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RECENT ACCRETION IN TWO MANAGED MARSH IMPOUNDMENTS IN COASTAL LOUISIANA[1]

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Abstract. Recent accretion was measured by the feldspar marker horizon method in two gravity-drained, managed, marsh impoundments and unmanaged reference marshes located on the rapidly subsiding coast of Louisiana. Water level management was designed to limit hydrologic exchange to the managed marsh by regulating the direction and rate of water flows. During a drawdown–flooding water management cycle, the unmanaged reference marshes had significantly higher vertical accretion rates, higher soil bulk density and soil mineral matter content, lower soil organic matter content, and higher rates of organic matter accumulation than the managed marsh. The rate of mineral matter accumulation was higher in both reference marshes, but was significantly higher in only one. Spatial variability in accumulation rates was low when analyzed in one managed marsh site, suggesting a primarily autochthonous source of matter. In contrast, the associated reference marsh apparently received allochthonous material that settled out in a distinct spatial pattern as water velocity decreased. The impoundment marshes experienced an accretion deficit of one full order of magnitude (0.1 vs. 1.0 cm/yr) based on comparison of accretion and sea level rise data, while the unmanaged reference marshes experienced a five-fold smaller deficit or no deficit. These data suggest that the gravity-drained impoundments likely have a shorter life expectancy than the reference marshes in the rapidly subsiding Louisiana coast.

Key words: accretion; accretion deficit; Louisiana; managed impoundment; organic matter accumulation; sea level rise; Spartina patens; *subsidence.*

INTRODUCTION

The extensive coastal marshes in Louisiana (2.7×10^6 ha, Field et al. 1991) are undergoing widespread deterioration (Gagliano et al. 1981, Turner and Cahoon 1987, Britsch and Kemp 1990) due in large part to an accretionary imbalance caused by high rates of subsidence-induced sea-level rise (often $\geq$1.0 cm/yr, Penland and Ramsey 1990), and insufficient accretion rates (DeLaune et al. 1983). The consequence of this accretionary imbalance is increasing submergence of the coastal marshes and intrusion of saltwater into low-salinity and fresh marshes. Submergence and saltwater effects result in lowered plant productivity in several different marsh types (Pezeshki et al. 1987, McKee and Mendelssohn 1989, Reed and Cahoon 1992), which can only exacerbate the accretionary imbalance in these marshes.

Louisiana coastal marshes are also being directly converted to other habitats by the dredging of drainage, navigation, and oil–gas access canals. Dredging of canals to access oil and gas drilling sites in coastal wetlands of Louisiana began in the early part of this century (Cahoon and Holmes 1989). Major navigation channels were dredged to support both onshore and offshore oil and gas exploration operations as well as shipping activities. By the 1960s, there were ≈7350 km of canals in coastal Louisiana (Barrett 1970). By the 1980s, there were 78 000 ha of canals (Lindstedt and Nunn 1985) with the total area of canals and spoil banks (accumulations of dredged material) approximately equal to the area of the natural drainage system (Turner 1985). This extensive and ever-growing network of canals with associated spoil banks is thought to contribute to the accretionary imbalance (Cahoon and Turner 1989) by altering the rate and direction of hydrologic couplings (Swenson and Turner 1987), resulting in saltwater–freshwater imbalances, prolonged flooding and drying of marsh soils, and altered tidal amplitudes and sediment distribution patterns.

Manipulated impoundments were constructed in Louisiana coastal marshes beginning in 1954 (Chabreck 1960, 1962) in an attempt to mitigate some of the hydrologic impacts related to canals, such as increased tidal amplitude and freshwater–saltwater imbalances. Traditionally, the purpose of marsh impoundments has been to reduce the degree of hydrologic coupling in wetlands altered by canals (i.e., manage water levels and control the spread of saltwater) so as to improve marsh habitat for use by waterfowl and wildlife. Today, impoundment management is often used to manipulate water levels seasonally (e.g., draw down water levels in the spring and maintain high water levels in the fall). This form of active water management has become increasingly popular in coastal

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Louisiana, with ≈70% of all new water control structures authorized by government permits during the late 1980s designed to manipulate water levels seasonally (Cahoon et al. 1990). As of 1985, Day et al. (1990) estimated that 25 279 ha of privately owned coastal marsh in Louisiana were impounded under government-authorized marsh management plans, and 37 218 ha of publicly owned coastal marsh were impounded for wildlife management. An additional 51 429 ha of privately owned coastal marsh were impounded without a marsh management plan (i.e., either implemented prior to or exempt from government regulation).

Strict regulation of water exchange is required to reduce the degree of hydrologic coupling in wetlands altered by canals. Hence, impoundment management requires the creation and maintenance of (1) a continuous barrier to surface water exchange around the entire perimeter of the marsh, usually achieved by use of existing spoil banks and natural ridges, or new levee construction; and (2) water control structures in connecting waterways designed to regulate (i.e., most often restrict and sometimes eliminate) channel water flows, particularly inflows. The structures are usually adjustable with flap-gates and stoplogs that can be used to regulate water levels by manipulating the direction and rate of water flows (Clark and Hartman 1990). The water management schedules of these impoundments are usually based on the life cycle requirements of the biota targeted for management (e.g., waterfowl or furbearers). Hence, scheduled water inflows often do not coincide with the times of peak availability of sediment and opportunity for sediment deposition (Cahoon 1991). For example, water is usually not allowed to enter the impoundment during a drawdown, but drawdowns are conducted in the spring when suspended sediment concentrations are high during annual river flooding. Therefore, managed impoundments have the potential to substantially reduce sediment deposition on the marsh surface and to contribute to the accretionary imbalance in this rapidly subsiding coastal environment (Cahoon and Day, *in press*).

The influence of impoundment management on sediment deposition has not been investigated in the rapidly subsiding marshes of coastal Louisiana. Some recent investigations suggest, however, that impoundments may result in lower marsh accretion rates. Cahoon and Turner (1989) reported that two hydrologically restricted brackish marshes influenced by a major levee system in southwestern Louisiana had significantly lower accretion rates than an adjacent marsh with direct hydrologic exchange. Taylor (1988) reported that fresh marsh sites in southeastern Louisiana with open access to natural waterways experienced significantly greater accretion rates than marsh sites behind a spoil bank. Reed (1992) reported that sediment deposition was lower behind fixed-crest weirs (without surrounding levees) than at reference sites outside the weirs in selected fresh, brackish, and saline marshes in south-central Louisiana. In the Pacific Northwest, Thom (1992) reported a threefold lower accretion rate in a diked marsh compared to an adjacent open marsh.

The objective of this study was to measure recent accumulation of matter on the marsh surface in two managed and nearby unmanaged reference marshes of the rapidly subsiding Louisiana coast. This study was part of a larger investigation of marsh water level management effects on several ecological processes in marshes, e.g., hydrology, flux of matter, primary productivity, soils, and fisheries utilization (Cahoon and Groat 1990).

Study Sites

Two managed impoundments, one each in the deltaic and chenier plains of coastal Louisiana (Fig. 1), were selected for study in consultation with a steering committee of regulatory agency personnel, landowners, marsh managers, and university scientists. Both sites are considered prime examples of structural marsh management using adjustable water control structures to manipulate water levels in the marsh. The Fina LaTerre mitigation bank site is located between Bayou du Large and Marmande Ridge on the Mississippi River Deltaic Plain, ≈40 km from the coast. The marsh is dominated by fresh and brackish vegetation types. On the Chenier Plain, Rockefeller State Wildlife Refuge and Game Preserve, Unit 4 encompasses marsh dominated by brackish and intermediate vegetation types and is located 4.5 km from the shore of the Gulf of Mexico. The borders of each impoundment consist, at least in part, of navigation canals and associated spoil banks. Unmanaged reference sites were chosen for comparison to the managed impoundments based on similarities in size, marsh type, degree and type of hydrologic alteration, and proximity. Detailed descriptions of the locations and habitats of both sites are provided in Cahoon (1990).

Drawdown technique and structure operation schedule

Active manipulation of water levels in impounded marshes occurs in two phases, drawdown and flood. In general, drawdowns are implemented in the spring to encourage the germination and growth of plant species required as food or habitat for waterfowl and furbearer species. A drawdown is achieved with a variable-crest flap-gated structure located on the south side of the impoundment where winter storms (i.e., cold-fronts) blowing from the north can push water out through the structure. During drawdown, the flap-gate on the outside of the water control structure is positioned to flap outward only. Hence, water can leave the impoundment when the water level outside is lower than the water level inside, but water cannot enter the impoundment when the gate is in this position. The flood stage is implemented in the fall and early winter

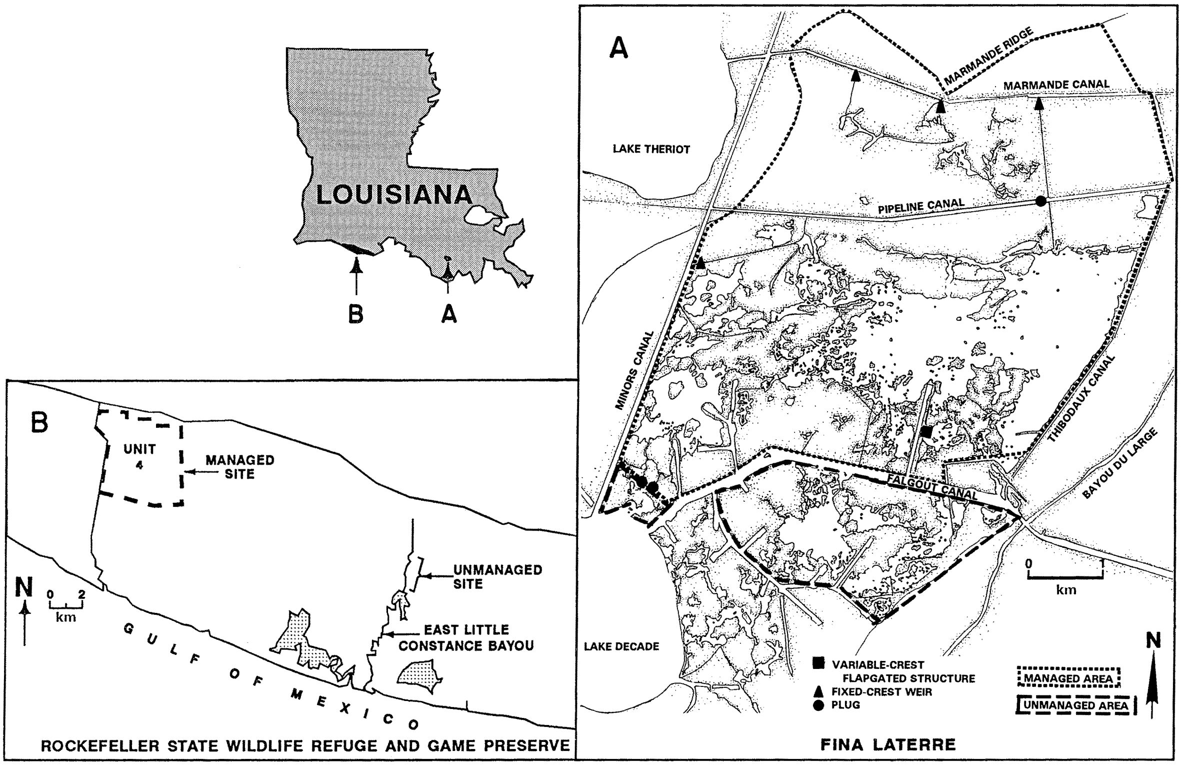

FIG. 1. Location map of study sites. The map of Fina LaTerre was adapted from Rogers et al. (1992).

to provide openwater habitat for waterfowl. Flood phase is implemented by placing stoplogs in the control structure and raising all the flap-gates. Stoplogs are usually set at or 15 cm below marsh surface elevation. The structure functions like a fixed-crest weir during this phase. A detailed description of two-phase water management as implemented in coastal Louisiana is provided in Clark and Hartman (1990).

Management was initiated at Fina LaTerre in 1985 and at Rockefeller Refuge in 1958. A two-phase water management scheme (drawdown–flood) was implemented at both sites from February 1989 to February 1990. This water management scheme was implemented at Fina LaTerre every year beginning in 1985 but only every third or fourth year at Rockefeller Refuge.

Fina LaTerre (deltaic plain).—Water level drawdown was achieved by a single variable-crest flap-gated structure (with two gates) located on the southern boundary of the impoundment (Fig. 1). Drawdown commenced in mid-February 1989 and continued until mid-July. During the drawdown phase all stoplogs were removed (sill level was 61 cm below the marsh surface) and the gates were in the down position and flapping out. The flooding phase was begun in mid-July by placing stoplogs in the structure to a level 15 cm below the marsh surface with the gates in the up position. With one exception, the structure was operated in this fashion until the next drawdown began in February 1990. In October, a hurricance entered the Gulf of Mexico. The gates were set in the down position during this storm event to prevent intrusion of saltwater. After the storm passed, the gates were returned to the up position. The water management plan incorporated into its drawdown-flooding regime a flow-through design for the purpose of enhancing the exchange of freshwater and sediment in the managed marsh. The design included four fixed-crest weirs located on the northern boundary (Fig. 1) to allow the inflow of freshwater and sediment, with water leaving the impoundment via the single variable-crest flap-gated structure on the southern boundary.

Rockefeller Refuge (chenier plain).—Water level drawdown was achieved by two variable-crest flap-gated structures, one located in the southeast corner of the impoundment (with four gates), the other located in the southwest corner (with seven gates). Drawdown was implemented from mid-February 1989 through mid-June with stoplogs set at 46 cm below the marsh surface and gates in the down position and flapping out. Exceptions to this operation schedule were made to allow post-larval shrimp into the management area. Some gates were opened on 17–18 May, 22–26 May, 2 June, and 15–19 June. From mid-June to early July, all gates were opened, with stoplogs set at 46 cm below marsh surface to allow fresh to low-salinity water into the impoundment. From early July to mid-February 1990, the stoplogs were set at 15 cm below marsh surface with the gates down and flapping out for the flooding phase of the annual water-level cycle. Hence, water inflows into the impoundment (other than precipitation) were limited to a short time span in late spring and early summer.

Experimental design

Field plots were established and data collected within managed marsh impoundments and nearby unmanaged marsh from February 1989 to February 1990. All plots were located in marsh areas dominated by *Spartina patens*. Slightly different experimental designs were employed at the two sites because of differences in the environmental setting (see Cahoon 1990). Both areas underwent a drawdown in the spring of 1989.

Fina LaTerre site.—A distinct vegetation gradient exists within the 2800-ha impoundment at Fina LaTerre: a mixture of freshwater plant species in the northern portion, and brackish water species, mainly *Spartina patens,* in the southern portion. Due to the logistical constraints of sampling four marsh areas (managed, unmanaged, fresh, and brackish) totalling over 4000 ha in size, the field effort was implemented in only the southern portion of the impoundment, i.e., in the managed marsh area closest to the influence of the drawdown water control structure. A *Spartina patens*-dominated brackish marsh in the southern portion of the managed area was selected for comparison to a *Spartina patens*-dominated brackish marsh area located immediately adjacent to the impoundment to the south. The two areas were once part of an unbroken expanse of marsh, but are now separated by Falgout Canal, a navigation channel that runs east–west through the area. The spoil bank on the north side of Falgout Canal (the southern boundary of the impoundment) was built up during construction of the impoundment. The spoil bank on the south side of Falgout Canal (the northern boundary of the reference site) had subsided and was in disrepair with several openings into the marsh.

Thirty-two sampling plots were established in marsh dominated by *Spartina patens* in four groups of eight. Two groups were located in the managed marsh; one group was located near the variable-crest flap-gated structure and the other 1–2 km away. Similarly, two groups of plots were located in the unmanaged area, one near the main point of water exchange through a cluster of openings in the subsided spoil bank (on the southern bank of Falgout Canal, southwest of the variable-crest flap-gated structure [Fig. 1]) and the other 1–2 km away. The locations of field plots within each group were selected randomly from a 500 × 500 m grid. The grids were located in marsh areas dominated by *Spartina patens* with a similar history of management (i.e., areas that had not been burned since water-level management was implemented [at least 4 yr]). All field plots were established 5 m in from the water's edge.

Rockefeller Refuge site.—The managed and unmanaged sites were selected for uniformity of dominant vegetation type (e.g., *Spartina patens*), distance from the coast, presence or absence of burning of the vegetation, and a direct hydrologic connection to the Gulf of Mexico. Unit 4, the 2400-ha managed site, included areas of unburned and recently burned vegetation. Because structural management of wetlands was prevalent throughout much of the refuge, the nearest unmanaged area of *Spartina patens*-dominated marsh located on the refuge and a similar distance from the coast was located 14 km east of Unit 4 at East Little Constance Bayou. Marsh on one side of the bayou had been burned 2 mo before the investigation began. Canal and levee density were lower in the unmanaged than in the managed area.

Forty sampling plots were established in the refuge, 20 each in the managed (Unit 4) and unmanaged (East Little Constance Bayou) areas. 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 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 freshwater, 5 burned and 5 unburned, and 10 plots were located farther downstream immediately north of the juncture with East Constance Lake, 5 burned and 5 unburned. The locations of 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, and 15–100 m from the edge of the bayou. 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.

Methods

A feldspar marker horizon was established at each of the plots in late January or early February 1989. Feldspar was laid in an even layer between the clumps of *Spartina patens* stems covering a 50 × 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 mo after establishment of the marker horizon, in August 1989 and February 1990. The 0–6 mo interval corresponded to the drawdown phase (February to June/July), and the 6–12 mo interval corresponded to the flooding phase

TABLE 1. Accumulation of organic and mineral matter in the soil at Fina LaTerre (means ± 1 SE).

Main effect	n	Vertical accretion (cm/–)‡		Bulk density (g/cm^3)		Organic/mineral content (%)		Accumulation (g·cm^{-2}·–$^{-1}$)§ Organic		Accumulation (g·cm^{-2}·–$^{-1}$)§ Mineral
Treatment										
Unmanaged	31‖	0.30 ± 0.09	*	0.13 ± 0.01	**	52/48 ± 4	**	0.015 ± 0.004	*	0.0337 ± 0.0178
Managed	31‖	0.07 ± 0.01		0.06 ± 0.004		75/25 ± 2		0.002 ± 0.0006		0.0008 ± 0.0002
Time										
6 mo	32	0.08 ± 0.04	**	0.11 ± 0.01	**	64/36 ± 4		0.004 ± 0.002	**	0.0082 ± 0.0069
12 mo	30‖	0.30 ± 0.08		0.08 ± 0.01		64/36 ± 4		0.013 ± 0.004		0.0269 ± 0.0172
Distance										
Near	31‖	0.28 ± 0.09	†	0.10 ± 0.01		59/41 ± 4		0.013 ± 0.004	†	0.0318 ± 0.0178
Far	31‖	0.09 ± 0.02		0.08 ± 0.01		68/32 ± 3		0.004 ± 0.001		0.0026 ± 0.0012

For each main effect, the means for the indicated variable are significantly different at the: * = .05, ** = .01, or † = .10 levels.
‡ Vertical accretion units are cm/0.5 yr for 6-mo samples and cm/yr for 12-mo samples.
§ Accumulation rates are g·cm^{-2}·(0.5 yr)$^{-1}$ for 6-mo samples and g·cm^{-2}·yr^{-1} for 12-mo samples.
‖ n = 32 for bulk density and percent organic/mineral matter.

(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). At 6 and 12 mo after marking, I collected a single core 5–10 cm long from each marker plot using a thin-walled aluminum core tube (6 cm in diameter) to determine the depth of the feldspar marker. Cores were taken from previously unsampled areas of the plot until the marker horizon was visible in the core hole. 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 from cores collected in the immediate vicinity of the marker horizon plots and at the same time as the accretion cores. Separate bulk density cores were collected away from the feldspar horizons because of the potential for the feldspar to contaminate the soil overlying the horizon. The percentage mineral and organic matter content of the bulk density cores was determined by loss to ignition at 375°C after 16 h (Cahoon and Turner 1989). The rate of accumulation of organic and mineral matter was calculated by multiplying the rate of vertical accretion by the soil bulk density and the percentage soil organic/mineral content.

SAS GLM statistical programs (SAS 1985) were used to conduct analysis of variance and tested at the 5% level. When interactions were significant, pairwise comparisons of means were made using SAS least squares means.

RESULTS

Fina LaTerre

Analysis of the main treatment effect (i.e., managed vs. unmanaged), averaged over time and distance to the point of water exchange, revealed that during a drawdown–flooding water management cycle, the sampled areas in 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 (percent dry mass), lower soil organic matter content (percent dry mass), and higher rate of organic matter accumulation than the sampled areas in the southern portion of the managed marsh (Table 1). The rate of mineral matter accumulation was considerably higher in the unmanaged marsh but the difference was not significant. The main effect of time of sampling was also significant, with higher accretion and organic matter accumulation rates measured after the 12 mo vs. 6 mo interval. Distance from the source of water had a significant effect (10% level) on the accretion and accumulation of matter, with marsh plots located near the source of water having higher rates than those farther away. Examination of the interaction terms of the main effects revealed significant responses for both vertical accretion and organic matter accumulation.

Vertical accretion.—Sampling time had a significant effect on vertical accretion (Table 1) due primarily to a significant increase (P = .004) in accretion from 6 to 12 mo in the unmanaged area (Fig. 2). Accretion increased between samplings in the managed area as well, but the increase was lower and not significant. Vertical accretion was twice as great in the unmanaged areas as in the managed areas after 6 mo (the drawdown phase), but the difference was not significant. However, there was a significant difference after 12 mo (the drawdown + flooding phase), indicating that vertical accretion in the managed marsh did not keep pace with vertical accretion in the unmanaged marsh, particularly during the flooding phase.

The effect of distance on accretion (Table 1) was due to a decrease (P = .0556) in accretion in the unmanaged area as distance from the source of water increased (Fig. 3). There was no effect of distance in the managed

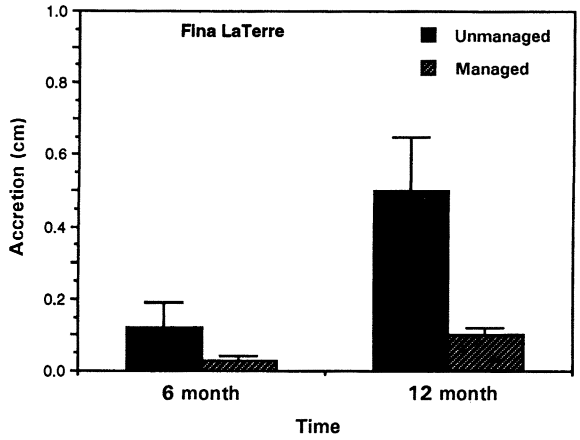

FIG. 2. Rates of vertical accretion after 6 mo and after 12 mo in managed and unmanaged marshes at Fina LaTerre (means and 1 SE).

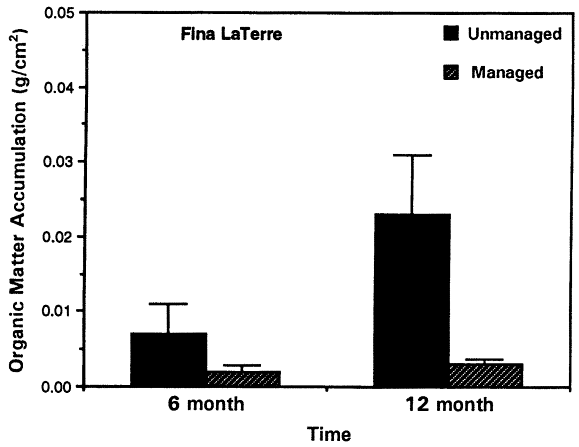

FIG. 4. Rate of organic matter accumulation after 6 mo and after 12 mo in managed and unmanaged marshes at Fina LaTerre (means and 1 SE).

area. Accretion was the same in both the managed and unmanaged areas far from the source of water.

Organic matter accumulation.—Organic accumulation increased between samplings in the unmanaged area (P = .002), but not in the managed area (Fig. 4). Like the variable accretion, organic accumulation was twice as great in the unmanaged areas as in the managed areas after 6 mo (the drawdown phase), but the difference was not significant (Fig. 4). However, there was a significant difference after 12 mo (the drawdown + flooding phase), indicating that organic accumulation in the managed marsh did not keep pace with organic accumulation in the unmanaged marsh, particularly during the flooding phase.

Organic accumulation decreased as distance increased in the unmanaged marsh (P = .04), but not in the managed marsh (Fig. 5), 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 (P = .047) but not at the far locations, so that after 12 mo the accumulation at the near sites was greater than that at the far sites (Fig. 6). The three-way interaction was nearly significant (P = .0548, analysis by least squares means revealed significant differences), suggesting that organic accumulation rates (1) were greater at near vs. far sites in the unmanaged marsh but not in the managed marsh, and (2) increased between samplings in the near unmanaged marsh but not in the far unmanaged marsh, while both the near and far sites in the managed marsh did not differ between samplings (Fig. 7).

These data indicate that organic matter accumulation (1) was higher in the unmanaged area, (2) occurred mostly near the source of water exchange in the unmanaged area, and (3) increased between samplings in

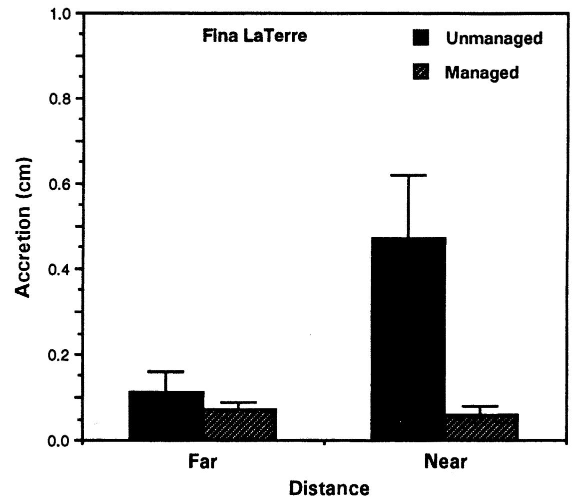

FIG. 3. Rates of accretion near and far from the source of water exchange in managed and unmanaged marshes at Fina LaTerre (means and 1 SE).

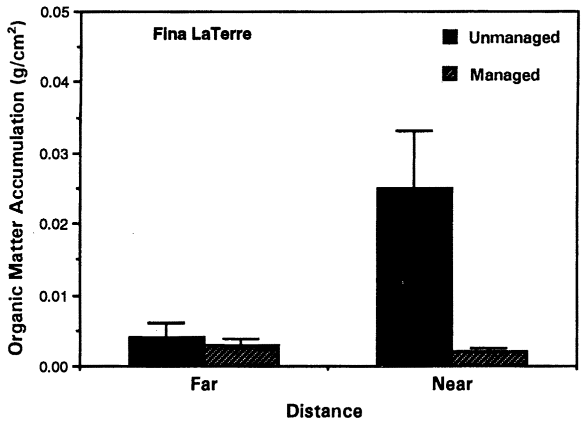

FIG. 5. Rate of organic matter accumulation near and far from the source of water exchange in managed and unmanaged marshes at Fina LaTerre (means and 1 SE).

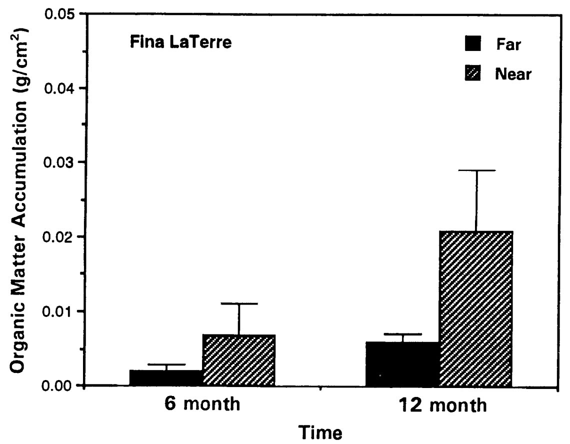

FIG. 6. Rate of organic matter accumulation after 6 mo and after 12 mo near and far from the source of water exchange at Fina LaTerre (means and 1 SE).

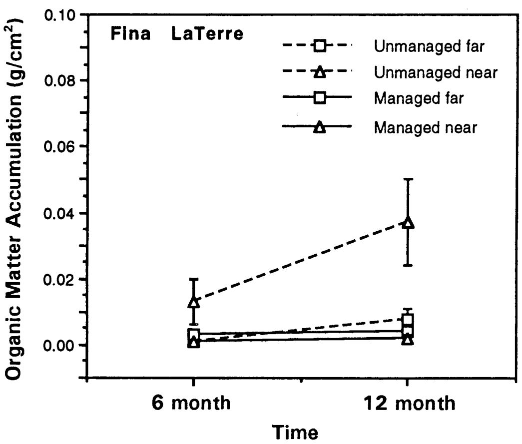

FIG. 7. Rate of organic matter accumulation after 6 mo and after 12 mo in unmanaged marsh near and far locations and managed marsh near and far locations at Fina LaTerre (means ± 1 SE).

the unmanaged area. By contrast, accumulation of organic matter was low in the managed marsh during the entire year at both near and far sampling areas.

Mineral matter accumulation.—The accumulation of mineral matter was low at both near and far sampling areas in the managed marsh (0.0008 ± 0.0003 g/cm^2, near sites; 0.0008 ± 0.0002 g/cm^2, far sites). In the unmanaged marsh, the average mineral accumulation was greater near the source of water exchange (0.061 ± 0.033 g/cm^2) than farther away (0.005 ± 0.003 g/cm^2), but the differences in mineral accumulation between near and far sites in the unmanaged marsh, and between managed and unmanaged marsh sites, were not significant.

Rockefeller Refuge

Analysis of the main treatment effect (i.e., managed vs. unmanaged), when averaged over time and burning, revealed that during a drawdown–flooding water management cycle, the sampled areas in the unmanaged marsh near East Little Constance Bayou had a significantly higher vertical accretion rate, higher soil bulk density and soil mineral matter content (percent dry mass), lower soil organic matter content (percent dry mass), and higher rate of organic and mineral matter accumulation than the sampled areas in the managed marsh (Table 2). The main effect of sampling time was also significant, with lower soil bulk density and higher soil organic matter content measured after the 12-mo vs. the 6-mo interval. Examination of the interaction terms of the main effects revealed significant responses for both vertical accretion and organic matter accumulation.

Vertical accretion.—Vertical accretion increased significantly (P = .02) between samplings at the unman-

TABLE 2. Accumulation of organic and mineral matter in the soil at Rockefeller Refuge (means ± 1 SE).

Main effect	n	Vertical accretion (cm/–)‡	Bulk density (g/cm^3)	Organic/mineral content (%)	Accumulation (g·cm^{-2}·–)§ Organic	Mineral
Treatment						
Unmanaged	40	0.98 ± 0.11 **	0.27 ± 0.01 **	26/74 ± 1 **	0.067 ± 0.010 **	0.202 ± 0.027 **
Managed	36‖	0.12 ± 0.04	0.14 ± 0.01	59/41 ± 3	0.002 ± 0.0006	0.009 ± 0.004
Time						
6 mo	37‖	0.53 ± 0.11	0.23 ± 0.02 **	39/61 ± 2 *	0.046 ± 0.012	0.105 ± 0.027
12 mo	39‖	0.61 ± 0.12	0.18 ± 0.01	45/55 ± 4	0.034 ± 0.007	0.115 ± 0.025
Burn						
Burned	38‖	0.67 ± 0.14	0.21 ± 0.02	40/60 ± 3	0.048 ± 0.012	0.127 ± 0.031
Unburned	38‖	0.47 ± 0.08	0.20 ± 0.01	45/55 ± 4	0.031 ± 0.005	0.093 ± 0.020

For each main effect, the means for the indicated variable are significantly different at the: * = .05, ** = .01, or † = .10 levels.

‡ Vertical accretion units are cm/0.5 yr for 6-mo samples and cm/yr for 12-mo samples.

§ Accumulation rates are g·cm^{-2}·(0.5 yr)$^{-1}$ for 6-mo samples and g·cm^{-2}·yr^{-1} for 12-mo samples.

‖ n = 40 for bulk density and percent organic/mineral matter.

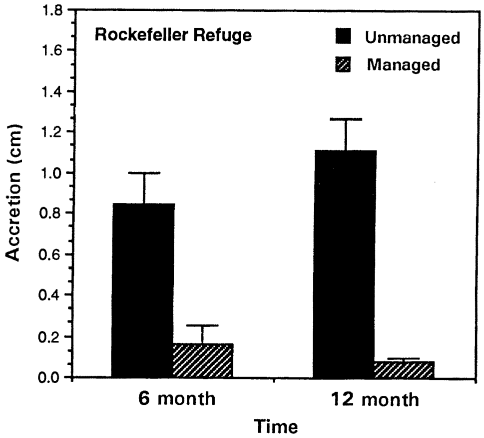

FIG. 8. Rates of vertical accretion after 6 mo and after 12 mo in managed and unmanaged marshes at Rockefeller Refuge (means and 1 SE).

aged site but not at the managed site (Fig. 8). These data indicate that accretion was high and increased between samplings in the unmanaged marsh, but was low during the drawdown phase and was essentially zero during the flooding phase in the managed marsh.

Organic and mineral matter accumulation.—Organic matter accumulation was not different between samplings in burned or unburned areas of the managed marsh (Fig. 9). However, organic matter accumulation in the unmanaged marsh was higher in the burned area after 6 mo, but subsequently decreased so that it was equal with the unburned area after 12 mo ($P = .0582$). There was no significant effect of time, burning, or any of the interactions on the accumulation of mineral matter.

DISCUSSION

Accretion and sea level rise

At Fina LaTerre, the low flux rate of water and sediment through the drawdown structure on the southern boundary (Boumans and Day 1990) and the low vertical accretion measured in the southern portion of the impoundment by this study suggest that, if sediment is being introduced into the impoundment through the fixed-crest weirs on the northern boundary, the flow-through system is delivering little if any of it to the marsh surface in the southern portion. Most probably the source of accreted matter in the southern part of the impoundment is primarily autochthonous (i.e., pond bottoms, with the material being resuspended and deposited on the marsh surface during periods of high water levels) with small allochthonous inputs over the stoplogs during times of high water when the gates are up and through leaks in the drawdown structure (e.g., the flapgates occasionally get jammed partially open by debris, thereby allowing water to leak into the impoundment during a drawdown (D. R. Cahoon, *personal observation*). In contrast, the unmanaged marsh apparently receives allochthonous matter through the channel openings that settles out in a distinct spatial pattern as the water loses velocity. However, the annual accretion rate of recently deposited material in both the unmanaged marsh (0.50 ± 0.15 cm/yr; see Fig. 2) and managed marsh (0.10 ± 0.02 cm/yr) is lower than the rate of relative sea level rise measured at Houma, Louisiana, located 12 km to the north (1.09 cm/yr from 1946 to 1988; Penland and Ramsey 1990). Distance from the coast (40 km) and nearest riverine source of sediment (45 km) is the most likely explanation for why the unmanaged marshes are not receiving sufficient sediment to keep pace with sea-level rise.

The rate of recent accretion in the unmanaged marsh at Rockefeller Refuge (1.1 ± 0.16 cm/yr; see Fig. 8) is similar to recent accretion rates measured by Cahoon and Turner (1989; 1.13 ± 0.22 cm/yr), but is greater than rates measured by DeLaune et al. (1983; 0.66 ± 0.23 cm/yr) in *Spartina patens* marshes located 40 km to the west near Cameron, Louisiana. The rate of accretion at the Rockefeller Refuge unmanaged marsh is comparable to the local rate of sea level rise (1.20 cm/yr) measured at the Cameron tide gauge 48 km to the west from 1954 to 1980 (DeLaune et al. 1983). The close proximity of this marsh to the coast and its direct hydrologic connection to the Gulf of Mexico is the most likely explanation for why it is keeping pace with sea level rise. The rate of recent accretion in the managed marsh at Rockefeller Refuge (0.08 ± 0.02 cm/yr; see Fig. 6) is lower than the rate reported by Cahoon and Turner (1989) for two hydrologically restricted *S. patens* marshes near Cameron, Louisiana (0.35 ± 0.12 and 0.43 ± 0.09 cm/yr). The average annual rate of relative sea level rise greatly exceeds the annual accretion rate of recently deposited material in the managed marsh at Rockefeller Refuge during a drawdown year.

These data from both the chenier and deltaic plains indicate that both managed impoundments experi-

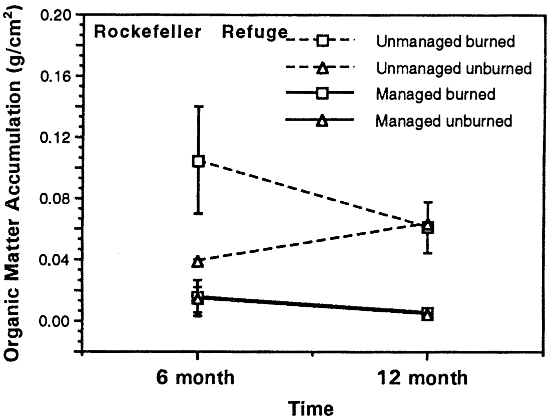

FIG. 9. Rate of organic matter accumulation after 6 mo and after 12 mo in unmanaged burned and unburned areas and in managed burned and unburned areas at Rockefeller Refuge (means ± 1 SE).

enced an accretion deficit during the 1989 drawdown–flooding water management regimen of at least one full order of magnitude (0.1 vs. 1.0 cm/yr), while the unmanaged reference sites experienced a substantially smaller deficit (Fina) or no deficit at all (Rockefeller). Data collected from Unit 4 at Rockefeller Refuge in July of the subsequent non-drawdown year (D. R. Cahoon, *unpublished data*) indicated the trend in accretion remained the same for both managed and unmanaged areas. The cumulative impact of an annual accretion deficit suggests that the marsh within these gravity-drained impoundments likely has a shorter life expectancy than the unmanaged reference marsh.

Drawdown vs. flooding effects

The adjustable water control structures were designed and operated to completely eliminate hydrologic inputs via channel flow during the spring drawdown and to reduce hydrologic exchange via channel flows during the remainder of the year whenever the stoplogs were set at or 15 cm below marsh level (Cahoon 1991). Therefore, the potential was high for both the drawdown and flooding management phases to limit the opportunity for sediment accumulation. At Rockefeller Refuge, there was a very limited opportunity for sediment input to the impoundment during either the drawdown or flooding phase. Scheduled inflows occurred only at the end of the drawdown and prior to the flooding stage to allow post-larval shrimp and freshwater into the impoundment, all of which occurred during the first sampling interval. These scheduled inflows likely account for most if not all of the accretion measured during the first 6-mo interval (Fig. 8). Indeed, Boumans and Day (1990) reported a net sediment flux out of the impoundment during two 48-h samplings in the fall of 1989. At Fina LaTerre, there was measurable accretion in the southern part of the impoundment during both the drawdown and flooding (12-mo minus 6-mo measures) phases but accretion amounts were lower than in the unmanaged marsh (Fig. 2). This result can be related to the operation of the structure. During the drawdown, the gates were down and prohibited inflow of water and sediment. During flooding, the structure functioned like a fixed-crest weir, a structure type which has been shown to significantly reduce sediment deposition in vegetated marsh in coastal Louisiana (Reed 1992). Some of the accumulated sediment may have entered over the fixed-crest weirs on the northern boundary of the impoundment.

Soil organic matter

At Fina LaTerre, the difference in soil organic matter content between managed and unmanaged sampling areas 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 lower aboveground productivity of *Spartina patens* in the more reduced soils of the managed marsh (see Flynn et al. 1990). Investigations of *Spartina alterniflora* response to flooded (i.e., reduced) soil conditions show reduced belowground biomass as well as aboveground biomass (Linthurst 1979, Mendelssohn and Seneca 1980). At Rockefeller Refuge, the greater and increasing organic matter content of the managed marsh soils may reflect slower rates of mineral accumulation and/or decomposition than in the unmanaged marsh, or a higher rate of organic matter production as measured by Flynn et al. (1990), or some combination of these. Decomposition studies need to be conducted in managed marsh soils to clarify this issue.

Interpreting management effects

Specific knowledge of soil properties and the rates of accretionary processes at the two sites prior to implementation of management is not available for comparison to the data presented in this paper. Consequently, it can be argued that the differences between managed and unmanaged areas measured in this study are not entirely the direct result of management. It is important to evaluate the probability that the managed and unmanaged areas were historically different, and if they were different, how the differences may have influenced, at least in part, recent soil measurements, e.g., soil bulk density, soil organic matter content, and vertical accretion.

Soil bulk density of the top 2 cm of soil was greater in both unmanaged marsh sites, and this likely reflects the differences in vertical accretion. The probability is low that the differences in bulk density are due to different soils present in the two areas prior to initiation of management. At Rockefeller Refuge, even a low annual accretion rate of 1–2 mm/yr would likely create >2 cm of soil during the 31 yr of management from 1958 to 1989, even considering compaction. Hence, the 2-cm-deep bulk density samples collected from Unit 4 likely consisted entirely of soil created after management was implemented. In addition, analysis of habitat type by aerial imagery at Rockefeller Refuge revealed that the brackish marsh zones existed at both the managed and unmanaged sites prior to initiation of management (Sweeney et al. 1990). At Fina LaTerre, both the managed and unmanaged areas were one contiguous expanse of fresh marsh before construction of Falgout Canal (Sweeney et al. 1990). Both areas changed from fresh marsh in 1956 to *Spartina patens*-dominated brackish marsh by the 1980s. However, if the soil type in the managed and unmanaged areas at Fina LaTerre 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.

I cannot say whether the low accretion rates measured in both impoundments are less than, greater than, or equal to rates that occurred prior to management. However, the results of this study were consistent: (1) between sites; (2) with the findings on hydrologic flux by Boumans and Day (1990) for the same two marshes; and, (3) with sediment deposition rates measured by Reed (1992) for Louisiana coastal marshes managed by weirs. Therefore, the potential is high for these impoundments to limit the opportunity for sediment accumulation.

Conclusions

During a drawdown–flooding water management cycle, annual rates of accretionary processes in two managed brackish marsh impoundments located along the rapidly subsiding Louisiana coast were lower than in unmanaged, reference, brackish marshes. It cannot be stated unequivocally that the lower accretion rates are the direct result of management. However, the data strongly suggest that water management reduced the rate of sediment deposition in the two impoundments. The managed marshes experienced a greater accretion deficit (accretion minus relative sea level rise) than the unmanaged marshes. These results strongly suggest that the managed marshes may have a shorter life expectancy than the reference marshes, in the face of rising sea levels. At Fina LaTerre, the flow-through system incorporated into the management regime apparently did little to enhance delivery of sediment to the marsh surface in the southern portion of the impoundment.

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