WETLANDS, Vol. 14, No. 4, December 1994, pp. 247–261

EFFECTS OF TWO LOUISIANA MARSH MANAGEMENT PLANS ON WATER AND MATERIALS FLUX AND SHORT-TERM SEDIMENTATION

Roelof M. Boumans
Jackson Estuarine Laboratory
University of New Hampshire
Durham, New Hampshire 03824-3427

John W. Day, Jr.
Department of Oceanography and Coastal Sciences and
Coastal Ecology Institute
Louisiana State University
Baton Rouge, Louisiana 70803

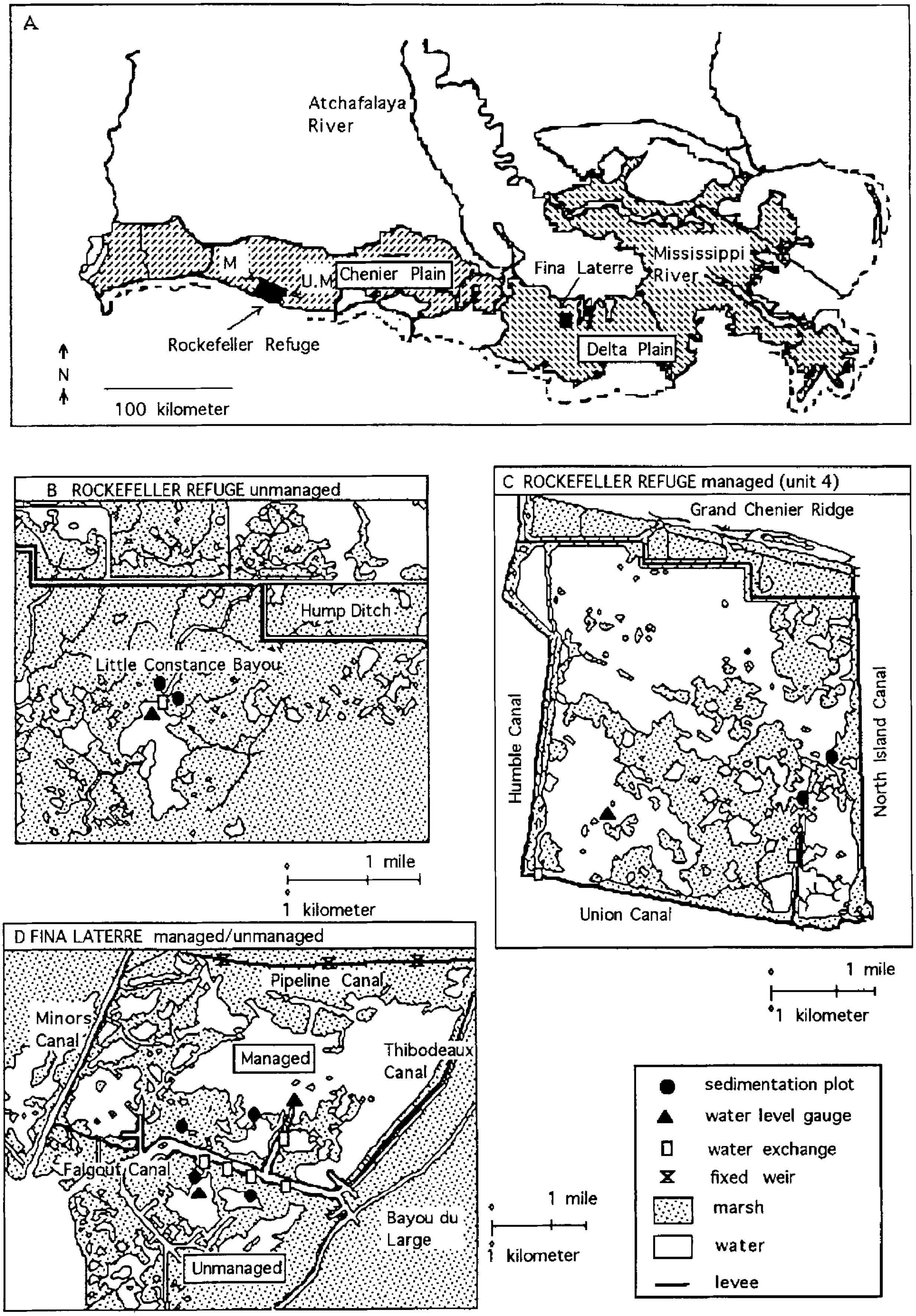
Abstract: The impact of two coastal Louisiana marsh management plans on water and materials flux, short-term sedimentation, and several soil parameters was evaluated between May 1989 and January 1990. The study was carried out in the Fina-Laterre Marsh Management Area and the Rockefeller State Wildlife Refuge in managed and unmanaged areas. Water and material flux was measured each two hours during twelve 48 h flux studies, and net fluxes per m^2 of drainage area were calculated for water, total suspended sediments, salinity, NO_3+NO_2, PO_4, and NH_4. Short-term sedimentation was measured as the weight of material deposited over 2–4 week intervals on petri dishes placed on the marsh surface. The managed sites experienced considerable reductions in total water exchange, leading to reductions in net material exchanges. When expressed on a per m^2 basis, the managed wetlands are much less tightly coupled to the surrounding estuary compared to unmanaged areas. Within the context of a general decrease of exchange, the two managed areas on average export materials to the estuary. In the managed areas, the results suggest that management can lead to reduced salinity and a loss of sediments and nutrients. Short-term sedimentation was less at the managed areas; expressed as g $m^{-2}d^{-1}$, total sedimentation rates were 0.57 for Fina managed, 1.02 for Fina unmanaged, 1.68 for Rockefeller managed, and 3.82 for Rockefeller unmanaged. Soil P was lower and soil organic matter was higher at the managed areas. Organic matter in the soil was low compared with recently deposited material, suggesting that most organic matter deposited on the surface of the marsh is lost through decomposition. Reduction of flooding during storm events is the likely mechanism leading to reduced sedimentation on the marsh surface in the managed areas.

Key Words: marsh management, Louisiana, material flux, tidal marsh, water-control structures

INTRODUCTION

For over three decades, one of the most intensively studied topics in coastal ecology has been the interaction between tidal wetlands and adjacent estuarine waters (Odum and de la Cruz 1967, Gardner and Kitchens 1977, Odum et al. 1979, Kjerfve and McKellar 1980, Nixon 1980, Dame et al. 1986, Stevenson et al. 1988, Day et al. 1989). There has been considerable controversy and discussion over the exact role of coastal wetlands, but there are large and important exchanges of water, suspended sediments, inorganic nutrients, organic matter, and living organisms between wetlands and estuarine waters. It has been shown, for example, that some coastal marshes export organic matter and provide habitat for estuarine nekton (Nixon 1980, Day et al. 1989). In coastal Louisiana, input of suspended sediment to wetlands is important in offsetting the relative sea-level rise (Baumann et al. 1984). An important concern for coastal managers, therefore, is the impact of management practices on such interactions between coastal wetlands and waters.

A practice widely used in the Louisiana coastal zone is marsh management. As used in Louisiana, marsh management refers to the use of low dikes and water-control structures to create impoundments in order to manipulate hydrology inside the impoundment. Such marsh management has been practiced for decades in Louisiana to improve marshes for waterfowl and fur bearers. More recently, marsh management has been promoted as a way of combating the high rates of coastal wetland loss (Cahoon and Groat 1990) based on the


A
Atchafalaya River
Mississippi River
M
U.M
Chenier Plain
Fina Laterre
Rockefeller Refuge
Delta Plain
N
100 kilometer
B ROCKEFELLER REFUGE unmanaged
Hump Ditch
Little Constance Bayou
1 mile
1 kilometer
C ROCKEFELLER REFUGE managed (unit 4)
Grand Chenier Ridge
Humble Canal
North Island Canal
Union Canal
1 mile
1 kilometer
D FINA LATERRE managed/unmanaged
Pipeline Canal
Minors Canal
Managed
Thibodeaux Canal
Falgout Canal
Bayou du Large
Unmanaged
1 mile
1 kilometer
sedimentation plot
water level gauge
water exchange
fixed weir
marsh
water
levee

belief that salinity intrusion and tidal scour are the most important agent leading to land loss (Gagliano and Wicker 1989). Water-control structures used in marsh management have mainly been fixed-crest wiers used to maintain a minimal water level in the managed area. This is termed passive management. Recently, more complex structures have been used that include variable crest wiers and flap gates to allow a greater control over hydrology. A primary objective of this active management is to draw down water levels to promote the growth of emergent vegetation (Cahoon and Groat 1990). At present, managed impoundments account for 17% of the Louisiana coastal zone (Day et al. 1990).

Recently, questions have been raised about marsh management concerning both the assumptions underlying justification of their use (i.e., the role of saltwater intrusion and tidal scour in wetland loss) and the impact of marsh management on estuarine processes such as flux of materials and sediment and access by estuarine-dependant species (Cowan et al. 1988, Day and Templet 1989, Cahoon and Groat 1990, Herke et al. 1992, Cahoon 1994). Our objectives in this study were to measure the effects of two marsh management plans on water and materials fluxes, short-term sedimentation, and soil parameters under different weather, tidal, and management conditions.

STUDY SITE

This study was part of a larger, comprehensive evaluation of marsh management practices in the Louisiana coastal zone (Cahoon and Groat 1990). As part of the larger study, 16 areas were selected for the analysis of habitat change from the mid-1950s to the mid-1980s using aerial imagery by a steering committee composed of landowners, state and federal agency representatives, marsh managers, and scientists. Each area included an operational marsh management plan typical of coastal Louisiana and a nearby non-managed area of similar size, marsh type, degree of hydrologic alteration, and degree of wetland deterioration. The 16 management plans included both actively and passively managed marshes. We report on two of the 16 areas, Rockefeller State Wildlife Refuge (Rockefeller) and the Fina-Laterre Marsh Management Area (Fina), which were chosen by the steering committee as representative of actively managed areas for more intensive study of the effects of management on hydrology, materials flux, vegetation ecology, soil parameters, water chemistry, accretion, and nekton (Boumans and Day 1990, Cahoon and Groat 1990).

Fina and Rockefeller are in two geomorphologically different areas of the Louisiana coastal zone: the deltaic plain and the Chenier plain (see Figure 1; for a more complete description of the area see Cahoon and Groat 1990). The deltaic plain was formed in an area of pleistocene erosion followed by direct deposition of Mississippi River sediments. In contrast, the Chenier plain has not been eroded and was formed by reworking of sediments carried to the area by westward littoral drift and deposited in the nearshore zone. In each area, measurements were carried out in a managed area and a nearby unmanaged area (Figure 1).

The deltaic plain managed area is the Fina site (2768 ha), which is located about 40 km from the coast (Figure 1). The goals of the management plan, which was begun in 1985, are to reverse wetland loss, increase freshwater and sediment input, decrease salinity, stabilize water levels, increase marsh production, and allow for immigration of marine fishery species. The area is surrounded by natural ridges or low dikes about one meter above mean high water. Four fixed-crest weirs on the northern boundary and one active structure on the southern boundary are used to control water levels. The southern structure consists of two adjacent openings each 2.8-m wide with individual flap-gates and variable-crest weirs. The openings in the structures are referred to as bays, and this terminology will be used throughout the text. The vegetation ranges from freshwater marsh in the north to a brackish *Spartina patens* (Ait.) Muhl. dominated wetland in the south. The unmanaged site (692 ha) is located south of the managed site across Falgout canal. Water flow is restricted by spoil banks, but four openings along Falgout Canal allow water exchange between Falgout Canal and the unmanaged area. The dominant vegetation is *Spartina patens*.

The Chenier plain managed site (2084 ha) is the Rockefeller area (Figure 1), which is located about 5 km from the coast. Since the state acquired the refuge in 1920, a program has been undertaken to counteract the effects of saltwater intrusion and altered hydrologic regimes. Improving waterfowl habitat and enhancing estuarine fisheries are the primairy management objectives. Like Fina, this managed area is bordered on all sides by low dikes about three meters above mean high water. The main water-control structure in the southwest corner has seven bays with flap-gated, variable-crest weirs. There is a second structure in the

←

Figure 1. Map showing locations of the study sites. The managed and unmanaged areas at Rockefeller are located 15 km apart in the chenier plain. The managed and unmanaged areas at Fina are adjacent in the deltaic plain. Note that Rockefeller is located closer to the coast than Fina.

eastern part of the area with five double flap gates. The unmanaged marsh (1604 ha) is 15 km east of the managed area and borders East Little Constance Bayou. This bayou has direct hydrologic exchange with the Gulf of Mexico about 5 km south of the study stations. The northern border is formed by a canal spoil bank with a variable-crest flap-gated culvert, which drains the wetlands north of the study site.

The marsh vegetation in the managed as well as in the unmanaged stations is dominated by *Spartina patens,* an indicator species for brackish marsh. *Spartina alterniflora* Loisel. also occurs in both areas. In the fresher, northern part of the managed area, fresher vegetation such as *Typha latifolia* (L.) and *Bacopa monnieri* (L.) Penn. occurs. Soils in both the managed and unmanaged areas are classified as Haplaquolls-Hydraquents association. Further descriptions of the two areas are given by Cahoon and Groat (1990), Rogers et al. (1992), and Cahoon (1994).

STRUCTURE OPERATION

The operation of water-control structures has a marked effect on the functioning of active marsh management projects. Variable-crest weirs with flap-gates like those at Rockefeller and Fina can be operated in a variety of ways. The flap-gates can be locked closed to prevent all water movement, held open to allow bidirectional flow, or operated in a down but unlocked position to allow water flow in one direction only. The structures are often operated in a two-phase, water-management schedule (Clark and Hartman 1990, Cahoon 1994). The The drawdown phase occurs in the late winter and spring by positioning the flap-gate to flap outward only. This allows outflow when water levels are lower outside the structure but prevents inflow when water levels outside are higher. Drawdown is most effective during cold fronts when coastal water levels are depressed and the head difference between the inside and outside of the management area is greatest. Structures for drawdowns are located on the south side of impoundments, and the north winds increase water levels in the southern part of impoundments, thus increasing the head difference and the efficiency of drawdown.

Drawdown is done to encourage the growth of vegetation for waterfowl or fur animals and to lower salinities. The flooding phase usually occurs from midsummer through mid-winter when impoundments are flooded to provide shallowwater habitat for waterfowl. The gates are held open and the crest of the weir is increased to hold water in the impoundment.

During our study, both Rockefeller and Fina used the two-phase water management approach (drawdown-flood). This is implemented each year at Fina and each three to four years at Rockefeller. At Fina, drawdown was from mid-February to mid-July. The weir crest was set at approximately 60 cm below marsh level, and the gates were set down but allowed to flap out so that water could flow outof but not into the impoundment. The gates were closed during the passage of Hurricane Gilbert in early October 1992. During the flooding phase from mid-July 1989 to February 1990, the gates were held open and the weir crest was set at 15 cm below marsh level. Thus, the May flux study was during a drawdown period, and the September and October sample periods were during the flooding phase. At Rockefeller, drawdown lasted from mid-February until mid-June when the weir crest was set at approximately 45 cm below marsh level and the gates were set down and flapping out. Some gates were opened during high tide on several occasions to allow acces of shrimp larvae (May 17–18, 22–26 and June 2, 15–19). During the sampling period of May 31–June 2, the gates were locked closed with the exception of the two-hour period at the end of the flux measurements when several gates were opened to allow water to flow in. From mid-July to mid-February 1990, the weir crest was set at 15 cm below marsh level and the gates were set down and flapping out. This was the condition during the September and October sample periods. A detailed description of pond structure and operation is given by Cahoon (1994).

METHODS

Flux Studies

Measurements of material flux were carried out at the two study areas. Field sampling was conducted on the following dates in 1989 to account for variation in climate, mean sea level, and operation of the structures: Rockefeller–May 31–June 2, September 21–23 and November 2–4; Fina–May 22–24, September 28–30 and October 26–28. At Rockefeller, measurements were carried out at the control structures in the south west corner of management unit 4 and in East Little Constance Bayou just above Little Constance Lake in te unmanaged site (Figure 1). At Fina, measurements were made at the main control structure just north of Falgout Canal and at the four inlets to the unmanaged area to the south of the Falgout Canal (Figure 1). Measurements of water and materials flux were made each two hours for the duration of each field trip at the control structures, East Little Constance Bayou, and at the largest channel into the Fina unmanaged area. At the four smaller channels at Fina unmanaged, water flux was measured approximately each two hours during daylight to estimate total water exchange between the unmanaged area and Falgout Canal. The cross sectional areas of the channels and control structures were measured. During each sampling period, field notes were made of weather conditions, structure operation, and other factors that might prove useful in analysis and interpretation of the data.

During each sampling period, water level and current velocity and direction were measured, and samples were taken for the determination of material concentrations at two h intervals for 48–50 hours (2 tidal cycles). At the unmanaged areas, samples were collected in the center of the channels at 30–40 cm, or if shallower at one half of total depth. Five channels (2.4–13 m wide, 0.2–1.2 m deep) connect the unmanaged area at Fina to Falgout Canal. Only one channel (25 m wide and 2–3 m deep) connects the unmanaged area at Rockefeller to the estuary. The channels at Fina are not typical tidal channels but connections that have eroded through a spoil bank that initially was continuous along the south side of Falgout canal. There is presently free tidal flow in all of the channels in the unmanaged sites. An earlier study of flux in a similar channel in coastal Louisiana showed that a single sample was sufficient to characterize flux in such channels (Stern et al. 1986, 1991). At Fina unmanaged, 2-h water samples were taken at the largest and most dominant channel. In addition, water samples were collected with an auto-sampler at one additional channel for the analysis of total suspended solids (TSS) only. For the managed areas, current measurements were made and water samples collected from the water flowing through the structures. At Fina, routine measurements were in the south bay of the structure. At several times during each trip, a number of additional current measurements were made in the north bay as well as in the approach channel on each side of the structure to ensure that measurements in the south bay were sufficient to characterize water flux. At Rockefeller, routine measurements were made at the main water-control structure in the center of bays 2, 4, and 6. Several times during each trip, current measurements were made 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+NO_2), ammonium (NH_4), soluble reactive phosphate (SRP), total suspended solids (TSS), and salinity. Samples for NO_3+NO_2, SRP, and NH_4 were filtered through 1.2 μm GF/C filters and frozen on dry ice in plastic autoanalyzer vials. All nutrient concentrations were determined according to EPA (1979). TSS were determined gravimetrically (Banse et al. 1963), and salinity was measured with a chloridity meter.

Current velocity was measured using a hand-held electromagnatic current meter. Water levels were read from staff gauges. The gauges were placed in the channels at the unmanaged areas and inside and outside of the structures at the managed areas. Instantaneous fluxes were calculated from each velocity, cross-sectional area, and concentration value. Changing cross-sectional area due to changing water level was accounted for (Stern et al. 1986). These calculations reflect the total amount of water and materials flowing through the structures at Rockefeller and Fina and at the two unmanaged areas. The net fluxes reported are the average of algebraic sums of instantaneous fluxes for each sampling period for each particular experimental area (Spurrier and Kjerfve 1988). Net fluxes were calculated per unit area of watershed (or experimental area). For both instantaneous and net fluxes, negative values refer to transport out of the study area, while positive values refer to transport into the study. Material concentrations and fluxes from unmanaged and managed areas were compared to determine possible effects of management.

Short-Term Sedimentation

Short-term sedimentation was measured at two- to four-week intervals between August 1989 and January 1990 as deposition on petri dishes placed in the marsh at the managed and unmanaged sites. Petri dishe collectors were constructed by drilling a hole in a 25 × 25 cm cedar board slightly larger than a 98-mm-diameter glass petri dish. The surface of the board was placed level with the marsh surface. 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 bottom up 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 when sampling. At each sampling site, 10 petri dishes were set out in two transects of 5 dishes each for a total of 40 dishes (Figure 1). Each transect consisted of dishes set out in the marsh at 5, 10, 15, 20, and 25 m from the water's edge. The petri dish technique is a modification of a technique used by Reed (1989, 1992), who measured short-term sedimentation on paper filters wired to the top of plastic petri dishes.

All material that had collected on the surface of a dish collector was placed in a plastic bag. Grass stems and other larger material were picked out by hand, and a razor knife was used to cut grass pieces, so that only material that was over the area of the petri dish was sampled. The petri dish was then carefully removed and placed over a funnel. Fine material 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 collected materials in each bag were placed in a crucible, and the water was evaporated at 60 °C. The crucible was then weighed, heated at 400 °C for 16 h, and re-weighed. The mass of material after combustion was considered mineral matter, and the loss on ignition was organic matter. The data were calculated on a g m^{-2} d^{-1} basis.

Soil Analyses

Sediment samples were taken with a 2.5-cm stainless steel corer at 16 randomly chosen stations in the southern part of the Fina managed area and in the Fina unmanaged area and at 20 randomly chosen stations in each of the Rockefeller sites. The upper 15 cm of each sample was homogenized for analysis of total phosphorus, Na^+, and % organic matter. Results are reported as the average of duplicate analyses that are within a 10% confidence interval. The results are based on oven dry mass (Soil Survey Staff 1972).

Statistical Analysis

Data for short-term sedimentation, soil parameters, and water parameters during the flux study were statistically analyzed as a random block design with a 2-by-2 factors treatments arrangement. We tested for differences between management (managed vs unmanaged), location within the coastal plain (Rockefeller vs Fina), and also among all individual cells. Where we determined a statistical difference among individual sites, we used Tukey's multiple comparison test. For these tests, we only used the water parameters when the water was flowing out to ensure that we were comparing water masses specific to the studied marsh areas.

RESULTS AND DISCUSSION

Water Level Variations During Flux Studies

In contrast to the impoundments, the outside of the managed areas, for both the Rockefeller and Fina sites, showed the clear tidal signals dominated by diurnal tides that are typical of the northern Gulf of Mexico. At Rockefeller, for example, a mixed tide was recorded with both diurnal and semi-diurnal components on September 21–23, while there was a diurnal tide on November 2–4 (Figure 2). The tide range varied from 16 to 38 cm at Rockefeller and from 12 to 14 cm at Fina. This was the expected pattern because tidal amplitude decreases with increased distances from the coast (Baumann 1987). Inside the managed areas, the water-level change was suppressed over the 48-h duration of the flux studies, especially at Rockefeller (Table 1, Figure 2). The variable water-level fluctuations at Fina on October 26–28 were not strongly effected by the tide. Strong and variable local winds at that time probably caused the water in the impoundment to slosh back and forth.

The tide range in the canal outside Unit 4 at Rockefeller was amplified because an extensive network of dikes prevented the water entering on the rising tide from spreading out over the marsh (Figure 2). Most of the area in the western part of the refuge is surrounded by levees, in contrast to the unmanaged area where flow is not restricted to channels and water spreads out over the marsh on the rising tide. The tidal range in the canal during the three tidal cycle studies ranged from 74 to 79 cm as compared to 16 to 38 cm in the unmanaged area (Table 1). At the Fina site, we did not measure any such amplification of the tidal range (Figure 2, Table 1). This is likely due to the greater distance from the coast and a much larger unrestricted tidal plain at Fina than in the western part of Rockefeller.

The amplified high tide at Rockefeller results in less time per tidal cycle that the main control structure can drain Unit 4. If the tidal range was not amplified, the water level would stay below the marsh surface for more than half of the time. Because the water level in the Humble and Union canals was more often higher than the water inside Unit 4, water would have flowed into the managed area for more time than it would have flowed out if the structure were left open at all times. When the water level outside the structure is below the inside levels, drainage was slow because of the limiting size of the structure openings.

Instantaneous Water Fluxes

The water flux measurements show a considerable reduction in total water exchange at the managed sites when compared with the unmanaged sites (Figure 3, Table 2). Instantaneous water flux at the unmanaged sites followed the tidal signal with significant inflows and outflows occurring. Control structures retarded water exchanges in both directions. Inflow was obstructed by the flapgates while outflow was retarded by the limited flow capacity of the structure and, at Rockefeller, by high water in the canal outside of the managed area.

At Rockefeller, peak fluxes ranged between 4 and 6 m^3 s^{-1} for the unmanaged site and between 1 and 2 m^3 s^{-1} for the managed site (Figure 3). The tidal cycle measurements at the end of May and early June occurred during a period of low winds, and thus, water fluxes were mainly tidally driven. At the unmanaged site, the water flux pattern reflected the mixed tide with a considerable flow in and out, but the net flux was relatively low. At the managed site, the structure was closed for the entire sampling period except during the

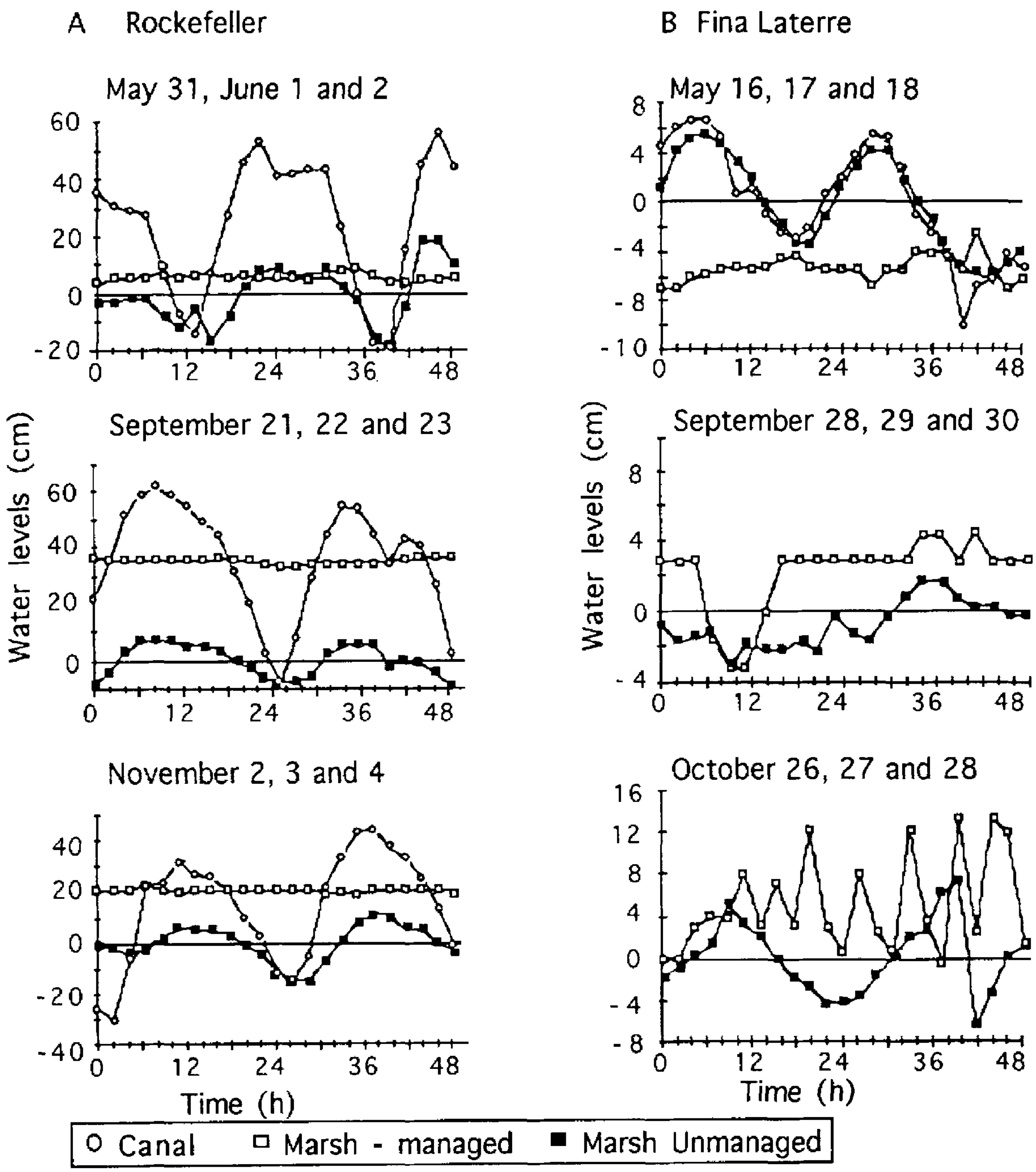


Figure 2. Water levels measured at the unmanaged and managed sites during the three tidal exchange studies. A. Rockefeller Managed out refers to water levels in the canal outside of the water control structure. The water-level scale is relative to an arbitrary datum. Water levels in and out of the managed area are absolute to each other. The curve for the unmanaged area is plotted such that low water coincides with low water for the canal. B. Fina. During the May study, water levels were measured both inside and outside of the water-control structure. During the September and October studies, the control structure was open, and water levels inside and outside the managed area were the same. The water-level scale is relative to an arbitrary datum, but the different curves are absolute to one another.

final hour, when it was opened for a short time to allow postlarval shrimp to enter the management unit. This resulted in the strong pulse of inflow at about 1700 (hour 48) on June 2. The measurements at Rockefeller in September occurred 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 East Little Constance Bayou, where flow out totaled 22-h and flow in 8-h. By comparison, the outflow at the managed area totaled only 14-h due to high water outside the structure. The November sampling also occurred during a period of strong north winds, with a strong net outflow

Table 1. Tidal range during the three flux studies for each of the study sites.

Study site		Measurement Tidal Range (cm) Spring	Fall	Late Fall
Fina LaTerre	Managed a	5	8	13
	Managed b	17		
	Unmanaged	12	12	14
Rockefeller	Managed a	5	5	3
	Managed b	76	79	74
	Unmanaged	38	16	27

"Managed a" refers to measurements taken within the water-control structure; "Managed b" levels were measured outside the water-control structure; Unmanaged refers to water levels in the main channel linking the unmanaged marsh to the estuary.

at the unmanaged area. Water flowed out of the bayou for 38-h and in for 8-h. At the managed site, outflow was only for 18-h. These results indicate that the amplified high tide in the channal adjacent to the managed site resulted in a reduction in the time the managed area drained as compared with the unmanaged site.

Water fluxes at the Fina unmanaged site showed the effects of the ebb and flood of the tide, but the peak fluxes were smaller than at Rockefeller (Figure 3). Peak fluxes were between 1.5 and 2.5 $m^3 s^{-1}$. By comparison, peak fluxes at the managed site were less than 0.5 $m^3 s^{-1}$. The May flux data for the unmanaged site, with a regular pattern of inflow and outflow, reflect the tidal signal and lack of strong winds. The managed area only had outflow for 8-h and and no inflow, as flap gates were closed by hydrostatic pressure. In September, the flap gates were positioned up and, therefore, inflow was not prevented The tidal range was again 12 cm but was influenced stongly by winds with variable speeds and shifting directions. This resulted in a somewhat irregular pattern of water flux without a clear diurnal tidal signal. The managed and unmanaged site both had inflows and outflows, with the larger flows at the unmanaged site. In October, the regular tidal signal resulted in a normal pattern of water flux at the unmanaged site. At the managed site, the flapgates were not positioned up, but water fluxes were low due to small differences in water levels inside and outside the structure. Overall, the unmanaged site had a slight net inflow for each of the three sampling trips.

Table 2. Net fluxes per m^2 of drainage basin for the three tidal flux studies. Negative values are materials leaving the basin while positive values indicate fluxes entering the basin.

		Water ($L\ m^{-2}\ d^{-1}$)		NaCl ($\mu mol\ m^{-2}\ d^{-1}$)		NH_4 ($g\ m^{-2}\ d^{-1}$)	
Study Site	Month	Unm	Man	Unm	Man	Unm	Man
Fina	May	6.02	−0.10	0.55	−0.20	35.62	−0.12
	Sep	5.07	−0.41	11.05	−3.85	30.46	3.80
	Oct	14.86	−0.22	11.76	−0.53	129	−0.21
	Aver	8.65	−0.25	7.79	−1.53	65.04	1.16
	StE	3.11	0.09	3.63	1.16	32.03	1.32
Rockefeller	May	1.21	0.42	11.26	2.35	26.32	3.18
	Sep	−4.50	−1.31	−45.10	−9.65	−1.92	−0.16
	Oct	−7.61	−2.03	−29.30	−57.30	−20.40	−3.17
	Aver	−3.63	−0.97	−21.10	−21.50	1.34	−0.05
	StE	2.58	0.73	16.78	18.21	13.58	1.83
		NO_2/NO_3 ($\mu mol\ m^{-2}\ d^{-1}$)		PO_4 ($\mu mol\ m^{-2}\ d^{-1}$)		TSS ($g\ m^{-2}\ d^{-1}$)	
		Unm	Man	Unm	Man	Unm	Man
Fina	May	117	−0.71	0.42	−0.03	0.35	0
	Sep	48	1.70	1.57	0.07	0.26	−0.01
	Oct	550	−1.55	12.24	−0.04	0.78	−0.01
	Aver	239	−0.19	4.74	−0.046	0.46	−0.01
	StE	157	0.98	3.76	0.035	0.16	0.002
Rockefeller	May	−5.89	9.25	0.81	0.76	0.16	0.14
	Sep	−4.41	−0.72	−5.58	−0.79	−0.41	−0.27
	Oct	−12.80	−2.35	−6.40	−1.01	−0.23	−0.25
	Aver	−7.70	2.06	−3.72	−0.34	−0.16	−0.12
	StE	2.59	3.63	2.28	0.56	0.17	0.13

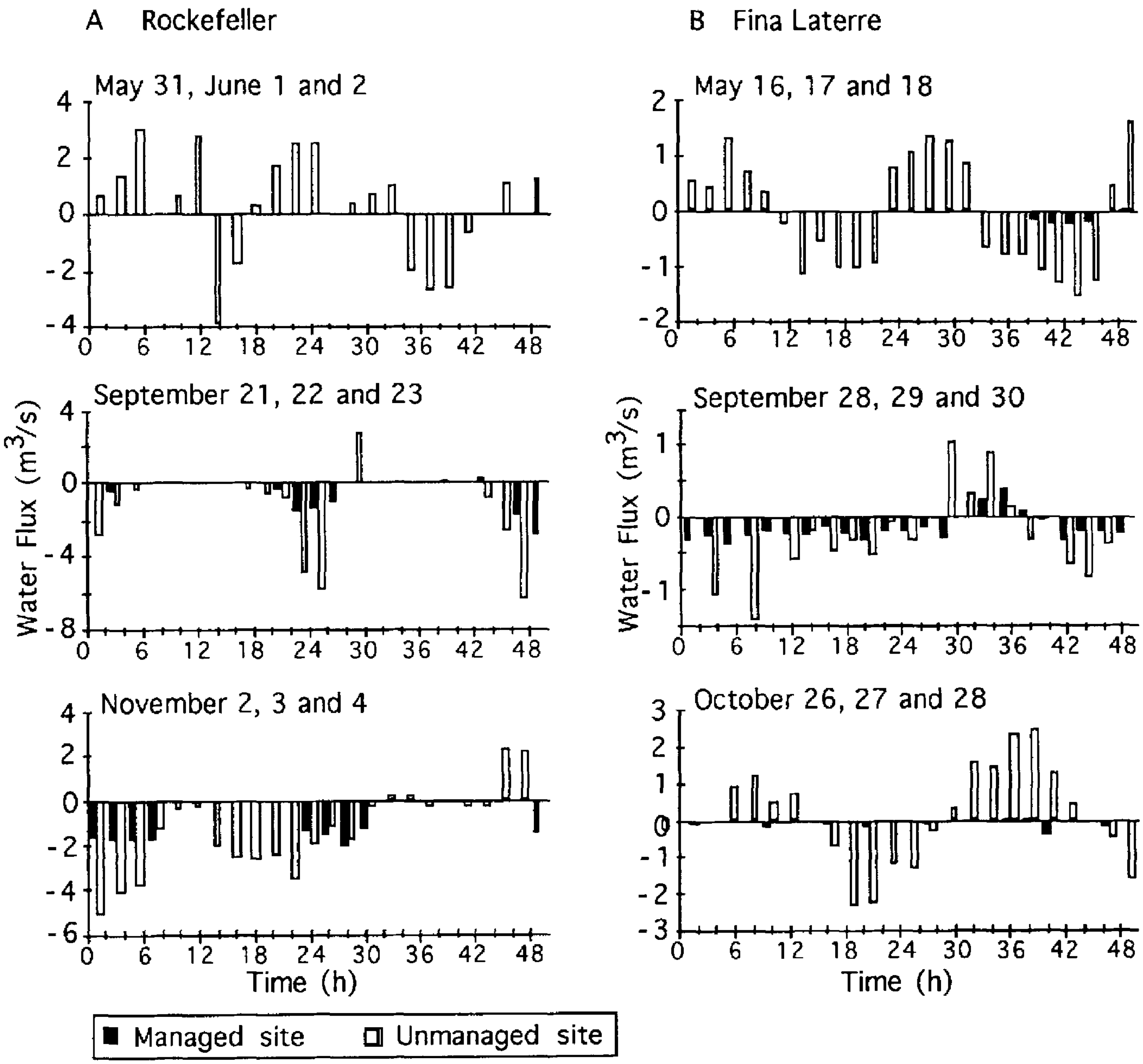


Figure 3. Instantaneous water fluxes per m² drainage area measured each two hours for three tids. Positive values indicate flux into the area, and negative values are flux out of the area. A. Rockefeller. Water flux for the managed area was measured at the control structure in the southwestern corner of Unit 4. Water flux for the unmanaged area is for water exchange in East Little Constance Bayou north of East Constance Lake. B. Fina. 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 at 5 points with Falgout Canal.

Net Material Fluxes and Material Concentrations

The data on instantaneous water fluxes and material concentrations were used to calculate net fluxes, which were then corrected for area of watershed to obtain total net material fluxes per m² of drainage area during each sampling period (Figure. 4). This allowed comparisons between the respective managed and unmanaged areas for similar forcings of tide and climate. The comparisons are for total net water and materials fluxes at the structures and channels measured. There is one additional structure at Rockefeller and several fixed crest weirs at Fina, but observations in the field and discussions with management staff indicate that the structures where measurements were carried out are responsible for most water flow. At Rockefeller unmanaged, there could have been some cross-marsh flow

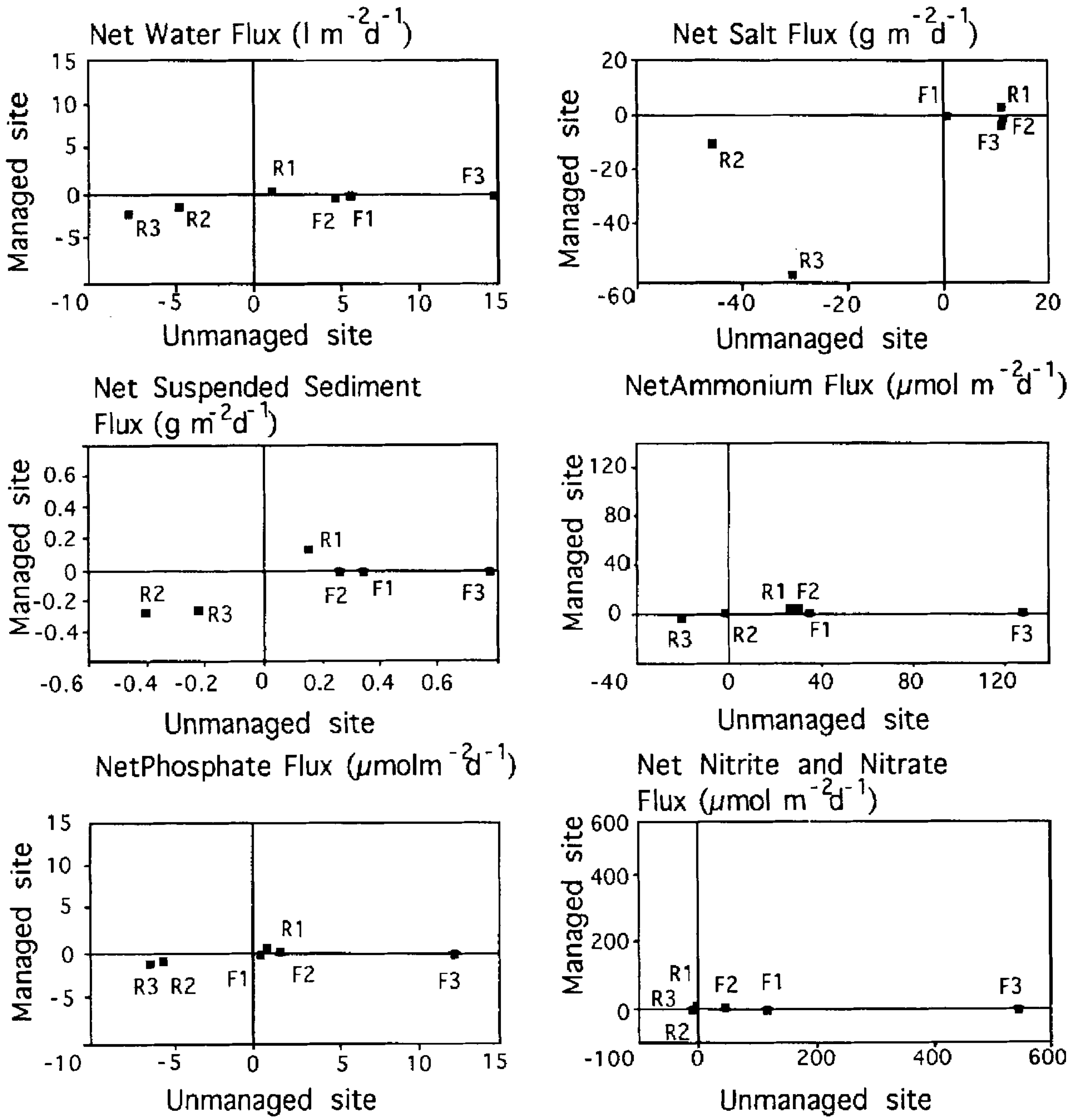


Figure 4. A comparison of net material fluxes per m^2 of the study area for the managed and unmanaged areas for each 48 h sampling period. The net fluxes for the unmanaged areas are on the horizontal axis and for the managed areas are on the vertical axis. Each circle compares the net flux between managed and unmanaged areas for a particular constituent (water, salt, suspended sediments, ammonium, phosphate, and nitrate plus nitrite) for an individual sampling trip. Positive values indicate flux into the area and negative values are flux out of the area. R and F stand for Rockefeller and Fina, respectively, and 1, 2, and 3 are for the first, second, and third trips.

between East Little Constance Bayou and bayous draining adjacent marsh areas. Corrections for these differences would be small compared to the large differences between managed and unmanaged areas (Table 2, Figure 4) and would not substantially change our conclusions.

In general, the magnitude of the net fluxes were much greater for the unmanaged areas, due mainly to the greater water transport. (Figure 4, Table 2). The unmanaged areas had a net material import on some trips and a net export on others, as would be expected for individual tidal cycles in unimpounded coastal marshes (Kjerve and Proehl 1979). The managed area at Rockefeller had a small import in May, while fluxes in September and November were generally near zero or exports. The import during May was a result of

Table 3. Mean and standard error of short term sedimentation rates, soil parameters, and concentrations of materials measured during flux studies for each of the study sites. (Tot Sed = total sedimentation, In Sed = inorganic sedimentation, Org Sed = organic sedimentation, % OM = % organic matter of deposited material.)

Parameter	Rockefeller		Fina		p Value
	Managed	Unmanaged	Managed	Unmanaged	
Short-term sedimentation					
Tot Sed (g m^{-2} d^{-1})	0.6 ± 0.8	1 ± 0.7	1.7 ± 0.6	3.8 ± 0.7	0.21
Min Sed (g m^{-2} d^{-1})	0.1 ± 0.3	0.1 ± 0.2	0.4 ± 0.2	1.6 ± 0.2	0.02
Org Sed (g m^{-2} d^{-1})	0.5 ± 0.6	0.9 ± 0.5	1.3 ± 0.5	2.3 ± 0.4	0.59
% OM	85 ± 3.5	82 ± 3.2	79 ± 3.1	51 ± 3	0.01
Medium-term sedimentation (Cahoon 1990)					
% OM after 1 y	59 ± 3	26 ± 1	28 ± 5	53 ± 8	
Soil parameters					
Phos (mg Kg^{-1})	101 ± 7.5	118 ± 7.7	111 ± 8.3	232 ± 7.8	0.01
Na (g Kg^{-1})	86 ± 1.5	6.5 ± 1.5	7.6 ± 1.6	9 ± 1.5	0.25
% OM	87 ± 0.2	7.2 ± 0.2	5.6 ± 0.2	5.8 ± 0.2	0.01
Material concentrations during flux studies					
Sus Sed (mg l^{-1})	28 ± 5	26 ± 11	160 ± 9	63 ± 7	0.01
Salinity (ppt)	2.3 ± 0.3	0.4 ± 0.6	9 ± 0.5	6.5 ± 0.3	0.50
NH_4 (μM)	3.1 ± 0.4	3.7 ± 0.8	5.4 ± 0.7	4.3 ± 0.5	0.19
NO_2/NO_3 (μM)	6.9 ± 0.8	8.8 ± 1.8	1.6 ± 1.4	2 ± 1	0.57
PO_4 (μM)	1.3 ± 1.1	1.5 ± 1.1	0.2 ± 0.1	0.7 ± 0.1	0.24

management when the gate was opened for a brief period at the end of the measurement period to allow the only water flow for the 48 hour period.

Water Fluxes

The net water fluxes per m^2 of drainage basin were 12 to 75 times higher for the unmanaged than the managed at Fina and 3 to 4 times higher at Rockfeller unmanaged than managed (Table 2). The strong net export of water in September and November at Rockefeller managed and unmanaged resulted from the north winds during the sampling trips. There was a slight net import during the May trip. The Fina unmanaged area had a net import of water at the unmanaged site for all three trips, while the managed area had a small net export of water for each trip. The net water transport patterns were the main driving forces affecting materials transport.

Total Suspended Solids

The most striking result of TSS transport is the strong net export from both managed and unmanaged areas at Rockefeller during September and November (Table 2). In contrast to the other measured parameters where net fluxes in the unmanaged areas were much greater than in the managed areas, TSS net fluxes per m^2 of drainage area at Rockefeller managed and unmanaged were similar. During all three trips, Fina had a net import of suspended solids into the unmanaged area and a slight export from the managed area. TSS were significantly higher in the managed areas ($p<0.001$) and higher at Rockefeller ($p<0.001$, Tables 2 and 3). These differences result from the high TSS concentrations at Rockefeller during the two trips with strong north winds. These results suggest that the common management practice of drawdown by draining during strong north winds may result in considerable sediment export from managed areas. This happens when bottom sediments are resuspended by wind waves and the suspended material flows out with the water (Tables 2 and 3).

Salt

The direction of the net flux of salt followed net water flux because salinity behaves conservatively in the short term and can be used as a tracer of water masses (Day et al. 1989). The Rockefeller managed and unmanaged areas had considerable net exports of salt in September and November and imports in May. The Fina unmanaged area had a net imports of salt on all trips, but the managed area always exported salt. These results suggest that when there is an net export of water from an area, there will be a corresonding net export of salt. Salinity levels during the flux studies were higher in the managed areas ($p<0.001$) and at Rockefeller ($p<0.001$, Tables 2 and 3). These data on salt flux and concentrations are reflective only of the period of the flux studies and not necessarily of longer term trends. For example, Rogers et al. (1992) reported that salinity was significantly higher in the Fina managed area during the drawdown period, a finding that is in agreement with our results. Flynn et al. (1990), however, reported lower average annual soil salinities in the Rockefeller managed area compared to the managed area.

Nitrogen and Phosphorus

The Fina unmanaged area showed a net import of NH_4, NO_3+NO_2, and PO_4 during all three trips. The Fina managed areas showed small net fluxes of these materials when compared to the unmanaged area. The net fluxes of NO_3+NO_2 at both Rockefeller unmanaged and managed sites were small on all three trips compared to Fina unmanaged area, reflecting the low NO_3+NO_2 concentrations during these periods. When expressed on a m^2 basis, the net nutrient fluxes at the managed areas of both sites were generally much lower than those at the unmanaged areas. In Fina, net fluxes per m^2 for NH_4, NO_3+NO_2, and PO_4 were from 16 to several hundred times greater for the unmanaged areas than the managed areas. In contrast to the conservative behavior of salt where net flux always followed the direction of net water flux, net inorganic nutrient fluxes were sometimes the opposite of net water flux. For example, during the May trip at Rockefeller, there was a net water import but a net export of NO_3+NO_2. Likewise, at the Fina managed site in September, there was a net export of water but a net import of NO_3+NO_2. There was also a strong net uptake of NO_3+NO_2 at the Fina unmanaged area on all three trips. These results show that there were active nutrient transformations taking place in both managed and unmanged areas (Table 2). Both NO_3+NO_2 and PO_4 concentrations were higher at Rockefeller ($p<0.001$), but NH_4 levels were higher at Fina ($p<0.001$, Table 3). PO_4 levels were higher at the unmanaged areas ($p<0.005$, Table 3).

Flux studies have been used to calculate material budgets for different wetlands (e.g., Woodwell et al. 1977, Dame et al. 1986) and to characterize the interaction between wetlands and adjacent waters under varying conditions of such forcing as tide range, river flow, temperature, and storm events (Childers and Day 1990a, b, Stern et al. 1991). We stress that it was not our objective to use the flux results to calculate a long-term budget. Rather, we wanted to get an idea of the behavior of the system under different conditions of physical forcing (tides and weather events) and structure operation.

Tidal exchange coupled with winds affected the direction and magnitude of flux at the unmanaged areas. Strong north winds (as in September and November at Rockefeller) caused strong net exports of water and materials. When water exchange was mainly tidally driven, net fluxes were much smaller. Net fluxes over a single tidal cycle can be very different from day to day and during different seasons (Kjerfve and Proehl 1979, Stern et al. 1991) depending on local climatic and hydrologic conditions. Thus, during the September and November trips at Rockefeller, north winds caused considerable net export of water, TSS, salt, ammonium, and phosphate from both the managed and unmanaged sites. The TSS loss resulted from resuspension of bottom sediments in shallow ponds and waterways and subsequent export with water flowing out of the areas. By contrast, the Fina unmanaged area had a net import of water and TSS on all three trips. Export of TSS has also been related to strong rainstorms at low tide (Settlemyre and Gardner 1975, Ward 1981, Childers and Day 1990a). Net uptake of TSS, such as we measured for the unmanaged area at Fina for all three trips, has also been reported (Wolaver et al. 1988).

Net fluxes per m^2 of drainage area were much lower at the managed areas. For the 72 individual net flux calculations (6 parameters, 4 sampling locations, and 3 sampling times), the net flux for the unmanaged areas was, on average, about 40 times greater than that for the managed areas. Net water fluxes were always greater at the unmanaged areas, and this was the primary reason for the greater net fluxes for the other constituents at the unmanaged areas. Even when flapgates were locked open, the structures in Fina and Rockefeller unit 4 carried less water than the natural channels in the unmanaged areas, especially when expressed on a unit area of the drainage basin basis (Figure 4). There were only two instances where the net flux of a parameter for a managed area was greater than the corresponding unmanaged area. Both of these were at Rockefeller, where the net flux of salt was 1.96 times greater during the November trip and the net flux of NO_3+NO_2 was 1.56 times greater during the May trip. In both cases, this was due to higher concentrations of salt and NO_3+NO_2, respectively, in the managed area. The results also indicate that the structures at Rockefeller are much more hydrologically effective than those at Fina. The net aerial water fluxes at Rockefeller unmanaged were 3 to 4 times higher than the managed area, while at Fina, the unmanaged net aerial fluxes were 12 to 75 times higher than the managed fluxes. Thus, during the periods we studied, management substantially lowered interactions between the managed wetlands and estuarine waters. When expressed on a per unit area basis, these results show that the managed wetlands when compared to the unmanaged areas are largely uncoupled from the surrounding estuary. A second affect of management during the periods we measured was to convert the managed systems, depending on wind and water-level conditions, from slightly to strongly exporting systems. Only at Rockefeller during the May trip was there a net input of water to the managed area. This happened because the structure remained closed for most of the trip and was opened only once to allow water to flow in. These results also show that management generally led to an export of salt from the managed areas during the periods we measured.

Short-Term Sedimentation

Short-term sedimentation was higher at the unmanaged sites compared to the managed sites and was higher at Rockefeller compared to Fina (Table 3 and Figure 5). Total sedimentation rates were significantly higher at Rockefeller than at Fina ($p<0.006$) and were higher in the unmanaged areas for both sites ($p<0.07$, Table 3). Deposition of mineral sediment was significantly higher at Rockefeller ($p<0.0003$) and at the unmanaged areas ($p<0.009$). Organic matter deposition was significantly higher at Rockefeller ($p<0.029$) than at Fina. The percent organic matter of deposited material was significantly higher at the managed sites compared to unmanaged sites ($p<0.0001$) and at Fina compared to Rockefeller ($p<0.0001$). Streamside sedimentation was significantly higher than inland sedimentation only for the Rockefeller unmanaged site (Figure 5).

Total sediment deposition for the different sampling periods at Fina ranged from 0 to 2.3 g m^{-2} d^{-1} and 0 to 1.32 g $m^{-2}d^{-1}$; mineral sediment deposition ranged from 0 to 0.26 g $m^{-2}d^{-1}$ and from 0 to 0.38 g $m^{-2}d^{-1}$ for the unmanaged and managed site, respectively. The organic fraction of the deposited material ranged from 26–100% for the unmanaged area and from 55 to 100% for the managed area. Total sediment deposition at Rockefeller ranged from 0 to 11.9 g $m^{-2}d^{-1}$ and 0 to 3.6 g $m^{-2}d^{-1}$, and mineral deposition ranged from 0 to 4.22 g $m^{-2}d^{-1}$ and from 0 to 1.08 g m^{-2} d^{-1} for the unmanaged and managed sites, respectively. The organic fraction values ranged from 9 to 74% for the unmanaged area and from 15 to 100% for the managed area. Reed (1989, 1992) reported short-term sedimentation rates from near zero to 40 g m^{-2} d^{-1} for a number marsh sites in the Louisiana coastal zone. Our findings of higher sedimentation rates at Rockefeller than Fina agrees with Reed (1989, 1992) who reported higher sedimentation rates nearer the coast.

Short-term sedimentation of allocthonous materials was less on the marsh surface in the managed areas than in the unmanaged areas. Reed (1992) reported lower short-term sedimentation at a number of marsh sites in coastal Louisiana that had fixed-crest weirs. In the same overall study, Cahoon (1994) found that vertical accretion over marker horizons was from 5 to 10 times lower in the managed areas. The material accumulated over marker horizons includes both allocthonous materials and root production. Thus, this suggests that areas with low short-term sedimentation rates will also have lower longer term accretion rates. This difference in sedimentation will likely affect the ability of marshes to maintain elevation against rising water levels.

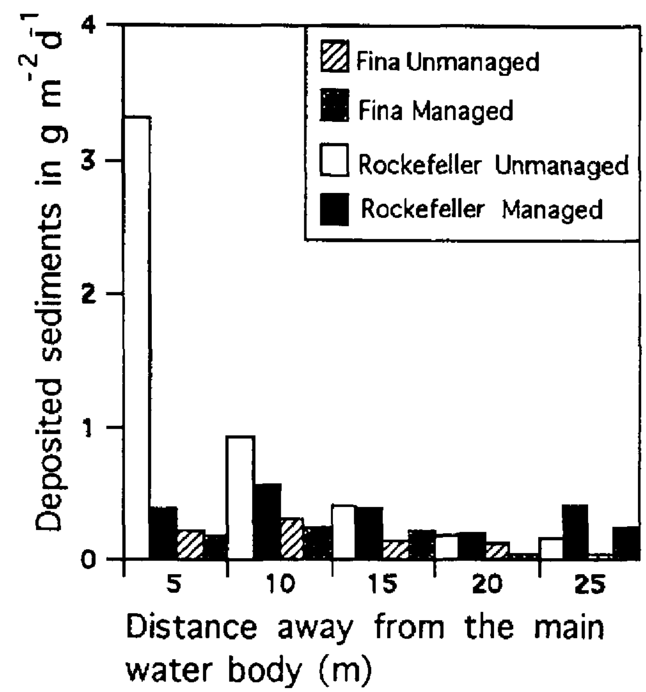


Figure 5. Total short-term sedimentation rates at the four sites. Values for each station are averaged over the period between August 1989 and January 1990.

Sedimentation was high after the passage of Hurricane Gilbert in all areas except Rockefeller managed. The importance of storm-dominated depositional patterns, especially by hurricanes, has been reported by a number of authors for both Louisiana and other coastal areas. (Baumann et al. 1984, Meeder 1987, Rejmanek et al. 1988, Reed 1989, Cahoon et al. 1994). Increased deposition of sediments in Louisiana coastal marshes occurs during storm events, and the greatest amount occurs during hurricanes when large amounts of sediments are mobilized through resuspension and moved onto the marsh during high tides. This deposition is important to maintaining marsh surface elevation. The reduction of sedimentation at Rockefeller managed but not at Fina managed during Hurricane Gilbert was a result of the height of the dikes. The lower dikes at Fina were overtopped while those at Rockefeller were not, thus allowing sediment deposition. Overtopping and high sedimentation occurred again at Fina during the passage of Hurricane Andrew in 1992 (pers. comm.,

D. McNally, Coastal Ecology Institute, Louisiana State University). These results indicate that complete exclusion of hurricane flood waters from marsh management areas will block an important mechanism of sediment delivery.

Soil Parameters

The percentage organic matter (OM) in sediments deposited on petri dishes was higher than either the materail accumulated in one year over marker horizons or soil samples from the upper 15 cm. The average fraction of OM on the petri dishes ranged from 85% at Fina managed to 51% at Rockefeller unmanaged (Table 3). The percent OM of materials accumulated over marker horizons ranged from 25 to 67% (Cahoon 1994). The amount of OM in soil samples, which ranged from 5.6 to 8.7%, was about 10% of the organic level of sediments found on the perti dishes (Tables 3 and 4). Thus, the percent OM decreases rapidly with depth; this suggests that very little of initially organic material is incorporated into the soil and that most soil OM is from *in situ* root production. Deposited organic material is mainly lost via decomposition and has little significance to maintenance of elevation (Nyman et al. 1990). The results of soil analyses showed that phosphorus was significantly higher in the unmanaged compared to managed areas ($p<0.001$) and significantly higher at Rockefeller compared to Fina ($p < 0.01$). We did not find significant differences for soil sodium among the different sites.

Studies on plant productivity and nekton dynamics carried out at the same time also showed differences among the areas. Flynn et al. (1990) studied productivity of *Spartina patens* at the two sites. They reported that productivity was higher at Rockefeller managed but lower at Fina managed as compared to the unmanaged sites. They concluded that the higher productivity at Rockefeller managed was due to an effective drawdown that led to greater soil oxidation and higher Eh values. The opposite was true at Fina managed where soils were more waterlogged and reduced than in the unmanaged area. Rogers et al. (1992) studied the effects of management on fishery communities. At Fina, more grass shrimp and resident minnows (least killifish, western mosquitofish, and golden top minnow) were collected in the managed area, while more marine-transient organisms (gulf menhaden, blue crab, and striped mullet) were collected in the unmanaged area.

CONCLUSIONS

Marsh management significantly reduced water and materials exchange at both Rockefeller and Fina during the periods of study. Short-term sedimentation was generally higher in the unmanaged areas at both sites and at Rockefeller. There were also significant differences in soil organic matter and soil P between managed and unmanaged sites and between Rockefeller and Fina. The reduced sediment input to the managed areas and reduced short-term sedimentation are reflected in longer term accretion rates (Cahoon 1994).

During the periods of our measurements of flux, the managed areas were net exporting systems. One of the goals of management is to lower salinity, and we measured net export of salt at both Fina and Rockefeller. Our results suggest a number of implications for marsh management. Drawdown, one of the most important management operations, is most effective when carried out during north winds when coastal water levels are low, which can lead to a net export of sediments and nutrients. Management may lead to freshening, a progressive sediment deficit, and a loss of fertility. It must be remembered, however, that these measurements were carried out at only two areas and during drawdown operation. Further study should be carried out for a wider variety of marsh management plans under different operational phases before broad generalizations can be made concerning structural marsh management.

ACKNOWLEDGMENTS

This study was funded by the U.S. Department of Interior, Minerals Management Service under contract number 14-12-0001-30401. We especially want to thank John Woodard and Danny LeBoeuf at Fina-Laterre and David Richard and Gunther Perry at Rockefeller Refuge for access to the sites, airboat and other logistical support, information provided on the sites, and valuable advice on the conduct of the study. Don Cahoon, Joanne Mossa, Rick Hartman, Irene Hesse, Tiny Sikkes, and many others helped with the field and laboratory work.

LITERATURE CITED

Banse, K, C. P. Falls, and L. A. Hobson. 1963. A gravimetric method for determining suspended matter in seawater using millipore filters. Deap Sea Reseach 10:634–642.

Baumann R. H., J. W. Day, and C. Miller. 1984. Mississippi deltaic wetland survival: Sedimentation versus coastal submergence. Science 224:1093–1095.

Baumann, R. 1987. Physical variables. p. 8–17 In: W. Conner and J. Day eds.) The Ecology of the Barataria Basin, Louisiana: An Estuarine Profile. U.S. Fish and Wildlife Service Biological Report 85(7.13).

Boumans, R. and J. Day. 1990. Short-Term sedimentation and water materials flux. p. 384–407. In: Cahoon, D. and C. Groat (eds.) A study of marsh management practice in coastal Louisiana, Volume III, Ecological Evaluation. Final Report submitted to the

Minerals Management Service, New Orleans, LA, USA. Contract No. 14-12-001-30410. OCS Study/MMS 90-0075.
Cahoon, D. 1990. Soil accretion in managed and unmanaged marshes p. 409–428 In: Cahoon, D. and C. Groat (eds.) A study of marsh management practice in coastal Louisiana, Volume III, Ecological Evaluation. Final Report submitted to the Minerals Management Service, New Orleans, LA, USA. Contract No. 14-12-001-30410. OCS Study/MMS 90-0075.
Cahoon, D. and C. Groat (eds.). 1990. A study of marsh management practice in coastal Louisiana, Volume III, Ecological Evaluation. Final Report submitted to the Minerals Management Service, New Orleans, LA, USA Contract No. 14-12-001-30410. OCS Study/MMS 90-0075.
Cahoon, D., D. Reed, J. Day, R. Boumans, J. Lynch, D. McNally, and N. Latif. 1994. The influence of hurricane Andrew on sediment distribution in Louisiana Coastal marshes. Journal of Coastal Research (in press).
Childers, D. and J. Day. 1990a. Marsh-water column interactions in two Louisiana estuaries. I. Sediment dynamics. Estuaries 13: 393–403.
Childers, D. and J. Day. 1990b. Marsh-water column interactions in two Louisiana estuaries. II. Nutrient dynamics. Estuaries 13: 404–417.
Clark, D and R. Hartman. 1990. Engineering and construction techniques of marsh management structures. p. 87–163. In: Cahoon, D. and C. Groat (eds.) A study of marsh management practice in coastal Louisiana, Volume III, Ecological Evaluation. Final Report submitted to the Minerals Management Service, New Orleans, LA, USA. Contract No. 14-12-001-30410. OCS Study/MMS 90-0075.
Conner, W., J. W. Day, R. Baumann, and J. Randall. 1989. Influence of hurricanes on coastal ecosystems along the northern Gulf of Mexico. Wetlands Ecology and Management 1:45–56.
Cowan, J., R. Turner, and, D. Cahoon. 1988. Marsh management plans in practice: Do they work. Environmental Management 12: 37–53.
Dame, R., T. Chrzanowski, K. Bildstein, B. Kjerfve, H. McKellar, D. Nelson, J. Spurrier, S. Stancyk, H. Stevenson, J. Vernberg, and R. Zingmark. 1986. The outwelling hypothesis and North Inlet, South Carolina Marine Ecological Progam Service 33:217–229.
Day, J. and P. Templet. 1989. Consequences of sea level rise: Implications from the Mississippi delta. Coastal Management 17: 241–257.
Day, J., C. Hall, M. Kemp, and A. Yáñez. 1989. Estuarine Ecology. Wiley Interscience, NY, USA.
Day, R., R. Holz and J. Day. 1990. An inventory of wetland impoundments in the coastal zone of Louisiana, USA: Historical trends. Environmental Management 14:229–240.
Environmental Protection Agency. 1979. Methods for chemical analysis of water and wastes. Methods Develop. Qual. Assurance Res. Lab. NERC EPA-62516-741003.
Flynn, K. M., B. J. Wilsey, and I. A. Mendelssohn. 1990. Vegetation and soil responses to marsh management. p. 440–482. In: Cahoon, D. and C. Groat (eds.) A study of marsh management practice in coastal Louisiana, Volume III, Ecological Evaluation. Final Report submitted to the Minerals Management Service, New Orleans, LA, USA. Contract No. 14-12-001-30410. OCS Study/ MMS 90-0075.
Gagliano, S. and K. Wicker. 1989. Processes of wetland erosion in the Mississippi river deltaic plain. p. 378–401. In W. D. Duffy and D. Clark (eds.) Marsh management in coastal Louisiana: Effects and Issues, Proceedings of a Symposium. U.S. Fish and Wildlife Service and The Louisiana Department of Natural Rescources. New Orleans, LA, USA.
Gardner, L. R. and W. Kitchens. 1977. Sediment and chemical exchanges between saltmarshes and coastal waters. p. 191–207. In: B. Kjerve (ed.) Transport processes in estuarine environments. Belle W. Baruch Library in Marine Science, University of South Carolina Press, Columbia, SC, USA.
Herke, W., E. Knudsen, P. Knudsen and B. Rogers. 1992. Effect of semi-impoundment on fish and crustacean nursery use and export. North American Journal of Fisheries Management 12: 151–160.
Kjerfve, B. and J. Proehl. 1979. Velocity variability in a cross-section of a well-mixed estuary. Journal of Marine Research 37: 409–418.
Kjerfve, B. and H. N. McKellar. 1980. Time series measurements of estuarine material fluxes. p. 341–357. In: V. S. Kennedy (ed.) Estuarine Perspectives. Academic Press, New York, NY, USA.
Meeder, J. 1987. Variable effects of hurricanes on the coast and adjacent marshes: A problem for marsh managers. p. 337–374. In: N. V. Brodtmann (ed.) Proceedings of the Fourth Water Quality and Wetlands Management Conference, New Orleans, LA, USA.
Nixon S. W. 1980. Between coastal marshes and coastal waters: A review of 20 years of speculation and research on the role of saltmarshes. p. 437–525. In: P. Hamilton and K.S. MacDonald (eds.) Estuarine and wetland processes. Plenum Press, New York, NY, USA.
Nyman, J. A., R. D. DeLaune, and W. H. Patrick Jr. 1990. Wetland soil formation in the rapidly subsiding Mississippi River Deltaic plain: mineral and organic matter relationships. Estuarine, Coastal and Shelf Science 31:57–69.
Odum E. P. and A. A. de la Cruz. 1967. Particulate organic detritus in a Georgia saltmarsh-estuarine ecosystem. p. 383–388. In: G. H. Lauff (ed.) Estuaries. The American Association for Advanced Scientific Publication 83:383–388. Washington, DC, USA.
Odum, W. E., J. S. Fisher, and J. C. Pickral. 1979. Factors controlling the flux of POC from estuarine wetlands. p. 69–80 In: R. J. Livingston (ed.) Ecological processes in coastal and marine systems. Plenum Press, New York, NY, USA.
Reed, D. J. 1989. Patterns of sediment deposition in subsiding coastal salt marshes, Terrebonne Bay, Louisiana: The role of winter storms. Estuaries 12:222–227.
Reed, D. J. 1992. Effect of weirs on sediment deposition in Louisiana coastal marshes. Environmental Management 16:55–65.
Rejmanek, M., C. Sasser, and G. Peterson. 1988. Hurricane-induced sediment depostion in a Gulf coast marsh. Estuarine, Coastal and Shelf Science 27:217–222.
Rogers, D., B. Rogers, and W. Herke. 1992. Effects of a marsh management plan on fishery communities in coastal Louisiana. Wetlands 12:53–62.
Settlemyre, J. L. and L. R. Gardner. 1975. Low-tide erosion in a salt marsh. Southeast Geology 16:205–212.
Soil Survey Staff. 1972. Soil survey laboratory methods and procedures for collecting soil samples. Soil Survey Investigations Report No. 1. USDA-SCS, Washington, DC, USA.
Spurrier, J. D. and B. Kjerfve. 1988. Estimating the net flux of nutrients between a salt marsh and a tidal creek. Estuaries 11:10–14.
Stern, M. K., J. W. Day, and K. G. Teague. 1986. Seasonality of materials transport through a coastal freshwater marsh: Riverine versus tidal forcing. Estuaries 9:301–308.
Stern, M. K., J. W. Day, and K. G. Teague. 1991. Nutrient transport in a riverine-influenced, tidal freshwater bayou in Louisiana. Estuaries 14:382–394.
Stevenson, J. C., L. G. Ward, and M. S. Kearney. 1988. Sediment transport and trapping in marsh systems: Implications of tidal flux studies. Marine Geology 80:37–59.
Stumpf, R. P. 1983. The process of sedimentation on the surface of a saltmarsh. Estuarine Coastal and Shelf Science 17:495–508.
Ward, L. G. 1981. Suspended-material transport in marsh tidal channels, Kiawah Island, South Carolina. Marine Geology 40: 139–154.
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 4:17–26.
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 22:833–838.

Manuscript recieved 31 August 1993; revision recieved 7 March 1994; accepted 5 May 1994.