Limnol. Oceanogr., 28(3), 1983, 494-502

Sedimentation, accretion, and subsidence in marshes of Barataria Basin, Louisiana[1]

R. S. Hatton, R. D. DeLaune, and W. H. Patrick, Jr.
Laboratory for Wetland Soils and Sediments, Center for Wetland Resources, Louisiana State University, Baton Rouge 70803

Abstract

Vertical accretion and sediment accumulation rates were determined from the distribution of ^{137}Cs in cores collected from freshwater, intermediate, brackish, and salt marshes in the Barataria Basin, Louisiana. Vertical accretion rates vary from about 1.3 $cm \cdot yr^{-1}$ in levee areas to 0.7 in backmarshes. Mineral sediment content of the marsh soil profile decreased with distance from the coast. However, vertical accretion rates were about equivalent in areas of the same type. Autochthonous organic matter appears to be an important factor defining the process and rate of vertical accretion, especially in the freshwater marshes. Except in natural levee areas, marsh accretion rates are less than subsidence measured by water level data, however this alone cannot account for observed land-loss patterns in the basin area.

In coastal marshes the substrate surface must remain adjusted relative to mean sea level in order for plants to survive. This stable equilibrium level is maintained as a balance between the rate of vertical accretion and changes in relative sea level. Land loss and marine transgression may generally be anticipated where aggradation is less than the relative rise in sea level.

Marshes in south Louisiana span some 3.2×10^6 ha, representing 41% of all wetlands in the United States (Turner and Gosselink 1975). With rapid subsidence and accelerating land loss in the area, a critical examination of natural land-building processes is of academic, managerial, and political interest. Salt marsh accretion rates reported (DeLaune et al. 1978; Baumann 1980) indicate that accretion is less than the rise in estimated sea level (Swanson and Thurlow 1973), except in natural levee areas. This result, which is consistent with the ongoing submergence of marshlands in south Louisiana, has been attributed to a deficiency in fluvial sediment influx into many relict deltaic marshes. Accretionary processes in adjoining but physiographically distinct, brackish, intermediate, and freshwater marshes of the Mississippi River Delta have not been adequately examined: Baumann (1980) found that visual particulate tracers (white feldspar clay) were not suitable for use in these low density substrates.

We here report rates of vertical marsh accretion and sediment accumulation calculated from ^{137}Cs profiles in freshwater, intermediate, brackish, and salt marsh soils of Barataria Basin, a delta-flank depression of the Mississippi River. Accretionary variations are discussed in relation to hydrology, sedimentation, subsidence, and vegetation with a view to further elucidation of the accretionary mechanism in marshes of each type.

Physiographic setting

Because an understanding of the cyclic nature of the Mississippi River Delta sedimentation is essential to the correct interpretation of our results, we review briefly the salient features of this deltaic system with specific reference to the study area. A detailed geologic description is given by Coleman and Gagliano (1964); vegetative characteristics have been described by Bahr and Hebrard (1976).

The coastal marshlands of south Louisiana comprise a series of recognizable physiographic units, uniquely defined by depositional history, hydrology, and vegetative distribution. Mississippi fluvial deposits form an extensive, seaward-

[1] This research was supported by funds from the Office of Sea Grant (NOAA).

thickening sequence of overlapping and contemporaneous delta lobes resulting from the process of primary channel switching at intervals of about 1,000 years (Frazier 1967). Periods of seaward progradation and fluvial dominance have alternated locally with periods of land loss and marine transgression. Rapid subsidence continues as a result of the concomitant processes of crustal downwarping caused by the sediment overburden, consolidation of the sediments of the Gulf Coast geosyncline, local consolidation, and tectonic activity; regional subsidence decreases with distance inland. Rates of subsidence and shoreline alteration generally diminish with increasing age of the delta lobe.

The modern deltaic system is partitioned by active and relict distributary channels bounding the lower interdistributary wetland basins which vary in age and state of deltaic alteration. Barataria Basin (Fig. 1) is the youngest such "interfluvial" entity, bounded by the present course of the Mississippi River, and its most recently abandoned channel to the west, Bayou Lafourche. Historically, spring overbank floods have maintained a supply of fluvial sediments to the interdistributary marshes, adding nutrients and contributing structurally to their stability. But progressive channelization of the Mississippi River over the past century for flood control purposes has prematurely terminated the fluvial phase of the basin's development. Secondary landward redistribution of earlier deltaic, marine, marsh, and bay sediments by tides, waves, and wind-induced water movements has replaced fluvial sources of inorganic sediments reaching the marsh surface. Hydraulic energy now decreases with distance from the Gulf of Mexico. Hydrologic alterations such as canals are believed to be responsible for accelerating the natural process of marsh deterioration during local interfluvial periods, resulting in a net loss of land along the historically advancing Louisiana coastline.

Kolb and Van Lopik (1966) recognized three major sedimentary marsh types which are generally correlated with hydrology, salinity, and distribution of vegetation. Freshwater floating marsh (or flotant) substrates comprise an extremely fibrous mat of roots and other plant remains admixed with a fine muck 0.1–0.35 m thick and underlain by 1–5 m of organic ooze that grades with depth to steel gray clay. Brackish-intermediate marsh soils comprise a vegetative mat with muck 0.1–0.2 m thick overlying 0.3–3.1 m of fibrous peat, underlain in turn by a blue-gray clay or silty clay containing lenses rich in organic matter. Saline to brackish marshes consist of a vegetative mat and muck 0.1–0.2 m thick underlain by 0.3–3.1 m of fibrous peat on a firm, blue-gray or black, coarse, silty clay. The seaward sequence from freshwater to salt marshes is characterized by an increase in grain size.

The four principal vegetative units examined in the present study have been described in detail by Bahr and Hebrard (1976) and are represented in Fig. 1. Freshwater marshes (salinity < 1‰), which cover roughly 19% of the basin, are characterized by dense stands of *Panicum hemitomon, Eleocharis* sp. and *Sagittaria falcata.* About 20% of the basin is termed brackish to intermediate marsh: the brackish system (salinity 5–10‰) is largely vegetated by *Spartina patens* with lesser amounts of *Distichlis spicata* and occasional intrusions of *Spartina alterniflora.* This predominance of *S. patens* increases into the intermediate marsh (salinity 10–15‰) where *S. alterniflora* is totally absent. Salt marsh vegetation covers some 14% of the basin and is widely interspersed with open water bodies; *Juncus romerianus* and *D. spicata* are secondary to *S. alterniflora* which represents about 60% of cover and up to 95% locally.

Methods

Representative sites in freshwater, intermediate, brackish, and salt marshes of the basin were selected on the basis of vegetation type, soil morphology, and hydrology. Ten cores were taken at known intervals on lateral transects from the stream or lake banks at each marsh type.

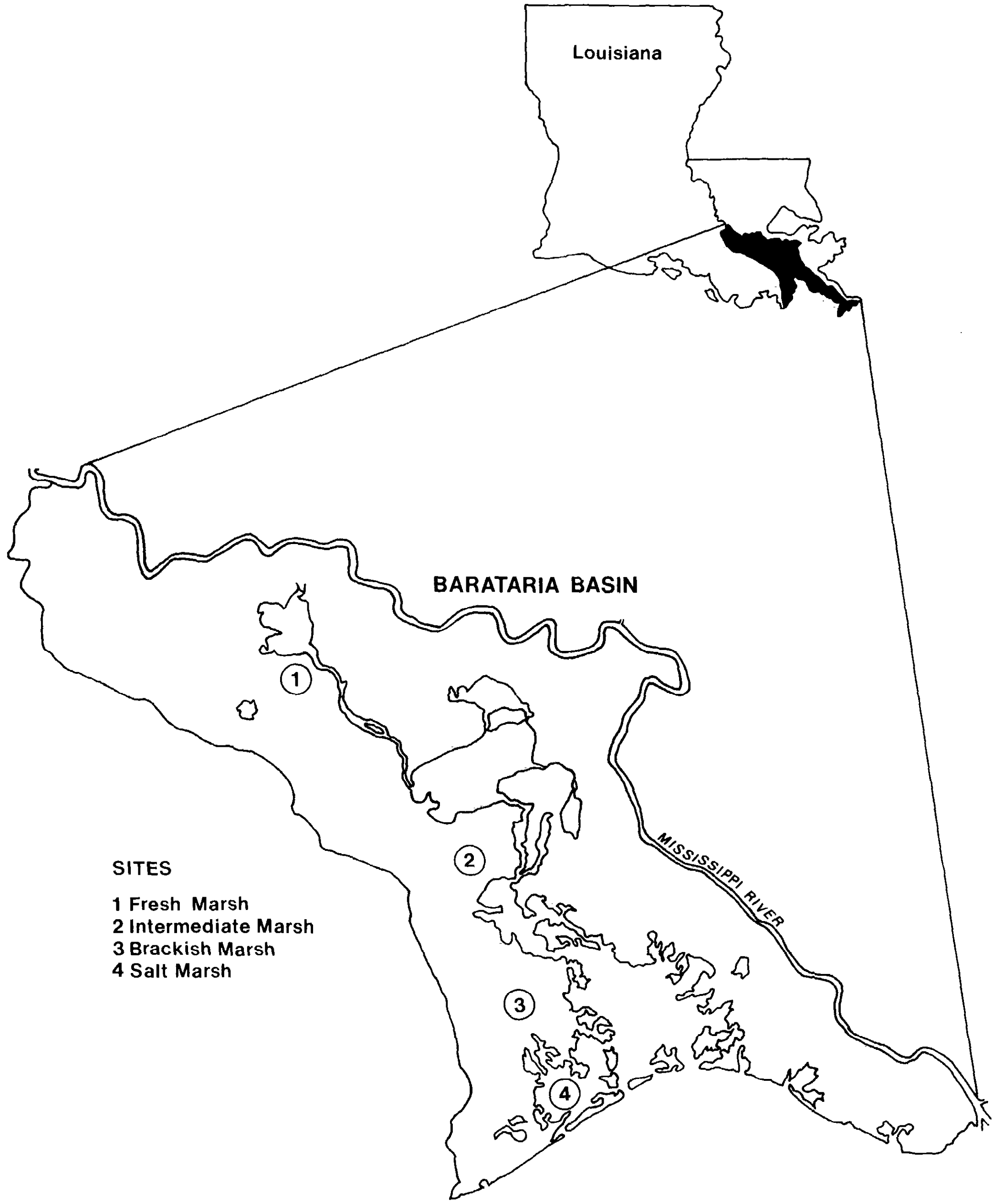

Fig. 1. Map of Barataria Basin showing delineation of marsh types (after Bahr and Hebrard 1976) and location of study sites.

Due to the exceptionally low density and high water content of these soils, special procedures were necessary to prevent compaction either through direct compression or water loss. Broad (15 cm) diameter, thin-walled (0.2 cm) aluminum coreliners with a sharpened cutting edge were carefully twisted into the substrate to a depth of 50 cm. Cores were capped in situ before being raised to the surface

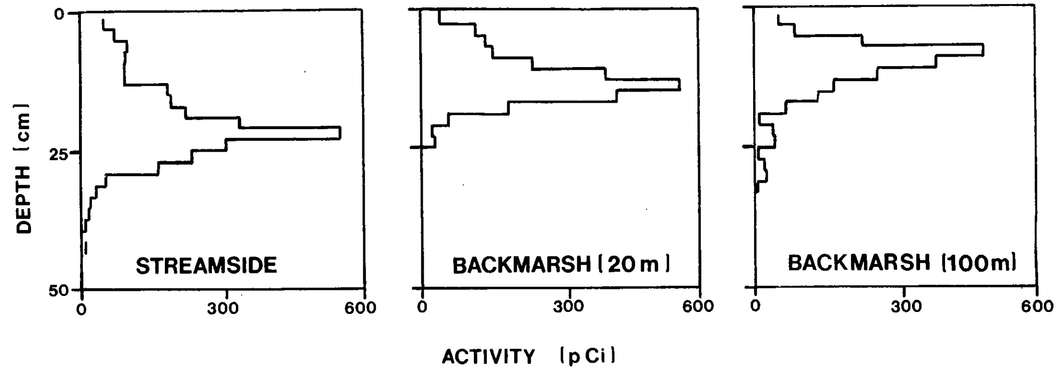

Fig. 2. ^{137}Cs profiles from the intermediate marsh illustrating levee effect. Values in parentheses indicate distance in meters from adjacent body of water.

and sealed with especially designed PVC caps and nylon straps. Entire cores were frozen and accurately sectioned into 2-cm horizontal subsamples with a bandsaw, allowing for blade thickness; freezing did not significantly alter the vertical distribution of sedimentary solids. Subsamples were weighed wet and again after drying to constant weight at 100°C. Bulk density was calculated from the dry weight and uniform sample volume.

^{137}Cs activity profiles were determined with an Ortec (model 8011-1620-S) coaxial, lithium-drifted germanium detector coupled to a multichannel analyzer (model 6240B). Entire sections were counted for a variable period determined statistically by the ^{137}Cs activity, but not exceeding 2×10^4 s. Vertical marsh accretion rates were computed directly from the depth of burial corresponding to 1963, the year of maximum ^{137}Cs fallout (DeLaune et al. 1978).

Selected cores were analyzed for organic carbon content; composite homogenized subsamples from alternate 2-cm intervals (0–2, 4–6, . . . , etc.) to a depth of 38 cm were analyzed by dry combus-

Table 1. Vertical accretion rates (R, mm·yr^{-1}), organic matter, and inorganic sediment data for marshes of Barataria Basin.

Site*	R		Soil bulk density (g·cm^{-3})	Organic matter			Inorganic sediments			Mean ^{137}Cs activity (pCi·g^{-1})
	Mean	Range		Dry wt (%)	Bulk density (g·cm^{-3})	A†	Dry wt (%)	Bulk density (g·cm^{-3})	A†	
Freshwater										
L	10.6	—	0.11 ± 0.03	41 ± 7	0.045	477	59	0.065	689	4.7
B	6.5	3.1–6.9	0.09 ± 0.01	52 ± 6	0.047	306	48	0.043	280	
Intermediate										
L	13.5	13.0–14.0	0.18 ± 0.04	33 ± 6	0.059	797	67	0.121	1,634	3.5
B	6.4	3.8–10.6	0.08 ± 0.01	52 ± 4	0.042	269	48	0.038	243	
Brackish										
L	14.0	10.6–16.9	0.27 ± 0.02	22 ± 3	0.059	826	78	0.211	2,954	1.3
B	5.9	3.8–8.1	0.14 ± 0.01	42 ± 3	0.059	348	58	0.081	478	
Salt										
L‡	13.5	—	0.35	20	0.050	675	80	0.200	2,700	0.9
B	7.5	5.9–9.4	0.29 ± 0.06	20 ± 3	0.058	435	80	0.232	1,740	

* L—Levee; B—backmarsh.
† Accumulation rate (g·m^{-2}·yr^{-1}).
‡ From DeLaune et al. 1981.

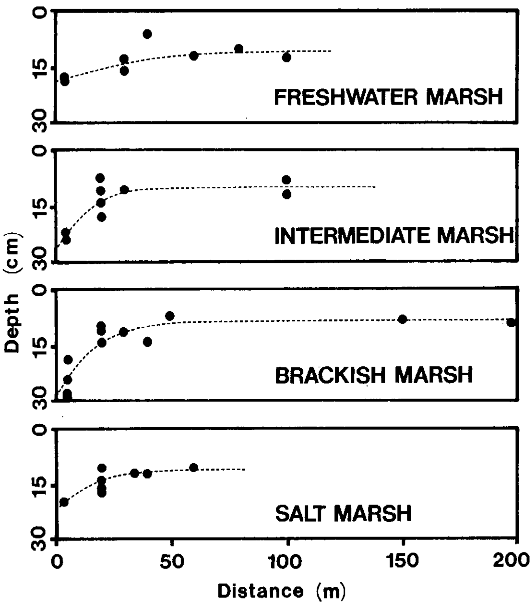

Fig. 3. Projected ^{137}Cs horizons in marsh soils illustrating limited lateral extent of levee. Individual core samples—●.

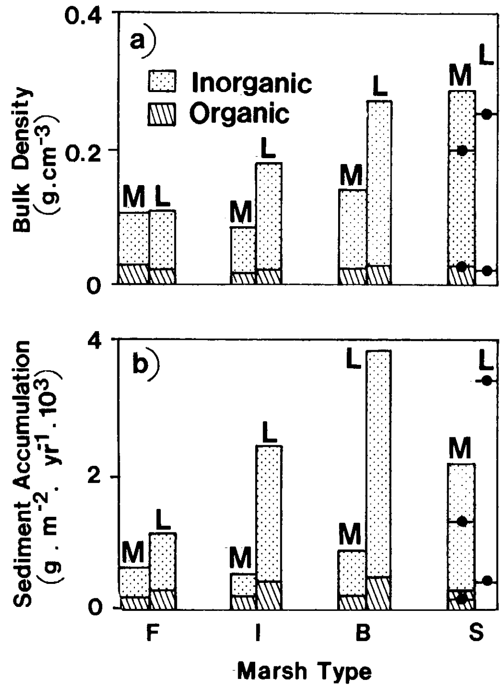

Fig. 4. Variation of (a) bulk density and (b) sedimentation with marsh type. L—Levee; M—backmarsh; —●— —data from DeLaune et al. 1981. F—Freshwater; I—intermediate; B—brackish; S—salt.

tion. Organic matter content was calculated from the organic carbon value determined by dry combustion in a carbon train, using the multiplier of 1.724 derived by Wilson and Staker (1932).

The rate of accumulation (A, $g \cdot m^{-2} \cdot yr^{-1}$) of mineral and organic sediments was calculated from dry weight percentages (C_d) and the vertical accretion rate (R, $cm \cdot yr^{-1}$) using the formula

$$A = C_d \times R \times D \times 10^2 \ (g \cdot m^{-2} \cdot yr^{-1})$$

(where D is total sediment bulk density).

Results

^{137}Cs activity profiles showed, with few exceptions, extremely well defined 1963 maxima (Fig. 2). Circumstantial evidence suggests that physical disturbance of the vegetated marsh surface is negligible except in established animal (*Nutrea nutrea*) paths which were not sampled. Occasional disturbance by burrowing crabs was observed only in streamside areas of brackish and salt marshes.

Vertical accretion rates (Table 1) calculated from 1963 ^{137}Cs activity maxima indicate that marsh accretion is an ongoing, but typically variable process in freshwater, intermediate, brackish, and salt marshes of the basin. Rates of vertical growth ranged from a maximum of 1.7 $cm \cdot yr^{-1}$ in streamside or natural levee deposits to as little as 0.31 in selected backmarsh areas; mean values were 1.3 and 0.7 $cm \cdot yr^{-1}$ in levee and adjacent backmarsh areas. Approximately similar accretion rates were identified in analogous areas of freshwater, intermediate, brackish, and salt marsh types (Table 1), within the limit of error of the determination.

Lateral transects from stream or lake banks consistently indicate the more rapid aggradation of levees than of backmarsh areas. The burial depth of the 1963 horizon (Fig. 3) attains a maximum at or near the waters edge, declining rapidly as the distance "inland" to attain a rela-

Table 2. Summary of available marsh accretion (R) data from North American Atlantic seaboard.

	Marsh type	R (mm·yr^{-1})	Mean sea level rise (mm·yr^{-1})	Method*	Source
Mass.	*S. alterniflora*	18.3 (1.5–51.8)	3.4	S	Redfield 1972
Conn.	*S. alterniflora*	8–10	2.5	P	Bloom (*cited in* Richard 1978)
Conn.	*S. patens*	2–5	2.5	P	Harrison and Bloom 1974
N.Y.	*S. alterniflora*	4.0	2.9	^{210}Pb	Muzyka 1976
N.Y.	*S. alterniflora*	4.7–6.3	2.9	^{210}Pb	Armentano and Woodwell 1975
N.Y.	*S. alterniflora*	2.0–4.2	2.9	P	Richard 1978
N.Y.	*S. alterniflora*	2.5	2.9	H	Flessa et al. 1977
Del.	*S. alterniflora*	5.1–6.3	3.8	P	Stearns and McCreary 1957
Del.	*S. alterniflora* (short)	5.0	3.8	^{210}Pb	Lord 1980
Ga.	*S. alterniflora*	3–5		^{137}Cs	Hopkinson pers. comm.
La.	*S. alterniflora* (Deltaic Plain)				
	i) streamside	13.5	9.2	^{137}Cs	DeLaune et al. 1978
	ii) inland	7.5	9.2	^{137}Cs	
La.	*S. alterniflora* (Chenier Plain)	4.7 (4.4–8.2)	9.2	^{137}Cs	DeLaune unpubl.
La.	*S. alterniflora* (Deltaic Plain)				
	i) streamside	15.2	9.2	P	Baumann 1980
	ii) inland	9.1			

* S—Stratigraphy; P—visual particulate, H—historic record.

tively uniform level at distances ≳40 m. Lateral variation is least apparent in the flotant freshwater marsh and most well defined in the brackish marsh.

Total soil bulk density showed a primary dependence on mineral sediment bulk density which decreased inland from the Gulf Coast; highest values occurred in the levee deposits (Fig. 4a). Organic carbon, by contrast, constituted an approximately constant mass in all soils. Inorganic sedimentation is therefore the principal determinant of variations in bulk density in this marsh system. Rates of mineral sediment and accumulation generally increased seaward from freshwater marshes toward the salt marshes, again with higher rates adjacent to natural bodies of water than in the distal backmarshes (Fig. 4b); organic carbon accumulation rates showed similar local variation but regional differences were not significant.

Discussion

The freshwater, intermediate, brackish, and salt marsh accretion rates measured here approximate values reported previously from salt marshes in the basin (DeLaune et al. 1978; Baumann 1980). Together these studies are consistent in showing the relatively rapid accretion of Louisiana marshes as compared to those of the U.S. Atlantic Coast, some of which are listed in Table 2. This result is probably indicative of the relatively rapid subsidence of south Louisiana.

Local variations in accretion rate from levee to backmarsh areas have been documented in salt marshes by several investigators, including Redfield (1972),

Table 3. Data for comparison of annual aboveground production with organic matter accumulating in brackish and salt marshes. Accumulation rates (A, $g \cdot m^{-2} \cdot yr^{-1}$) are expressed as a percentage equivalence ($E\%$) of the annual aerial production (AP) calculated from peak standing crop (PSC, $g \cdot m^{-2}$) measurements from this study, and the ratio AP*:PSC* from Hopkinson et al. (1978) and White et al. (1978): $E\% = A \div PSC \times AP^*:PSC^* \times 10^2$.

Marsh type	PSC	A	AP*:PSC* Hopkinson	AP*:PSC* White	E% Hopkinson	E% White
Brackish	2,508	348	2.5	0.79	6	17
Salt	1,648	435	1.7	2.23	16	23

DeLaune et al. (1978), and Baumann (1980). Our data further illustrate the lateral and vertical expression of natural levee deposition in four distinct marsh types. Except in the freshwater marsh, the projected slope of the ^{137}Cs horizon declined sharply with distance from the streambank, attaining a relatively constant value at distances >40 m. The faster aggradation in the proximity of natural bodies of water forming levees is generally attributed to lateral hydraulic and associated inorganic sedimentation gradients extending from the streambank (Frey and Basan 1978). The observed distribution of mineral sediments (Fig. 4b) is consistent with this hypothesis. The relative uniformity of freshwater marsh accretion rates conforms to the lateral uniformity in mineral sediment distribution (Fig. 4a), which itself appears to result from the continuing erosion of the lake shoreline sampled.

The regional uniformity in vertical accretion rate of spatially predominant backmarshes is somewhat paradoxical in view of the apparent local relationship between inorganic sedimentation and accretion (Fig. 3) and the fact that the regional inorganic sedimentation gradient exceeds that expressed locally in each marsh type (Fig. 4). Inorganic sediment is thus clearly not the sole or principal determinant of the vertical growth rate of these marshes. By necessity, therefore, soil organic matter must be invoked as the controlling factor. Evidence to support this hypothesis includes the volumetric constancy of soil organic matter content (organic matter bulk density) shown in Fig. 4a and the structural role and buoyancy of macroorganic matter immediately apparent on examination of these substrates. Especially in less saline systems, inorganic particles are clearly interstitial constituents of a primarily organic matrix; organic matter may comprise >50% of the dry weight of these soils (Table 2). These results support McCaffrey's (1977) concept of a "vegetative growth mechanism" whereby marshes deficient in inorganic sediments accrete as a result of plant growth in response to changing water level. The same concept is consistent with the levee effect, in that plant production is greatest in hydrologically dynamic streamside areas which would act synergistically with lateral hydraulic or depositional gradients to increase the aggradation rate locally. Interpretation of these data, however, is complicated by vegetative and hydraulic gradients which parallel the regional sedimentation gradient. Whereas organic materials clearly dominate freshwater marsh soils, the relative role and thus the necessity of the inorganic fraction appear to increase as the hydraulic energy increases seaward in the basin.

The species-specific response of marsh plants to inorganic sediment deficiency and their natural productivity are inadequately understood to assess fully their role in the accretionary process or how this varies from one marsh type to another. Calculations based on clip-plot production measurements made in our study and previous production data from Louisiana (Hopkinson et al. 1978; White et al. 1978), summarized in Table 3, suggest that organic matter equivalent to 6–23% of aerial production accumulates in brackish and salt marshes. However accumulated organic matter appeared to be primarily root material, the production of which is not documented for the Louisiana marshes.

DeLaune et al. (1978) and Baumann (1980) have observed that except in natural levees, salt marshes in Barataria Basin have shown an accretionary deficit with respect to post-1959 rise in sea level. Figure 5 shows that the same is generally true of less saline marshes in the basin. If we assume a worldwide eustatic rise in sea level of 0.12 $cm \cdot yr^{-1}$ (Gutenberg 1941; Swanson and Thurlow 1973; Belknap and Kraft 1977), the relative rise in the basin can be largely ascribed to subsidence, which is therefore estimated to be of the order of 1.0–1.2 $cm \cdot yr^{-1}$. The current accretionary deficit responsible for the continuing loss of marshlands in the area is generally attributed to increased subsidence. However, channelization resulting in saline intrusion is also increasingly being implicated as accelerating the natural rate of marine transgression. It is also conceivable that, at least in the geologic short term, floating marshes may persist independently of the subsiding basement so that an accretionary deficit need not be an immediate result in land submergence.

^{137}Cs dating has been successfully applied to geochronological investigations of lacustrine (Pennington et al. 1973) and salt marsh environments (DeLaune et al. 1978). The technique is subject to the constraint that sedimentary ^{137}Cs profiles accurately reflect the yearly fallout pattern. With one exception (Alberts and Muller 1979), available data indicate that this element is not subject to significant postdepositional remobilization even under reduced conditions and in a variety of sediments (Eyman and Kevern 1975; Gardner and Skulberg 1964; Tamura 1964). Supportive evidence from our study and previous studies in the basin includes a well defined 1963 ^{137}Cs maximum in most of the profiles examined and the close agreement between salt marsh accretion rates reported here and independent estimates based on a visual particulate method (Baumann 1980). Field observations suggest that bioturbation by macrofauna is not significant.

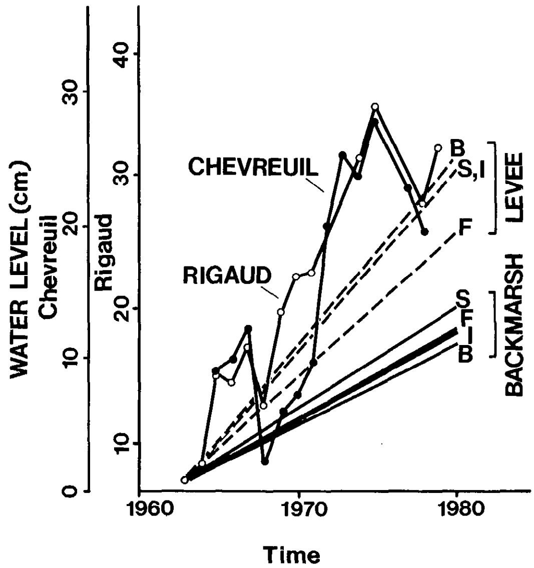

Fig. 5. Water level rise in Barataria Basin for 1963–1980 (from Baumann 1980) and marsh accretion projected from mean accretion rates in Table 2. Gauging stations at Chevreuil and Rigaud near freshwater and salt marsh sites indicated in Fig. 1.

Conclusions

Despite extensive loss of marshlands in the area, vertical marsh accretion is a rapidly continuing process in freshwater, intermediate, brackish, and salt marshes in the Barataria Basin. In general, accretion rates of levee marshes seem to be keeping pace with subsidence as measured by water level data. However, the spatially predominant backmarsh areas are accreting at about half the regional subsidence rate, a result which is consistent with continuing land loss by submergence. Substrate buoyancy may contribute to the persistence of marshes experiencing such an accretionary deficit in the geologic short term. Whereas the accretionary process is conventionally attributed largely to inorganic sedimentation, the regional independence of measured accretion rates from the inorganic sediment supply is testimony to the accretionary role of organic matter in this low-energy system, which is poor in inorganic sediments. However the structural necessity for inorganic particles seems to increase with increased hydraulic energy toward the

Gulf Coast. The production and accumulation of autochthonous organic matter, and its controls and consequences, deserve greater emphasis in considerations of the mechanism of marsh accretion, particularly in view of the accelerating marshland deterioration in south Louisiana. Management practices such as burning and channelization with salt water intrusion, which may retard the production and accumulation of organic matter, thus have serious consequences for marsh accretion and land loss.

References

ALBERTS, J. A., AND R. N. MULLER. 1979. The distribution of $^{239,240}Pu$, ^{238}Pu and ^{137}Cs in various particle size classes of Lake Michigan sediments. J. Environ. Qual. **8:** 20–22.

ARMENTANO, T. V., AND G. M. WOODWELL. 1975. Sedimentation rates in a Long Island marsh determined by ^{210}Pb dating. Limnol. Oceanogr. **20:** 452–456.

BAHR, L. M., AND J. J. HEBRARD. 1976. Barataria Basin: Biological characterization. Louisiana State Univ. Sea Grant Publ. T-76-005. 144 p.

BAUMANN, R. H. 1980. Mechanisms of maintaining marsh elevation in a subsiding environment. M.S. thesis, Louisiana State Univ. 90 p.

BELKNAP, D. F., AND J. C. KRAFT. 1977. Holocene relative sea level changes and coastal stratigraphic units on the northwest flank of the Baltimore canyon trough geosyncline. J. Sediment. Petrol. **47:** 610–629.

COLEMAN, J. M., AND S. M. GAGLIANO. 1964. Cyclic sedimentation in the Mississippi River deltaic plain. Trans. Gulf Coast Assoc. Geol. Soc. **14:** 67–80.

DELAUNE, R. D., W. H. PATRICK, JR., AND R. J. BURESH. 1978. Sedimentation rates determined by ^{137}Cs dating in a rapidly accreting salt marsh. Nature **275:** 532–533.

———, C. N. REDDY, AND W. H. PATRICK, JR. 1981. Accumulation of plant nutrients and heavy metals through sedimentation processes and accretion in a Louisiana salt marsh. Estuaries **4:** 328–334.

EYMAN, L. D., AND N. R. KEVERN. 1975. Cesium-137 and stable cesium in a hypereutrophic lake. Health Phys. **28:** 549–555.

FLESSA, K. W., K. J. CONSTANTINE, AND M. K. KUSHMAN. 1977. Sedimentation rates in a coastal marsh determined from historical records. Chesapeake Sci. **18:** 172–176.

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

FREY, R. W., AND P. B. BASAN. 1978. Coastal salt marshes, p. 101–159. *In* R. A. Davis, Jr. [ed.], Coastal sedimentary environments. Springer.

GARDNER, K., AND O. SKULBERG. 1964. Sorption phenomena of radionuclides to clay particles in river water. Int. J. Air Water Pollut. **8:** 229–233.

GUTENBERG, B. 1941. Changes in sea level, post glacial uplift, and mobility of the earth's interior. Geol. Soc. Am. Bull. **52:** 721–772.

HARRISON, E. Z., AND A. L. BLOOM. 1974. The response of Connecticut salt marshes to the recent rise in sea level. Geol. Soc. Am. Abstr. **6:** 35–36.

HOPKINSON, C. S., J. G. GOSSELINK, AND R. T. PARRONDO. 1978. Aboveground production of seven marsh plant species in coastal Louisiana. Ecology **59:** 760–769.

KOLB, C. R., AND J. R. VAN LOPIK. 1966. Depositional environments of the Mississippi River deltaic plain—Southeastern Louisiana, p. 17–61. *In* M. L. Shirley [ed.], Deltas in their geologic framework. Houston Geol. Soc.

LORD, J. C. 1980. The chemistry and cycling of iron, manganese, and sulfur in salt marsh sediments. Ph.D. thesis, Univ. Delaware.

MCCAFFREY, R. J. 1977. A record of the accumulation of sediment and trace metals in a Connecticut, U.S.A., salt marsh. Ph.D. thesis, Yale Univ. 156 p.

MUZYKA, L. J. 1976. ^{210}Pb chronology in a core from the Flax Pond marsh, Long Island. M.S. thesis, SUNY, Stony Brook. 73 p.

PENNINGTON, W., R. S. CAMBRAY, AND E. H. FISHER. 1973. Observations on lake sediments using fallout ^{137}Cs as a tracer. Nature **242:** 324–326.

REDFIELD, A. C. 1972. Development of a New England salt marsh. Ecol. Monogr. **42:** 201–237.

RICHARD, G. A. 1978. Seasonal and environmental variations in sediment accretion in a Long Island salt marsh. Estuaries **1:** 29–35.

STEARNS, L. A., AND B. MACCREARY. 1957. The case of the vanishing brick dust. Mosquito News **17:** 303–304.

SWANSON, R. L., AND C. I. THURLOW. 1973. Recent subsidence rates along the Texas and Louisiana coasts as determined from tide measurement. J. Geophys. Res. **78:** 2665–2671.

TAMURA, T. 1964. Selective adsorption reactions of Cs with mineral soil. Nucl. Saf. **5:** 262–268.

TURNER, R. E., AND J. G. GOSSELINK. 1975. A note on standing crops of *Spartina alterniflora* in Texas and Florida. Contrib. Mar. Sci. **19:** 113–118.

WHITE, D. A., T. E. WEISS, J. M. TRAPANI, AND L. B. THIEN. 1978. Productivity and decomposition of the dominant salt marsh plants in Louisiana. Ecology **59:** 751–759.

WILSON, B. D., AND E. V. STAKER. 1932. Relation of organic matter to organic carbon in the peat soils of New York. J. Am. Soc. Agron. **24:** 477–481.

Submitted: 4 December 1981
Accepted: 21 September 1982