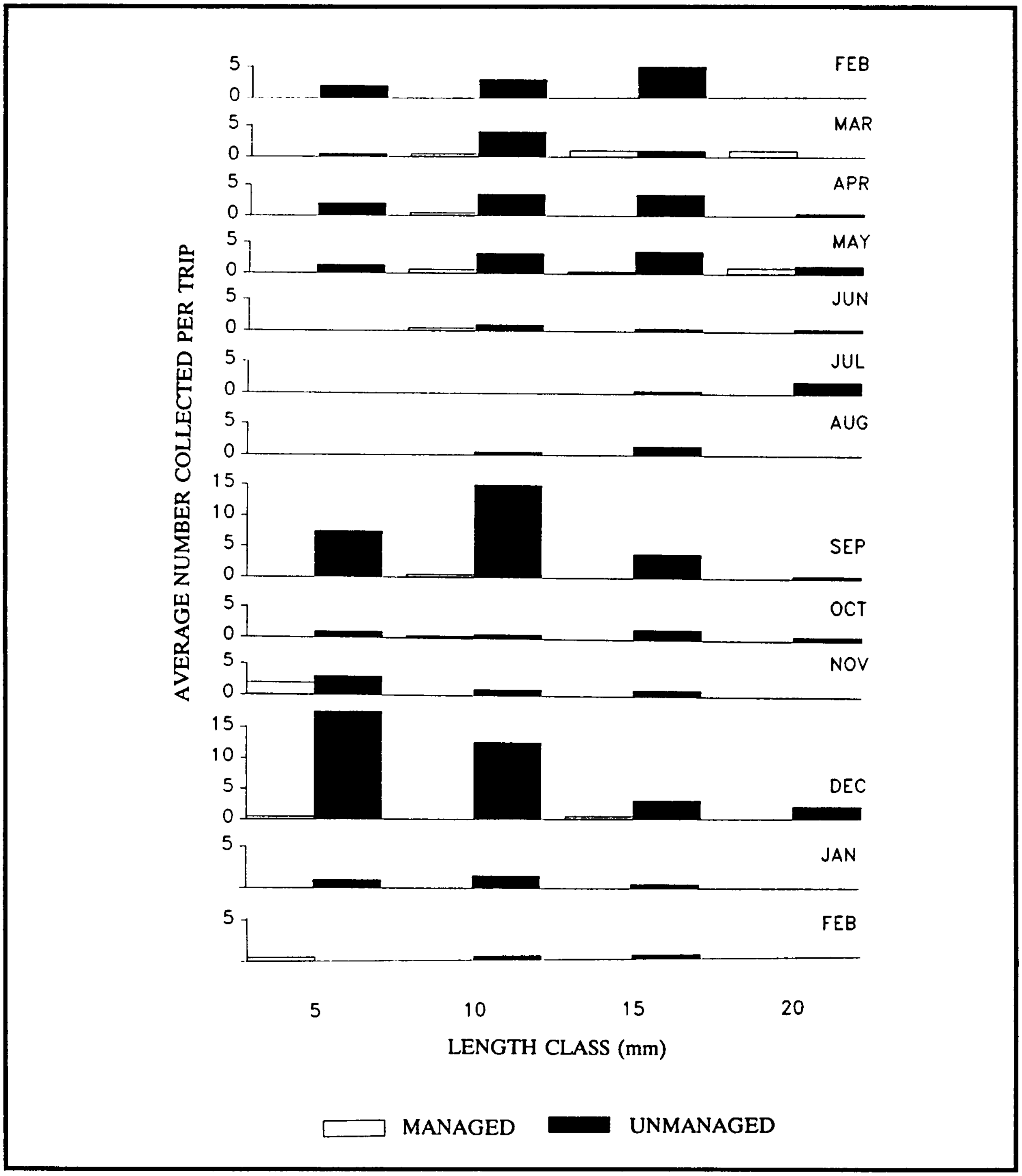

Figure 142. Length frequencies of small blue crabs in each area, by month.

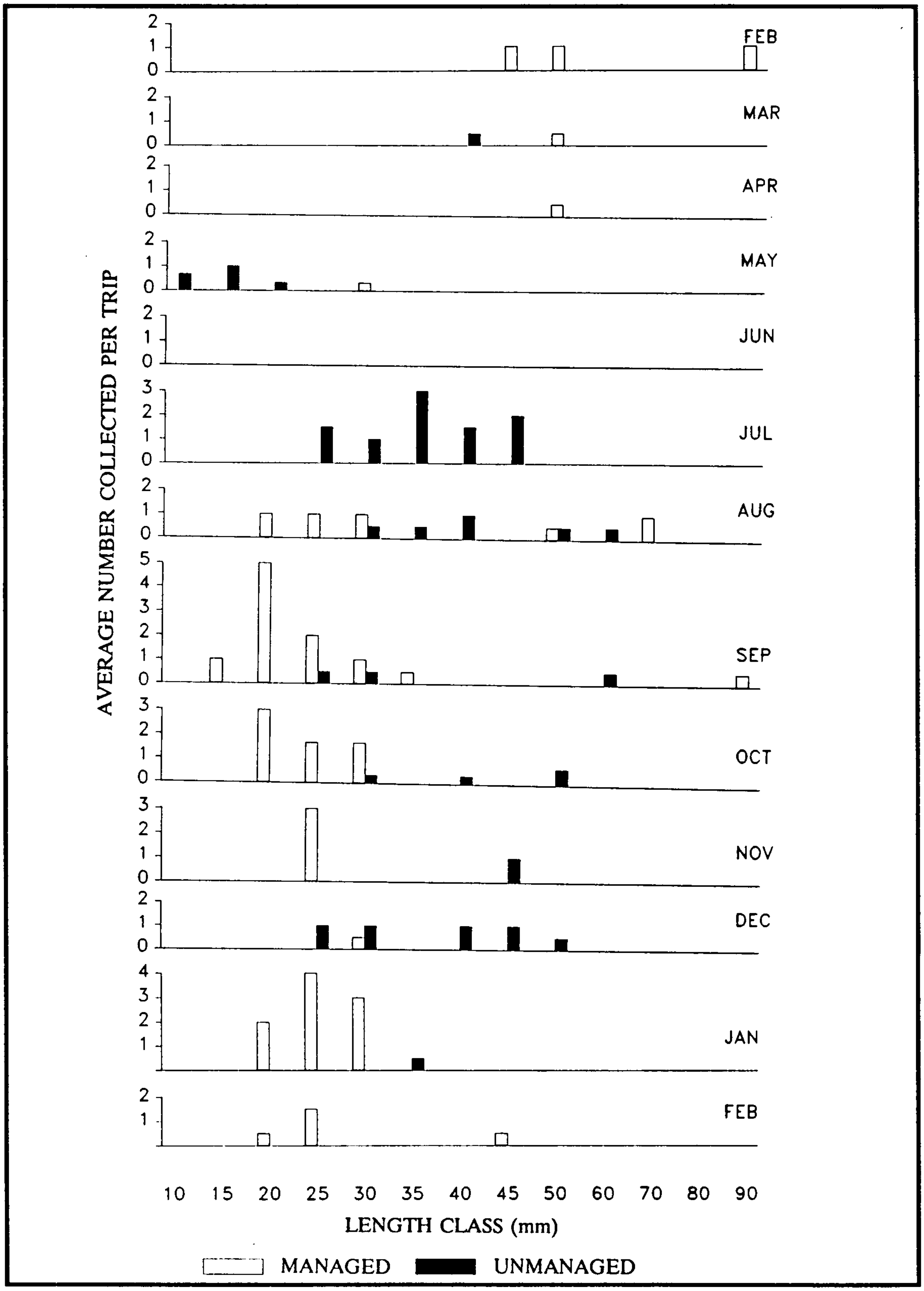

Figure 143. Length frequencies of redear sunfish in each area, by month.

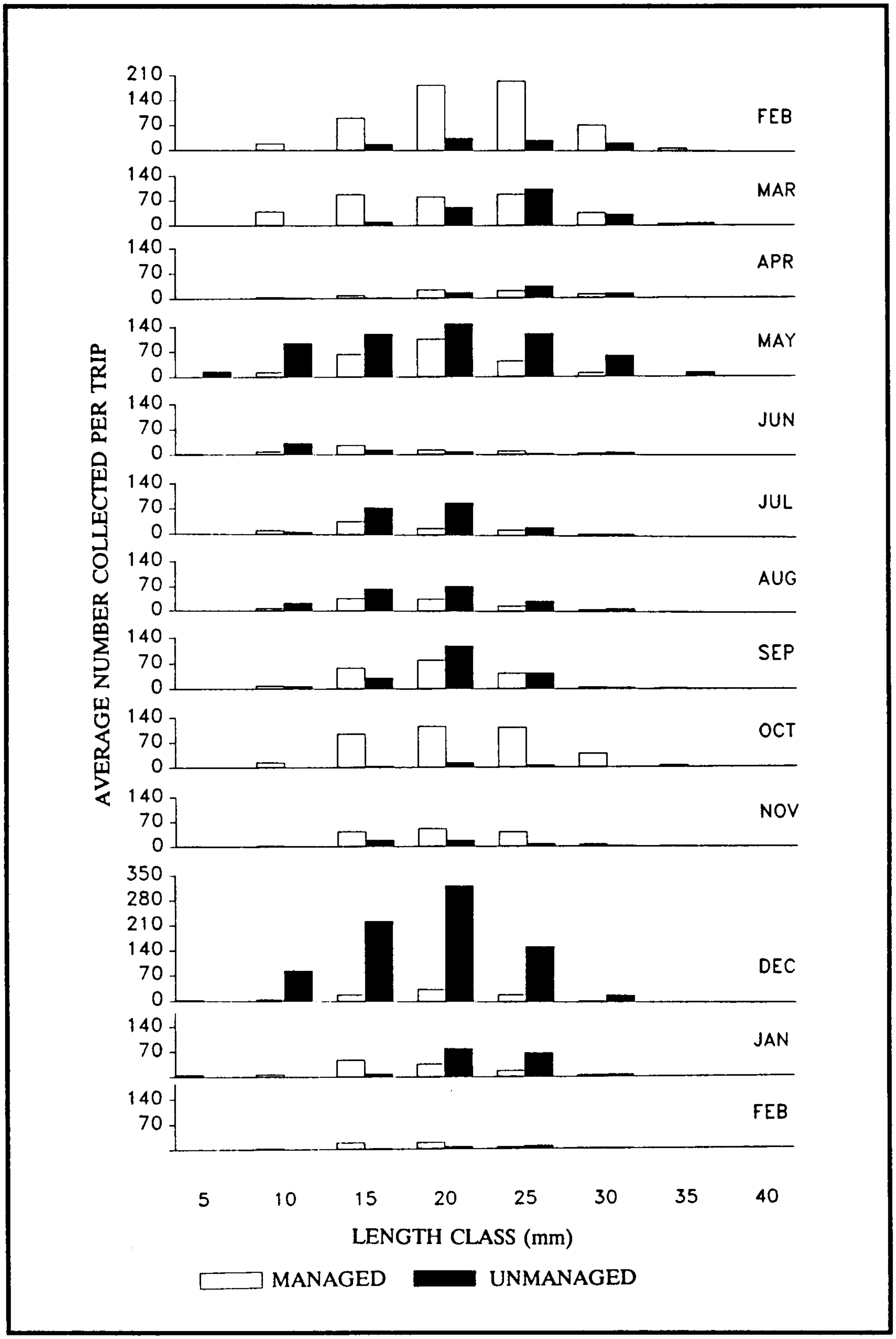

Figure 144. Length frequencies of rainwater killifish in each area, by month.

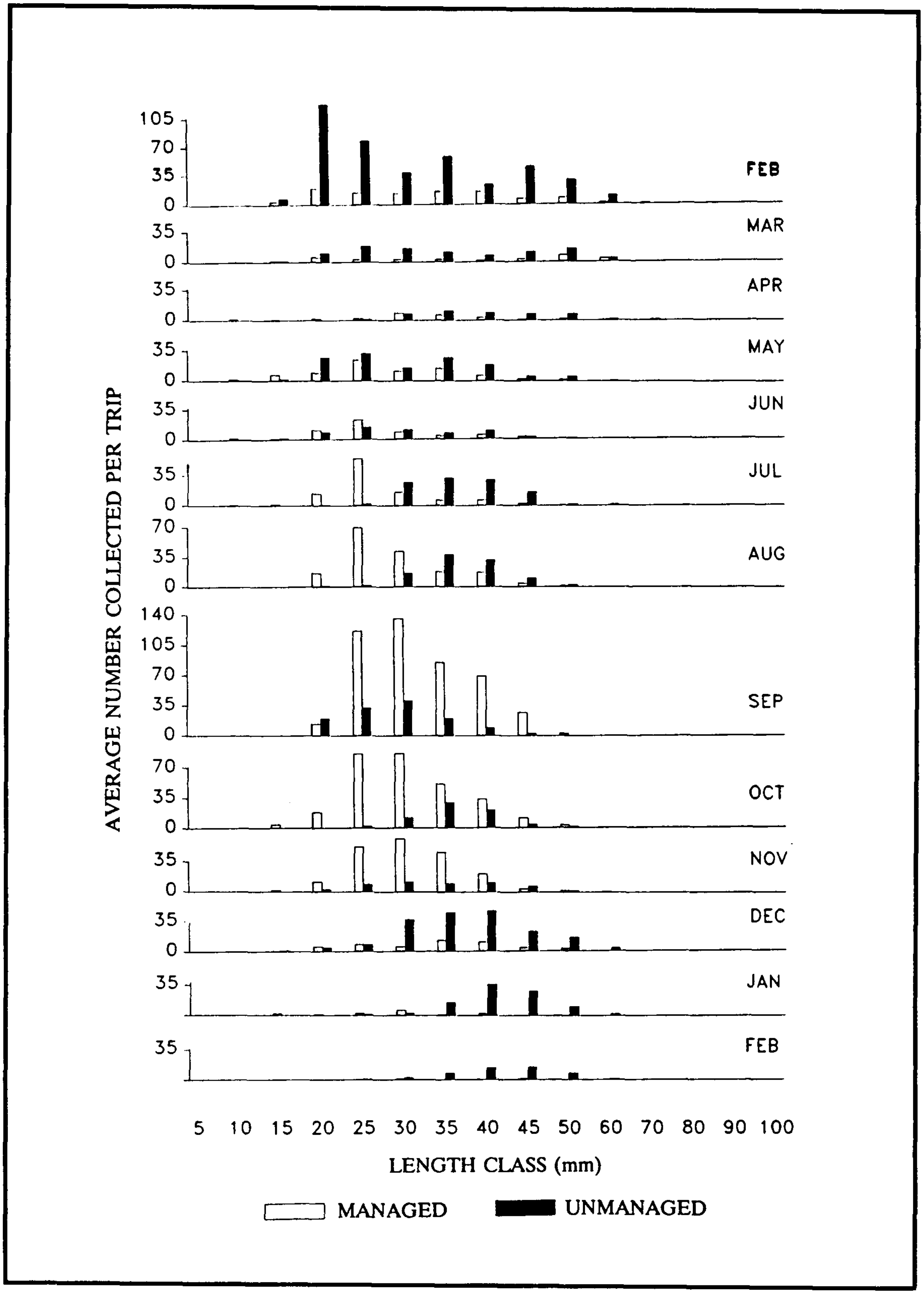

Figure 145. Length frequencies of inland silversides in each area, by month.

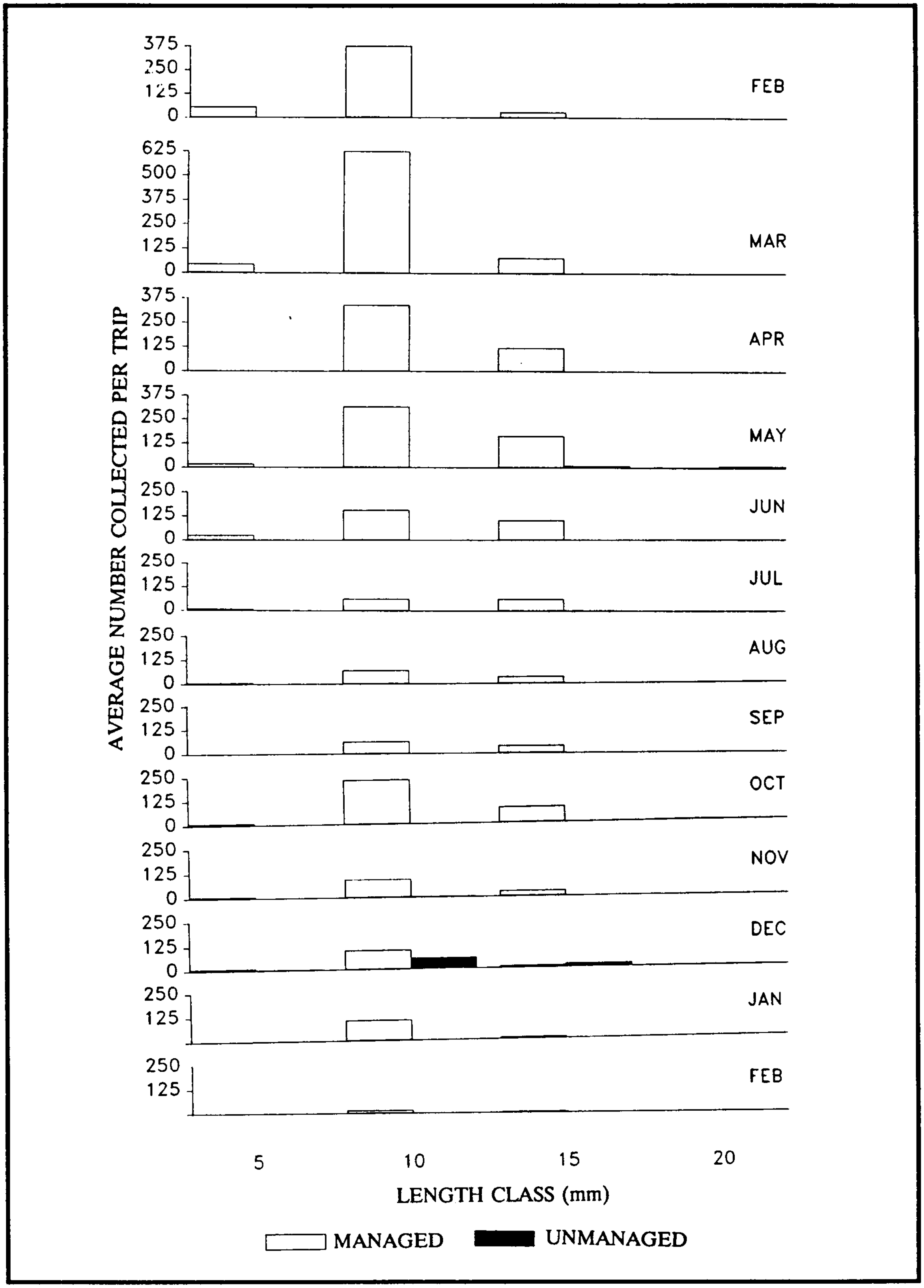

Figure 146. Length frequencies of least killifish in each area, by month.

Table 76. Relative abundances in the summer and fall of floating and submerged aquatic vegetation for each station in both areas.

Species	Unmanaged Area Stations						
	U1	U2	U3	U4	U5	U6	U7
Azolla caroliniana							T
Ceratophyllum demersum	H[a]	H	H	H	T	M	M
Cladophora sp.	H	T	T	T	H	H	H
Eichhornia crassipes	H	T	T	T			T
Elodea (=*Egeria*) *densa*	H	M	T	T			
Lemna minor			T			T	
Myriophyllum spicatum	H	M	H	H	T	H	M
Najas guadalupensis	H	M	M	T	L	M	H
Nostoc sp.					T	T	
Pistia stratiotes			T				
Potamogeton crispus		T					
Potamogeton pusillus	T	H	M	M	L	M	T
Rhizoclonium sp.	H	T	T	T	T	M	T
Ruppia maritima	T						
Salvinia rotundifolia	H	T	T	T	T	L	T
Valisneria americana	T						T
Overall Rating	L	L	M	M	M	L	M

Species	Managed Area Stations						
	M1	M2	M3	M4	M5	M6	M7
Ceratophyllum demersum			H	H	T	M	H
Chara sp.	H	H	H			T	
Cladophora sp.	T	H	H	H	H	H	H
Eichhornia crassipes			T		T		H
Myriophyllum spicatum	M	H	H	T	T	T	H
Najas guadalupensis			H		T	M	T
Nostoc sp.	T	M	T	H	M	T	T

Table 76. Relative abundances in the summer and fall of floating and submerged aquatic vegetation for each station in both areas. (continued)

	Managed Area Stations						
Potamogeton pusillus					H		T
Rhizoclonium sp.	T	T	T	T	T	T	T
Ruppia maritima	T	T	T			M	T
Salvinia rotundifolia							H
Overall Rating	H	H	H	M	L	M	L

[a]H=heavy M=medium L=light T=trace

Note: Ratings within an area-station combination compare relative composition of vegetative types within a station and not between stations. Two stations with an H rating do not necessarily have the same amount of floating and submerged aquatic vegetation. Overall ratings compare between stations.

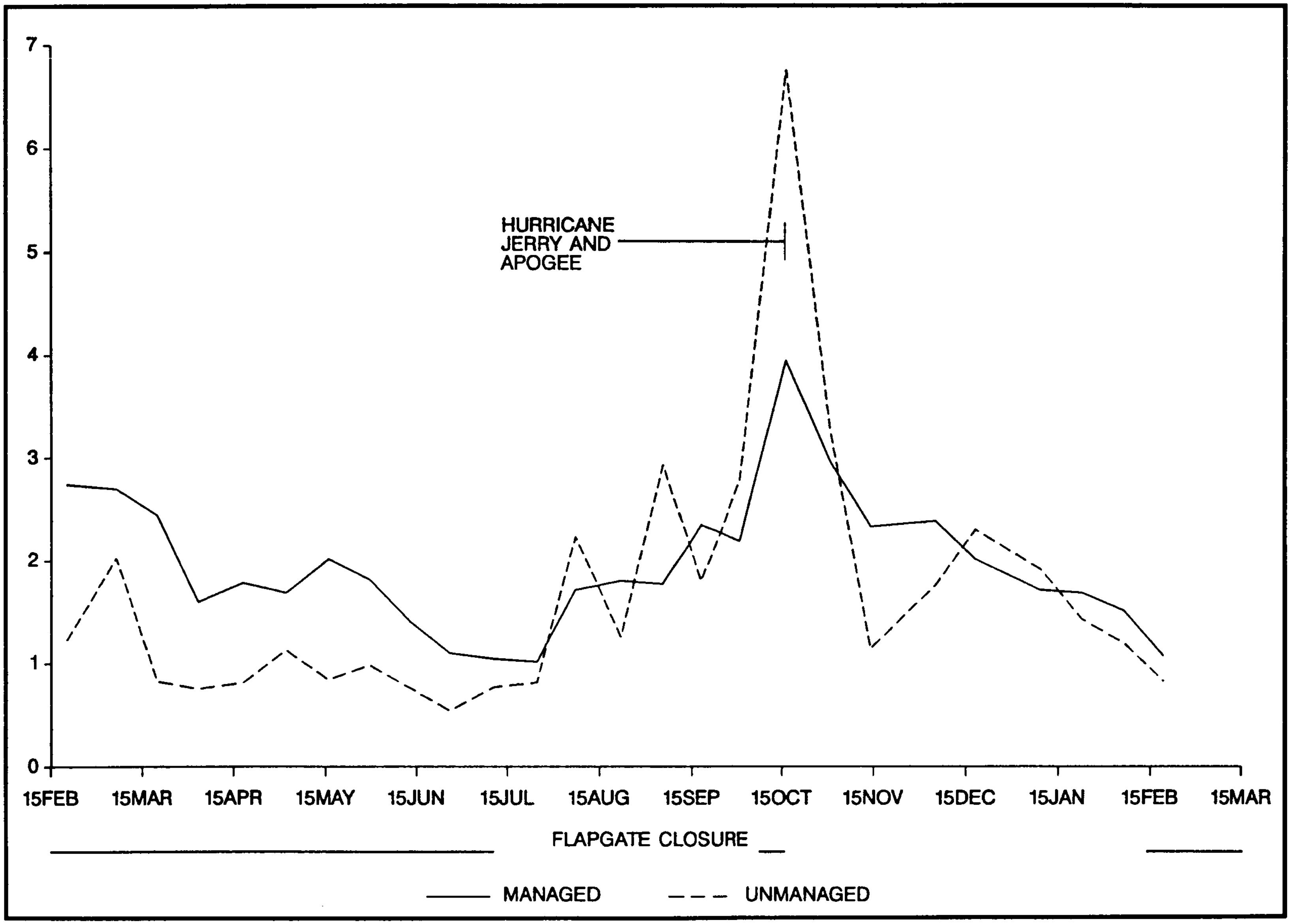

Figure 147. Average salinities (o/oo) of each area, by date. Dates of flapgated closure are indicated by the bar under the graph.

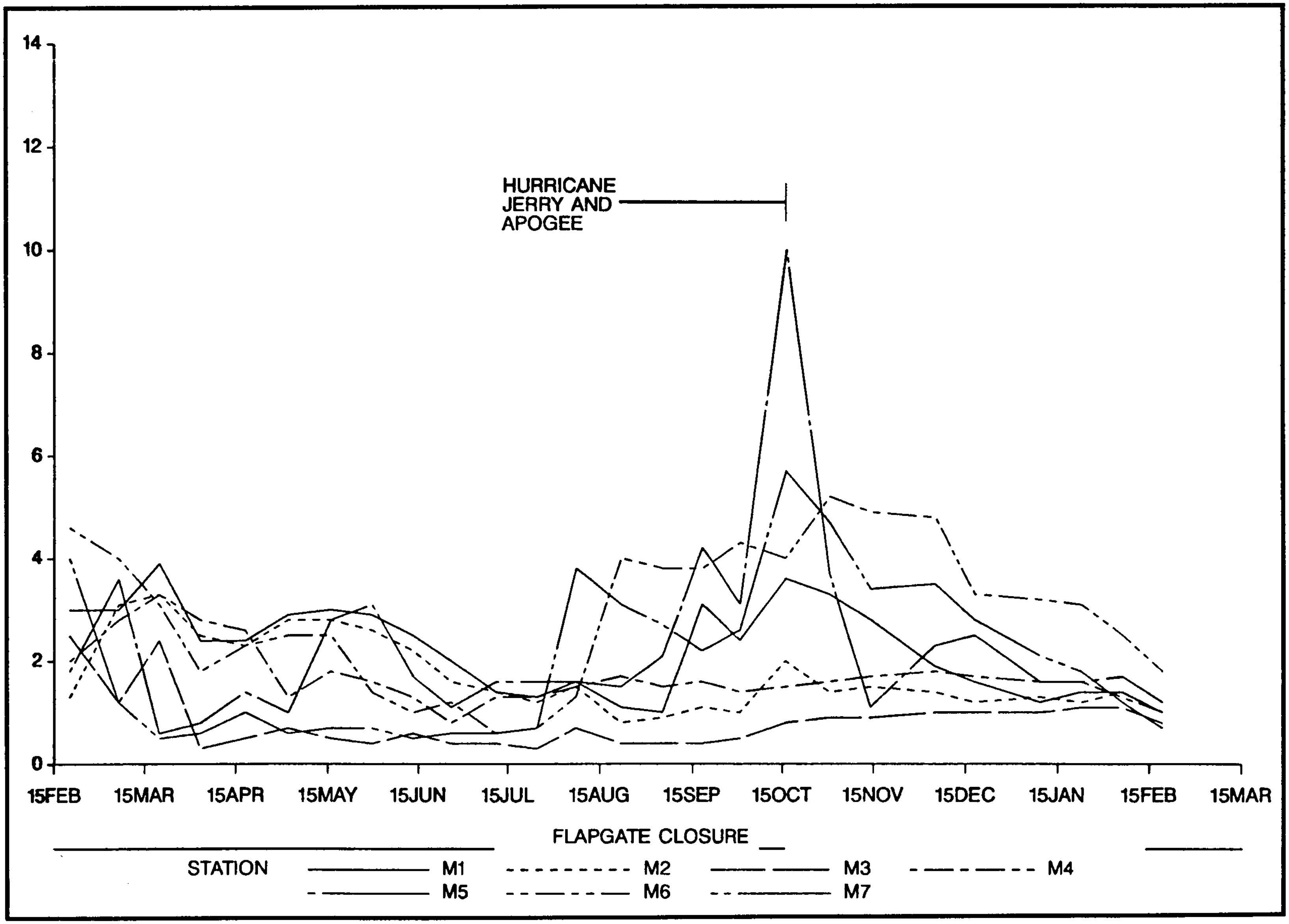

Figure 148. Salinities (o/oo) of each station in the managed area, by date.

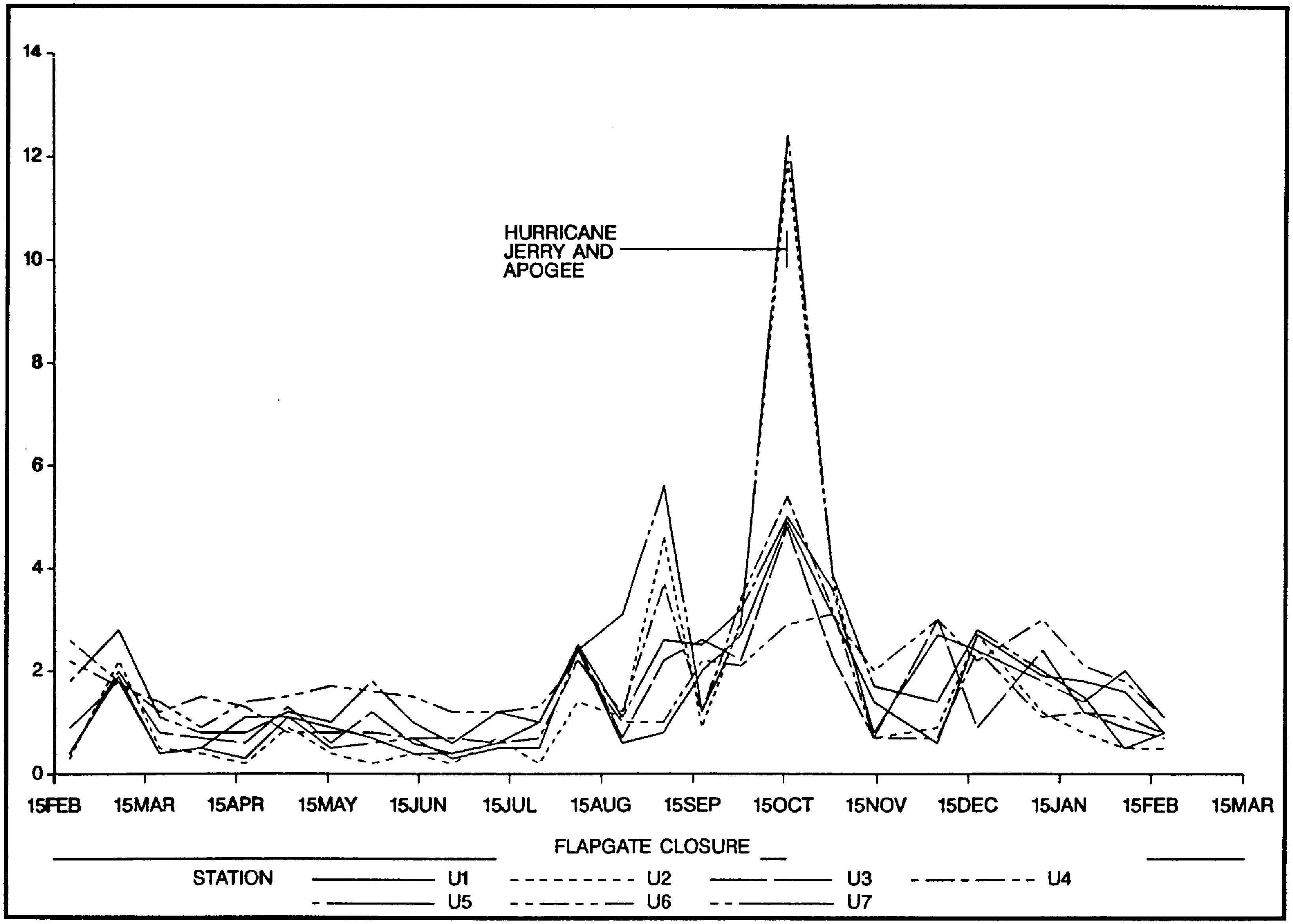

Figure 149. Salinities (o/oo) of each station in the unmanaged area, by date.

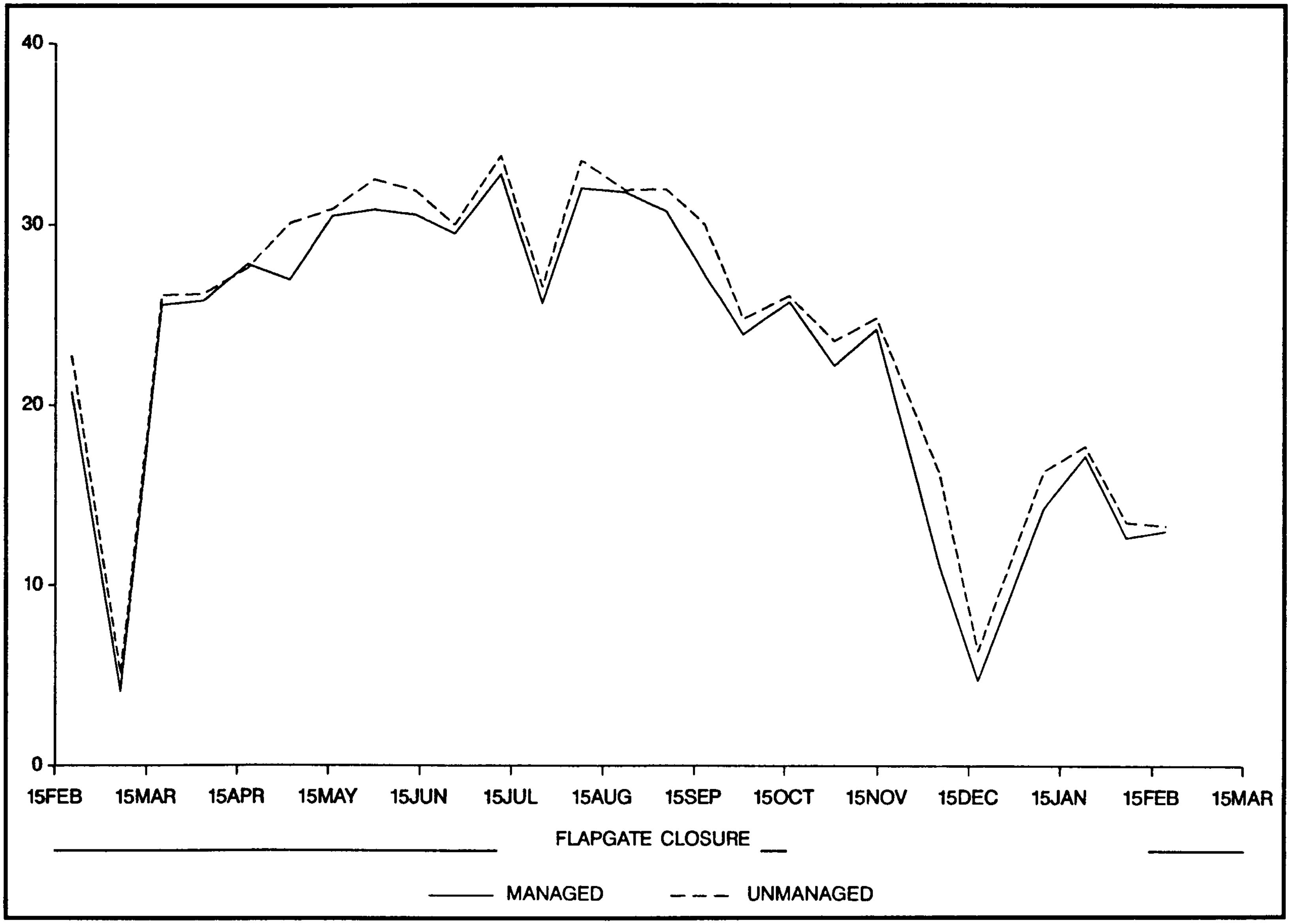

Figure 150. Average water temperatures (degrees C) of each area, by date.

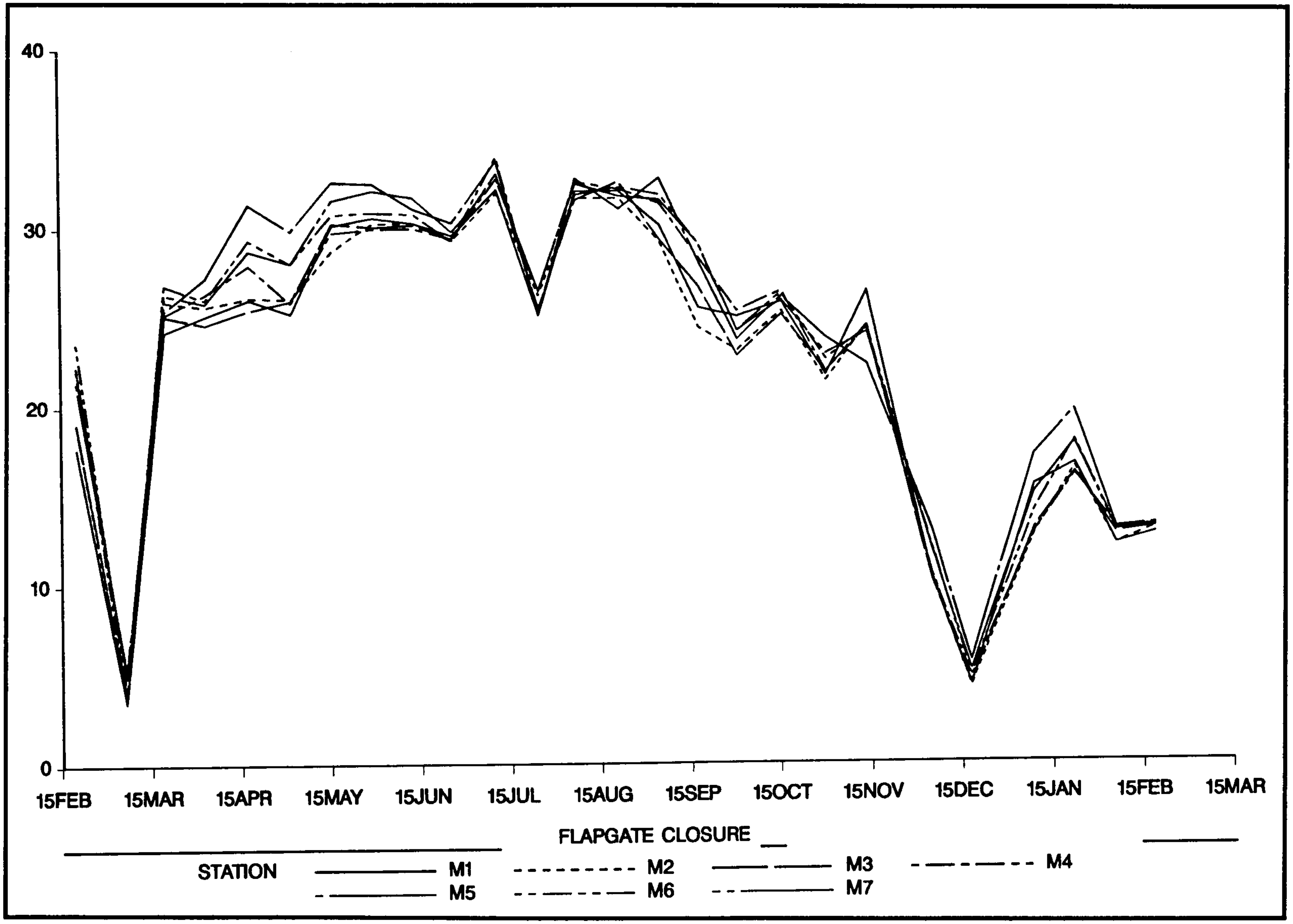

Figure 151. Water temperatures (degrees C) of each station in the managed area, by date.

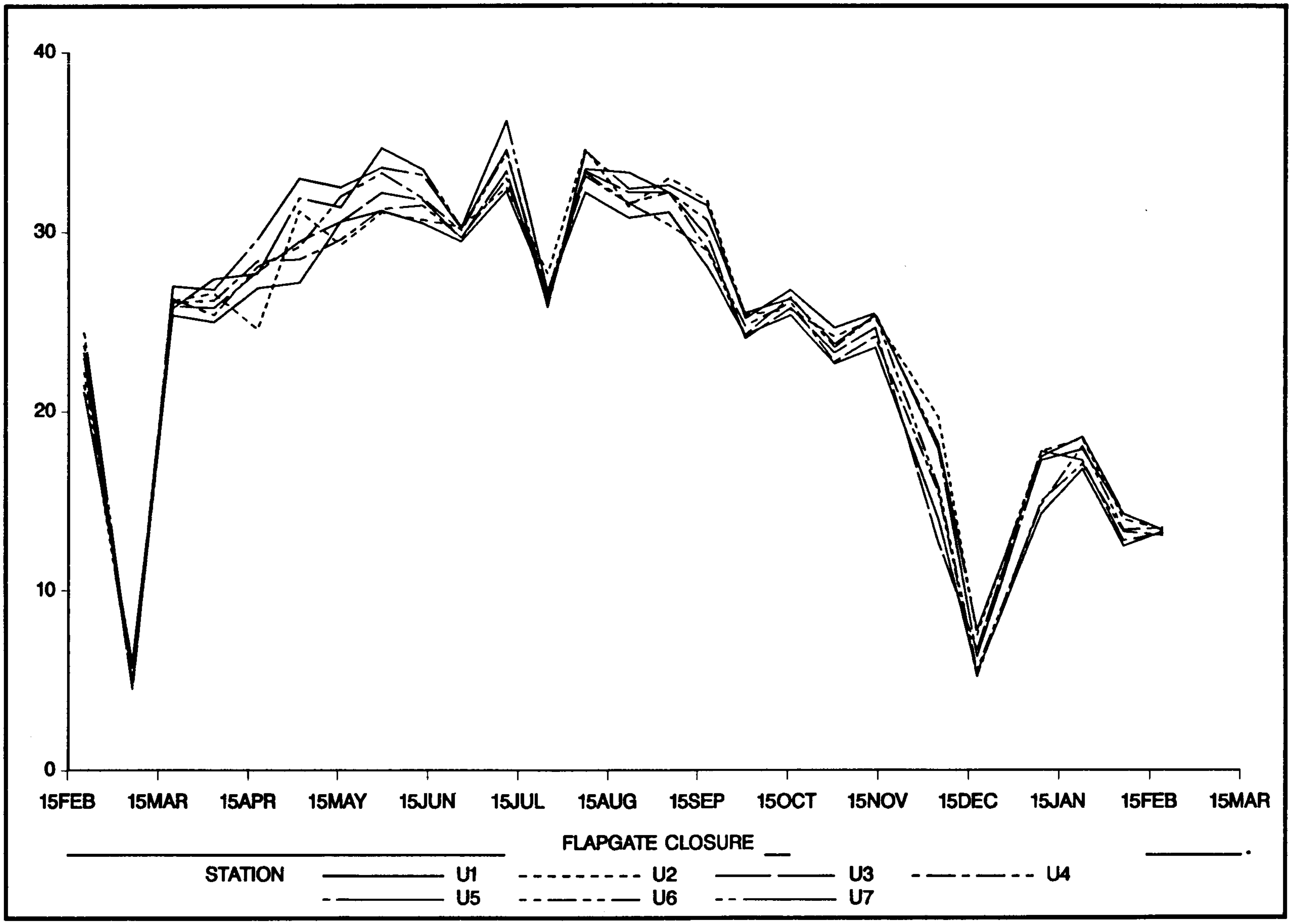

Figure 152. Water temperatures (degrees C) of each station in the unmanaged area, by date.

There were no consistent differences in dissolved oxygen levels between the two areas (figure 153). Dissolved oxygen levels at stations in both areas were often highly variable (figures 154, 155).

Discussion

Biological Data

The differences in catches of marine transient organisms between the unmanaged and managed areas were primarily due to restricted access because of the control structure. The other differences in catches between the two areas, and between stations within the areas, appeared to be primarily due to differences in water depth and submerged aquatic vegetation. The management structures may have caused these differences by lowering water levels in the area and promoting greater production of submerged aquatic vegetation. The smaller numbers of organisms collected at the deeper stations and the smaller numbers collected when water levels were high in both areas were probably due to several factors. First, the higher water levels provide more area for organisms, both vertically and horizontally when the base of the emergent vegetation is inundated. Clairain (1974) noted that water depth affected dispersion of Atlantic croaker and subsequent susceptibility to trawling. Many authors have reported on the use of the emergent marsh surface by organisms during flooding tides (e.g., Miller and Guillory 1982; Zimmerman and Minello 1984). Second, the trawl could not sample the entire water column in deeper water. Also, during times of lower water, the trawl pushed through the rooted submerged aquatic vegetation and collected the species in the vegetation. When water levels were greater, the trawl could pass over most of the vegetation. Third, differences in trawl efficiency may be primarily responsible for the greater numbers of organisms collected in lower water. The trawl may have been selective for different species in the two areas, and for stations within the areas, because of the differences in water depths. The trawl could pass over the more bottom-dwelling species such as larger blue crabs and gobies. Many large blue crabs were seen in both areas in the path of the trawl, but they were collected in much smaller numbers than were apparently present in the area. The trawl probably passed over many of them in the unmanaged area, and the blue crabs in the managed area were seen to escape the trawl by burrowing into the very soft bottom. The trawl was selective in both areas against faster and larger organisms. The faster-swimming organisms could evade the trawl, and the bars across the mouth of the trawl reduced the numbers of large organisms caught, though several large gar, mullet, centrarchids, and a water snake were collected.

In spite of the disparity in the numbers of organisms collected in the two areas, the total biomasses collected were similar because larger individuals of some species were collected in the unmanaged area. Comparisons of average weights of species in the two areas are also confounded by the wide size ranges of some of the species collected. Of the species with relatively narrow size ranges, some interesting differences are apparent. The smaller average size of small blue crabs in the unmanaged area was due to the large numbers of very small crabs collected in this area. A few large bluegills were collected in the unmanaged area, whereas large redear sunfish were collected in the managed area.

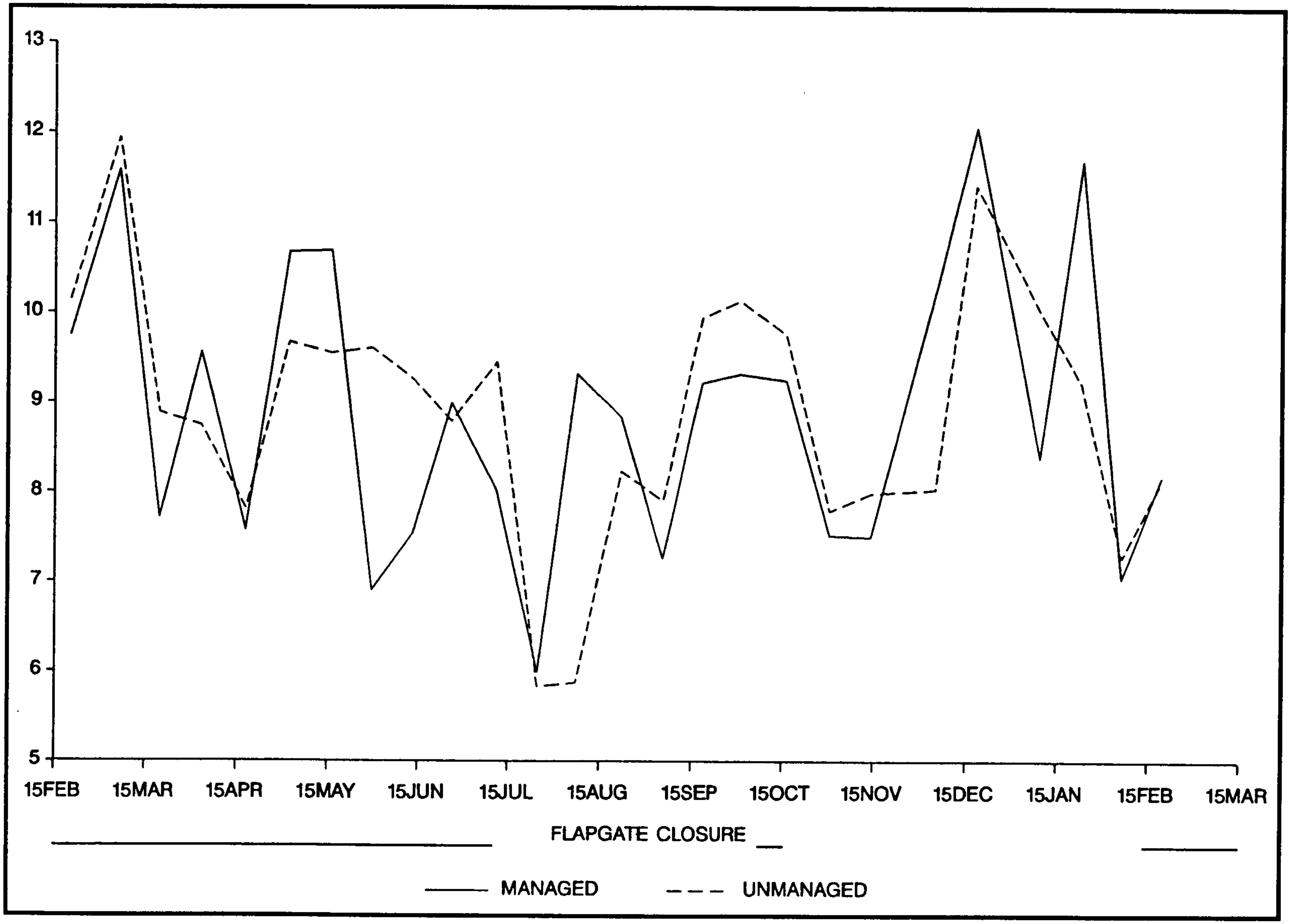

Figure 153. Average dissolved oxygen levels (ppm) of each area, by date.

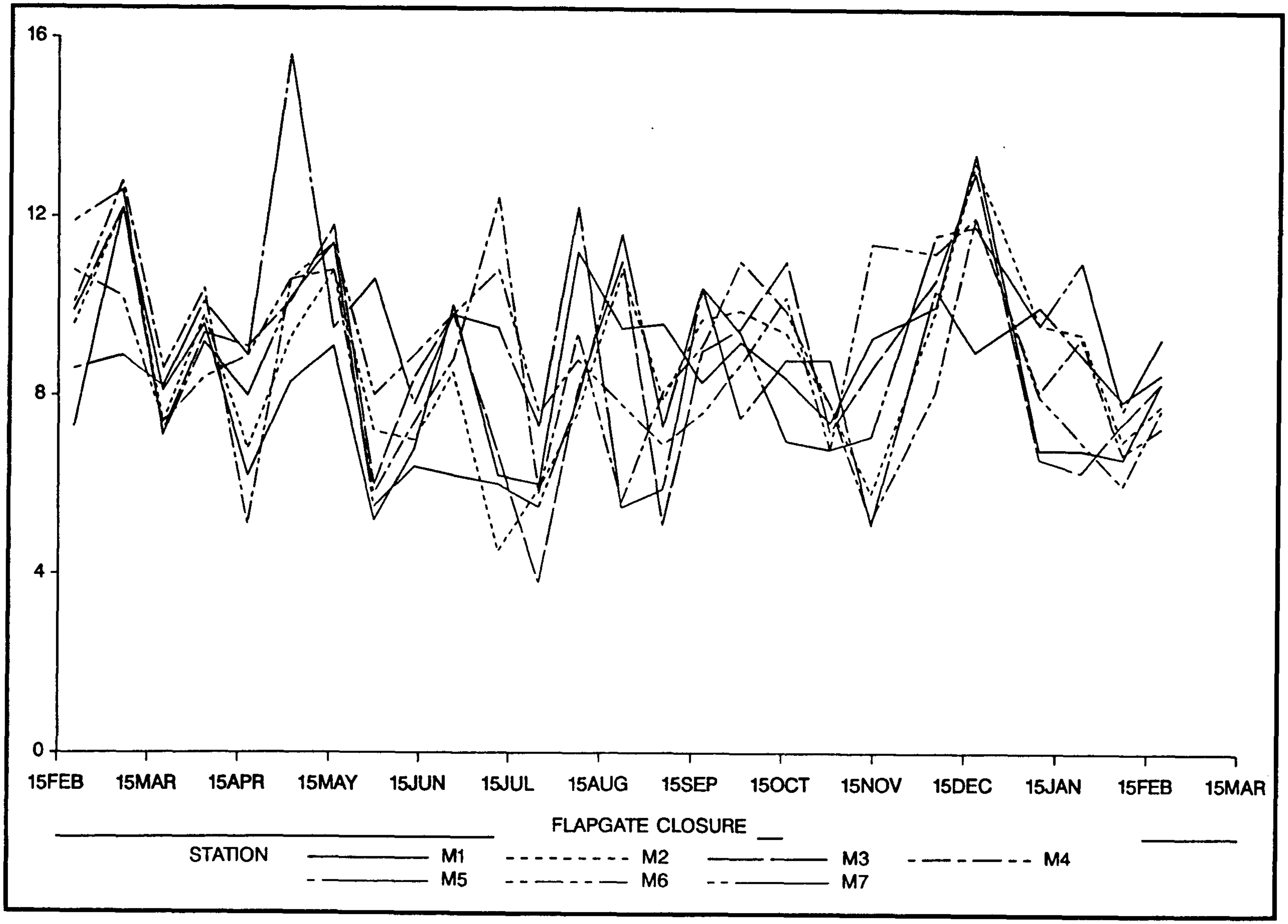

Figure 154. Dissolved oxygen levels (ppm) of each station in the managed area, by date.

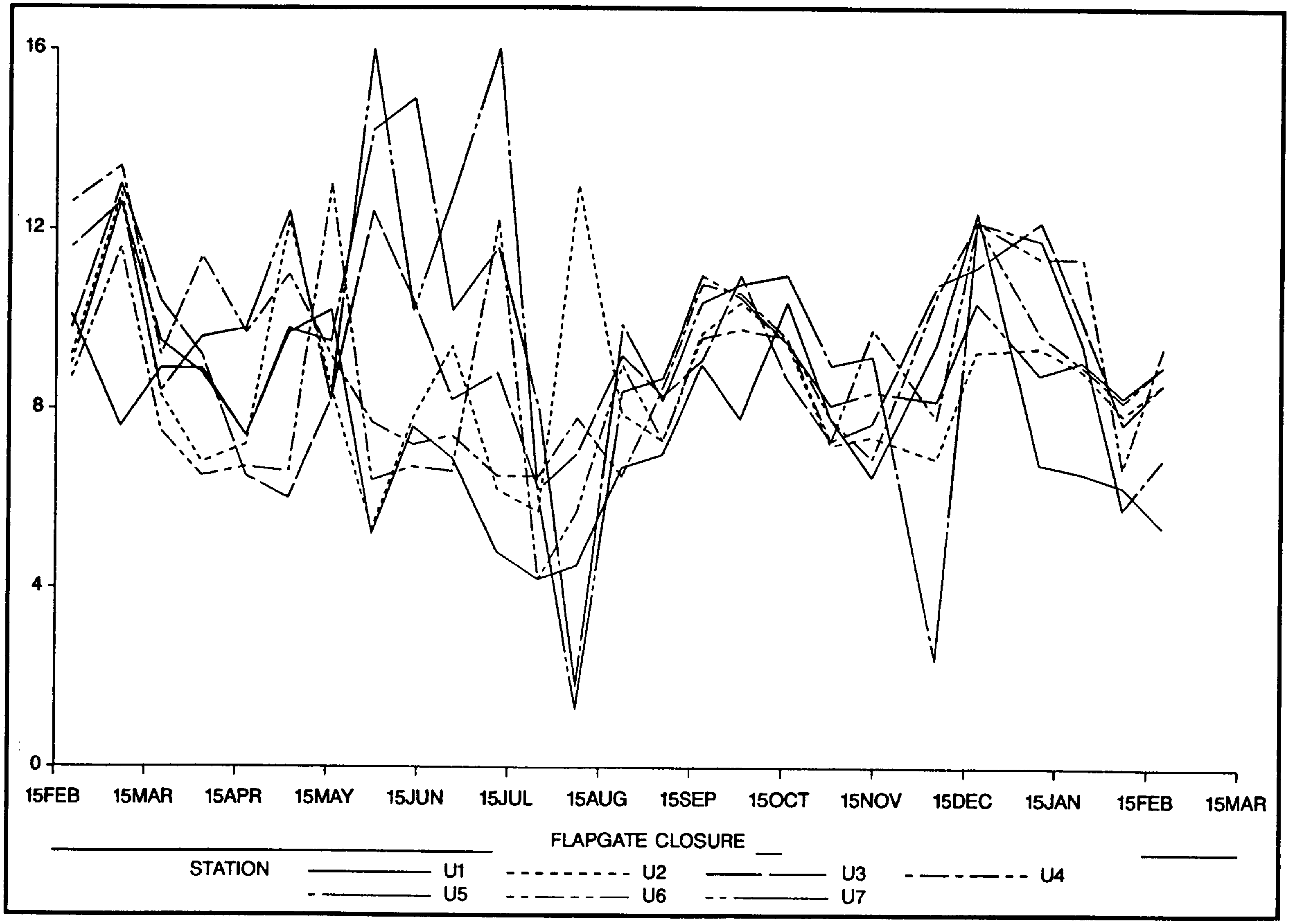

Figure 155. Dissolved oxygen levels (ppm) of each station in the unmanaged area, by date.

More small individuals of species such as grass shrimp and least killifish were collected in the managed area because of the more abundant vegetation.

Marine transient species. Except for the bay anchovy, which was collected at stations M5 and M6 near the structure, very few marine transient species were collected in the managed area. During the drawdown period, the blue crab and a few striped mullet, gulf menhaden, spot, and ladyfish were collected. Had the structure not been blocked open after the drawdown, most of the marine transient organisms might have been unable to use the area. The transient organisms collected in the managed area did not appear to distribute themselves within the area; they were collected only near the openings into the area.

Freshwater and estuarine resident species. Nearly all of the freshwater and estuarine resident organisms collected in both the managed and unmanaged areas were of species having no commercial or sport value. Nevertheless, they are of ecological significance, and of value in the food chain of commercial and sport species if they are available to members of these species. The large numbers of freshwater and estuarine resident species collected in the managed area as compared with the unmanaged area appear to be primarily due to differences in the abundance of submerged aquatic vegetation and to lower water depths in the managed area. Management may be primarily responsible for these differences because the structures lower water levels in the area at the times of sampling, making the organisms more susceptible to capture, and promote larger quantities of submerged aquatic vegetation. The much greater total number of organisms taken in the managed area was attributable to the abundance of only four species: grass shrimp, least killifish, sailfin molly, and mosquitofish. Of the remaining 21 categories, the total number collected in the managed and unmanaged areas was nearly equal (16,225 vs. 15,370). Despite the much greater numbers taken in the managed area, the biomass of all freshwater and estuarine residents caught did not differ as much as the numbers indicate (11,712 g managed vs. 9,589 g unmanaged).

Although at least eight primarily freshwater species (the mosquitofish, bluegill, redear sunfish, golden topminnow, dwarf crawfish, yellow bullhead, largemouth bass, and pirate perch) were collected in the two areas, only the bluegill, redear sunfish, and mosquitofish were common in both areas, and one each of the dwarf crawfish and golden topminnow was collected in the unmanaged area. The freshwater species collected in the managed area were taken throughout the study, an indication that they are resident populations. The freshwater species collected in the unmanaged area, with the possible exceptions of the bluegill and redear sunfish, were collected irregularly and in small numbers. Possible explanations for this include gear inefficiency, sampling outside the preferred habitat, low resident populations, and the possibility that these species are transient freshwater species. If the latter is the case, the structure may impede these species from entering the managed area.

Length-Frequency Data

Length frequencies of most species were difficult to compare because of the discrepancies in numbers in catches between the two areas. In addition, the trawl was generally limited to catching small organisms, and the organisms were measured in 5-mm increments. Of the marine transient species, the low numbers of very small blue crabs collected could mean that they are hindered from entering the managed area. Of the resident species, redear sunfish appears to be recruited in the fall in the managed area and in the spring in the unmanaged area. The collection of slightly larger organisms in the unmanaged area was probably due to the large amounts of submerged aquatic vegetation collected in the managed area. The vegetation collected often trapped very small organisms, especially small grass shrimp and least killifish, that would otherwise escape through the mesh of the net. Weaver and Holloway (1974) noted the collection of small fish in surface and otter trawls taken in vegetated weired areas.

Aquatic Vegetation

Aquatic vegetation was abundant in most of the stations sampled in the managed area. Submerged aquatic vegetation was much less abundant overall in the unmanaged area. The trawl pulled up much more vegetation in the managed area. The vegetation may result in lower predation rates and more available food. Heck and Thoman (1981) found that high densities of submerged aquatic vegetation resulted in reduced predation rates of grass shrimp by killifish. It was impossible to determine whether particular species were generally associated with certain types of vegetation because of the great diversity of vegetation at each station.

Environmental Data

Average salinities in the managed area were slightly higher than those in the unmanaged area during drawdown; closing the structure may trap higher-salinity waters behind it, or evapotranspiration and lack of flushing may contribute to these higher salinities. Average salinities within the managed area after the drawdown were less variable than those in the unmanaged area; the structure appears to mediate salinities. Herke (1971) found that weirs slowed exchange of waters of different salinities. Chabreck et al. (1979) found slightly higher concentrations of salt in areas behind weirs. The combination of the storm surge of hurricane Jerry and apogee high tides resulted in higher-salinity waters at several stations within both areas. The high variability of salinities among the stations in the managed area when compared with the unmanaged area was probably due to lowered circulation within the managed area. Portions of the managed area to the north and west are freshened by the influx of lower-salinity water from Marmande Canal, Miners Canal, and Lake de Cade. The primary source of higher-salinity water appears to be from the Houma navigation canal through Falgout Canal.

Water temperatures in the unmanaged area appear to be slightly higher than those in the managed area because the unmanaged area was sampled later in the day. The absence of dead redfish within the managed area after the freezing weather is probably an indication of their low use of the managed area.

The high variability in the dissolved oxygen levels at the stations in both areas appeared to be due mainly to differences in the amount of submerged aquatic vegetation and its photosynthetic activity.

The stations sampled are relatively shallow and are generally well mixed. The deeper stations may stratify if the proper conditions exist.

Summary

The following summary is based on data collected during a drawdown year only. Drawdowns have occurred usually every fourth year at Rockefeller Refuge, while at Fina LaTerre a drawdown has been implemented every year since management began in 1985. For the Fina LaTerre site, the conclusions pertain only to the southern portion of the managed area and the unmanaged reference area south of Falgout Canal.

1. More marine transient fisheries organisms were caught in the unmanaged area. The levees and water control structures appear to impede transient marine (and possibly some transient freshwater) species from utilizing the managed area. The marine transient organisms collected in the managed area were collected only at the stations nearest the openings.

2. The managed area at Fina LaTerre had larger populations of grass shrimp, least killifish, sailfin molly, and mosquitofish. Management may be primarily responsible for causing these differences by lowering water levels and promoting production of submerged aquatic vegetation. The numbers of the remaining resident estuarine and freshwater fishery species were similar for the two areas.

3. Total biomasses collected in the managed and unmanaged areas were very similar.

4. More species were collected in the unmanaged area than in the managed area.

5. Catches among stations within each area were highly variable. This was probably a function of differences between stations in water depth and vegetation.

6. The weir may trap higher-salinity waters behind it when the flap gates are closed, or evapotranspiration and lack of flushing may contribute to these higher salinities. When the structure is open, it may mediate salinities.

7. Pockets of slightly different salinity waters were found within the managed area, but not within the unmanaged area. Thus, the managed area appears to have less circulation than the unmanaged area.

SYNTHESIS

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The ecological consequences of structural water-level management on marshes at the Fina LaTerre mitigation banksite and Rockefeller Wildlife Refuge are summarized in table 77. The effect of management on physical processes in the marsh are reviewed first, followed by management effects on biological processes in the marsh, effectiveness of management, and implications of the

Table 77. Ecological consequences of marsh management at Fina LaTerre and Rockefeller Refuge, January 1989 to January 1990.

Variable	Fina LaTerre				Rockefeller		
	Managed		Unmanaged		Managed		Unmanaged
Hydrology							
Tidal amplitude & frequency		<		Rock>Fina		<	
Flux							
Materials		<				<	
Sediment loss	no		no		yes[a]		yes
Accretion							
Vertical accretion		<				<	
Bulk density		<				<	
Organic matter content		>				>	
Mineral matter content		<				<	
Organic matter accumulation		<				<	
Mineral matter accumulation		no difference				<	
Near/far	no		yes		N/A		N/A
Burning							
organic mat. con.	N/A		N/A			greater in unburned	
organic mat. accum.	N/A		N/A			initially higher in burned	
Plant growth							
Biomass		<				>	
CO_2 fixation		<				>	
Leaf area index		<				>	
Interstitial salinity		>				<	
Eh (soil reduction)		>				<	
Sulfides		no difference				<	
Plant Species Composition							
Emergent sp.		no difference				>	
Aquatic sp.		no difference				>	

Table 77. Ecological consequences of marsh management at Fina LaTerre and Rockefeller Refuge, January 1989 to January 1990 (continued).

	Fina LaTerre			Rockefeller		
Variable	Managed		Unmanaged	Managed		Unmanaged
Fisheries						
marine transient						
total count		<			<	
mean count		<				
resident						
total count		>			<	
biomass		>			<	

[a]In the managed area of the Rockefeller site, this loss occurred under low-water conditions.

results. This synthesis is based on data collected during a drawdown year only. Drawdowns have occurred usually every fourth year at Rockefeller Refuge, while at Fina LaTerre a drawdown has been implemented every year since management was initiated in 1985. For the Fina LaTerre site, the conclusions pertain only to the southern portion of the managed area and the unmanaged reference area south of Falgout Canal.

Management Effects on Physical Processes

Fina LaTerre

Water-level management reduced tidal amplitude and frequency in the southern portion of the managed area. The results of the flux and accretion analysis are consistent with this hydrologic pattern and with each other. The amount of water and matter exchanged with the southern portion of the managed area through the drawdown structure was low compared to that of the unmanaged area, and vertical accretion and matter accumulation were uniformly low throughout this region. Rates of vertical accretion and matter accumulation are not sufficient to keep pace with local rates of relative sea level rise in both the managed and unmanaged areas. Water and interstitial soil salinities in the southern portion of the managed area were equal to or higher than water and interstitial salinities in the unmanaged marsh throughout the entire year. Soils were more reduced in the brackish vegetation zone of the managed marsh during the plant growing season but there was no difference in sulfide concentrations. Three months after commencement of drawdown (May 1989), water levels in the southern portion of the managed area were drawn down to 5-10 cm below marsh level. Analysis of material fluxes and accretionary processes in the northern portion of the managed area is needed in order to understand management effects on the physical processes of the entire management area.

Rockefeller Refuge

Water-level management reduced tidal amplitude and frequency in unit 4 at Rockefeller Refuge and the results of the flux and accretion analysis are consistent with this hydrologic pattern and with each other. The flux of water and matter, and the rate of vertical accretion and matter accumulation, were greatly reduced in the managed area. Under certain hydrologic conditions, more sediment may flow out of the managed marsh than flows in. Rates of vertical accretion and matter accumulation are not sufficient to keep pace with local rates of relative sea level rise in the managed marsh. In contrast, the unmanaged marsh experienced regular exchange of matter and accretion rates comparable to local relative sea level rise rates. However, substrate conditions were more conducive to plant growth in the managed marsh. Interstitial soil salinity, soil reduction, and sulfide concentrations all were significantly lower in the managed marsh. Water levels were drawn down 20-30 cm below the marsh surface three months after commencement of drawdown (May 1989) and 1-2 weeks after two of seven flap-gates were opened for a total of four days to allow ingress of shrimp larvae.

Summary

The impacts of management on hydrology and sedimentology were similar in the southern portion of the Fina LaTerre site and Unit 4 at Rockefeller Refuge. Tidally driven flux and accretion were significantly reduced. The implications for sea level rise effects need to be investigated.

Management Effects on Biological Processes

Fina LaTerre

The southern portion of the managed area was still dominated by Spartina patens in 1989. The productivity of Spartina patens was lower and substrate conditions were more stressful to plant growth in the brackish vegetation zone of the managed marsh. Plant species diversity was the same in both the southern portion of the managed area and the unmanaged area, although more fish species were collected in the unmanaged area. Total biomass of fish was the same for both the southern portion of the managed area and the unmanaged area. The southern portion of the managed area had significantly more individuals of resident estuarine and freshwater species and significantly fewer individuals of marine transient species than the unmanaged marsh.

Rockefeller Refuge

The productivity of Spartina patens was higher and substrate conditions were less stressful for plant growth in the managed marsh compared to the unmanaged marsh. Plant species diversity was also higher in the managed marsh. There were fewer individuals of both marine transient and resident fish species in the managed marsh. Biomass of resident fish species was also lower in the managed marsh. [The reader is referred to the fisheries study at Rockefeller Refuge conducted during 1989 (Hoese et al. 1990) for additional information on fisheries species composition and biomass at Rockefeller Refuge.]

Summary

Although management effects on hydrology and sedimentology were similar at both sites, management effects on plant growth and stress differed significantly. Growth of Spartina patens and plant species diversity were enhanced at Rockefeller Refuge but not in the southern portion of the managed area at Fina LaTerre.

Effectiveness of Management

The effectiveness of management at achieving stated objectives was evaluated by comparing monitoring results from this chapter and chapter 11 to the objectives described in the section entitled Management Goals and Operation Schedule at the beginning of this chapter.

Fina LaTerre

Management effects in the southern portion of the managed area can be compared to the objectives of the management plan, particularly those objectives which pertain specifically to the southern portion. During 1989, freshwater and sediment inflow were not increased, vertical accretion was low, the salinity trend was not reversed, substrate conditions were less conducive to growth of *Spartina patens*, the dominant vegetative type, and the biomass and productivity of *Spartina patens* was lower in the southern portion of the managed area than in the unmanaged marsh. Although reduced growth of *Spartina patens* could be interpreted as a positive influence of management if the intent is to eliminate this species, the cause for reduction of growth does not appear to be related to the management objective of reversing the salinity trend (salinities were higher in the southern portion of the managed marsh than in the reference marsh). The reduction in growth was more likely related to soil reduction although further research is needed to determine the specific cause. In addition, there was no indication three and four years after implementation of management that the *Spartina patens* marsh had been replaced by a fresher marsh type as projected by Soileau (1984).

Analysis of habitat change (chapter 11) within the entire managed area and both unmanaged areas indicates that, after three years of management, there was no difference in the change of herbaceous marsh acreage (i.e., excluding shrub/scrub), marsh-to-water ratio, or aquatic vegetation acreage between the managed and unmanaged areas. Herbaceous marsh acreage decreased, the marsh-to-water ratio remained the same, and aquatic vegetation acreage increased in both the managed and unmanaged areas. However, shrub/scrub habitat acreage increased in the managed area, contrary to projections (Soileau 1984).

Rockefeller Refuge

After more than 30 years of management, substrate conditions were more conducive to plant growth and production of *Spartina patens* was greater in unit 4 than in the unmanaged area. Management has achieved the objectives of reducing salinities, increasing cover of aquatic vegetation, and increasing production of the dominant plant species when compared to the unmanaged area. The influence of management on marsh-to-water ratios is not as easily discernible. Although marsh management did not prevent the decline in marsh-to-water ratio from 1956 to 1978, the marsh-to-water ratios have improved in the managed marsh since 1978.

IMPLICATIONS OF FIELD MONITORING RESULTS

One of the primary purposes of structural marsh management is to restrict tidal exchange and regulate water levels in order to enhance plant production and consequently improve secondary production of waterfowl and wildlife. A review of the file monitoring data demonstrated (chapter 10) that the influence of restricted tidal exchange and regulated water levels on plant growth and the flux of matter into the managed marsh had not been measured before this study. Thus there has been no documentation that the assumed benefits actually occurred. The results of this study of two brackish marsh impoundments indicate that management severely limited both the flux of matter and vertical accretion. The implications of these results for managed brackish marsh in a rapidly subsiding environment are that vegetative growth and organic matter accumulation may be the only means of maintaining marsh elevation. Unfortunately, plant growth may be limited, and organic matter accumulation has been shown to be significantly reduced by management whether or not plant production was enhanced. These findings raise this question: even if vegetative growth is enhanced, will it compensate for relative sea level rise in the absence of mineral sediment input? If not, managed marshes would experience a sediment deficit. What are the implications of this consequence and how do these implications coincide with observed environmental change in managed marshes?

The implications of these findings can be presented as an hypothesis which serves to highlight potential impacts and the need for research on the interaction of marsh management and relative sea level rise. Hypothesis: the cumulative impact of an annual sediment deficit in an impounded marsh limits the life expectancy and usefulness of a management site because the marsh eventually will subside until natural gravity-induced drainage is no longer possible. Given the low rates of vertical accretion, organic matter accumulation, and plant production at Fina LaTerre, this hypothesis may be reasonable for at least the southern portion of this site. It can be confirmed, however, only from a long-term data base, which does not exist for any site on the delta plain. However, the marsh in unit 4 at Rockefeller Refuge on the chenier plain has been managed for nearly 30 years and it has not yet become submerged. Given the low accretion and organic accumulation rates that were measured during a drawdown year, what are the possible explanations for this?

It is possible that unit 4 is not undergoing a sediment deficit over its entire management cycle. Rockefeller Refuge draws down its water levels every three or four years. The rates of flux, accretion, organic matter accumulation, and plant growth during the other three years of the management cycle are unknown. What is the effect on plant growth of holding water levels at or near the marsh surface for three years? What is the effect of stabilized water levels (without a drawdown) on flux and accretion? Perhaps the amount of flux, accretion, and organic matter accumulation is larger during this management phase--sufficient to compensate for the sediment deficit during the drawdown year. If so, the hypothesis is disproven for this marsh in the chenier plain. But if the rate of change of these variables is not higher during this management phase, how can the fact that unit 4 is not submerged be explained?

If the rates of vertical accretion during the entire management cycle are not keeping pace with relative sea level rise, then there is a sediment deficit in the managed marsh. This deficit may not yet be apparent for at least two reasons. First, the subsidence rate and therefore the sediment deficit for the chenier plain is lower than that for the delta plain. Consequently, it would take longer for a cumulative sediment deficit to become apparent in the chenier plain. Second, marshes in the chenier plain, particularly between cheniers, may lie at higher elevations than those in the delta plain. If so, managed marshes in the chenier plain would start out "ahead" in elevation, improving the ability to draw down water levels and prolonging the effectiveness of management, even with an annual sediment deficit. The life expectancy of a managed site would still be limited, but it would take longer for the effects of the sediment deficit to become apparent.

Whatever the correct explanation, this example demonstrates how little is known about the impact of structural management on accretionary and plant growth processes, and ultimately marsh surface elevation. The field monitoring findings indicate that water-level drawdowns in two brackish impoundments severely limited the flux of matter, accretion, and accumulation of matter. To predict accurately the long- and short-term consequences of using manipulated impoundments in the rapidly subsiding environments of coastal Louisiana, a better understanding of the effects of such techniques on plant growth and marsh accretionary processes must be acquired. Several research topics have been identified and specific issues related to each are discussed below.

RECOMMENDATIONS FOR RESEARCH

Marsh Accretionary Processes

The impact of management on the flux of matter, vertical accretion, accumulation of matter, and plant growth needs to be evaluated for fresh, intermediate, brackish, and saline marsh. In addition, all these variables should be measured during drawdown and non-drawdown years. So far they have been measured only in two brackish marshes and only during drawdown years. These data should be synthesized with data on surface elevation changes in managed and unmanaged marshes.

Plant Growth

The determinants of successful vegetative growth in manipulated impoundments should be isolated by both experimentation and monitoring of natural populations. In particular, the rates of above- and belowground plant production and plant decomposition should be determined.

Fisheries Access

A sizable body of literature indicates that manipulated impoundments and weir management diminish fisheries access to managed marshes. Future research should be directed at determining the feasibility of retrofitting management structures to allow for ingress and egress of aquatic organisms.

Monitoring Procedures

Standardized monitoring procedures should be developed and used at all managed sites. Standard methodologies should be employed to monitor a prescribed set of variables related to water quality, accretionary processes, substrate conditions, plant growth rates and species composition, and waterfowl, wildlife, and fish production. A standardized monitoring program will facilitate comparison of data collected at different managed sites.

Once databases of sufficient size have been accumulated, computer models should be developed which, in conjunction with the new monitoring data, can be used to develop management plans with the most appropriate designs and schedules of operation.

Cumulative Impacts

To overcome the lack of knowledge about the cumulative effects of structural management, three approaches are recommended. First, the influence of management on adjacent marshes should be investigated. Pre- and post-implementation data collected from managed and unmanaged areas should be compared to determine the effect of management on neighboring marshes. Second, the interaction of structural water-level management with other management techniques, such as fresh water and sediment diversions, should be determined. Techniques should be developed to capture sediment and fresh water in managed marshes at diversion outfalls; otherwise the managed marsh probably will not benefit from the diversions. Third, regional impacts to sediment distribution, water flows and levels, and marsh health should be determined. Computer models should be developed from the standardized monitoring data bases within a basin to facilitate this analysis.

Questions Addressed

Our field evaluation of the environmental impacts of current marsh management practices at two managed sites can be summarized by answering the questions asked by the Technical Steering Committee (table 47, chapter 9). An evaluation of the effectiveness of structural management in achieving the stated objectives for the Fina LaTerre and Rockefeller marshes based on the answers to these questions and their management implications is also presented in chapters 14 and 15.

The questions in table 47, chapter 9, addressed by the results presented in this chapter are listed in this section with summaries of the corresponding findings. The following answers are based on data collected during a drawdown year only. Drawdowns have occurred usually every fourth year at Rockefeller Refuge, while at Fina LaTerre a drawdown has been implemented every year since management was implemented in 1985. For the Fina LaTerre site, the conclusions pertain only to the southern portion of the managed area and the unmanaged reference area south of Falgout Canal.

What impact does structural marsh management have on sediment transport, vertical accretion, erosion, and organic matter accumulation within manipulated impoundments compared to unmanaged areas (question I.A.2)?

This study's analysis of two management areas indicates that, during years when water levels are drawn down, exchange of water and associated suspended and dissolved materials was greatly reduced through the water control structure. At Fina LaTerre, exchange measurements were only made at the main water control structure on the south side. It is not known what influence the structures in the northern area have on materials exchange. In regards to accretionary processes, these data suggest that management significantly reduced vertical accretion, soil bulk density, soil mineral matter content, and accumulation of organic and mineral matter. All of these variables were uniformly low during each operational phase of the structure in the managed areas. The influence of management on accretionary processes in the northern portion of the managed area at Fina LaTerre is not known. These data suggest that the effect of management on the flux of matter and accretionary processes was the same for management areas near and far from the coast.

How does management influence vascular plant production (emergent, floating, and submerged) compared to that in unmanaged areas (question I.B.1.a)?

The results of this study reveal that in Spartina patens-dominated brackish marsh, marsh management can either positively or negatively affect plant health and net primary productivity depending on the local environmental conditions and marsh management-associated factors (e.g., operation schedule, design, and drawdown ability).

This one-year field analysis indicated that the marsh management plan at Fina LaTerre resulted in lower leaf CO_2 exchange rates and net aboveground primary productivity than in the adjacent unmanaged marsh. The cause of the lower productivity cannot be determined unequivocally, but we hypothesize that the greater soil-reducing conditions in the managed marsh may have been the primary factor. Soil interstitial salinity differences between the managed and unmanaged marshes at Fina LaTerre were not large enough to have caused this effect on productivity. At Rockefeller Refuge, the effect of marsh management was exactly the opposite of that found at Fina LaTerre: the total leaf CO_2 exchange rates and net aboveground primary productivity were significantly greater in the managed area than in the unmanaged marsh. The more productive vegetation in the managed marsh was most likely due to the less-reduced soil conditions and the lower salinity within this management unit.

In summary, if the marsh can be managed without causing increased soil biochemical reduction and salinity, Spartina patens health and vigor can be maintained or even improved. However, this investigation has demonstrated that these objectives are not always possible to achieve.

How effective are different types of water control structures in reducing saltwater intrusion and salt concentrations (question I.B.1.b.)?

Interstitial soil salinity. Again we find a difference between the Fina LaTerre and Rockefeller Refuge managed marshes. At Rockefeller Refuge, marsh management significantly reduced salinity levels, presumably through a combination of decreased tidal-water inundation and increased containment of fresh water from precipitation. At Fina LaTerre, management's ability to reduce salinity depended on time of the year and distance of the particular marsh site from the water control structure. Interstitial salinities in May and July were higher in the managed marsh closest to the water control structure, while salinity in the unmanaged marsh increased as ambient salinities increased during the year. As a result, by September and November 1989, salinities were the same in the managed and unmanaged marshes. Thus, though marsh management at Fina LaTerre did have some influence on salinity, the effect was not great enough to lower the marsh salinity below ambient.

Water salinity. The salinity of pond water in both the managed and unmanaged marshes at Fina LaTerre exhibited a similar temporal pattern. During the drawdown phase, however, water salinity was consistently higher (1 ppt) in the managed marsh. During the drawdown, the structure may trap higher-salinity waters behind it, or evapotranspiration combined with lack of flushing may contribute to higher salinities. When the structure is open, it may mediate salinities.

How do the various water control structures influence water levels and frequency and duration of inundation in manipulated impoundments compared to unmanaged marsh areas (question I.B.1.c.)?

Water levels were stabilized in managed marshes with the elimination of diurnal tidal effects. Consequently, the frequency of inundation was decreased in these marshes. During the drawdown phase of operation, water levels can be lowered to below the marsh surface. The ability to draw down the water levels was directly related to the efficiency of the structural design, meteorological conditions, and tidal amplitude at the site. We have no data on the duration of inundation.

Do manipulated impoundments influence the rate of sediment and nutrient exchange between the impoundment and the marsh outside it (question I.B.1.d.)?

Our analysis of two management areas indicated that the import of sediment and nutrients into the managed marshes was significantly reduced. The pattern of sediment and nutrient exchange through the control structures studied was similar for marshes near and far from the coast. Under certain hydrologic conditions, especially those encountered during drawdown operations, the data suggest that sediment may be exported from Rockefeller Refuge. These conclusions for Fina LaTerre are for the southern water control structure and it is not known what influence the structures in the northern area have on total flux.

No data were collected on surface elevation changes (question I.B.2.a). See the answer to question I.B.1.b. for discussion of the impacts to soil salinity (question I.B.2.b). No data were collected on the decomposition of soil organic matter and rates of soil subsidence.

How does structural marsh management influence soil oxidation state, presence of toxic compounds, and cycling of nutrients between plants, soil, and water (question I.B.2.c)?

Management can affect soil redox potential positively or negatively. At Fina LaTerre, a lower soil redox potential was associated with marsh management. At Rockefeller Refuge, the ability to draw down the water level of the management area 20-30 cm below the marsh surface has resulted in a more oxidized soil environment than in the unmanaged marsh.

How does management affect fisheries production, standing crop, species composition, access to nursery and foraging areas, and harvest of commercially important species (question II.A.1)?

<u>Fina LaTerre</u>. Our study was not designed to measure secondary productivity, just standing crop. Fishery organisms were grouped into two

categories: (1) resident species that spend their entire life cycles in the estuary, and (2) transient species that spend only part of their lives in the estuary. The management plan affected the two categories differently. The standing crop of resident organisms (primarily grass shrimp, least killifish, sailfin molly, and mosquitofish) was larger in number, but not in biomass, in the managed area than in the unmanaged area. Individuals of these species are tiny and have no economic importance. They are important ecologically as forage for commercial and sport species. However, it is probable that relatively few were consumed by marine transient species in the managed area because few marine transients were captured there. We have no information on the numbers or biomass of these tiny resident organisms that were exported out of the managed area. The managed marsh had a smaller standing crop of marine transient organisms than the unmanaged marsh. Management appears to limit access of the marine transient organisms to nursery and foraging areas within the managed marsh. Because very few economically important marine transient organisms are able to utilize the managed area, the area probably does not contribute many organisms to the commercial or sport harvest. Productivity of an area is a combination of standing crop and turnover rate (the rate at which the population is replaced). Assuming all individuals are of the same weight, two areas may have the same standing crop (i.e., number of individuals), but if the population in one area is replaced at twice the rate of that in another area, then the area with the faster turnover rate has twice the annual production. Because the structures limit water and organism movement, managed areas have the potential for lower turnover rates than unmanaged areas.

How do the various water control structures and management in general affect ingress/egress of estuarine-dependent fisheries and nekton (question II.A.2.)?

Fina LaTerre. Because our study was designed to sample only standing crops of organisms, we can only hypothesize that because the numbers of marine transient organisms were so low in the managed area, their ingress into the area was probably impeded.

What size and type of openings in structures allow optimal movement of organisms (question II.A.3)?

Of course, for marine transient organisms, the larger the openings in the structures, the better. Openings deeper than those of standard fixed-crest weirs, such as vertical slots, would provide bottom-dwelling organisms better access into and out of the area as well as allow a longer period of incoming water movement.

To what extent do managed areas interfere with transport of detritus out of the enclosed area (question II.A.4)?

The export of detritus from the two managed marshes we monitored was significantly reduced during the times we sampled.

No data were collected on benthic meiofauna populations (question II.A.5).

Do provisions for ingress and egress of marine organisms result in or contribute to adverse impacts to the managed area caused by increases in salinities, breakdown of soils, loss of vegetation, etc. (question II.B)?

Fina LaTerre. We did not notice any adverse effects from such provisions during the course of our study at Fina LaTerre. The salinities were slightly higher in the managed marsh during drawdown, but when the structure was open, the salinities were mediated.

If water circulation is reduced, what effect does this have on water quality and consequently on fisheries production in manipulated impoundment areas (question II.C)?

Fina LaTerre. The reduced water circulation in the managed area resulted in pockets of different salinities within that area, but this probably did not cause adverse impacts because changes in salinities were small. During the study, daytime dissolved oxygen levels within the managed area did not reach a level considered to adversely affect fisheries organisms. However, if low dissolved oxygen levels were to occur (which is more likely at night), and the organisms were prevented from leaving the area, mortality could result. The same could be true if the structures prevent movement to deeper water during severe cold spells.

No data were collected on wildlife usage (question III.A.1).

What are the differences in plant species diversity, dominance, and composition in managed versus unmanaged areas?

Our monitoring of two management areas revealed important differences in the impacts of management on plant species diversity, dominance, and composition. At Rockefeller Refuge, which has been managed for nearly 30 yr, plant species were much more diverse at the managed marsh. At Fina LaTerre, however, which has been managed for only 4 yr, no important differences existed in species diversity or composition between the managed and unmanaged brackish marsh zones. The effect of management on species diversity in the fresh marsh zone was not measured.

How are the rate of change of species composition and dominance different in managed and unmanaged areas (question IV.A.3)?

No data were collected on the rate of change of species composition and dominance in managed and unmanaged marshes. File data may provide some information on the rate of change within managed marshes, but do not provide corresponding information from unmanaged marshes for comparison. Because our field monitoring effort collected data for only one year, we cannot estimate rates of change.

Question IV.A.4 is too general and vague to answer with the present data base. Question IV.A.5 repeats question I.B.1.b; see the response for that question. Question IV.A.6 repeats question I.B.2.a; see the response for that question. No data were collected on the influence of aquatic vegetation on the rate of pond closure to address question IV.A.7.

How does water-level management affect landscape changes and ecological processes within marshes near the management area (question VI.A)?

The results from Rockefeller Refuge suggest that tidal amplitude will steadily increase in waterways bordering management areas as the waterways are increasingly leveed. The impact of this change on gravity drainage of water from the managed areas and on water exchange in unmanaged marshes nearby has not been investigated. However, the water-level data from Rockefeller Refuge suggest that managed marshes may have fewer hours of drainage per tidal cycle.

What is the cumulative effect of using many marsh management plans within one basin or sub-basin (question VI.B)?

The results from Rockefeller Refuge suggest that the presence of many marsh management units within an area can increase tidal amplitude and alter marsh drainage patterns. The results of the flux and accretion analyses at both marsh sites indicate that management greatly reduces the tidally driven flux of water and suspended matter into managed areas. The influence of riverine driven fluxes is unknown at Fina LaTerre. Consequently, if many management areas were implemented within a region, it is likely that much of the water and sediment entering the upper basin would flow past the managed marshes without being utilized, thus altering flushing rates and sediment distribution patterns within the region. The interaction of structural management with other management techniques such as diversions of fresh water or sediment should be investigated. Our data suggest that unless special provisions are made in the design and operation of management units to capture fresh water and/or sediment from the diversions, the managed marshes will be relatively isolated and not benefit from regional increases in fresh water and sediment load.

Other regional impacts are not known and should be investigated. For example, will reducing tidal fluxes in numerous managed areas likely increase tidal fluxes in unmanaged areas? If so, what will the effects of this be? In regards to managed areas, will design specs on existing water control structures become obsolete with higher tidal ranges? What will be the cumulative effect of numerous managed areas in a region on fisheries production? There is still much to be learned concerning cumulative effects of water management.

What is the long-term impact of implementing and then abandoning a marsh management plan (question VI.C)?

The data from both Fina LaTerre and Rockefeller Refuge indicate that rates of vertical accretion and matter accumulation are low in managed marshes (approximately 1 mm/yr) during drawdown years. Unless accretion is greater during non-drawdown years or the marshes are able to compensate for the lack of vertical accretion by increased plant production (which our plant growth data for Fina LaTerre suggest is not happening), these accretion data suggest that managed marshes will not keep pace with relative sea level rise. Because Fina LaTerre draws down water levels each year and plant production was reduced in the managed marsh, this suggestion seems reasonable for this site. At Rockefeller Refuge, however, rates of vertical accretion and plant production during non-drawdown years (three out of every four) should be measured to verify this suggestion.

The long-term implication of this suggestion is that managed marshes have a sediment deficit, which has two potential impacts. If management ceases (i.e., the structures are not operated, and the levees and structures are not properly maintained) and the elevation of the managed marsh surface is lower than the surface of the unmanaged marsh because of the cumulative effect of many years of sediment deficit, sea level in the managed marsh will instantaneously rise. The impact to vegetation health of such a change could be detrimental. Even if the management area is never abandoned, the cumulative effect of many years of sediment deficit could result in a gradual lowering of the marsh surface with a concomitant decrease in the ability to drain the marsh by gravity. Eventually, gravity drainage may cease. Surface elevation changes in managed marshes should be investigated.

Chapter 13

MONITORING PROGRAM SYNTHESIS: COMPARISON OF FILE AND FIELD DATA

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The ability to evaluate the effectiveness of any resource management program in achieving stated goals is defined by the quantity and quality of data available and the validity of data interpretations. Because much of the controversy surrounding the impacts of marsh management in Louisiana stems from differences of opinion regarding data quality (including the need for data) and data interpretations, we have been asked by the Minerals Management Service to compare data sets and data validity of the file (chapter 10) and field analyses (chapter 12).

The file and field monitoring programs differ substantially in experimental design, variables measured (i.e., assumptions made), and validity of the data. A comparative evaluation of each of these factors is presented below.

EXPERIMENTAL DESIGN

Current monitoring programs employed by landowners often are of limited spatial and temporal sampling density and usually are not based on a valid statistical sampling design. For example, most programs compare repeated measurements of managed site characteristics over time. This experimental design has a major shortcoming in that, for most variables, no measurements are made in nearby unmanaged marshes. Management effectiveness can be validly interpreted for variables that are occasionally measured in unmanaged marshes (e.g., habitat change). Data collected for variables not measured in unmanaged marsh (e.g., the vast majority of variables measured) can be used to characterize changes in the managed marsh, but not to determine whether marsh management is achieving its goals because the same changes may be occurring in unmanaged marshes during the same sampling period. Hence, interpretations of management effectiveness based on this experimental design are equivocal. Did unmanaged marshes exhibit the same changes as managed marshes? Are the changes in the managed marsh caused by some other factor besides or in addition to management?

The experimental design employed in the field monitoring program of this study included measurements in unmanaged marshes selected as reference areas for the managed marshes. In addition, even though the spatial and temporal sampling densities of some of the variables were limited, a valid statistical sampling design was employed. Hence, statistically significant interpretations concerning the effect of management on various marsh processes could be made.

VARIABLES MEASURED

The variables measured and the way the measurements are interpreted strongly influence the ability to evaluate management effectiveness. The landowner management programs are predicated on combatting saltwater intrusion and tidal scour to improve target-species habitat. Consequently, these monitoring programs concentrate on measuring plant species composition, water parameters (e.g., mainly water levels, salinity, and turbidity), habitat change, and occasionally harvest of waterfowl and furbearers. Variables related to plant growth (e.g., biomass, leaf elongation, CO_2 fixation), substrate conditions that influence plant growth, flux of matter in and out of the marsh, and soil accretion and soil properties have not been measured in any of the landowner monitoring programs. Apparently, it has been assumed that management enhances plant growth and organic matter accumulation, and that the enhanced organic matter accumulation will counteract relative sea level rise (Craft 1989). Hence, some interpretations of management effectiveness in landowner monitoring programs are based on untested assumptions. Data from the field monitoring program indicate that some of these assumptions are not always valid. For example, organic matter accumulation has not been enhanced at Fina LaTerre and Rockefeller Refuge.

One variable measured in every landowner monitoring program, plant species composition, has occasionally been used incorrectly as an indicator of plant growth. This has resulted in invalid interpretations of the effect of management on plant biomass and productivity.

In the field monitoring program employed in this study, the major goal was to assess the effects of installing levees and water control structures, and manipulating water levels, on ecological processes related to hydrology (e.g., salinity, water levels, flux of water and matter), accretion (e.g., accumulation of organic matter and soil bulk density), plant growth (e.g., substrate conditions and rates of plant growth), species composition, and access of estuarine organisms (e.g., fish). Consequently, nearly all of the file monitoring program variables were measured as well as all the variables described above that were omitted from the file program. In addition, all variables were measured in both managed and unmanaged marsh. Consequently, assessments of management effectiveness are based on data interpretations, not on untested assumptions, and therefore are valid statements of the effects of management.

VALIDITY OF DATA INTERPRETATION

The validity of data interpretation differs substantially between the file and field monitoring programs. The field monitoring program was based on questions raised by the regulatory community from which hypotheses were developed and study objectives determined. The fieldwork was directed at achieving the objectives and testing the hypotheses. The data interpretations resulting from the field monitoring program are useful in describing implications of the findings and in answering the questions posed. Monitoring at most sites in the file monitoring program was based on a statistically weak experimental design and, for some variables, on uncritical acceptance of assumptions based on little or no data. Consequently, the validity of interpretations of management effectiveness is questionable in many cases.

PART VI

ECOLOGICAL EVALUATION
OF
MARSH MANAGEMENT

Chapter 14

BIOLOGICAL CONSEQUENCES OF MARSH MANAGEMENT IN COASTAL LOUISIANA

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A wide array of data on the environmental consequences of marsh management was collated, analyzed, and interpreted in the preceding chapters. This chapter examines the biological response to marsh management activities designed to conserve and improve wetland habitat and the productivity of target resources (waterfowl, furbearers, fish, multiple resource management), and monoculture of stocked and indigenous populations (agriculture, aquaculture, and mariculture). However, because the main goals of marsh management are to conserve and improve wetland habitat and productivity of target species, and because monoculture is not a principal public interest goal (see chapters 3 and 4), this review focuses mainly on the former.

The term biological response is used here to mean not only changes in growth and composition of biota brought about by management; but also changes in ecological processes, such as water circulation and flows (e.g., mixing and its effect on salinity and turbidity), nutrient cycling, and vertical accretion. Our synthesis focused mainly on the use of hydrologic controls and their timing. However, other issues considered were human and organism access, harvesting techniques, dredging, threatened and endangered species, and nonstructural measures (marsh burning, chemical intervention). In addition, a design evaluation was performed for all activities involving structures.

Although there were several different target resources (waterfowl, furbearers, and fish) and therefore different goals for managing a marsh, one management technique was employed most often to enhance productivity of all these resources: water-level manipulation. For this reason, all the target resources were considered collectively in most of the discussion that follows. An exception is that in the discussion of hydrologic controls, environmental conditions or responses specific to a given resource were identified and the influence of the structural management of one resource on other resources was described. Similarly, agriculture, aquaculture, and mariculture were considered collectively because such monoculture usually employs a single management technique (manipulated or unmanipulated impoundments). The influence of monoculture on other resources was described.

The biologic response and design concerns for each management activity used for habitat enhancement and monoculture production were discerned from a review of the secondary literature (chapter 2), engineering and construction techniques (chapter 5), and the monitoring data (chapters 10, 11, and 12). The design analysis reviewed the structural requirements of particular management techniques and described environmental consequences of each type of structural manipulation. Four biologic responses were recognized: (1) increase, (2) decrease, (3) no response, and (4) response unknown.

The limitations of the existing marsh management monitoring data base should be noted. It does not contain information from all management sites or all the important environmental variables from each site. Most of the data analyzed in this report are from 16 or fewer management plans and not all of those 16 generated field monitoring data. Only a few of the managed sites have been carefully monitored for any length of time (see chapter 10), and only a few of those have compared managed and unmanaged marshes. Abandoned management areas or those with only partially implemented plans usually generate little or no monitoring data. Probably 20 to 30 of the approximately 50 implemented management areas fall into this category. Hence, this analysis of management effects is based on an incomplete understanding of only the best examples of management.

Additional uncertainty about the consequences of marsh management stems from a dispute over the causes of wetland loss in coastal Louisiana. It is not clear what portion of wetland loss is caused by saltwater intrusion, tidal scour, increased flooding, or decreased sedimentation, but this information should determine the goals and direction of future management efforts. The absence of definitive knowledge about this issue leads to concern over whether marsh is always being managed for the right kind of wetland loss. If not, is management contributing to wetland loss, even indirectly?

IMPROVING WETLAND HABITAT AND PRODUCTION OF TARGET SPECIES

All the issues described above are germane to marsh management aimed at improving the habitat and production of waterfowl, furbearers, fish, or some combination of these resources. Each issue is discussed separately below.

Hydrologic Controls and the Timing of Their Use

Of the three methods employed to control hydrology (weir management, manipulated impoundments, and unmanipulated impoundments), only manipulated impoundments and weir management have been used routinely in coastal Louisiana during the past decade, and the emphasis has been on manipulated impoundments. Unmanipulated impoundments were implemented in the 1950s and 1960s (e.g., at Rockefeller Refuge) but are rarely built today. Therefore, this discussion will focus primarily on manipulated impoundments and weir management.

Manipulated Impoundments

It has been demonstrated that manipulated impoundments can improve habitat and enhance production of waterfowl and wildlife, but there is some concern about the interaction of water quality (i.e., salinity and turbidity) and availability (tides, rivers, precipitation), structural design and timing of operation, the resource (or resources) being managed, and the potential impact on other resources. The interaction of these variables may result in adverse environmental impacts and/or limit the effectiveness of management. For example, a primary function of water control structures is to limit tidal exchange. Unfortunately, this often restricts the ingress and egress of aquatic organisms, particularly during drawdown. Opening the gates occasionally during drawdowns to let in aquatic organisms usually decreases the effectiveness of management at maintaining freshwater conditions and drawing down the water table. Not opening the gates adversely affects transient marine species.

An excellent illustration of the consequences of this interaction is provided at Rockefeller Refuge units 3 and 4. These two units lie side by side and share a common source of water. For the past 10 years unit 3 has been managed with much success as a freshwater impoundment primarily for waterfowl. Unit 4 has been managed for waterfowl and shrimp production. Although the waterfowl habitat is good in unit 4, it is not as good as that in unit 3 (Richard 1989). The most likely reason for this is that the management strategy for shrimp production requires opening the gates, which lets in saline water and diminishes the drawdown. The refuge is installing a water control structure on the north side of unit 4 to create a flow-through system to help lower salinities by introducing fresh water, but if the structure must be opened during a drawdown, the drawdown's effectiveness would be decreased.

In another example, spring floods bring high volumes of fresh water and suspended sediment into the coastal basins. Also during the spring, manipulated impoundments are operated for drawdowns to encourage plant germination, which means that the flap-gates are in the lowered position. Unless special measures are taken during drawdown to capture this water (e.g., opening the gates or using structures on the north side to create a flow-through system) the sediment-laden water will flow past the managed marsh without entering it. Yet, the effectiveness of the drawdown itself is diminished if special measures are taken to let this water into the managed marsh. An excellent illustration of this situation is found at the Fina LaTerre Mitigation Bank site. Fixed-crest weirs on the north side of the area allow the sediment-laden spring flood waters flowing down Minors Canal and Bayou du Large to enter the managed marsh when water levels are high. This does limit the ability of the structure on the south side to lower the water level.

As these examples illustrate, marsh management by means of manipulated impoundments often necessitates a series of trade-offs. Benefits to target resources sometimes may be achieved only at the expense of another resource. Because manipulated impoundments are closed systems, the operation of which is mandated by the natural cycles of plant growth and wildlife behavior, it may not be possible for a management plan to take full advantage of freshwater and sediment resources or always to avoid such detrimental impacts as decreased population size of transient marine species, reduced vertical accretion, or increased plant stress related to flooding. The cumulative effects of these trade-offs also must be considered. For example, what are the long-term implications for coastal fisheries production of reduced vertical accretion rates in managed marshes or of extensive networks of impoundments? Structural management is constantly evolving in an attempt to minimize the consequences of these trade-offs. But until trade-offs are no longer necessary, if ever, the biological response and the success of management in general depend on the interaction of the environmental setting, the management objectives, the types of structures employed, and the schedule of operation of the structures. Hence, the biological response to structural management often varies from site to site.

The biological consequences of and design concerns related to manipulated impoundments are summarized in table 78. As the findings in chapters 2, 5, 10, 11, 12, and 17 indicate, manipulated impoundments may cause the rate or state of a variable to increase or decrease, or may not affect it at all, depending on the interaction of the factors described above. Some effects of management, particularly cumulative impacts, are not known. Data from the literature indicate that management enhances waterfowl and wildlife production but usually

Table 78. Biological response to and structural design concerns about manipulated impoundments and the timing of their use.

BIOLOGICAL RESPONSE

Increase: emergent plant biomass, primary production of emergent species, plant species diversity, cover of aquatic species, vegetated marsh area, marsh-to-water ratios, waterfowl density, wildlife production, resident fish populations, water salinity, soil interstitial salinity, soil sulfide concentrations, soil reduction (Eh), soil organic matter content, water levels

Decrease: emergent plant biomass; primary production of emergent species; vegetated marsh area; marsh-to-water ratios; marine fish populations; fisheries species composition; water salinity; soil interstitial salinity; soil reduction (Eh); soil sulfide concentrations; vertical accretion; accumulation of organic and mineral matter; soil mineral matter content; soil bulk density; flux of water, sediment, and nutrients; tidal amplitude; water levels

No response: water salinity, marsh-to-water ratios, plant species composition

Response unknown: cumulative effects related to marsh surface elevation, fisheries production, interaction with other management techniques (e.g., freshwater and sediment diversions), structural failure and/or abandonment of managed area, water levels and flows in adjacent unmanaged marshes

STRUCTURAL DESIGN CONCERNS

Effectiveness: manipulated impoundments must provide complete hydrologic control of the managed marsh; this requires impounding the marsh with levees and regulating water levels and flows with water control structures

Water control structures must be able to restrict tidal exchange, drawdown water levels, keep out salt water, let in fresh water, fish, sediment, nutrients

Levees must eliminate exchange of water via surface flows (i.e., keep out salt water and retain precipitation), and therefore should be high enough to keep out all but major storm tides and continuous with no gaps except to accommodate water control structures

Table 78. Biological response to and structural design concerns about manipulated impounements and the timing of their use (continued).

<u>Consequences or trade-offs:</u> depending on the timing of operation, some material resources will be diminished or underutilized (i.e., traded for other resources) in order to achieve management objectives; attempts to maximize more than one target resource at a time, such as fish and waterfowl, will often reduce the production of both; any trade-off listed below can be read in either direction, depending on the management goal

Water control structures: in some instances, managers must trade (1) fish, sediment and nutrients for reduced salinities and controlled water levels; (2) fish for waterfowl and wildlife; (3) fresh water and sediment for spring drawdowns.

Levees: trade (1) fish, sediment, and nutrients for reduced salinities and controlled water levels; (2) fish for waterfowl and wildlife; (3) fresh water and sediment for spring drawdowns.

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limits fisheries access. Field data acquired during this study indicate that manipulated impoundments significantly decreased the flux of matter (water, sediment, and nutrients), vertical accretion, and organic matter accumulation in two managed brackish marshes (see chapter 12). Plant productivity and soil substrate conditions conducive to plant growth in brackish marsh may be enhanced or diminished by this type of management. Analysis of aerial photography indicates that management may increase or decrease marsh area and marsh-to-water ratios. The consequences of the timing of the operation are related to the trade-offs managers must accept in order to achieve their objectives. In general reduced salinities and controlled water levels are often incompatible with the optimization of fish, sediment, and nutrients, and spring drawdowns diminish freshwater and sediment access.

Weir Management

Weir management in coastal Louisiana has been accomplished mainly with fixed-crest and occasionally with variable-crest weirs. Because no levees are used and marsh surface water exchange is maintained, there are fewer trade-offs associated with this type of structural management than with manipulated impoundments. Consequently, the success of weir management depends mostly on the environmental setting. Also, because of the smaller number of environmental factors to be considered, it may be easier to decide on the optimal trade-offs.

The biological consequences and design concerns related to standard fixed-crest weirs are summarized in table 79. Because no new field data were collected on the biological effects of fixed-crest weirs, this summary is based primarily on findings presented in the literature. The one exception is the habitat change analysis presented in chapter 11.

As the findings in chapters 2, 5, 10, 11, and 17 indicate, weir management may cause the rate or state of a variable to increase or decrease, or may not affect it at all. The influence of weir management on marsh vertical accretion in sediment-poor inland environments is not known. Data from the literature indicate that weir management often enhances aquatic vegetation production and therefore improves waterfowl habitat. Weir management appears to have little impact on mammal density in the marsh. Weirs can increase, decrease, or have no effect on water turbidity and salinity. Weirs may or may not influence vegetative cover, plant species diversity, or plant species richness. Plant biomass and soil substrate conditions conducive to plant growth are sometimes decreased. The major design concern is that weirs act as barriers to aquatic organisms. Because weirs are essentially low dams across waterways, they can severely limit estuarine organism access to the marsh. However, vertical-slotted and rock weirs apparently provide feasible alternatives that lessen the impact on fisheries resources.

Regulate Human Access

Anti-trespassing measures have been incorporated into some management plans (see chapter 7). Management aimed at regulating boat access through navigable channels in the marsh may influence habitat and production of waterfowl, wildlife, and fish resources by reducing bank erosion from boat wakes and the rate of harvesting. There are no quantitative data in the literature on

Table 79. Biological response to and structural design concerns about weir management.

BIOLOGICAL RESPONSE

<u>Increase:</u> production and cover of aquatic vegetation, waterfowl density, non-game bird density, water salinity, soil salinity, hydroperiod

<u>Decrease:</u> fish populations, maximum standing crop of emergent vegetation, water level fluctuations and tidal exchange, stormwater runoff, water salinity, turbidity, soil Eh and pH, pond siltation rate, vegetated marsh area

<u>No response:</u> water salinity, water oxygen, turbidity, soil salinity, soil organic content, aquatic vegetation cover, vegetated marsh area, plant species diversity and richness, marsh-to-water ratio, waterfowl density, non-game bird density, mammal density

<u>Response unknown:</u> short-term marsh vertical accretion rates in sediment-poor environments

STRUCTURAL DESIGN CONCERNS

<u>Effectiveness:</u> weirs must restrict tidal flow, stabilize water levels, and prevent complete de-watering of marsh ponds

<u>Consequences or trade-offs:</u> trade (1) some fish species for stabilized water levels and aquatic vegetation; (2) some fish species for waterfowl; (3) shrub-scrub for emergent vegetation

the success of this type of management at reducing the loss of marsh habitat through channel widening and preventing the overharvesting of fish and wildlife resources. The primary design concern of an anti-trespassing structure is that it must prohibit or regulate unwanted boat traffic without influencing water levels and flows, unless it is also part of the water management scheme. In other words, the barriers should be cables, chains, floating logs, or pilings that allow the water to flow around, under, or through the barrier.

Harvest Technique

The harvesting activity with the greatest impact on marsh resources is the construction of trenasses, shallow ditches that give trappers and hunters access to interior marsh. This activity, described in chapter 5, is frequently part of a marsh management plan. This management activity gives rise to two major design concerns. Trenasses may allow the marsh to drain for long periods during low water. It was this consequence that apparently prompted the invention of the fixed-crest weir in the 1940s (O'Neil 1949; Nyman 1989). Trenasses may also provide avenues by which salt water can spread through the marsh. This could be especially detrimental if the trenasse connects two different marsh types. Trenasse construction therefore may result in vegetation changes associated with altered drainage of the marsh and marsh loss or vegetation changes associated with saltwater intrusion if proper steps are not taken to manage drainage and water quality.

Dredging

Dredging is needed to repair spoil banks, construct levees, and install water control structures. Because many of the levees of managed impoundments are the spoil banks of navigation canals, the loss of habitat associated with dredging and spoil bank construction should be attributed to navigation, not to marsh management. However, new levee construction is sometimes required to implement a management plan (see chapter 7). In these cases, the impacts of dredging would have to be weighed against the potential benefits of management. The amount of dredging required to install a water control structure is usually minor and not considered a substantial environmental impact.

Threatened and Endangered Species

Marsh management is not usually implemented for the primary purpose of benefitting threatened and endangered species (see chapter 7). However, any such species living within or near the managed area likely will experience the consequences of management, at least indirectly. If the habitat or other resource is improved or degraded, the threatened or endangered species may be affected accordingly. The impacts of construction on such species can be avoided by scheduling construction during nonbreeding and non-nesting seasons.

Nonstructural Management

Two nonstructural management activities may be used alone or in conjunction with structural management: marsh burning and chemical control of undesirable vegetation.

Marsh Burning

Marsh burning has been widely used in coastal Louisiana for many different purposes, but Chabreck et al. (1989) report that its value to management is often questionable. Burning has been effectively used to remove dense stands of vegetation and attract snow geese which feed on the newly exposed roots and tubers, prevent encroachment of woody plants in freshwater marshes, and encourage the growth of Scirpus olneyi over Spartina patens in manipulated brackish marsh impoundments where water salinities and levels can also be managed to favor S. olneyi (Chabreck et al. 1989). Caution should be used in controlled burns in order that the organic substrate not be destroyed. Organic matter is an important component of marsh building, especially in the subsiding environment of coastal Louisiana. Therefore, the marsh should not be burned when dry. Ideal burning conditions include low humidity and moist soil (Stutzenbaker and Weller 1989).

Field monitoring data from Rockefeller Refuge (chapter 12) indicate that burning had no effect on primary production but that water-level management and burning combined to lower plant biomass in the fall. Burning caused a decrease in soil bulk density and the rate of organic matter accumulation but both variables recovered to pre-burned states within 12 months. The data from Rockefeller Refuge also suggest that burning decreases the organic matter content of the soil.

Chemical Intervention

Such vegetation as water hyacinth (Eichornia crassipes), alligator weed (Alternanthera philoxeroides), and other noxious plant species grows rapidly, has little value to wildlife, competes with food plants desirable to waterfowl and wildlife and may clog waterways and water control structures. If these species cannot be controlled with salt water, herbicides can be used. The use of herbicides has been limited in coastal Louisiana but probably will become more popular (Chabreck et al. 1989). This is a very localized management technique with impacts to water quality and aquatic life being the primary environmental concern. For example, the potential exists for rapid depletion of oxygen when large masses of vegetation die quickly in shallow water bodies with slow turnover rates.

MANAGEMENT FOR MONOCULTURE PRODUCTION

Mariculture and aquaculture activities are not considered by the regulatory agencies to be marsh management (chapter 4). However, manipulated impoundments provide the control over organism ingress and egress needed to conduct a mariculture operation. Therefore, manipulated impoundments have been used for mariculture by placing screens or nets in the water control structures. This activity was supported by the state legislature (chapter 4), despite the direct conflict with regulatory agency policies. Mariculture can also be accomplished by using unmanipulated impoundments.

The main management activity of mariculture operations in manipulated impoundments is the restriction of ingress and egress of aquatic organisms. Migratory and resident species that feed in the marsh during parts of the day but spend the rest of the time in bayous and channels will not have access to marsh managed for mariculture. In addition, in stocked mariculture impoundments competition between hybrid and natural species will occur, including predation upon wild organisms by hybrid ones. This may influence the gene pool of natural populations.

Mariculture operations conducted in unmanipulated impoundments result in completely isolating the managed habitat from the natural system. The biological consequences of this type of activity are the same as those for manipulated impoundments except that no water exchange (and organism ingress and egress) is permitted. Because water turnover is eliminated and commercial food is usually added to the system, the risk of eutrophication and high biological oxygen demand is high. Aeration with pumps may be required.

Chapter 15

SUITABILITY OF MARSH MANAGEMENT

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Having thoroughly reviewed the environmental conditions in which management occurs and its potential environmental consequences in the previous chapters, it is appropriate to conclude this report with an analysis of marsh management's suitability to coastal Louisiana. The suitability of management is defined as the potential of management to improve the resource. This chapter compares the physical characteristics of the Louisiana coastal zone to management objectives in order to determine the suitability of management to the diverse environments of coastal Louisiana. The suitability of each relationship is rated and presented in a matrix to draw together the findings of the study into a single reference with practical management applications.

The suitability analysis and matrix are intended as a guide to management suitability; they should be useful to regulatory personnel in their reviews of permit applications and in identifying and focusing on important management issues related to a proposed activity and site. The analysis and matrix are not intended to supplant specific site data or thorough case-by-case reviews of each marsh management permit application. Only the suitability of structural management techniques are analyzed because nonstructural ones (e.g., marsh burning and chemical intervention) do not require a federal permit and occur only on a very local scale. The limitations of the data base from which this matrix is derived (chapter 14) should be kept in mind.

MATRIX METHODOLOGY

The matrix compares three management objectives (waterfowl habitat, furbearer habitat, and fish monoculture) with five physical characteristics: vegetation association (based on species composition and salinity), soil type, water quantity (freshwater availability and saltwater intrusion), sediment (water turbidity and sediment availability), and physiography (physiographic setting, canal density, and wetlands loss). Each of the physical characteristics has been divided into high and low conditions whenever possible. The suitability rating indicated in the matrix (table 80) applies to manipulated impoundments because this form of structural management is the primary type permitted during the past decade (see chapter 7). The suitability of weir management and unmanipulated impoundments is indicated only when special conditions warrant its discussion.

The suitability of management is rarely determined by a single environmental factor, but rather by the interaction of a suite of factors. Therefore, suitability is indicated in the matrix as a range with three levels: high, low, and unsuitable. If the suitability of marsh management to a particular characteristic is rated as a range (e.g., high-low), the factors influencing the degree of suitability are discussed. The level of suitability is determined from the scientific literature, the monitoring program (chapters 2, 9, 10, 11, 12,

Table 80. A general guide to suitability of marsh management in coastal Louisiana.

	Resource		
	Waterfowl Habitat	Furbearer Habitat	Fisheries Culture
PHYSICAL CHARACTERISTIC			
Vegetation Association			
saline	low-U[2]	low	high
brackish	high-low	high	high
intermediate	high-low	high-low	high-low
fresh	high-low	high-low	high-low
Soil Type			
mineral	high	high	high
organic	high-low	high-low	high-low
highly organic muck or flotant	U	U	U
Water Quantity			
freshwater availability			
high	high	high	high-low
low	low	low	high-low
saltwater intrusion			
high	high-U	high-U	high-low
low	high-low	high-low	high-low
Sediment			
water turbidity			
high	high-low	high-low	low
low	high-low	high-low	high
sediment availabilty			
high	high-low	high-low	high-low
low	high-low	high-low	high-low
Marsh Physiography			
physiographic setting			
chenier plain	high	high	high
delta plain	low	low	high
canal density			
high	high-low	high-low	N/A[3]
low	high	high	N/A

Table 80. A general guide to suitability of marsh management in coastal Louisiana (continued).

	Resource		
	Waterfowl Habitat	Furbearer Habitat	Fisheries Culture
wetland loss			
high	high-low	high-low	N/A
low	high	high	N/A

[1]Suitability generally is determined by the interaction of several factors. Therefore, all factors listed in this table should be considered when making a determination of suitability. The influence of cumulative impacts on management suitability was not covered in this analysis.
[2]U=unsuitable
[3]N/A=not applicable

and 14), environmental conditions along the coast (chapter 6), and structural feasibility (chapters 5 and 8).

Because cumulative impacts are difficult to quantify and the potential long-term impacts of management on marsh elevation are not well understood, these factors were not included in the suitability analysis. This does not mean, however, that they are not important and may not be overriding factors which limit the suitability of management in the long term. This matrix should be used tempered with the understanding that the degree of suitability (i.e., attainment of management objectives) could be substantially lower if potential cumulative impacts are considered. Hence, it would be best to assume that the matrix indicates the potential for short-term improvements in the resource. When more data and longer-term data bases are generated, the potential for realizing long-term improvements can be evaluated. Finally, given that the data analyses presented in the previous chapters are based on the best examples of management (i.e., contains fully implemented and operational plans with few, if any, partially implemented or abandoned plans), this suitability analysis also represents a best-case scenario of marsh management.

RESULTS AND DISCUSSION

Although the matrix presents the three objectives separately, the discussions of the suitability of marsh management to enhancing waterfowl and furbearer habitat are combined because furbearer habitat is almost never a primary goal of management (see chapter 7). Rather, management for waterfowl is usually the primary goal and furbearer resources benefit from the stabilized water levels and the reduction in prolonged droughts, floods, and large changes in salinity. The unique suitability of management to furbearer habitat enhancement is discussed when appropriate.

Waterfowl and Furbearers

The diverse marsh environments of coastal Louisiana can be highly suitable or unsuitable to management for waterfowl and furbearer resources, depending on the physical characteristics of the site.

Vegetation Association

The suitability of management for waterfowl varies substantially with marsh type as indicated by plant species associations and water salinity. Saline marsh is generally considered a poor habitat for waterfowl and is not easily converted to a less-saline type because of its proximity to the coast. Therefore, the suitability of management for waterfowl ranges from low to nonexistent, even though saline marsh soils can easily support artificial water control structures. Fresh and intermediate marshes provide prime habitat for waterfowl, and brackish marsh can support large waterfowl populations if aquatic vegetation is available. These marsh types are usually highly suitable to management, but soil conditions may decrease that suitability rating to low, particularly in intermediate and fresh marsh. These two marsh types consist of organic soils, and if the soil is too organic or the marsh is flotant, the substrate will not be able to support the levees and structures needed to provide water-level control.

The suitability of management for furbearer habitat also varies with marsh type and for similar reasons, but it also depends on the species of furbearer. Because muskrat prefer brackish marsh but also live in saline marshes, the suitability rating is high for brackish but low for saline marshes. Because nutria prefer fresh marsh habitat, fresh and intermediate marsh types are considered highly suitable to management. However, suitability may be diminished in marshes with highly organic soils or in flotant marsh.

Soil Type

Because of its influence on structural feasibility, soil type strongly affects the suitability of management. Mineral soils are well suited to structural management by levees and water control structures. Management suitability varies in organic soils depending on their organic content: the more organic matter in the soil, the less suitable the soil is for marsh management. Highly organic muck soils and flotant marshes are unsuitable, because they cannot support the levees.

Water Quantity

Because fresh water is a prime requirement of good waterfowl and furbearer habitat, sites with fresh water are better suited to management for resource production than areas with little fresh water. Consequently, the suitability rating of this characteristic ranges from high to low.

Waterfowl and furbearer management is influenced greatly by saltwater intrusion; hence suitability ranges from high to unsuitable. If salt water is intruding into a marsh, the suitability of waterfowl and furbearer management depends on the availability of fresh water, the marsh type, and the furbearing species present. Low-salinity or fresh marshes with a high degree of saltwater intrusion and very little fresh water available to freshen the area (i.e., precipitation only) may be unsuitable or only poorly suited to management. Saltwater intrusion would decrease the suitability of management for nutria more than it would for muskrat because of their different habitat requirements.

Sediment

The availability of sediment influences the suitability of waterfowl and furbearer habitat management. The amount of sediment available throughout the region determines the amount available to enhance plant nutrition and maintain the surface elevation of managed marshes. The higher the sediment load in neighboring waterways, the greater the potential for capturing sediment and maintaining overall marsh health. However, waterfowl management is more suitable in ponds of low turbidity because aquatic vegetation grows best under those conditions. Therefore, when determining its influence on management suitability, turbidity should be evaluated in relation to marsh type and subsidence potential. The suitability of management ranges from high to low depending on marsh type, subsidence potential, water turbidity levels, and the ability of the structure to move sediment-laden water into the managed area.

Physiography

The suitability of management for waterfowl and furbearer habitat varies with the geologic setting. The chenier plain is more geologically stable, has lower rates of subsidence, and has soils better suited to structural management (see plate 8) than does the delta plain. In addition, the major concentrations of waterfowl are located in western and central Louisiana (Chabreck et al. 1989). Consequently, management is more suitable to the chenier plain than to the delta plain.

The density of canals affects management suitability, depending on the tidal amplitude, degree of saltwater intrusion, and marsh type. In general, the lower the density the higher the suitability for management because tidal amplitude is less likely to be altered and there are fewer opportunities for saltwater intrusion. Increased tidal energy and saltwater intrusion would have more impact in fresh marshes with organic soils than in saline marshes with typically mineral soils.

The extent of wetland loss at a site can influence management suitability. Management can be used to restore at least partially an area that has lost nearly 100% of its vegetated wetlands (e.g., Amoco West Black Lake), depending on soil type, sediment availability, and the ability to draw down the water levels (with pumps, for example).

Fisheries Culture

The suitability of the diverse environments of coastal Louisiana to fisheries culture does not vary as much as it does for waterfowl and furbearer management. The site characteristics are generally either highly suited or unsuited to fisheries culture, or they are irrelevant because the culture activities will create an artificial environment for the target species anyway, rather than modifying or restoring altered environmental conditions as is the case in waterfowl habitat management. Culture activities may take place in a manipulated or unmanipulated impoundment. Often the natural diets of the fish or crustaceans are supplemented with commercial food. It is not the purpose of culture to alter water salinity but rather to maintain a particular level and to culture species acclimated to that ambient salinity. Another purpose of culture is to isolate the target species from its surrounding environment to prevent escape and minimize interspecific competition. Typically, these environmental conditions either clearly can or cannot be met at a particular site.

Vegetation Association

Provided that an impoundment can be built and maintained and that the target species is adapted to the salinity and habitat of the site, all four marsh types are equally suitable to management.

Soil Type

As with waterfowl management, the ability to build and maintain an impoundment depends on the soil present at the site. Mineral soils are very suitable and highly organic muck soils are unsuitable for structural management.

Water Quantity

The availability of fresh water and the extent of saltwater intrusion may influence the suitability of a site in intermediate and fresh marshes. Raising large masses of a single species requires keeping environmental conditions fairly constant. If freshwater availability and saltwater intrusion vary greatly, the suitability of a fresh marsh site may be diminished.

Sediment

If sediment is readily available, then the suitability of the site may be diminished. Highly turbid water may not provide optimum growing conditions for some species of fish.

Physiography

Provided that an impoundment can be built and maintained, the chenier and delta plains should be equally suitable for fish monoculture. Canal density and wetland loss rates should not influence the suitability of a site for management if the target species is adapted to the environmental setting.

PART VII

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Chapter 16

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Wicker, K. M. 1989. Preparation of Habitat Maps for Selected Marsh Management Areas in Coastal Louisiana. Report prepared for the Environmental Protection Agency under contract to Lee Wilson and Associates, Inc. Baton Rouge: Coastal Environments, Inc.

Wicker, K. M., D. Davis, and D. Roberts 1983. Rockefeller State Wildlife Refuge and Game Preserve: Evaluation of Wetland Management Techniques. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Section. 86 pp., 8 plates.

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Wilkinson, P. M. 1987. Management innovations to enhance the use of impoundments by estuarine transient species. Pp. 72-86 in Coastal Wetland Impoundments: Management Implications. Workshop Proceedings. Technical report #SC-SG-TR-87-1. Charleston: South Carolina Sea Grant Consortium.

Windham, Michael 1990. Personal communication on March 2. New Orleans: Louisiana Department of Wildlife and Fisheries, Fur and Refuge Division.

Wiseman, W. J., Jr., and E. M. Swenson 1987. Long-term salinity trends in Louisiana. Pp. 101-21 in R. E. Turner and D. R. Cahoon, eds., Causes of Wetland Loss in the Gulf of Mexico, Vol. 2: Technical Narrative. OCS Study/MMS 87-0120. Final report submitted to the Minerals Management Service. Baton Rouge: Louisiana State University, Center for Wetland Resources.

Wolaver, T. G., and J. C. Zieman 1983a. Tidal exchange of nitrogen and phosphorus between a mesohaline vegetated marsh and the surrounding estuary in the Lower Chesapeake Bay. Estuarine, Coastal and Shelf Science 16:321-32.

Wolaver, T. G., and J. C. Zieman 1983b. Effect of water column, sediment, and time over the tidal cycle on the chemical composition of tidal water in a mesohline marsh. Marine Ecology Progress Series 12:123-30.

Wolaver, T., R. Dame, J. D. Spurrier, and A. B. Miller 1988. Sediment exchange between a euhaline saltmarsh in South Carolina and the adjacent tidal creek. Journal of Coastal Research 4(1):17-26.

Wolaver, T. G., R. L. Wetzel, J. C. Zieman, and K. L. Webb 1980. Nutrient interactions between salt marsh, mudflats, and estuarine water. Pp. 123-33 in V.S. Kennedy, ed., Estuarine Perspectives. New York: Academic Press. 533 pp.

Wolaver, T., G. Whiting, B. Kjerfve, J. Spurrier, H. McKellar, R. Dame, T. Chrzanowski, R. Zingmark, and T. Williams 1985. The flume design--a methodology for evaluating material fluxes between a vegetated salt marsh and the adjacent tidal creek. Journal of Experimental Marine Biology and Ecology 91:281-91.

Wood, L. D. 1989. The Forums Proposal to Delegate §404 to the States: A Bad Deal for Wetlands. National Wetlands Newsletter 11(4):2-5.

Woodwell, G. M., C. A. S. Hall, D. E. Whitney, and R. A. Houghton 1979. The Flax Pond ecosystem study: exchanges of inorganic nitrogen between an estuarine marsh and Long Island Sound. Ecology 60(4):695-702.

Woodwell, G. M., D. E. Whitney, C. A. S. Hall, and R. A. Houghton 1977. The Flax Pond ecosystem study: exchanges of carbon in water between a salt marsh and Long Island Sound. Limnology and Oceanography 22(5):833-38.

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Zedler, J. B., T. Winfield, and P. Williams 1980. Salt marsh production with natural and altered tidal circulation. Oecologia 44:236-40.

Zimmerman, R. J., and T. J. Minello 1984. Densities of Penaeus aztecus, Penaeus setiferus, and other natant macrofauna in a Texas salt marsh. Estuaries 7(4A):421-33.

Chapter 17

ANNOTATED BIBLIOGRAPHY

Richard D. Hartman
Louisiana Geological Survey

Baldwin, W. P. 1968. Impoundments for waterfowl on South Atlantic and Gulf coastal marshes. Proceedings of the Marsh and Estuary Management Symposium: 127-133.

Describes the management of several types of manipulated impoundments (regularly and irregularly flooded salt marshes, saltmeadows and salt flats, and coastal fresh marshes) for producing vegetation beneficial to waterfowl. Describes vegetation in, construction, management, and value of each impoundment type. Concludes that managers skilled in marsh management can compensate for the loss of natural marsh with intensified management of impoundments.

Bradshaw, W. H. 1985. Relative Abundance of Small Brown Shrimp as Influenced by Semi-impoundment. M.S. thesis. Baton Rouge: Louisiana State University. 61 pp.

Measured the effects of a fixed-crest weir on brown shrimp abundance using Renfro beam trawls taken in a weired pond and in an adjacent, natural pond. Catch was less and average shrimp length slightly greater from the weired pond. Annual variation in abundance suggests the effects of a weir may be mitigated by environmental variations.

Broussard, L. J. 1988. Report on current marsh management engineering practices. Alexandria, La.: U.S. Department of Agriculture, Soil Conservation Service. 44 pp. + figures.

Describes the types, uses, and construction of water control structures, including fixed- and variable-crest weirs, embankments, plugs, and level ditches. Describes the advantages and disadvantages of each type structure, where to place, how to build, and materials best suited. Summarizes environmental considerations (soil composition, salinity, soil properties) and describes various water management schemes. Summarizes new engineering techniques and new water structures.

Burleigh, J. G. 1966. The Effects of Wakefield Weirs on the Distribution of Fishes in a Louisiana Saltwater Marsh. M.S. thesis. Baton Rouge: Louisiana State University. 69 pp.

In comparing areas affected by fixed-crest weirs to unweired areas, the author used trammel nets, rotenone, and cast nets to sample fish abundance. Results indicate weirs affected the distribution of spotted sunfish, redear sunfish, pinfish, spotted gar, sea catfish, and blue crab. All but sea catfish were more abundant on the landward side of the weir. The weir was reported to have no effect on salinity.

Carlson, D. B. 1987. Salt marsh impoundment management along Florida's Indian River lagoon: historical perspective and current implementation trends. Pp. 358-371 in Proceedings of a Symposium on Waterfowl and Wetlands Management in the Coastal Zone of the Atlantic Flyway. Wilmington: Delaware Department of Natural Resources and Environmental Control, Delaware Coastal Management Program.

Describes the use, type, amount, and history of Indian River manipulated impoundments. Provides recommended management techniques, including rotational management and rotary ditching. Rotational management uses culverts with flapgates to connect the impounded marsh with the estuary. Culverts are opened fall-winter and closed spring-summer. During the summer, pumps keep water at a minimum height for mosquito control. Rotational management allows exchange of detritus and organisms and maintains most marsh vegetation. Rotary ditching provides a hydrologic connection between mosquito-producing areas and larvivorous fish-holding areas.

Carlson, D. B., and J. D. Carroll, Jr. 1985. Developing and implementing impoundment management methods benefiting mosquito control, fish and wildlife: a two year progress report about the technical subcommittee on mosquito impoundments. Journal of the Florida Anti-Mosquito Association 56(1):24-32.

Describes the use and management of Florida's manipulated impoundments for water quality, fish, and mosquito control. Summarizes research results and suggests management guidelines. Calls for: streamlining the review/permitting process; allowing long-term, flexible implementation of management plans; finding methods to encourage property owners to reconnect impoundments to the estuary without losing future mitigative options; and making it less expensive for applicants to implement management plans.

Carney, D. F. 1977. The Evaluation of Waterfowl Habitat Improvement Practices in a Southeastern Louisiana Freshwater Marsh. M.S. thesis. Baton Rouge: Louisiana State University. 78 pp.

Evaluates vegetative biomass, seed availability, vegetative coverage and composition, and waterfowl usage of a freshwater marsh managed for waterfowl. The manipulated impoundment, managed with a pump, experienced a drawdown during the summer months. It produced more waterfowl plant foods than the control area and experienced 9 times and 4 times greater winter usage by ducks and coots respectively than did the natural area.

Carney, D. F., and R. H. Chabreck 1977. An evaluation of spring drawdown as a waterfowl management practice in floating fresh marsh. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 31:266-271.

Compares the effects of a drawdown in a manipulated impounded freshwater marsh to a natural marsh. The impoundment produced more waterfowl foods and fewer

water hyacinths. In winter, ducks and coots used the impounded area more than the control area.

Chabreck, R. H. 1959. A study of marsh management techniques, in Louisiana coastal marshes. Unpublished research report. Baton Rouge: Louisiana Wild Life and Fisheries Commission. 16 pp.

Compares vegetative production in marsh ponds managed with weirs or earthen dams with natural, unmanaged marsh ponds. Concludes marsh ponds are more productive when properly managed. Percent frequency of widgeongrass in weired ponds was 4 times that in natural ponds. However, widgeongrass production in ponds behind earthen dams was similar to that of unmanaged ponds. States that although few differences in vegetative composition between managed and unmanaged ponds were noted, marshes behind weirs were probably more consistent producers of desired vegetative types.

Chabreck, R. H. 1960. Coastal marsh impoundments for ducks in Louisiana. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 14:24-29.

Summarizes a study comparing three types of impoundments (permanent brackish water, permanent fresh water, and manipulated fresh water) to control areas similar in water depth and salinity. In general, impoundments produced a more diverse flora, produced more species considered good duck food, and had greater duck usage than did control areas. Includes brief descriptions of impoundment management and construction.

Chabreck, R. H. 1962. Better duck habitat. Louisiana Conservationist (April):17-20.

Summarizes benefits to coastal marshes provided by manipulated impoundments. Describes manipulated impoundments at Rockefeller Wildlife Refuge, their construction and management techniques, and the benefits provided by each type. Manipulated impoundments were cited as beneficial for ducks (by encouraging beneficial vegetation), alligators, and deer.

Chabreck, R. H. 1968. Weirs, plugs and artificial potholes for the management of wildlife in coastal marshes. Proceedings of the Marsh and Estuary Management Symposium: 178-182.

Describes the use and construction of weirs, earthen plugs, and artificial potholes and evaluates their effects on factors beneficial to wildlife. Weirs and plugs helped control water level fluctuations, but neither structure affected vegetation, turbidity, or salinity. Winter duck usage of areas affected by weirs and plugs was greater than nearby unmanaged marshes. Potholes and ditches benefited furbearers and alligators but not waterfowl.

Chabreck, R. H. 1981. Effects of impoundments in marshes on wildlife and fisheries. Pp. 21-29 in R. C. Carey and J. B. Kirkwood, eds., Proceedings of the U.S. Fish and Wildlife Service Workshop on Coastal Ecosystems of the Southeastern United States. Washington, D.C.: U.S. Fish and Wildlife Service, Biological Service Program FWS/OBS-80/59.

Reviews the effects of several types of manipulated impoundments on waterfowl, coots, furbearers, alligators, fishes, and crustaceans. Permanently flooded and manipulated fresh water and brackish impoundments are described and their effects summarized. Each impoundment type varied in its effects on each resource. Manipulated impoundments improved habitat for waterfowl, coots, wading birds, nutria, mink, otter, alligator, freshwater fishes, and crawfish. They reduced muskrat, geese, and estuarine fisheries abundance.

Chabreck, R. H. 1981. Freshwater inflow and salt water barriers for management of coastal wildlife and plants in Louisiana. Pp. 125-38 in R. D. Cross and D. L. Williams, eds., Proceedings of the National Symposium on Freshwater Inflow to Estuaries, volume II. FS/OBS-81/04. Washington, D.C.: U.S. Department of the Interior, Fish and Wildlife Service.

Describes habitat types, waterfowl, and wildlife in wetlands of Louisiana's coastal zone. Cites manipulated impoundments and freshwater diversions as two procedures useful for preventing salt water intrusion. Recommends the use of both techniques to reestablish marsh types to their 1943 locations.

Chabreck, R. H., and C. M. Hoffpauir 1962. The use of weirs in coastal marsh management in Louisiana. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 16:103-112.

Compares marshes behind weirs with unweired marshes as to vegetative composition and water conditions. Weirs were found to have little to no effect on salinity, turbidity, and emergent vegetation but did stabilize water levels and produced a greater occurrence of aquatic vegetation.

Chabreck, R. H., and G. M. Junkin 1989. Marsh impoundments for the management of wildlife and plants in Louisiana. Pp. 112-19 in W. G. Duffy and D. Clark, eds., Marsh Management in Coastal Louisiana: Effects and Issues--Proceedings of Symposium. Biol. Rept. 89(22). Slidell, La.: U.S. Fish and Wildlife Service and Louisiana Department of Natural Resources.

Reviews the types of impoundments found in coastal Louisiana and their vegetation and wildlife characteristics. Discusses the advantages and disadvantages of manipulated impoundments and where they may not be appropriate. Concludes that the use of manipulated impoundments improves marshes for ducks but that manipulated impoundments are costly to construct

and maintain. Also, impoundments without pumping facilities result in poor food production during unusually wet or dry years.

Chabreck, R. H., and J. A. Nyman 1989. The effects of weirs on plants and wildlife in the coastal marshes of Louisiana. Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La.: U.S. Fish and Wildlife Service.

Reviews literature regarding the effects of weirs on aquatic and emergent vegetation, soil chemistry, waterfowl, and mammals. Weirs stabilized water levels, increased aquatic plant production 400%, and concentrated ducks.

Chabreck, R. H., R. J. Hoar, and W. D. Larrick, Jr. 1979. Soil and water characteristics of coastal marshes influenced by weirs. Proceedings of the Coastal Marsh and Estuary Management Symposium 3:129-146.

Water depth, salinity, turbidity, siltation, dissolved oxygen, dissolved hydrogen sulfide, Redox potential, pH, and organic matter content were measured in marshes and other water bodies influenced by weirs, then compared with similar areas not affected by weirs. A major difference was found only in water depth. Minor differences in turbidity, siltation, and Redox potential were noted in some areas.

Chabreck, R. H., R. K. Yancey, and L. McNease 1974. Duck usage of management units in the Louisiana coastal marsh. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 28:507-516.

Water depth, vegetation, and duck usage were compared in fresh and brackish manipulated water impoundments managed for ducks, in marsh pump-out units managed for cattle, and in natural marshes. Freshwater manipulated impoundments averaged four times the duck usage of other areas; however, during the fall duck usage of brackish manipulated impoundments was seven times greater than usage of freshwater manipulated impoundments. Duck usage was lowest in the pump-out marshes. Vegetation, water depth, and time of year affected duck usage.

Clark, D., J. Barras, J. Demond, and F. Zeringue 1988. Wetland management plan atlas and preliminary statistical analysis. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division. 15 pp.

Provides summary data pertinent to marsh management plans in the Louisiana coastal zone. Total number (130), total acreage (197,982 ha), percentage of coastal zone (16%), average size (1522 ha), number permitted (95), number implemented (52), and the number of plans by parish, year, and marsh type with summary statistics are provided in the report. Also compares percentage of marsh under management in Louisiana (30%) with that in North Carolina (3%), South Carolina (7-14%), Georgia (2%), and Florida (16%).

Conner, J. V., and F. M. Truesdale 1973. Ecological implications of a fresh water impoundment in a low-salinity marsh. Proceedings of the Coastal Marsh and Estuary Management Symposium 2:259-276.

Results of a three-year study near Galveston Bay suggest shallow, low-salinity waters are prime habitat for larval and juvenile, commercially-important taxa. Peripheral marshes are thought to be more productive than open bay waters. Asserts that a 7,200-acre area to be impounded by levees within those marshes may be more important to fishes and crustaceans than nearby, open water areas. Calls for the estimation of habitat values to aid in evaluating construction projects in coastal marshes.

Conner, W. H., J. G. Gosselink, and R. T. Parrondo 1981. Comparison of the vegetation of three Louisiana swamp sites with different flooding regimes. American Journal of Botany 68(3):320-331.

Compares plant community structure and productivity among permanently flooded, seasonally flooded, and naturally flooded freshwater swamps. The permanently flooded swamp was characterized by changes in community structure, reduced competition, and low productivity. The seasonally flooded swamp exhibited changes in community structure, but productivity remained high. The flooding regime was found to be an important controlling factor in each swamp.

Coastal Management Division and Soil Conservation Service 1988. Louisiana Coastal Resources Program Marsh Management Manual. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division. 290 pp.

Contains a variety of data helpful to marsh managers. Includes a description of marsh management techniques, their engineering, and costs. Describes environmental policies and guidelines used by the Coastal Management Division to evaluate permit applications and makes recommendations concerning marsh management. Provides diagrams of structures used in marsh management, a list of wetland plants, and copies of Technical Notes (soil conservation service publication) pertinent to coastal marshes. Includes data on life history requirements of fish and shell fish found in coastal waters.

Coastal Restoration Technical Committee 1988. Executive summary: report on measures to maintain, enhance, restore, and create vegetated wetlands in coastal Louisiana. Unpublished report. Baton Rouge, La.: Office of the Governor, Coastal Restoration Policy Committee.

This report recommends goals, policies, objectives, and tools to deal with the protection and restoration of the coastal zone. Specific recommendations concerning structural marsh management include: 1) assuring the continued operation of structures in the Cameron-Creole watershed; 2) maintaining water levels in Grand and White Lakes at least

once every three years; 3) managing the wetlands between U.S. 90 and the Clovelly Oil Field; 4) developing and implementing a water management plan for the Grand and White Lakes impoundment; 5) developing and implementing a water management plan for the marshes between Calcasieu and Sabine Lakes; 6) constructing a water control structure at Black Bayou; 7) encouraging wetland preservation and management by private landowners; 8) developing uniform state policy and guidelines for marsh management to obtain regulatory relief, and 9) providing incentives to landowners for restoration and enhancement of wetlands to the substantial benefit of the general public.

Copeland, B. J. 1974. Impoundment systems. Pp. 168-179 in H. T. Odum, B. J. Copeland, and E. A. McMahan, eds., Coastal Ecological Systems of the United States, Vol. III. Washington, D.C.: The Conservation Foundation.

Provides examples of various coastal impoundments and generally describes their effects on natural resources, hydrography, nutrients, and fisheries products. Provides a few specific examples of impoundments altering the natural hydrology, resulting in vegetational change and in a decrease in fisheries production. Describes hurricane protection dikes and provides examples of their effects.

Cowan, J. H., Jr., R. E. Turner, and D. R. Cahoon 1986. A preliminary analysis of marsh management plans in coastal Louisiana. Work Assignment 9. Baton Rouge: Louisiana State University, Center for Wetland Resources, Coastal Ecology Institute. 30 pp. + appendixes + figures

Provides background information on marsh management and marsh management plans in coastal Louisiana. Lists and describes guidelines, permitting, assessment, and monitoring regulations. Describes the various types of manipulated impoundments, explains their purposes and functions. Evaluates marsh management in the chenier plain. Provides the results of interviews with local, state, and federal agencies, private consultants, and landowners concerning goals for marsh management, the permitting process in practice, the effects of changes in state policy, and the effectiveness of management in slowing erosion. Provides sample permit applications, marsh management plans, monitoring reports, and schematics of water control structures.

Cowan, J. H., Jr., R. E. Turner, and D. R. Cahoon 1988. Marsh management plans in practice: do they work in coastal Louisiana? U.S.A. Environmental Management 12(1):37-53.

Reviews marsh management permitting authority and procedures. Describes the various types of manipulated impoundments and water control structures used in marsh management. Evaluates management of manipulated impoundments at Rockefeller Refuge, cites the lack of data on marsh management, and summarizes the results of interviews with agencies concerned with marsh management. Concludes there is little agreement among landowners, agencies, and scientists and calls for monitoring and inventory of existing marsh management plans, for development of new management techniques, and for determination of cumulative marsh management impacts.

Craft, B. R., and D. Kleinpeter 1989. Vegetation and salinity changes following the installation of a fixed crest weir at Avery Island, Louisiana (1982-1986). Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La.: U. S. Fish and Wildlife Service.

Evaluates the effects of a fixed-crest weir on vegetation and salinity near Avery Island. Vegetation was measured yearly and salinity monthly from 1982 to 1986. Plant diversity increased, woody plant occurrence decreased, and herbaceous plant cover increased. Salinity usually was lower upstream of the weir.

Davidson, R. B., and R. H. Chabreck 1983. Fish, wildlife and recreational values of brackish marsh impoundments. Pp. 89-114 in R. J. Varnell, ed., Proceedings of the Water Quality and Wetland Management Conference. Metairie: Louisiana Environmental Professionals Association.

A sampling of fish and wildlife, a visitor survey, and a creel census were used to evaluate two manipulated impoundments and a weir-managed brackish marsh. Waterfowl use of all areas was similar, but alligator nesting was inhibited in the impoundments due to forced drying. In the manipulated impoundments nutria and white-tailed deer were common, and fish and shellfish biomass were three times greater than in the weir-managed marsh. Most of the shrimp harvested by visitors were taken from inside and most of the redfish were taken outside the manipulated impoundments.

Davidson, R. B., and R. H. Chabreck 1989. Recreational use of management units in brackish marsh. Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La.: U. S. Fish and Wildlife Service.

Reports on the recreational use of two manipulated impoundments and of one weir-managed area on Rockefeller Wildlife Refuge. Fishing, crabbing, and cast netting for shrimp were the primary recreational activities. Most of the shrimp were taken from weirs and other water control structures, most alligator gar from impoundments, and most redfish from outside the manipulated impoundments (the two fish taken in greatest abundance). Advocates construction of more water control structures to allow more shrimp cast netting opportunities.

Davis, D. J., D. W. Roberts, and K. M. Wicker 1983. Components and controlling principles of coastal wetland management. Pp. 41-65 in R. J. Varnell, ed., Proceedings of Water Quality and Wetland Management Conference. Metairie: Louisiana Environmental Professionals Association.

Discusses basic components (weirs and flapgates) and principles for effective marsh management. Uses specific wetland systems to show how marshes are affected by hydrology and salinity and presents a conceptual model for the role of both. Concludes that knowledge of a marsh's hydrology should determine the tool used to manage it and that water control structures should not be installed without hydrologic research.

Day, J. W., Jr., R. Costanza, K. Teague, N. Taylor, and R. Day 1986. The effects of impoundments: a global survey and comparison with the Louisiana coastal zone. Baton Rouge: Louisiana State University, Center for Wetland Resources, Coastal Ecology Institute. 185 pp.

Reviews the history, use, and management of tidal impoundments throughout the world and within Louisiana. Describes the types of impoundments found in Louisiana, the effects of impoundments on hydrology, salinity, nutrients, temperature, sedimentation, erosion, productivity, diversity, and succession. Discusses the cost effectiveness of impoundments and of alternatives to impoundments. Concludes the most important factors affecting impoundment effectiveness were storm surge, precipitation, and oxidation-subsidence rates. Judges weir management as the most effective type of impoundment, because it least damages the productive natural system. Recommends no management of highly productive natural systems.

Day, J. W., Jr., ed. 1989. An analysis of semi-impoundment wetland management practices in the Louisiana coastal zone. Unpublished manuscript. 91 pp.

Describes wetland and coastal hydrology, wetland vegetation, nekton, benthos and wildlife in the coastal zone and describes the effects of structural marsh management on each variable. Concludes that the use of fixed-crest weirs have led to decreased productivity of the marsh and that more active management using variable-crested or flap-gated structures has the potential to avoid some problems associated with fixed structures. Also discusses cumulative impacts, sedimentation, freshwater diversion, and saltwater intrusion and how each relates to marsh management. Calls for comprehensive, coordinated planning of marsh management that will lead to greater benefits for both public and private interests.

de la Bretonne, L., Jr., and J. W. Avault, Jr. 1972. Movements of brown shrimp, *Penaeus aztecus*, and white shrimp, *Penaeus setiferus*, over weirs in marshes of south Louisiana. Proceedings of the Annual Conference Southeastern Association Game and Fish Commissioners 25:651-654.

Movements of brown and white shrimp over weirs in south Louisiana were influenced by tides. Brown shrimp concentrations inside the weir were greatest on incoming tides while white shrimp concentrations inside a weir depended on water level differences between weired and outside waters. Greatest white shrimp catches inside the weir occurred with approaching cold fronts. Shrimp catch overall was greatest at night.

DeVoe, M. R., and D. S. Baughman, eds. 1987. South Carolina Coastal Wetland Impoundments: Ecological Characterization, Management, Status and Use. Technical Report SC-SG-TR-86-1, Volumes 1 and 2. Charleston: South Carolina Sea Grant Consortium. 653 pp.

Three years of data collection provide physical, ecological, and biological descriptions of impoundments on Cat Island, South Carolina. Discusses the effects of impoundment management on target species, water quality, fisheries migration, and mosquito production and how each could be improved with better management.

Eggler, W. A., and W. G. Moore 1961. The vegetation of Lake Chicot, Louisiana, after eighteen years impoundment. The Southwestern Naturalist 6(3-4):175-83.

Examines the vegetation of the Lake Chicot basin after 18 years of manipulated impoundment and compares it to vegetation at the time of impoundment. Cypress had decreased in density in the channels but increased in shallow peripheral areas. Radial growth of cypress was unaffected, but all upland forest trees died. The lake was dominated by submerged vegetation, a problem not solved by winter drawdown.

Ensminger, A. B. 1963. Construction of levees for impoundments in Louisiana marshes. Proceedings of the Annual Conference Southeastern Association Game and Fish Commissioners 17:440-446.

Briefly describes the importance of manipulated impoundments to waterfowl abundance, the history of manipulated impoundments, and the construction of manipulated impoundments on the Rockefeller Wildlife Refuge. Describes problems with impoundment levees and with maintenance of levees. Perpetual maintenance of levee systems and of water control structures is expected due to continuous subsidence of levee systems and to erosion in canals. The chenier plain soils are more suitable to the building of levees than delta and sub-delta marshes. About 80% of all ducks on Rockefeller Refuge used impoundments.

Epstein, M. B., and R. L. Joyner 1985. Managed and open tidal marsh utilization by waterbirds: preliminary results. Abstract. Estuaries 8(2B):42A.

A study of waterbird utilization in impounded and natural tidal marshes in South Carolina. Waterbird use and diversity were highest in managed areas, with water level being the main factor influencing waterbird use. Indicates multi-species management greatly enhances overall wetland value for wildlife.

Fredrickson, L. H., and T. S. Taylor 1982. Management of seasonally flooded impoundments for wildlife. Resource publication 148. Washington, D.C.: U.S. Fish and Wildlife Service. 29 pp.

Describes advantages and disadvantages of moist soil management in freshwater manipulated impoundments, the cost of such management, and the structures necessary to make management successful. Techniques for encouraging various plant and animal species are described, as are methods to control undesirable vegetation. Success of manipulated impoundment management depends on good levees, control structures for precise water manipulations, and a pump system. Manipulated impoundments managed correctly can provide a low-cost variety of forage for many species of wildlife. Authors recommend creating several small impoundments rather than one large one so that several management techniques may be implemented to encourage a diversity of wildlife.

Gagliano, S. M., and D. Roberts 1987. Management of private wetlands in coastal Louisiana. Loose addition (9 pp., out of sequence) to N. V. Brodtmann, Jr., ed., Proceedings of the Fourth Water Quality and Wetlands Management Conference. Metairie: Louisiana Environmental Professionals Association.

Briefly discusses the definition of marsh management, public funding sources, alternatives, benefits, and criticisms. Concludes that structural marsh management is the only feasible alternative available within the foreseeable future to reduce erosion. Lists the reduction of wetland loss, habitat improvement, and the creation of jobs as benefits of marsh management.

Gilmore, R. G. 1987. Fish, macrocrustacean and avian population dynamics and cohabitation in tidally influenced impounded subtropical wetlands. Pp. 373-394 in Proceedings of a Symposium on Waterfowl and Wetlands Management in the Coastal Zone of the Atlantic Flyway. Wilmington: Delaware Department of Natural Resources and Environmental Control, Delaware Coastal Management Program.

Describes in broad terms the results of a three year study done in Florida mosquito manipulated impoundments. Provides information on fish, crustacean, and avian species assemblages, along with temporal and spatial distribution. Fisheries numbers and diversity were highest in impoundments in late fall and winter and were correlated to high sea water levels. Tidal and seasonal flooding helped maintain diverse vegetative communities. Discusses the interdependence of various species and stresses the incompatibility of managing manipulated impoundments for specific biological resources while providing for the natural functions of these interdependent systems.

Gilmore, R. G., C. J. Donahoe, and D. W. Cooke 1982. A comparison of the fish populations and habitat in open and closed salt-marsh impoundments in east-central Florida. Northeast Gulf Science 5:25-37.

Compares a complete impoundment closed to tidal influence with one opened to the tides via a culvert. The closed impoundment contained a depauperate ichthyofauna, salinities that fluctuated from 2 to 200 ppt, and dissolved oxygen levels that were at times lethal to fishes. The opened impoundment contained a much more diverse ichthyofauna, had better water quality, and demonstrated extensive regrowth of marsh vegetation.

Gunter, G., and W. E. Shell, Jr. 1958. The study of an estuarine area with water-level control in the Louisiana marsh. Proceedings of the Louisiana Academy of Science 21:5-34.

Describes water temperatures, salinities, and the seasonality of marine and freshwater fauna in two large estuarine lakes in the Mermentau Basin. Compares the management plan for their lock gates to the seasonal presence of commercially important fishes and crustaceans; recommends minor changes in the closing of the gates so as to allow extended migration between the Gulf of Mexico and the lakes.

Harrington, R. W., Jr. and E. S. Harrington 1982. Effects on fishes and their forage organisms of impounding a Florida salt marsh to prevent breeding by salt marsh mosquitoes. Bulletin of Marine Science 32:523-531.

Compares fish abundance and food organisms taken by fish in a Florida salt marsh before and after complete impoundment. After impoundment eleven of sixteen species were absent, numbers of others were reduced, and only two species were abundant; insect fauna were impoverished and many plant species destroyed. Remaining fishes shifted to plant materials (primarily detritus and algae) for food, with algae expected to become ultimately the last food source.

Harrison, R. W., and W. M. Kollmorgan 1947. Drainage reclamation in the coastal marshlands of the Mississippi River delta system. The Louisiana Historical Quarterly 30:654-709.

Describes Louisiana coastal wetlands and provides a history of land reclamation in these marshes from the early 1800's to the mid 1940's. Most reclamation failed because of levee failure, poor soil condition, storm overwash, or financial hardship. Authors conclude: 1) marsh reclamation in Louisiana was attempted without sufficient knowledge of the physical setting; 2) the high cost of drainage makes it essential that high priced crops be produced; and 3) in many areas, hunting and trapping on unaltered wetlands represent the highest economical use of the land.

Hartman, R. D., C. F. Bryan, and J. W. Korth 1987. Community structure and dynamics of fishes and crustaceans in a southeast Texas estuary. Baton Rouge: Louisiana State University, School of Forestry, Wildlife and Fisheries, Louisiana Cooperative Fish and Wildlife Research Unit. 116 pp.

Reports on the seasonal presence and abundance of ichthyoplankton in a tidal channel near Port Arthur, Texas. Tidal cycle and photoperiod were found to affect significantly the distribution, placement, and abundance of organisms. Recommends a weir design and management program to optimize immigration at times of day and at levels in the water column where organisms are most abundant.

Hartman, R. H., D. R. Cahoon, and S. G. Leibowitz 1988. Development of management strategies for Barataria Basin. Final Report prepared by Louisiana Geological Survey for Louisiana Department of Natural Resources under Interagency agreement 21911-88-11. Baton Rouge: Department of Natural Resources, Coastal Management Division. 133 pp. + figures.

Reviews estuarine management plans used elsewhere, describes the habitat and environmental problems of Barataria Basin, recommends general and specific methods (including structural marsh management) to alleviate landloss problems and recommends a Geographic Information System to model and predict habitat alterations under various management strategies. Recommendations related to structural marsh management include: 1) investigation of marsh management potential for Hwy 90 to Clovelly Oil Fields area, Salvador Wildlife Management Area, Jean Lafitte National Park and at Bayou Villars near Lake Salvador; 2) installation of a water control structure at the Lake Salvador/Bayou Villars connection; and 3) the placement of a water control structure in the lower Barataria Waterway.

Herke, W. H. 1968. Weirs, potholes and fishery management. Proceedings of the Marsh and Estuary Management Symposium: 193-211.

Describes the effects of a weir on abundance of fishes and crustaceans. The weir appeared to benefit *Callinectes sapidus* adults and *Lucania parva*, while harming *Leiostomus xanthurus*, *Micropogonias undulatus*, and *Penaeus aztecus*, and had no effect on *Brevoortia patronus*. Weirs also stimulated the growth of rooted aquatic vegetation.

Herke, W. H. 1971. Use of Natural, and Semi-Impounded, Louisiana Tidal Marshes as Nurseries for Fishes and Crustaceans. Ph.D. dissertation. Baton Rouge: Louisiana State University. 242 pp.

Studies emigration of juvenile fishes from a brackish marsh and finds the process to be a "bleeding off" of the larger individuals in the nursery. Describes growth rate data for several species and documents the use of the marsh as a nursery for others. Describes the effects of weirs on several species and concludes that weirs delay emigration, promote growth

rates, result in heavier individuals, delay recruitment, and encourage the growth of submerged vegetation.

Herke, W. H. 1979. Some effects of semi-impoundment on coastal Louisiana fish and crustacean nursery usage. Proceedings of the Coastal Marsh and Estuary Management Symposium 3:325-346.

Summarizes several studies concerning the effects of weirs on fish and crustacean abundance. Conclusions: 1) weirs present barriers to fish migrations; 2) forage and predatory species congregate near weirs; 3) weirs delay and diminish recruitment into marshes; 4) weirs diminish nursery use by migratory salt-water species; and 5) weirs increase use by freshwater and non-migratory estuarine species.

Herke, W. H., and B. D. Rogers 1984. Louisiana's coastal marsh: a nursery for saltwater fish and crustaceans. Louisiana Agriculture 27(2):4-5.

Summarizes the results of a four-year study conducted on the Sabine National Wildlife Refuge concerning the movement of fishes and crustaceans throughout the refuge. The study provides information necessary for the operation of weir gates to allow fishery access through water control structures. Data obtained indicates which months species migrate and need to pass through a weir, what time of day the species move, and in what level of the water column they are located.

Herke, W. H., and B. D. Rogers 1989. Threats to coastal fisheries. Pp. 196-212 in W. G. Duffy and D. Clark, eds., Marsh Management in Coastal Louisiana: Effects and Issues--Proceedings of a Symposium. Biol. Report 89(22) Slidell, La.: U.S. Fish and Wildlife Service and Louisiana Department of Natural Resources.

Reviews the results of fisheries studies done in managed marshes and discusses the effects of management on landloss rates. Concludes: 1) marsh management seriously decreases the population of fishery species, the loss of which is acceptable only if management reduces marsh nursery loss, and 2) there are no studies showing that weir management reduces marsh loss over the long term, and some studies indicate it may hasten marsh loss. The authors call for the non-issuance of marsh management permits until the most important questions concerning weir management are answered. They also state that the use of marshes for aquaculture is not in the public interest and that laws allowing the practice should be repealed.

Herke, W. H., E. E. Knudsen, Z. X. Chen, N. S. Green, P. A. Knudsen, and B. D. Rogers 1987. Final report for the Cameron-Creole watershed fisheries investigation. Baton Rouge: Louisiana State University, School of Forestry, Wildlife and Fisheries, Louisiana Cooperative Fish and Wildlife Research Unit.

419 pp.

Two year study compares the effects of a fixed-crest weir on a brackish marsh pond to an adjacent unweired pond as to numbers, biomass, size, mortality, and migration of fish and shellfish. The weir reduced the numbers of most species, resulting in decreases as high as 93% for *Brevoortia patronus*. Fish tended to be larger behind the weir and emigrated later than did those from the control area. Also discusses diel differences in catch, the effects of weirs on salinity, and the design and operation of water control structures for the benefit of estuarine-dependent fisheries organisms.

Herke, W. H., E. E. Knudsen, P. A. Knudsen, and B. D. Rogers 1987. Effects of semi-impoundment on fish and crustacean nursery use: evaluation of a "solution." Proceedings of the Coastal Zone '87 Symposium: 2562-2576.

Compares fish and crustacean emigration from a pond having a fixed-crest weir and from an adjacent unweired pond. The weir caused substantial reductions in both number and total weight of most of the important estuarine-dependent species migrating toward the Gulf. Lower numbers in the weired pond were due to reduced immigration, caused by the weir, of the planktonic young of those species.

Herke, W. H., E. E. Knudsen, B. D. Rogers, and P. A. Knudsen 1987. Effects of Louisiana semi-impoundment on estuaries-dependent fisheries. Pp. 404-23 in W. R. Whitman and W. N. Meredith, eds., Waterfowl and Wetlands Symposium: Proceedings of a Symposium on Waterfowl and Wetlands Management in the Coastal Zone of the Atlantic Flyway. Dover: Delaware Department of Natural Resources and Environmental Control, Coastal Management Program.

Summarizes data of several studies on the effects of water control structures on fisheries production and utilization. Conclusions include: 1) water control structures decrease marsh nursery use by important salt water species; 2) there is no time of year when movements of some important migratory species are not potentially impeded by water control structures; 3) emigration of some species is delayed by structures; 4) immigration of many species is reduced; and 5) a vertical slot in a weir reduces a structure's interference with fish migration without seriously affecting the weir hydrodynamics.

Herke, W. H., E. E. Knudsen, B. D. Rogers, and V. L. Prenger 1985. Effects of a fixed-crest water control structure on the abundance of fish and crustaceans migrating from a shallow marsh nursery toward the Gulf of Mexico. Abstract. Estuaries 8(2B):21A.

Fish abundance in a natural pond was compared with that in a pond managed with fixed-crest weirs. All fish, shrimp, and crabs leaving the ponds were captured and counted daily. Comparison of catches indicated the fixed-crest weir caused major reduction in both numbers and biomass of many

important marine species migrating back toward the Gulf of Mexico.
Herke, W. H., B. D. Rogers, and E. E. Knudsen 1984. Habits and habitats of young spotted seatrout in Louisiana marshes. Research report no. 3. Baton Rouge: Louisiana State University, School of Forestry, Wildlife and Fisheries, Louisiana Agricultural Experiment Station. 48 pp.

Summarizes data from two studies conducted at the Sabine National Wildlife Refuge concerning seasonal presence and habitat preference of juvenile spotted seatrout in coastal marshes. The only conclusion applicable to marsh management is that conventional fixed-crest weirs are detrimental to the immigration of young spotted seatrout into marsh habitats.

Herke, W. H., W. W. Wengert, Jr., and M. E. LaGory 1987. Abundance of young brown shrimp in natural and semi-impounded marsh nursery areas: relation to temperature and salinity. Northeast Gulf Science 9(1):9-28.

Compares brown shrimp abundance between natural marshes and those managed with fixed-crest weirs. Total otter trawl catch was four times greater in the natural than in the weired marsh. Brown shrimp stayed longer in weired than in natural marshes and emigrated at a large size. Concludes that weirs interfere with the natural stocking process in marshes by reducing tidal exchange.

Hess, T. J., Jr., R. H. Chabreck, and T. Joanen 1976. The establishment of *Scirpus olneyi* under controlled water levels and salinities. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 29:548-554.

Compares the effects of six water level and salinity treatments on *Scirpus olneyi* culm density and rhizome growth. Salinities of 20 ppt reduced culm density but not rhizome growth. Growth was best when water levels were slightly below soil surface.

Hess, T. J., Jr., R. F. Paille, R. J. Moertle, and K. P. Guidry 1989. Results of an intensive marsh management program at Little Pecan Wildlife Management Area. Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division and Slidell, La.: U.S. Fish and Wildlife Service.

Describes the structures, manipulated impoundments, and impoundment management on Little Pecan Wildlife Management Area. Flap-gated, variable-crested weirs were used in conjunction with pumps to control water levels. Weired areas were managed for waterfowl, alligators, furbearers, and fin and shellfish, with waterfowl the top priority. Results indicate management success in decreasing vegetated wetland loss and in increasing furbearer and waterfowl utilization and harvest.

Hoar, R. J. 1975. The Influence of Weirs on Soil and Water Characteristics in the Coastal Marshlands of Southeastern Louisiana. M.S. thesis. Baton Rouge: Louisiana State University. 65 pp.

Salinity, turbidity, dissolved oxygen, soil salinity, hydrogen sulfide, pH, oxidation-reduction potential, and organic matter content were compared between weired areas and control areas. Weirs buffered changes in water and soil salinity, both of which were higher behind weirs than in control areas.

Jemison, E. S., and R. H. Chabreck 1962. The availability of waterfowl foods in coastal marsh impoundments in Louisiana. Proceedings of the North American Wildlife Conference 27:288-300.

Measured the amount of seeds on the marsh floor and the amount of available vegetative food other than seeds in the fall prior to waterfowl arrival at Rockefeller Wildlife Refuge. The seeds of sawgrass, bull whip, cyperus, millet, dodder, and widgeongrass were present in the greatest amounts. There was little relationship between vegetation present and available seeds. Ducks ate only 20% of available seeds, but consumed most of the available widgeongrass.

Joanen, T., and L. L. Glasgow 1966. Factors influencing the establishment of widgeongrass stands in Louisiana. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 19:78-92.

Describes management designed to achieve maximum widgeongrass production and describes waterfowl utilization of widgeongrass. Turbidity, fluctuating water levels, and water depth controlled the establishment and growth of widgeongrass. Soluble salts in soils inhibited seed germination. Algal cover was the most important biotic factor affecting plant growth.

Joyner, R. L. 1987. Multi-species utilization of waterfowl impoundments. Pp. 53-62 in Coastal Wetlands Impoundments: Management Implications: Workshop proceedings. Technical Report #SC-SG-TR-87-1. Charleston: South Carolina Sea Grant Consortium.

Reports on a study of bird use of manipulated impoundments and adjacent, unimpounded wetlands in coastal South Carolina. Concludes bird use is directly related to lowering water level with spring water level the most important variable. Managed marshes were the most heavily utilized sites and use increased with an increase in impoundment size. Recommends methods to improve impoundments for bird habitat.

Kadlec, J. A. 1962. Effects of a drawdown on a waterfowl impoundment. Ecology

43(2):267-81.

Evaluates the effects of a drawdown of a southern Michigan impoundment on vegetation, waterfowl, soil, water, and benthos. Results show an increase in plant nutrients, emergent vegetation, and waterfowl utilization. Invertebrate population and submerged vegetation decreased. Wetland food production during the drawdown was poor. Vegetative species composition did not change.

Kadlec, J. A., and W. A. Wentz 1974. State-of-the-art survey and evaluation of marsh plant establishment techniques: induced and natural. Volume 1: Report of Research. Contract Report D-74-9. Vicksburg, Ms.: U. S. Army Corps of Engineers, Waterways Experiment Station. 231 pp. + appendixes

Provides information on water management to encourage the establishment and growth of various species of vegetation in differing marsh types. Lists species with growth improved by drawdowns, those that require stable water levels, and those that grow best in brackish water. Lists specific water depths that favor various species. Describes techniques using water levels to control competitors and wave action.

Kelley, B. J., Jr. 1985. Primary production and community metabolism in coastal salt water impoundments. Abstract. Estuaries 8(2B):40A.

Manipulated impoundments and adjacent tidal marshes were compared as to primary productivity, aquatic community metabolism, grass production, aquatic respiration, and edaphic microalgae biomass. The primary productivity of *Spartina alterniflora* and the standing stock of edaphic microalgae were greater in manipulated impoundments than in control marshes.

Konikoff, M., and H. D. Hoese 1989. Marsh management and fisheries on the State Wildlife Refuge--overview and beginning study of the effect of weirs. Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La: U. S. Fish and Wildlife Service.

Compares gill net and otter trawl samples in a natural marsh pond with one affected by a fixed-crest weir. Over a short sampling period, fewer numbers of *Brevoortia patronus*, *Leiostomus xanthurus*, and various other species were captured in the weired as compared to the natural pond.

Landers, J. L., A. S. Johnson, P. H. Morgan, and W. P. Baldwin 1976. Duck foods in managed tidal impoundments in South Carolina. Journal of Wildlife Management 40(4):721-728.

Describes the vegetative composition in managed fresh and brackish manipulated impoundments in South Carolina and provides a small amount of technical information concerning how to manage each impoundment type to produce optimal amounts and types of duck food forage. Seeds of *Polygonum* and *Panicum* along with rhizomes and seeds of *Lachnanthes* were the principal duck foods in freshwater manipulated impoundments that had been drained in the summer and flooded in the fall. Seeds and vegetation of *Ruppia* in deeper ponds and seeds of *Scirpus* in shallower ponds were the principal waterfowl vegetation in the brackish manipulated impoundments.

Larrick, W. J., Jr. 1975. The Influence of Weirs on Vegetation of the Coastal Marshlands of Louisiana. M.S. thesis. Baton Rouge: Louisiana State University. 97 pp.

Compares vegetation, salinity, water depth, and turbidity of weir-managed marshes with natural marshes in Barataria Basin. Weirs had no effect on species composition; however, weirs increased aquatic species coverage and decreased emergent vegetative coverage. Weirs stabilized water levels, reduced tidal exchange rates, and helped prohibit pond bottom exposure.

Larrick, W. D., Jr., and R. H. Chabreck 1976. Effects of weirs on aquatic vegetation along the Louisiana coast. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 30:581-589.

Aquatic vegetation (species, abundance, and relative abundance) was studied in three brackish-saline marshes influenced by weirs. Ponds influenced by weirs were found to contain significantly more diverse flora, more aquatic vegetation, and had a greater relative abundance compared to control ponds.

Lehto, B., and J. Murphy 1989. Effects of drying and water management on a seriously eroded marsh. Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La.: U. S. Fish and Wildlife Service.

Reports the effects of drawdowns from 1986-1988 on vegetation, soil salinities, turbidity, and wildlife utilization. Widgeongrass production increased greatly, the number of plant species increased 100%, soil salinities decreased, turbidity decreased, and wildlife utilization increased as a result of the water management plan.

Louisiana Department of Natural Resources, Coastal Management Division 1988. Louisiana Coastal Resources Program Marsh Management Manual. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Alexandria, La.: U.S. Department of Agriculture, Soil Conservation Service. 386 pp.

Describes techniques used in marsh management and defines environmental policies and technical guidelines used by Coastal Management Division in reviewing marsh management applications. Provides diagrams and estimated costs of various marsh management structures. Includes technical papers on managing various plant species. Provides information on life history requirements of fin and shellfish found in coastal waters.

Manzi, J. J., V. G. Burrell, and W. Z. Carson 1977. A comparison of growth and survival of subtidal *Crassostrea virginica* (Gmelin) in South Carolina salt marsh impoundments. Aquaculture 12:293-310.

Compares salt marsh manipulated impoundments with their associated tidal creeks for the culture of the American oyster. Oyster growth and survival were measured monthly as were primary production, phytoplankton, and total organic carbon. Growth was greater in ponds than creeks and greater in floating than bottom trays. There was no difference in survival among locations. Growth was directly correlated with primary production and phytoplankton biomass.

McKellar, H. N., Jr., and W. D. Marshall 1985. Aquatic productivity and tidal nutrient exchanges in coastal wetland impoundments of South Carolina. Proceedings of the Coastal Marsh and Estuary Management Symposium 4:85-102.

Examines differences in orthophosphate, ammonia, and chlorophyll export as well as differences in productivity between a manipulated impoundment and a breached impoundment. Manipulated impoundments concentrated orthophosphates while breached impoundments exported this nutrient and also ammonia. Both impoundments produced high phytoplankton biomass.

Meeder, J. F. 1986. Resource inventory and analysis of the Paul J. Rainey Wildlife Sanctuary and adjacent wetlands. First annual report: introduction and site descriptions. New Orleans: National Audubon Society. 81 pp. + figures.

Describes the physiography, climate, geology, soils, hydrology, and habitats of the Rainey Wildlife Sanctuary. Provides site descriptions for studies to be done on the sanctuary. Describes management objectives, management practices, management units, levee systems, and water control structures. Management practices include: 1) maintenance of levee systems; 2) installation of water control structures; 3) burning; 4) construction and maintenance of ditch systems; 5) cattle grazing; 6) control of problem species; and 7) plugging abandoned deepwater channels.

Montague, C. L., A. V. Zale, and H. F. Percival 1987. Ecological effects of coastal marsh impoundments: a review. Environmental Management 11(6):743-756.

Concludes that changes in primary production and organic material transport due to impounding are small. Expresses concern that impounding reduced marsh access for estuarine fish and shellfish; also, for the loss of unrestrained emigration for impounded organisms under unfavorable water conditions.

Morgan, P. H., A. S. Johnson, W. P. Baldwin, and J. L. Landers 1976. Characteristics and management of tidal impoundments for wildlife in a South Carolina estuary. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 29:526-539.

Discusses construction, use, management, and costs of diked manipulated impoundments. Most impoundments were managed to encourage vegetation growth by manipulating water levels and salinities, thereby attracting waterfowl. Provides harvest estimates along with management and hunting costs.

Morton, T. 1973. The Ecological Effects of Water Control-Structures on an Estuarine Area, White Lake, Louisiana. M.S. thesis. Lafayette: University of Southwestern Louisiana. 46 pp.

Compares the nekton community of White Lake in 1972-73 after the implementation of flood control using lock gates with the nekton community as reported by others in 1958, prior to flood control. The salinity decreased, and there was a reduction in the abundance of marine species and an increase in freshwater species. Concludes White Lake has become fresher due to the prevention of salt water intrusion by the water control structures, and the construction of such structures has eliminated White Lake's function as an estuarine area.

Neely, W. W. 1958. Irreversible drainage--a new factor in waterfowl management. Transactions of the North American Wildlife Conference 23:342-348.

Comments on the possible uses of manipulated impoundments with cat-clay (polysulfide) soils. When such soils are dried the sulfides oxidize and soil pH becomes highly acidic. Such areas are limited to rice culture, brackish water impoundments for fish, and duck impoundments.

Neely, W. W. 1961. Managing *Scirpus robustus* for ducks. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 14:30-34.

Describes the result of field trials undertaken in an attempt to identify vegetation that will grow in salinities of 1-10 ppt and is suitable duck food forage. *Scirpus robustus* was the only plant found to adequately fulfill both conditions. Describes a water control device which automatically permits water level fluctuations conducive to the growth of *Scirpus robustus*.

Neely, W. W. 1962. Saline soils and brackish waters in management of wildlife, fish and shrimp. Proceedings of the North American Wildlife Conference 27:321-335.

Describes management and use of brackish water manipulated impoundments for growing and harvesting fish, shrimp, ducks, snipe, and geese. Recommends the stocking of freshwater fish into brackish ponds or allowing estuarine waters with larval fish or shrimp to flow into ponds through large mesh screens. The best harvesting method was a sluice box. Briefly provides details on managing marshes to provide vegetation beneficial to waterfowl. Describes possible management to reduce polysulfides in cat-clay soils.

Nichols, L. G. 1959. Rockefeller Refuge levee study. Technical Bulletin. New Orleans: Louisiana Wild Life and Fisheries Commission, Refuge Division. 17 pp.

Reports on levee construction on the Rockefeller Wildlife Refuge, southwestern Louisiana. Analyzes the effects of subsidence and shrinkage on levees and reports a direct relationship between marsh moisture content and subsidence. Recommends constructing levees during dry periods when moisture content is low and building them on top of marsh vegetation, if possible. Concludes the thickness of the surface organic layer controls the amount of immediate subsidence and that maximum shrinkage takes place in one good drying year.

Odum, E. P., J. B. Birch, and J. L. Cooley 1983. Comparison of giant cutgrass productivity in tidal and impounded marshes with special reference to tidal subsidy and waste assimilation. Estuaries 6(1):88-94.

Aboveground and belowground live standing crops of giant cutgrass were measured in similar freshwater tidal and impounded marshes. Although the standing crop in each was similar, productivity was greater in the tidal marsh because of a faster turnover rate of plant biomass. Also discusses the potential of freshwater marshes for tertiary waste treatment.

Olmi, E. J., III, and P. A. Sandifer 1985. Recruitment patterns of penaeid shrimps and fishes to waterfowl impoundments and non-impounded salt marsh in South Carolina. I. Penaeid shrimps. Abstract. Estuaries 8(2B):41A.

Reports on the recruitment of fishes and crustaceans into marshes managed for waterfowl habitat as compared to unmanaged salt marsh. Recruitment into the manipulated impoundments was restricted by management techniques employed for waterfowl.

Paille, R. F., T. J. Hess, Jr., R. J. Moertle, and K. P. Guidry 1989. A comparison of white shrimp production within actively versus passively managed semi-impounded marsh nurseries. Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La.:

U.S. Fish and Wildlife Service.

Compares white shrimp production between impoundments managed by fixed-crest weirs (passive) and manipulated impoundments. Concludes that white shrimp production in the manipulated impoundment area may have been greater than that in the weir-managed area, because managers were able to allow greater access to the actively managed site when shrimp immigration was high. Timing of flap gate operation was found to be the most important variable in the relationship.

Penfound, W. T., and J. D. Schneidau 1946. The relation of land reclamation to aquatic wildlife resources in southeastern Louisiana. Transactions of the North American Wildlife Conference 10:308-318.

Compares vegetation, usage, and condition of three drainage projects after 12 years of study. Projects consisted of: 1) a brackish, drained, and operating impoundment; 2) another that was brackish, drained, and abandoned; and 3) one that was fresh, drained, and abandoned. Concludes that land reclamation for agriculture purposes was a failure but tended to result in open water areas that provided good wildlife habitat. Recommends that reclamation projects not be initiated just to provide wildlife areas. Comments on the management of wetlands for furbearers, wildlife, and fisheries.

Perry, R. D. 1987. Methods to enhance target species production in freshwater impoundments. Pp. 33-43 in Coastal Wetland Impoundments: Management Implications: Workshop Proceedings. Technical Report #SC-SG-TR-87-1. Charleston: South Carolina Sea Grant Consortium.

Describes various management techniques used in South Carolina's coastal freshwater manipulated impoundments. Describes soil water conditions necessary to encourage different plant varieties and recommends specific flooding and burning cycles that will improve fresh marshes for waterfowl. Recommends against using impoundments for agriculture because of the high cost of implementing such activities in wetlands and because of the effects such activities have on wetland fish, amphibians, and reptiles.

Perry, W. G. 1976. Standing crops of fishes of an estuarine area in southwest Louisiana. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 30:71-81.

Reports on standing stocks of fishes at several stations on the Rockfeller Wildlife Refuge. Documents the presence of large numbers of estuarine-dependent marine species at most stations, some of which are hydrologically controlled by water control structures. The only specific comment related to structural marsh management stated that one station managed with a water control structure contained unusually large standing crops as a result of the trapping of schools of seasonally migratory species and because water flowing through the structure attracts forage and predatory fish.

Perry, W. G. 1978. Distribution of fish in the Rockefeller-Grand Lake tidal bayou complex, southwest Louisiana. Proceedings of the Louisiana Academy of Sciences 41:101-114.

Reports on fisheries abundance as measured with trawls in several canals near and on the Rockefeller Wildlife Refuge. Documents the presence of marine species on the landward side of several water control structures, indicating that the system, although influenced by water control structures, is not a closed system. Suggests that variation in water salinity offers additional evidence of periodic water exchange between managed and exterior waterways.

Perry, W. G. 1981. Seasonal abundance and distribution of brown and white shrimp in a semi-impounded Louisiana coastal marsh. Proceedings of the Louisiana Academy of Science 44:102-111.

Documents the abundance and distribution of brown and white shrimp within a marsh managed with fixed-crest weirs. Shrimp were collected in every month except March. Brown shrimp were captured April-August; white shrimp catches were greatest July-October. Large shrimp emigrated ahead of smaller shrimp. Brown shrimp emigration was stimulated by rising water temperatures and white shrimp by falling water temperatures.

Perry, W. G., and T. Joanen 1986. Seasonal abundance and distribution of marine organisms in a semi-impounded Louisiana wildlife management area. Proceedings of the Louisiana Academy of Science 49:34-44.

Documents the seasonal presence and distribution of fish and crustaceans in an area managed with fixed-crest weirs on the Rockefeller Wildlife Refuge. Demonstrates that marine organisms entered and were distributed throughout the managed area. Concludes that weirs: 1) buffered salinity and depth fluctuations and did not allow complete dewatering of the managed area; and 2) did not prohibit ingress or egress of marine organisms. Calls for the consideration of the use of weirs or other structures to provide for the maintenance and productivity of coastal Louisiana.

Perry, W. G., Jr., A. B. Ensminger, and W. R. Latapie 1973. Marsh pond construction. Proceedings of the Annual Workshop, World Mariculture Society 3:149-65.

Reports on the construction of ponds for mariculture in coastal wetlands of Louisiana. Describes the basic marsh types and discusses pond construction for each. Concludes the chenier plain is better suited for pond construction because construction and maintenance of necessary levee systems are simplified on the soils in the chenier plain.

Perry, W. G., Jr., T. Joanen, and L. McNease 1970. Crawfish-waterfowl, a multiple use concept for impounded marshes. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 24:506-513.

Reports on a study to determine if manipulated impoundments at Rockefeller Refuge could be managed for both waterfowl and crawfish. Management entails dewatering ponds in early June, allowing lake beds to dry and seeds to germinate. Ponds are reflooded in September, providing access for waterfowl and allowing crawfish to leave burrows and feed on the vegetation. Managed ponds had excellent crawfish crops and duck usage.

Prevost, M. B. 1989. Methods to enhance target species production in brackish and saline impoundments. Pp. 44-52 in Coastal Wetland Impoundments: Management Implications: Workshop proceedings. Technical Report #SC-SG-TR-87-1. Charleston: South Carolina Sea Grant Consortium.

Describes various water management techniques used in brackish and saline manipulated impoundments in South Carolina to encourage vegetation desirable to waterfowl. Also describes modifications to management schedules to enhance mosquito control and water quality potential and improve non-game wildlife and estuarine fisheries management. Growth of vegetation beneficial to waterfowl can be very successful in manipulated impoundments if adequate numbers of water control structures and timely water level manipulations are used.

Prevost, M. B., A. S. Johnson, and J. L. Landers 1979. Production and utilization of waterfowl foods in brackish impoundments in South Carolina. Proceedings of the Annual Conference Southeastern Association Fish and Wildlife Agencies 32:60-70.

Reports on waterfowl food production, availability, and use in South Carolina brackish manipulated impoundments. *Ruppia*, *Eleocharis*, and seeds of *Scirpus* made up over 90% of the vegetation consumed by waterfowl. Most of the vegetative crop was consumed by pintails.

Prevost, M. W. 1968. Managing impounded salt marsh for mosquito control and estuarine resource conservation. Proceedings of the Marsh and Estuary Management Symposium: 163-171.

Discusses the use and misuse of complete impoundment for mosquito control. Summarizes how the practice of permanently flooding marshes affects vegetation, birds, fishes, and invertebrates. Concludes that effects on each variable are great, but suggests that impoundment may be beneficial for resource management depending on the objectives of the landowner.

Roberts, D. W., and D. J. Davis 1984. Report on proposed water control structures and management levees on the north bank of the Lake Borgne canal/Bayou Dupre, and the mouth of Bayou Chaperon. Baton Rouge: Coastal Environments, Inc. 15 pp.

Describes the physical and biological characteristics and the proposed management of a brackish marsh in St. Bernard Parish. Levees, in conjunction with two 48-in double flap-gated culverts, two 36-in double flap-gated culverts, and one 36-in single-gated structure were to be used to control the hydrology of the marsh. Authors conclude the proposed work will allow freshwater into the area for much of the year, can be used to dewater the area to encourage revegetation of mud flats, and will provide stable water levels during the winter for trappers and waterfowl.

Roberts, D. W., and D. J. Davis 1986. Harry Bourg Corporation marsh management plan: management unit 1. Baton Rouge: Coastal Environments, Inc. 22 pp.

Describes the hydrology, habitats, and proposed management of 3162 ac of marsh in Terrebonne Parish. Management plan goals were to control surface water and salinities to allow re-establishment of vegetation, improve habitat for waterfowl and furbearers, enhance the production of marine fishes in suitable areas, and introduce supplemental fresh water to revitalize the marsh. Levees and three variable-crest, reversible flap-gated structures were the components of the management system. Management strategies included drawdowns, freshwater input, placement of dredge material to elevate the substrate, and marsh grass plantings.

Roberts, D. W., and R. S. Pierce 1987. Lafourche Realty Company estuarine management program, 1986 environmental monitoring report. Baton Rouge: Coastal Environments, Inc. 37 pp.

Reports on hydrology, water chemistry, vegetation and nekton changes, and on standing crop at various stations within Lafourche Realty managed marshes. Concludes that brackish marsh vegetation increased while salt marsh species decreased.

Roberts, D. W., and R. Sauvage 1988. Lafourche Realty Company estuarine management program, 1987 environmental monitoring report. Baton Rouge: Coastal Environments, Inc. 26 pp.

Reports on hydrology, water chemistry, vegetation, and nekton at various marshes managed by Lafourche Realty in 1987. Concludes that marsh was changing in some areas from saline to brackish vegetation and that the salinity regime had stabilized and was not increasing. Water levels within the managed area had increased. The quantity of brown shrimp found inside the managed area was one-third of that found outside the system. Some water control structures were not in optimal locations.

Rogers, B. D., and W. H. Herke 1985. Estuarine-dependent fish and crustacean movement and weir management. Proceedings of the Coastal Marsh and Estuary Management Symposium 4:201-219.

Summarizes the results of a two-and-one-half year study investigating the seasonal presence and movement of fishes and crustaceans and their use of habitat types in coastal marshes. Results showed that one or more economically important species utilized the canals and marshes at all times of the year, that most species moved in the upper and middle water column, and that most species moved mainly at dusk and night. Cold front passages initiated large fish emigrations one to three days later. Discusses weir management and structure types to maximize fish and crustacean immigration.

Rogers, B. D., W. H. Herke, and E. E. Knudsen 1987. Investigation of a weir design alternative for coastal fisheries benefits. Final report. Baton Rouge: Louisiana State University, School of Forestry, Wildlife and Fisheries, Louisiana Cooperative Fish and Wildlife Research Unit. 98 pp.

Compares fish and shrimp abundance, salinity, water level, and water temperature in an impoundment controlled by a standard fixed-crest weir to a manipulated impoundment having a fixed-crest weir with a vertical slot. Over 241% more shrimp and 60% more fishes emigrated from the pond having the slotted weir. Slotted and standard weirs had similar effects on salinity and water level fluctuations. Concludes that a slotted weir enhances fishery access and utilization.

Rose, C. D., A. Harris, and B. Wilson 1975. Extensive culture of penaeid shrimp in Louisiana salt-marsh impoundments. Transactions of the American Fisheries Society 104(2):296-307.

Reports on a study of brown, white, and pink shrimp cultures in brackish manipulated impoundments southeast of Houma. Determined the effects of predators and competitors on shrimp survival (four-fold decrease) and measured daily growth rates for each shrimp species. Brown shrimp egress correlates with full and new moons; white shrimp emigration relates to decreasing water temperatures. Concludes that shrimp culture is "ethically" unsound due to destruction of small estuarine organisms, reduced nutrient export, and reduced recreational opportunities.

Simmering, R., B. Craft, J. Woodard, and D. Clark 1989. An evaluation of the Tenneco-LaTerre Mitigation Bank Management Plan. Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La.: U.S. Fish and Wildlife Service.

Provides vegetative, salinity, and water level results for 1986 and 1987 from the Tenneco-LaTerre Mitigation Bank area. In 1986 salinities, water levels, and the amount of submerged vegetation were higher and turbidity lower in managed areas compared to outside areas. In 1987 water levels and the amount of submerged vegetation were higher, while salinity and turbidity were lower in the managed area compared to outside areas. Waterfowl and alligators increased in managed areas from 1986 to 1987.

Sklar, F. H., and W. H. Conner 1979. Effects of altered hydrology on primary production and aquatic animal populations in a Louisiana swamp forest. Proceedings of the Coastal Marsh and Estuary Management Symposium 3:191-210.

Examined community structure variations among a complete impoundment, a crawfish farm, and a control area in a fresh water swamp. The fewest hardwood species and the lowest diversity, leaf litter biomass, and live biomass were found in the impounded area. The average number of benthic animals per square meter was highest in the control site and lowest at the crawfish farm.

Smith, T. B., and Son, Inc. 1985. Bush Canal-Bayou LaCache, Terrebonne Parish, Louisiana, past and present habitat conditions and environmental problems, proposed marsh management plan. Houma, La.: T. Bakes Smith and Son, Inc. 28 pp.

Describes the vegetation, nekton, and water quality of a 4,000 acre brackish marsh in southeastern Terrebonne parish. Describes habitat problems and describes management recommendations to alleviate problems. Recommendations include levee construction and refurbishment, gated water control structures, variable-crest structures, and pumps. Hydrology was to be managed to decrease salt-water intrusion, control water levels, and vegetation enhancement. Variable crest structures were expected to allow ingress and egress of estuarine-dependent marine species.

Soil Conservation Service n.d. Unpublished marsh management manual. Alexandria, La.: U.S. Department of Agriculture, Soil Conservation Service. 84 pp.

Briefly describes the biology of coastal marshes and marsh management techniques such as weirs, plugs, culverts, revegetation, level ditches, burning, and impoundments. Engineering section tells how to build and use levees, pits, channels, and impoundments. Summarizes policies and guidelines used by Soil Conservation Service and Coastal Management Division concerning marsh management.

Soil Conservation Service 1957. Louisiana gulf coast marsh handbook. Alexandria, La.: U.S. Department of Agriculture, Soil Conservation Service. 90 pp.

Describes important aspects of gulf coast marshes (soils, vegetation, drainage, etc) and grades soil types on their capability to support various uses. Describes range management for muskrat, nutria, ducks, geese, and cattle. Describes structures used in marsh management and provides guidelines for their construction.

Soil Conservation Service 1986a. Lafourche-Terrebonne Cooperative River Basin Study Report. Alexandria, La: U.S. Department of Agriculture, Soil Conservation Service. 69 pp.

Describes the natural resources in those parts of the Barataria and Terrebonne basins that make up Lafourche and Terrebonne parishes. Describes the problem of coastal erosion and lists the economic, natural, and social consequences. Describes problem areas in the West Fork Bayou L'Ours and the Bayou Penchant-Lake Penchant watersheds. Describes existing and potential projects to combat erosion, most of which consist of water control structures (with little specific data on placement). Expects that private landowners in areas identified by the Soil Conservation Service will apply for management plans, which will follow the general outline of plans provided by the Soil Conservation Service.

Soil Conservation Service 1986b. Final report: Vegetation and Salinity Changes Following the Installation of a Fixed-Crest Weir at Avery Island (1982-1986). Alexandria, La: U.S. Department of Agriculture, Soil Conservation Service. 18 pp.

Reports on the effects of a fixed-crest weir on vegetative communities, salinities, and water levels near Avery Island, Louisiana. Plant diversity and herbaceous plant cover increased, while woody plant cover decreased. In general, salinity was lower upstream of the weir. Water levels behind the weir were adequate for access during the five-year evaluation period.

Soil Conservation Service 1987a. Marsh management plan monitoring report, Tenneco Mitigation Bank project. Report to Coastal Management Division, Louisiana Department of Natural Resources. Alexandria, La.: U.S. Department of Agriculture, Soil Conservation Service. 5 pp. + tables

Discusses the effects of the Tenneco LaTerre marsh management plan on vegetative communities, water levels, salinity, and land/water ratios during the previous year. Salinities did not decrease inside the managed area; however, fresh-intermediate vegetation was appearing where only brackish vegetation had occurred previously. Structures successfully stabilized water levels but did not reduce land loss.

Soil Conservation Service 1987b. Watershed plans and environmental assessment for watershed protection West Fork Bayou L'Ours watershed, Lafourche Parish, Louisiana. Alexandria, La.: U.S. Department of Agriculture, Soil Conservation

Service. 49 pp. + appendixes.

Describes a land treatment plan to be installed in Barataria Basin to reduce land loss through the development of several kinds of marsh management. Included in the report is a description of the project setting, alternatives to the plan, the recommended plan, and the expected effects of the plan. Vegetative plantings, weirs, plugs, and levees are the primary means to decrease erosion, but information on the placement of such structures is not provided.

Soil Conservation Service 1987c. Watershed plan and environmental assessment for watershed protection. Bayou Penchant-Lake Penchant watershed, Terrebonne Parish, Louisiana. Alexandria, La.: U.S. Department of Agriculture, Soil Conservation Service. 51 pp. + appendixes

Describes a land management program to control coastal erosion in the fresh-intermediate marshes of Terrebonne Parish near Lakes Penchant and DeCade. Includes watershed resource data, problem descriptions, alternatives, impacts, and costs. Individual landowners would develop and carry out the project by installing weirs, dams, and dikes and by planting vegetation.

Soil Conservation Service 1988a. Monitoring of selected parameters on three marsh management plans. Phase II, Task 5, Final Report. Alexandria, La.: U. S. Department of Agriculture, Soil Conservation Service. 75 pp. + appendixes

Provides monitoring data (vegetative composition, water stage, salinity, and land loss) for Avoca Island, Vermilion Corporation Platform 1, and Amoco Production West Black Lake marsh management areas. Although no conclusions were drawn, data indicates that water levels were usually greater inside the managed area than outside. Salinity and vegetative composition comparisons could not be made. Land-to-water ratios from 1985 to 1988 increased 20% at Avoca Island from 1983 to 1988, increased 1% from 1985 to 1988 at Vermilion Corporation Platform 1, and increased 5% at Amoco West Black Lake from 1985 to 1988.

Soil Conservation Service 1988b. Monitoring of selected parameters on two marsh management plans. Phase 1, Task 6, Final report. Alexandria, La.: U.S. Department of Agriculture, Soil Conservation Service. 18 pp. + appendixes

Summarizes vegetation, salinity, water level, and land loss fluctuations in the Vermilion Corporation Platform 1 and Avoca Island marsh management areas. Monitoring time (3 months) was so short that no trends were discerned.

Soil Conservation Service 1988c. Second annual Tenneco-LaTerre marsh management monitoring report. Alexandria, La.: U.S. Department of Agriculture, Soil

Conservation Service. 7 pp. + tables + figures

Summarizes data concerning water salinities, vegetative community changes, water level fluctuations, open water/vegetation ratio, and the numbers of waterfowl and furbearers harvested in the Tenneco-LaTerre Marsh Management area. Results showed: 1) lower salinities and water level fluctuations within the management area than without; 2) no noticeable change in water/land ratio since 1985; 3) an increase in alligator harvest and decrease in deer harvest; and 4) no change in the vegetative community.

Soil Conservation Service 1988d. East Central Barataria Cooperative River Basin Study Report: Draft copy. Alexandria, La.: U.S. Department of Agriculture, Soil Conservation Service. 112 pp.

Describes the causes and consequences of erosion in east central Barataria Basin and provides a description of its natural resources. Describes existing and potential SCS projects in the area and lists social impacts with and without the implementation of the projects. Cites general practices such as critical area plantings, water control structures, dikes, burning, and proper grazing that are being used in 15 management plans covering 72,000 acres and that have the potential to be used on 174,000 acres in the watershed.

Soil Conservation Service 1989. Third annual Fina Laterre marsh management monitoring report. Alexandria, La.: U.S. Department of Agriculture, Soil Conservation Service. 105 pp.

Summarizes data concerning water salinities, vegetative community changes, water level fluctuations, marsh:water ratio, and hunting and trapping results in the Fina-Laterre mitigation bank area for 1988. Results showed: 1) salinities were higher in 1988 than 1987; 2) average inside water elevation was higher than outside levels; 3) water levels inside were stabilized 145% as compared to outside marshes; 4) vegetative diversity increased, reportedly in response to fresher conditions; and 5) marsh:water ratio improved from 66% marsh in 1985 to 72% marsh in 1988.

Spicer, B., D. Clark, and J. deMond 1986. Marsh management and the Louisiana coastal resources program. Miscellaneous publication. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division. 31 pp.

Describes activities within the coastal zone subject to the Coastal Use Permit process and describes guidelines used by Coastal Management Division to review permits. Describes marsh management techniques and effects of structural components (weirs, levees, plugs, etc) and non-structural components (burning, weed control, vegetative plantings). Summarizes marsh management permit applications from 1981 through 1984.

Spiller, S. F. 1975. A Comparison of Wildlife Abundance between Areas Influenced by Weirs and Control Areas. M.S. thesis. Baton Rouge: Louisiana State University. 76 pp.

Compared wildlife populations between areas affected by weirs and by natural marshes. More ducks, coots, and non-game birds used managed marshes than control areas during winter low water periods. Weirs had no effect on furbearer and small mammal populations. Discusses population trends in relation to study area, pond size, and seasonal changes.

Spiller, S. F., and R. H. Chabreck 1975. Wildlife populations in coastal marshes influenced by weirs. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 29:518-525.

Compares wildlife populations between marshes managed with weirs and natural marshes. More ducks, coots, and non-game birds used managed marshes during the winter, because natural areas were devoid of, or had little, water. With the exception of the swamp rabbit, weirs had no effect on furbearer and small mammal populations.

Swenson, E. M., and R. E. Turner 1987. Spoil banks: effects on a coastal marsh water-level regime. Estuarine, Coastal and Shelf Science 24:599-609.

Compares above and below ground water-level fluctuations between a partially-impounded area and a control area having an unrestricted hydrologic connection to an adjacent bayou. The partially-impounded area had limited hydrologic connection to an adjacent bayou because of the presence of a dredged canal spoil bank. Authors concluded the partially-impounded area was flooded 141 hours more per month than the control area, had fewer but longer flooding events, had fewer but longer drying events, and had reduced water exchange, both above and below ground.

Taylor, N. C., and J. W. Day, Jr. 1989. Ecological characterization of Jean Lafitte National Historical Park, Louisiana: basis for a management plan. Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La.: U. S. Fish and Wildlife Service.

Presents management plans for Jean Lafitte National Historic Park based on surface hydrology, salinity, soil characteristics, and historic vegetative community patterns. Management strategies are designed to restore natural hydrology and enhance sediment input. Recommendations include shoreline erosion control, revegetation, breaching and eliminating spoil banks, rollover weirs, and fresh water and sediment diversions.

Turner, D. D. 1966. Distribution and Abundance of Fishes in Impoundments of Lacassine and Sabine National Wildlife Refuges. M.S. thesis. Baton Rouge: Louisiana State University. 52 pp.

Reports on the use of rotenone, block-off nets, electric shocker, trammel nets, and gill nets to determine standing crops of fishes in three impoundments on the Sabine National Wildlife Refuge and one impoundment on Lacassine National Wildlife Refuge. Documents the presence of marine species in brackish impoundments at Sabine and freshwater finfish in freshwater impoundments at Lacassine. Sabine results suggest a large percentage of the population were harvestable size fish, but of non-game species. Lacassine populations had lower harvestable populations, but most of the harvestable weight was game fish species.

Turner, R. E., and C. Neill 1983. Revisiting the marsh after 70 years of impoundment. Pp. 309-332 in R. J. Varnell, ed., Proceedings of the Water Quality and Wetland Management Symposium. Metairie: Louisiana Environmental Professionals Association.

Compares impoundments surveyed in 1915 with their presence in 1978 to document the long-term effects of impoundments. Subsidence was highest the first years after impoundment and higher under cultivation. Eighty-two percent of areas impounded in 1915 and not currently being used for agriculture, urban areas, or navigation are now partially or wholly open water.

Turner, R. E., D. R. Cahoon, and J. H. Cowan, Jr. 1988. Marsh management needs and myths in Louisiana. Pp. 420-423 in J. A. Kusler, M. L. Quammen, and G. Brooks, eds., Proceedings of the National Wetland Symposium: Mitigation of Impacts and Losses. Technical Report 3. Berne, N.Y.: Association of State Wetland Managers.

Discusses assumptions dealing with marsh habitat and shrimp production, the indirect impacts of canal dredging, and the effectiveness of management plans. At the current rate of permitting for marsh management, 25% of coastal Louisiana will be managed by the year 2000, yet it is questionable if marsh management is appropriate in some marshes. Lists many other marsh management assumptions that need to be examined scientifically.

Turner, R. E., J. H. Cowan, Jr., I. A. Mendelssohn, G. W. Peterson, R. F. Shaw, C. Swarzerski, and E. M. Swenson 1989. Experimental marsh management impoundments. Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La.: U. S. Fish and Wildlife Service.

Describes a research initiative designed to test the effects of impounding on land loss rates, plant and soil properties, etc., and to develop better management practices for coastal wetlands. Outlines the proposed project, including the study area, variables to be measured, and importance and limitations of the study.

Turner, R. E., J. W. Day, Jr., and J. G. Gosselink 1989. Weirs and their effects in coastal Louisiana wetlands (exclusive of fisheries). Unpublished proceedings of the Marsh Management in Coastal Louisiana: Effects and Issues Conference. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division, and Slidell, La.: U. S. Fish and Wildlife Service.

Summarizes unpublished data from conferences, theses, etc., concerning the effects of weirs on water quality, soils, vegetation, erosion, and wildlife. Suggests that weirs have no effect on salinity, lowered turbidity and Eh values (increased soil waterlogging), increased submerged aquatic vegetation, decreased emergent vegetation and sedimentation, and increased wintering waterfowl.

van Beek, J. L., and S. M. Gagliano 1988. Protection and management requirements for Lafourche Parish. Baton Rouge: Coastal Environments, Inc. 28 pp.

Briefly describes the natural resources and environmental changes occurring in Lafourche Parish. Recommends and describes projects needed to provide flood protection and maintain the estuarine resource base. Primary recommendations include freshwater diversion and structural management to restore beneficial marsh hydrology, thereby maintaining 235,000 acres of wetlands in the parish.

van Beek, J. L., S. M. Gagliano, R. E. Emmer, and D. W. Roberts 1988. Prioritization and implementation of protection measures for Louisiana's coastal wetlands. Draft report. Baton Rouge: Louisiana Department of Natural Resources. 111 pp.

Describes each basin in coastal Louisiana and summarizes environmental trends. Describes general counter measures and specific programs to combat environmental problems in each basin. Technical recommendations vary to include bank stabilization projects, freshwater diversions, outfall management plans, and marsh management.

Weaver, J. E. 1969. Otter Trawl and Benthic Studies in an Estuary at Marsh Island, Louisiana. M.S. thesis. Baton Rouge: Louisiana State University. 88 pp.

Compares fish communities between an unweired marsh and two marsh areas managed with weirs, one having submerged aquatic vegetation and another having no vegetation. Salinities were higher and turbidities lower in the weired habitats. *Penaeus setiferus* and *Mugil cephalus* dominated the unweired habitat; *Leiostomus xanthurus* predominated in the weired, unvegetated marsh. *Palaemonetes* sp. and *Lepisosteus spatula* dominated catch numbers and biomass respectively in the weired, vegetative community.

Weaver, J. E., and L. F. Holloway 1974. Community structure of fishes and macrocrustaceans in ponds of a Louisiana tidal marsh influenced by weirs. Contributions in Marine Science 18:57-69.

Reports on fisheries community in weired and unweired ponds on Marsh Island, Louisiana. Two communities were found: an open-water community in the unweired and weired non-vegetated ponds, and a vegetated community in the weired vegetated ponds. (There were no unweired vegetated ponds.) Weirs encouraged submerged vegetation, and salinities were higher in the weired ponds than in control ponds. The catch of many commercially important, estuarine-dependent species was less in the weired than in unweired ponds.

Wengert, M. W., Jr. 1972. Dynamics of the Brown Shrimp, *Penaeus aztecus* Ives 1891, in the Estuarine Area of Marsh Island, Louisiana in 1971. M.S. thesis. Baton Rouge: Louisiana State University. 94 pp.

Compared *Penaeus aztecus* distribution, growth, and abundance between natural and weired areas at Marsh Island, Louisiana. More brown shrimp were caught per trawl in the natural marsh. Shrimp stayed longer in weired areas, grew faster, and emigrated at a larger size. Salinity fluctuations were less in weired marshes.

Wenner, C. A., H. R. Beatty, and W. A. Roumillat 1985. Comparisons of the ichthyofauna in South Carolina coastal wetland impoundments and adjacent tidal creeks. Abstract. Estuaries 8(2B):41A.

Compares ichthyofauna between manipulated impoundments and adjacent tidal creeks. Species diversity and richness were greater in creeks than in manipulated impoundments. Management strategy (time of flooding and duration of water exchange) determines larval fish recruitment into impoundments, and in summer dissolved oxygen values determine what taxa survive. Impoundment structures interfere with normal life history patterns of many species by preventing their movement into the marshes when young and from the marshes as they increase in size.

Wenner, E. L., and H. R. Beatty 1985. Seasonal and spatial relationships of macrobenthos from coastal impoundment, tidal creek and salt marsh habitat. Abstract. Estuaries 8(1B):41A.

Compares benthic populations between two manipulated impoundments and their adjacent tidal creeks and salt marshes. Polychaetes were most common outside the manipulated impoundments, while molluscs and insects had greater densities within the impoundments. Densities overall were lowest in the perimeter ditches within the manipulated impoundments; diversity was greatest at the open marsh and creek bottom sites.

Wenner, E. L., and H. R. Beatty 1988. Macrobenthic communities from wetland impoundments and adjacent open marsh habitats in South Carolina. Estuaries 11(1):29-44.

Core and grab samples were used to compare benthic communities in two South Carolina manipulated impoundments, an adjacent tidal creek, and a salt marsh habitat. Density was highest at the impounded site, dominated by *Scirpus robustus;* oligochaetes were also abundant. Total number of taxa was highest at the open marsh and creek sites. Perimeter ditches within impoundments were depauperate. The manipulated impoundment habitat exhibited a different species assemblage than in the adjacent marshes, suggesting that physical differences between habitats affected distribution patterns.

Whetstone, J. M. 1987. Combination management for aquaculture and waterfowl. Pp. 63-71 in Coastal Wetland Impoundments: Management Implications: Workshop Proceedings. Technical Report #SC-SG-TR-87-1. Charleston: South Carolina Sea Grant Consortium.

Water level fluctuations required to manage for widgeongrass, a highly desireable waterfowl forage, coincide with those beneficial for the culture of white shrimp or crawfish. This allows manipulated impoundments to be used for more than just waterfowl management. Describes management potential and techniques to produce white shrimp or crawfish in manipulated impoundments managed to encourage beneficial vegetation.

Whigham, D. F., J. O'Neill, and Margaret McWethy 1982. Ecological implications of manipulating coastal wetlands for purposes of mosquito control. Pp. 459-476 in B. Gopal, R. E. Turner, R. G. Wetzel, and D. F. Whigham, eds., Wetlands: Ecology and Management. Jaipur, India: National Institute of Ecology.

Compares vegetation, productivity, and water quality among three marsh types: 1) those open to tidal circulation; 2) those having water control structures controlling tidal flux; and 3) a marsh completely closed to tidal exchange. *Distichlis* and *Iva* became dominant vegetations in the open and controlled marshes; *Spartina patens* dominated the closed marsh. No water quality differences were found among marshes, but the open marsh consistently exported all nutrients measured.

Wicker, K. M., G. C. Castille, III, D. J. Davis, S. M. Gagliano, D. W. Roberts, D. S. Sabins, and R. A. Weinstein 1982. St. Bernard Parish: A Study in Wetland Management. Contract No. 168-909. Chalmette, La.: St. Bernard Parish Police Jury. 132 pp.

Describes the physical setting and cultural and natural resources of St. Bernard Parish marshes. Describes the various types of management structures (weirs, plugs, pipes, pumps) used in passive and active marsh management and how these structures help manage marsh hydrology, vegetation, wildlife, and fisheries. Divides wetlands into hydrologic units and proposes various management strategies to achieve the objectives of each unit.

Wicker, K. M., D. J. Davis, and D. W. Roberts 1983. Marsh management techniques employed on the Rockefeller Refuge, Louisiana. Pp. 67-88 in R. J. Varnell, ed., Proceedings of the Water Quality and Wetland Management Conference. Metairie: Louisiana Environmental Professionals Association.

Describes the four management programs on Rockefeller Wildlife Refuge and documents the results of each. The suitability of a marsh for management of a target species determined the management technique used. Passive management marginally succeeded in producing waterfowl foods but produced high use by important fisheries organisms. Controlled management with flap gates and weirs allowed adequate fisheries production and waterfowl vegetation growth. Gravity drainage was relatively successful in inducing revegetation of an area. Forced drainage using pumps was the most successful of all techniques for consistent vegetation production, but did not allow for fisheries production.

Wicker, K. M., D. Davis, and D. Roberts 1983. Rockefeller State Wildlife Refuge and Game Preserve: evaluation of wetland management techniques. Baton Rouge: Louisiana Department of Natural Resources, Coastal Management Division. 84 pp. + figures

Describes four types of management units on the refuge: 1) passive estuarine using fixed-crest weirs; 2) controlled estuarine using variable-crest, reversible flap-gated structures; 3) gravity drainage using levees and flap-gated culverts; and 4) forced drainage using levees and pumps. Each management type affected fish and vegetation resources differently. In general, the more active the management, the better the control of vegetation communities and the greater the decrease in estuarine fisheries utilization.

Wilkinson, P. M. 1970. Vegetative succession in newly controlled marshes. Project No. W-38-6, Job Completion Report for Period: April 1, 1967 to June 30, 1970. Charleston: South Carolina Wildlife Resources Department.

Five newly diked marshes in South Carolina were managed with different flooding regimes (fully flooded, slowly rising, saturated soil, dry, and tidal) and measured over three years for plant coverage and succession, waterfowl usage, pH, calcium, phosphorus, and salinity. The various flooding regimes resulted in different vegetational community changes. The fully flooded manipulated impoundment attracted the greatest number and diversity of waterfowl, followed by the impoundment managed with slowly rising water, then the tidal impoundment. The other two manipulated impoundments had little waterfowl usage.

Wilkinson, P. M. 1987. Management innovations to enhance the use of impoundments by estuarine transient species. Pp. 72-86 in Coastal Wetland Impoundments: Management Implications: Workshop Proceedings. Technical Report #SC-SG-TR-87-1. Charleston: South Carolina Sea Grant Consortium.

Describes how openings in water control structures (trunks) used in South Carolina impoundments can be manipulated to increase the migration of marine organisms between managed marshes and natural waterways. Concludes management for fisheries access and waterfowl is possible but requires more time and financial effort if management for both is to be successful. While combination management for several target species may decrease the production of a target species as compared to management solely for that species, it results in greater total production for all target species.

Wilson, K. A. 1962. North Carolina wetlands: their distribution and management. Raleigh: Game Division, North Carolina Wildlife Resources Commission. 169 pp.

Describes types, ownership, use, and development of North Carolina wetlands. Provides recommendations for managing these wetlands for wildlife. Describes the construction of wooden and earthen dikes for water impoundment and gives methods to encourage food plant propagation in various marsh types.

Zedler, J. B., T. Winfield, and P. Williams 1980. Salt marsh productivity with natural and altered tidal circulation. Oecologia 44:236-240.

Compares a well-flushed marsh with two modified wetlands characterized by reduced water flow. Increased productivity was found in one impounded area, possibly caused by freshwater runoff into the impoundment, by decreased soil salinity, and by nutrients retained within the marsh. Below-average rainfall in impoundments would reduce productivity, because evaporation would concentrate salts and lead to hypersalinity.

Chapter 18

KEYWORDS

accretion
active wetland (marsh) management
after-the-fact permitting
alienation of state water bottoms
alienation
alligators
alluvion
aquaculture
arms of the sea
arms of the Gulf
Atchafalaya Basin
Attorney General
Audubon Society
banks of navigable rivers, streams, and lakes
banks of navigable water bodies
Barataria Basin
barricades
boat barricades
brackish marsh
brackish
Breton Sound Basin
Calcasieu Basin
canals
chenier plain
chenier
Clean Water Act (see Federal Water Pollution Control Act)
Coalition to Restore Coastal Louisiana
Coastal Management Division guidelines
Coastal Restoration Technical Committee
Coastal Zone Management Act of 1972
coastal zone
Coastal Use Permit
Coastal Management Division
coastal erosion
Coastal Restoration Policy Committee
coastal use guidelines
coastal use permit
Coastal Management Division
commercial fisheries
commercially important species
Corps of Engineers
critical habitat
culverted control structures
dams
delta
deltaic plain

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. The 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 interest 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.