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Mat Movement in Coastal Louisiana Marshes: Effect of Salinity and Inundation on Vegetation and Nutrient Levels

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MAT MOVEMENT IN COASTAL LOUISIANA MARSHES: EFFECT OF SALINITY AND INUNDATION ON VEGETATION AND NUTRIENT LEVELS

by

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August 1992

Approved by:

Frank P. Day, Jr. (Director)

ABSTRACT

MAT MOVEMENT IN COASTAL LOUISIANA MARSHES: EFFECT OF SALINITY AND INUNDATION ON VEGETATION AND NUTRIENT LEVELS

Christopher Martin Swarzenski
Old Dominion University, 1992
Director: Dr. Frank P. Day, Jr.

The present research compared and contrasted the physical structure of floating and rooted marshes, their differing responses to open-water salinities and inundation, as well as the nutrient distribution in the porewaters and sediment. The effects of the physical differences in the two marsh types on the ocurrence of the dominant emergent vegetation was discussed.

The main difference in physical structure of the two marsh types was the presence of a mineral, non-buoyant layer at 25-45 cm depth in the rooted marsh, which could serve as an anchor for the overlying highly organic mat layer found in both marsh types. Porewater salinities in floating marshes tracked open-water salinities more closely than they did in rooted marshes. Under the prevailing, mostly fresh conditions, porewaters in the rooted marsh contained significantly higher salt levels. Here also, there was a more pronounced vertical gradient in salt levels than found in floating marshes. With the three years of data it was possible to demonstrate the more extensive exchange of belowground water with open waters in the floating marshes, rather than the rooted marsh.

Surprisingly, the different hydrodynamics of floating and rooted marshes did not appear to affect inorganic porewater nutrient levels. It appeared that dominant aboveground vegetation determined these levels. The two dominant species of emergent vegeta-

tion have clearly contrasting tolerances to ambient salinites and flooding. Thus, the continued persistance of the more salt-tolerant species in this mostly fresh area is thought to be attributable to the recurring, but infrequent years of high salinity.

The significance of floating marshes in the rapidly subsiding Mississippi River Deltaic Plain, with concomittant increases in ambient salinities is obvious. Their potentially unique responses to these environmental forcing functions deserve closer attention when mitigation measures are conceptualized and implemented. It is quite possible that a majority of the low-salinity marshes in the deltaic plain may be floating.

ACKNOWLEDGEMENTS

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I received different forms of assistance from many people. Mr. Mike Windham of the Louisiana Department of Wildlife and Fisheries (LDWF) provided access to the Lake Salvador Wildlife Management Area and its facilities. Mr. Irving Dares, Rock, Flat and family (LDWF) helped with sample collections, transport to and from camp facilities, and greatly enhanced my working environment. Mr. Charles Sasser of the Coastal Ecology Institue at Louisiana State University (CEI) provided the support with which it was possible to complete my research in Louisiana. Also at the Coastal Ecology Institute, Mr. Erick Swenson provided technical help in all aspects of this project and Mr. Thomas Oswald was an amicable host while I was traveling in Louisiana. Without the goodwill and generosity of all of these people, this project would not have come to fruition.

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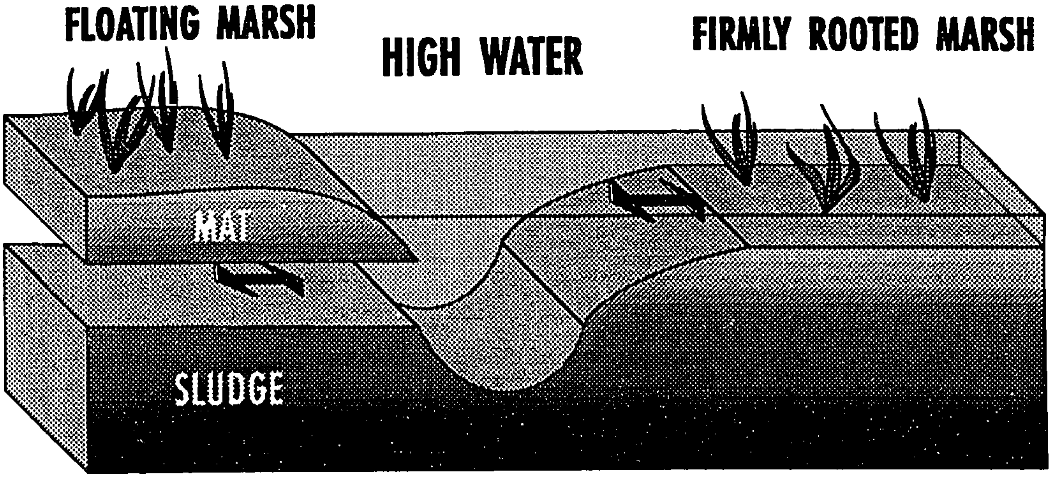
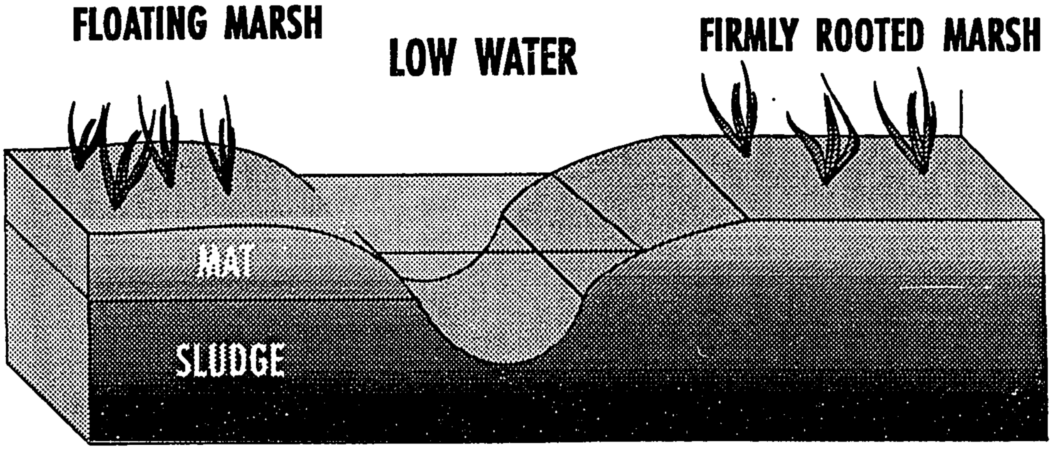
Chapter I

INTRODUCTION

Louisiana contains up to 40% of the wetlands in the lower 48 states in the USA (Turner and Gosselink 1975) These wetlands support productive commercial and recreational fisheries, a fur industry, and are an extremely valuable resource. In recent times marshes have been reverting to open water at a rate of 50 to > 100 km^{-2} per year (Gagliano 1981). Much of the loss can be attributed to a sediment accretion deficit brought about by the leveeing of the Mississippi River and continued compaction of the unconsolidated sediments (Coleman et al. 1989). The deterioration has been made worse by the extensive dredging and channelization associated with the ubiquitous oil and gas exploration in these wetlands. The natural flow regime and sediment distribution processes in these marshes have been altered. A considerable amount of money and research is being applied to this problem of wetland loss and efforts to slow or even reverse the trends are proceeding. A thorough knowledge of the structure and processes associated with each of the elements of the wetland landscape forms the basis for such efforts. I present results of research on one such element in the Mississippi River Deltaic Plain (MRDP), floating marshes, which although quite common, are relatively less studied than those marshes firmly rooted in a non-buoyant substrate. Through mat adjustemt to changes in ambient water levels, the hydrology, especially the exchange of water between adjacent surface water and the marsh, is altered in comparison to the rooted marsh (Fig. 1) The responses of floating marshes to the principle environmental stresses in the Delta Plain, namely subsidence of the marsh surface below mean water levels and the encroachment of saline Gulf waters in an inland direction, are likely to differ substantially from those in rooted marshes.

FIG. 1. Schematic of water exchange between marsh and adjacent open water in a floating and a rooted marsh.


FLOATING MARSH
HIGH WATER
FIRMLY ROOTED MARSH
MAT
SLUDGE


FLOATING MARSH
LOW WATER
FIRMLY ROOTED MARSH
MAT
SLUDGE

1.1 Introduction to the study area

The Louisiana Gulf Coast contains about 15,000 square kilometers of marshes (Chabreck 1972), the majority of which occur in the Mississippi River Deltaic Plain (MRDP). The marshes flank the uplands in a band the width of the state, and comprise four distinct vegetation zones based on differences in plant tolerances to the gulfwards increasing salinity gradient (Chabreck 1972). The MRDP was formed by the active deposition of sediments carried by the Mississippi River during the last 6,000 to 8,000 years, after sea levels stabilized to near their current levels. The MRDP is comprised of six to seven overlapping lobate deltas (Frazier 1967). The delta lobes formed as the river switched channels to follow a hydraulically more efficient path to the Gulf of Mexico. The switching of channels and loci of delta building has created a physiography of gulfwards trending natural levees bounding large areas of lower-lying marshes termed interdistributary basins.

Floating marshes occur commonly in the fresh to intermediate salinity zones of the MRDP (Swarzenski 1987). Anecdotal accounts of their occurrence can be found from before the turn of the century (cf. Russell 1942). Russell (1942) presented an initial overview of their occurrence in the MRDP. This was followed by the descriptions of O'Neil (1949). More recently, Sasser and colleagues (1984, 1991) and Swarzenski et al. (1991) have presented results of detailed studies of floating marshes in the MRDP. Studies of the geologic record suggest that floating marshes are a recurring feature of the MRDP landscape (Yi-ih 1988).

Two contrasting theories for the formation of floating marshes have been put forward. Russell (1942) suggested that open water accumulating organic debris to the point where emergent vegetation could establish itself was the major way these marshes formed. O'Neil (1949) hypothesized that the primary mode of formation was instead by the buoyant detachment of formerly rooted marshes. This latter mode of formation has special relevance in a region where subsidence is rapid, and vertical accretion rates, which are among the highest known for any wetland, are insufficient to keep pace. Such a mode of formation literally suggests the eventual detachment of the large areas of freshwater marshes in the MRDP.

1.2 The current study

Results of research on three marshes in the intermediate salinity zone (0.5-5ppt) of the MRDP, at Lake Salvador, Louisiana. are reported here. The same physical and ecological data were collected from all three marshes differing in vegetation and/or the degree of mat movement. This study sought to learn how floating and rooted marshes are similar, how they differ, how they respond to physical forcing of the environment (salinity and levels of inundation). The analyses and interpretations offered here provide some insight into the structure and functioning of these marshes.

Chapter I compares the subsurface geology and bulk soil parameters among the three sites, and examines the influence of these factors on the buoyancy of the marsh mat. In Chapter II, three years of data on chloride distribution in the upper 100 cm of substrate are presented. The data suggest potential responses of the two marsh types to salinity changes in the adjacent open water. In Chapter III, nitrogen and phosphorus dynamics in the porewaters and substrate of the marshes are examined. Vegetation and hydrology influenced levels of the different fractions of N and P. Finally, Chapter IV examines how variability in soil salinity and inundation regimes generated by the extent of mat movement may permit the co-occurrence of two species with differing salt and flooding tolerances in an area subject to the same outside forcing.

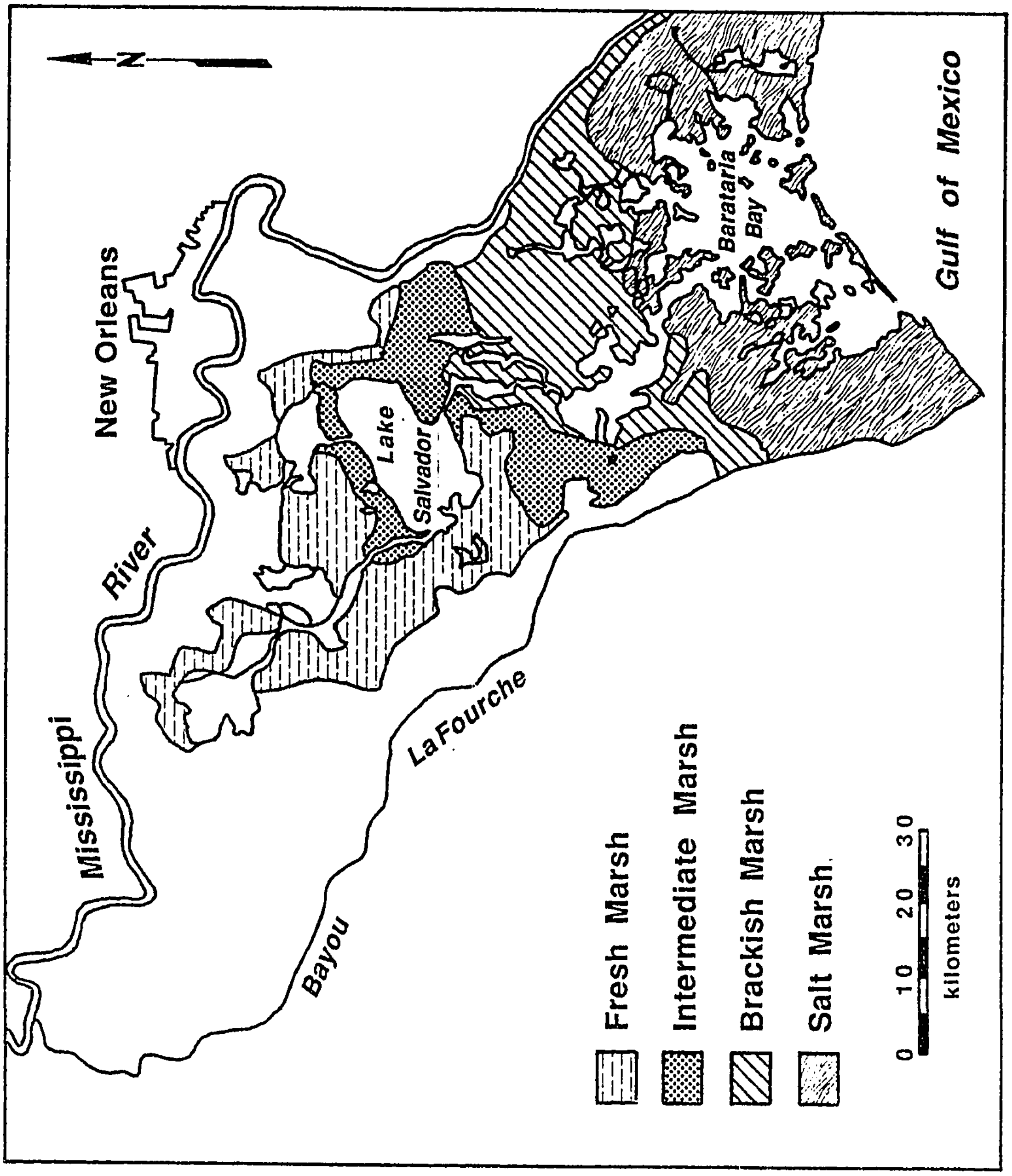
Summarizing the different elements of the study: The extent of mat movement controlled the levels of marsh flooding and soil salinity experienced at a given marsh. In turn, the physical environment controlled the emergent vegetation through differential tolerances to stress by different species. It also appeared that emergent vegetation controlled nutrient levels in the porewaters, in addition to hydrological differences based on mat movement.

1.3 Site Description

The study area was located in the low-salinity (0.5-5 ppt) upper reaches of Barataria Basin (BB, Fig. 2), a large interdistributary basin in the MRDP, centered on N 29-31°, W 90°. The basin lies between the current leveed channel of the Mississippi River and its most recently abandoned channel, Bayou Lafourche. The two water courses flank the basin in the shape of a V opening on the Gulf of Mexico in a southeasterly direction. Freshwater enters the basin mainly in the form of rain. Saline waters enter from the Gulf of Mexico. The marshes in the upper reaches of interdistributary basins, BB included, accrete primarily through organic material produced by the marsh plants themselves due to the paucity of mineral sediment and subsidence rates of around 1 cm yr^{-1} (Hatton et al. 1983).

The study sites were three marshes located on the north shore of Lake Salvador. The marshes are connected hydrologically to Lake Salvador and hence to the rest of Barataria Basin through the Gulf canal. Site 1 was located on a side canal off this main canal. Sites 2 and 3 were located 2 km closer to the lake, on opposite sides of the main canal. Sites 1 and 3 were dominated by *Sagittaria falcata*. Site 2 was co-dominated by this species and by *Spartina patens*.

FIG. 2. Map of study site in Barataria Basin, Louisiana.


N
New Orleans
Mississippi
River
Lake
Salvador
Barataria
Bay
Gulf of Mexico
Bayou
LaFourche
Fresh Marsh
Intermediate Marsh
Brackish Marsh
Salt Marsh
0
10
20
30
kilometers

1.3.1 Marsh Inundation and Salinities

The primary sources of stress to the emergent vegetation in the MRDP, including the intermediate salinity zone, are marsh inundation and the salt content of the surrounding waters. With increasing distance from the Gulf of Mexico, the importance of astronomical tides in determining marsh inundation regimes and ambient salinities diminish. In the long-term both parameters are heavily influenced by the ongoing rapid submergence of the marsh surface below ambient waterlevels. Flooding and salinity levels are gradually increasing in many parts of the Delta Plain.

Coastal submergence is measured as the difference between vertical accretion of the marsh and apparent sea-level rise. Although accretion rates of coastal Louisiana marshes are among the highest anywhere in the world, it is generally assumed that these are not sufficient to keep pace with sea-level rise (Hatton et al. 1983). Marsh inundation parameters are affected by submergence. In the upper reaches of Barataria Basin, where water levels are more affected by precipitation and windtides, there is less day to day variation in levels. Every centimeter of submergence reduces the frequency of inundation and increases the total duration of marsh flooding more so here than along the Gulf Coast, where tidal fluctuations lessen the impact of coastal submergence.

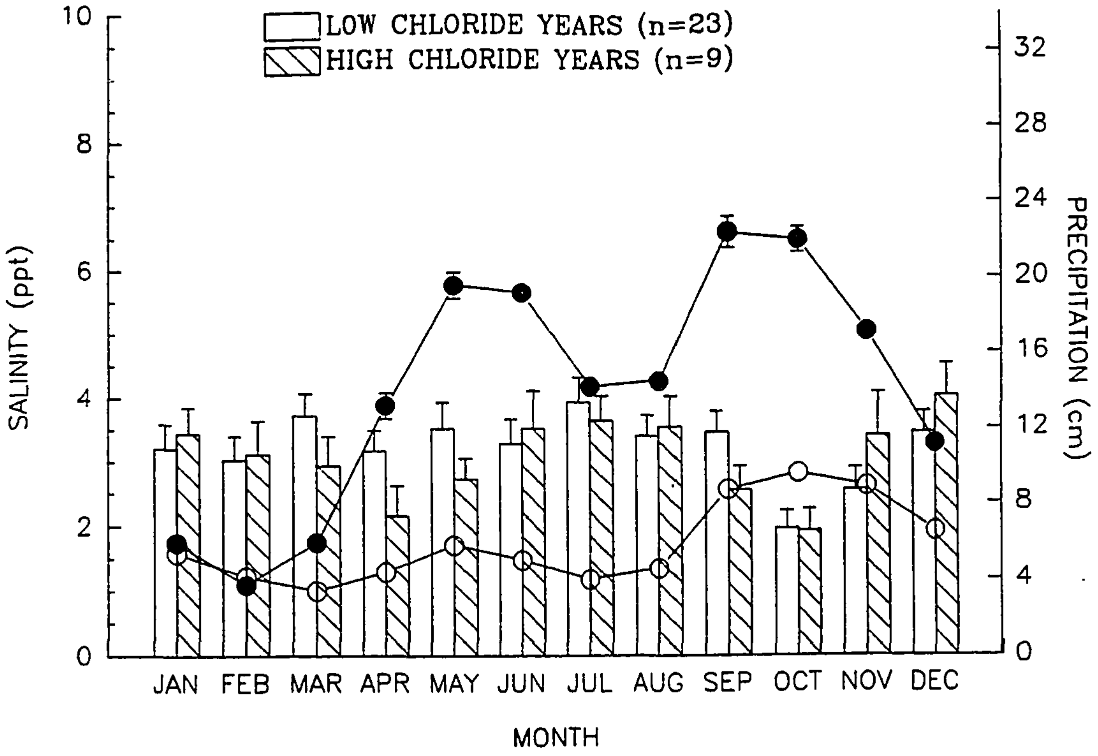
Salinities in the intermediate region of the MRDP exhibit a distinct seasonality, with peaks in the spring and again in the fall. Mean salinities are about 2 ppt (Byrne et al. 1976). For the salinities in this region to increase, the water mass closer to the Gulf of Mexico must encroach in an inland direction. This occurs when freshwater runoff (derived almost entirely from precipitation) is low and/or Gulf sealevel is high. In the spring, discharge from the Mississippi River peaks. The fresh water disperses the high-salinity waters near the Gulf shores and displaces some of this water mass into the basin interior, in an inland direction. The fall peak occurs when Gulf levels are at their highest yearly levels due to thermal expansion. Facilitating the movement of water within the basin is the extremely low topographic gradient.

Analyses of daily chloride data taken from Bayou Barataria at Lafitte from 1956 to 1987 (U.S. Army Corps of Engineers, New Orleans District) suggest two patterns superimposed on long-term monthly means (Fig. 3a). There appear to be almost entire years when salinities are substantially above average. These years occurred when precipitation was below average during the crtical spring and even fall time frames. Under conditions of reduced freshwater flow, the inland encroachment of higher salinity waters is enabled. Such episodic events occurred throughout the period of record.

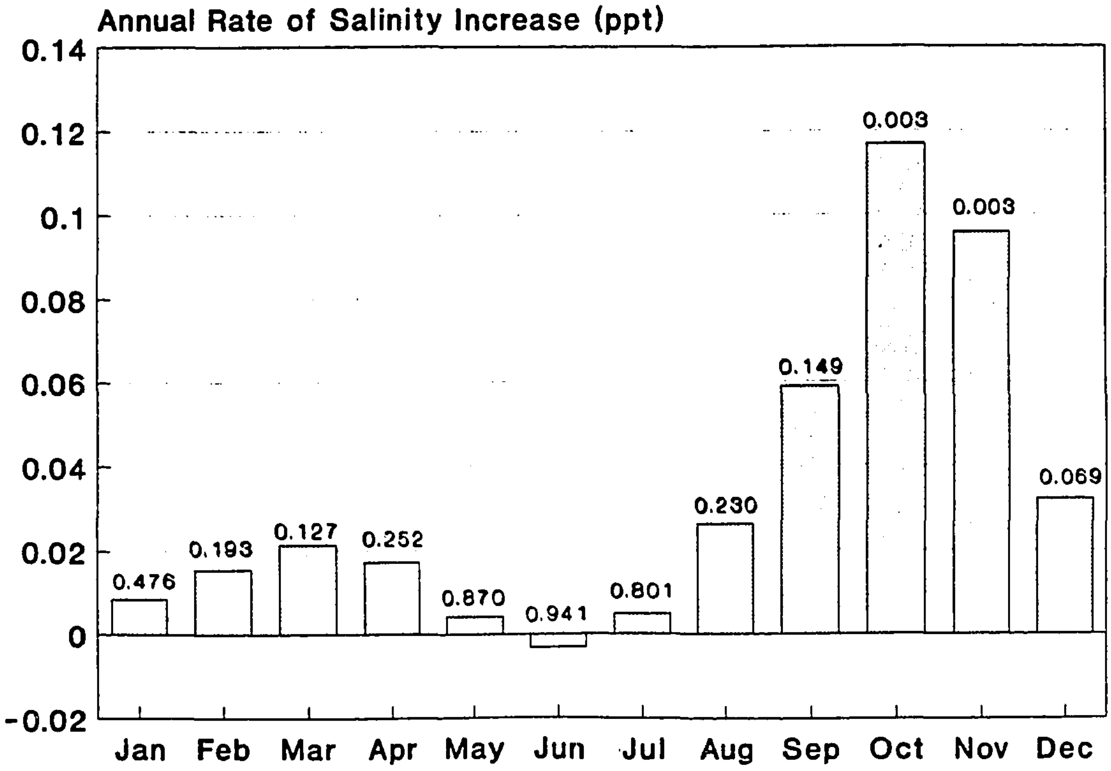
During this same time period, annual mean salinities were increasing gradually (ca. 1 ppt). Broken down by month, the fall period figured disproportionately in the increase. Rates in November and December were about 5 x greater than annual rates. By inference, the impact of the annual fall rise in sea-level on ambient salinities is increasing, suggesting that the marsh surface is subsiding relative to sea level.

The salinity patterns important to the emergent vegetation of the local marshes are i) the periodic and predictably recurring episodes of elevated salinities which are related to climatic variability and are independant of any long-term trends; ii)a gradual long-term increase in salinities; and iii) the seasonally much greater rates of long-term salinity increase.

FIG. 3. a) Monthly-averaged salinities at Bayou Barataria at Lafitte, near Lake Salvador for years when salinities were ≥ 4 ppt for at least 100 days (high salinity years) and the remaining years (low salinity years). Monthly averaged precipitation values are shown for the same two salinity classes. b) Long-term salinity trends at Bayou Barataria at Lafitte, near Lake Salvador, Louisiana. Trends were determined with the non-parametric Kendals Tau statistic (Hirsch et al. 1982) adjusted by month. Numbers on chart indicate level of significance. The annual rate is ~0.021 ppt y^{-1} ($p < 0.000$)


LOW CHLORIDE YEARS (n=23)
HIGH CHLORIDE YEARS (n=9)
SALINITY (ppt)
PRECIPITATION (cm)
0
2
4
6
8
10
0
4
8
12
16
20
24
28
32
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

a)


Annual Rate of Salinity Increase (ppt)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
0.476
0.193
0.127
0.252
0.870
0.941
0.801
0.230
0.149
0.003
0.003
0.069
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

b)

Chapter II

MAT MOVEMENT IN RELATION TO SOIL CHARACTERISTICS

2.1 Introduction

Floating marshes are mats of emergent vegetation that, together with below-ground roots, associated organic matter and mineral sediment, rise and fall with changes in ambient water levels. Gases from anaerobic decomposition and oxygen from below-ground roots contribute to the buoyant forces in the vegetation mat (Hogg and Wein 1988). The emergent vegetation is exposed to hydrologic and edaphic conditions unique among wetland types. The water table is usually near the marsh surface and marsh flooding is reduced or absent.

Floating marshes commonly occur in coastal and inland freshwater wetlands (Swarzenski 1987) in a variety of environmental settings, ranging from mats covering small lakes in northern peatlands (e.g. Buell and Buell 1943) to the floating reed beds (Plaur) in the Danube Delta which cover 100,000 ha (Rodewald-Rodescu 1974). Floating papyrus swamps are widespread in Africa, and may dominate some wetlands there (e.g. Sudd on the Nile, Migahid 1947). Floating marshes develop either directly by plant growth through lateral encroachment over open water (Kratz and DeWitt 1986), or they may result from the buoyant detachment from the solid subsurface of a formerly well-anchored mat (Krusi and Wein 1987, Rodewald Rodescu 1976). Floating marshes may be transient, a stage in the classical 'Verlandungs' scheme (Weber 1908) or they may persist indefinitely (Tallis 1983), depending primarily on the balance between rates of organic material accumulation and changes in water level relative to the marsh surface.

Floating marshes are also widespread in the Mississippi River Deltaic Plain (MRDP) in coastal Louisiana, where they may cover as much as 100,000 ha. The distribution of the floating marshes there has been described in general terms (O'Neil 1948 and Kosters et al. 1987). They occur in the central, low-salinity (0-5 ppt) parts of interdistributary basins. At least two major vegetation types, dominated by *Sagittaria falcata* and *Panicum hemitomon,* have the ability to float (Swarzenski et al. 1991). Not all of these marshes will float. Although the principle factors contributing to mat buoyancy (anaerobic gas generation and characteristic root system; Hogg and Wein 1988, Swarzenski et al. 1991) have been described, the relation of substrate to mat movement is less well understood.

The objectives of this work were to measure mat movement in relation to properties of the marsh soil, describe the physical features of floating and non-floating marshes and discuss the occurrence of floating marshes in relation to the environmental setting of the MRDP.

2.2 Methods

At 50 m distance from the adjacent canal a conventional water level recorder (Fisher & Porter) was adapted to continuously measure mat movement. The float of the recorder was replaced with a cork-screw type anchor twisted 20 cm into the substrate. Mat elevation was measured at hourly intervals during the year 1990 at all three sites. At Site 1 open-water levels were also measured with the same type of gage. Results were digitized and averaged into daily means.

The subsurface at each site was sampled to depths of 180 cm with a MacAuly auger and visually characterized according to consistency and organic and mineral content. At least ten cores were taken at each site in a transect from 50 m inland perpendicular to and towards the canal. In addition, five replicate cores were taken 50 m inland at each site to a depth of 45 cm with a stainless-steel coring tube (11 cm i.d.) serrated along the bottom edge. Samples were sectioned into 5-cm increments in the field, sealed in plastic bags and returned to the laboratory. Wet weights were recorded immediately, and the samples were then oven-dried at 75 °C to constant weight to determine dry bulk density. Dried samples were homogenized and placed in a muffle furnace (500 °C, 4 hours) to determine loss-on-ignition of organic material. Mineral densities of the samples were calculated by converting organic contents to densities and subtracting from bulk densities.

Analysis of variance was used to examine organic matter content and dry bulk density at each depth interval using site as the main effect. Where indicated by ANOVA, significant differences among means were tested using the Tukey multi-comparison test (SAS, 1983).

Buoyant tendencies of the shallow subsurface were measured using the 'contribution to buoyancy' formula given in Hogg and Wein (1988):

$B = V_{fc}(1 - D_{fc})$, with units of kg m^{-2}, where

V_{fc} = volume of wet soil per unit area (liters per square meter),

D_{fc} = density of wet soil (g ml^{-1}).

Empty polyethylene containers ($V = 500\ cm^{-3}$, $n=4$) were emplaced in the marshes (top of container at 45 cm depth) with openings perpendicular to the marsh surface (2.5x4 cm) to measure root growth. Growth into the empty container was measured at Sites 1 and 3. The containers were set out on March 8, 1990 and recovered August 1, 1990.

2.3 Results

2.3.1 Mat movement

The responses of the marsh mat to surface-water fluctuations differed at each site. At Site 3 the mat did not move at all during the year of measurement. At Site 1 the response of the mat differed according to the time of the year (Fig. 4). From January through early June, the mat responded only slightly to open-water movement. The response increased progressively, until by late summer the mat floated directly with water-level fluctuations except for extreme high and low water events. The mat at Site 2 also exhibited seasonal variation in response to open-water fluctuations, but with less of a seasonal effect. In contrast to the mat at Site 1 the mat here continued to float during the winter, although with less vertical range.

2.3.2 Soil bulk properties

Results of soil bulk analyses are presented in Fig. 5. Bulk densities were about 0.065 g cm^{-3} for the entire 45 cm profile at Site 1. Variability was slightly higher in the lower 25 cm. At Site 2 mean dry bulk densities of about 0.075 g cm^{-3} decreased to 0.065 g cm^{-3} below 30 cm. At Site 3, bulk densities were similar to those at Site 1 in the upper 20 cm, but increased rapidly to 0.14 g cm^{-3} below this depth. Mineral densities were also similar above 25 cm at Sites 1 and 3, varying between 0.005 and 0.01 g cm^{-3}. At Site 2 mineral densities were slightly more than double these values at depths of 25 cm and less. Densities remained low at Sites 1 and 2, but, as with bulk density, increased at Site 3 with depth.

The soil at Sites 1 and 3 decreased from over 90% organic matter near the surface to levels of about 75%-80% at 25 cm depth. At Site 3, the anchored marsh, soil organic matter content decreased further with depth to about 60%-65% dry weight. At Site 1

FIG. 4. Marsh mat movement relative to open water fluctuations at the floating marshes at Site 1 and Site 2 near Lake Salvador, Louisiana in winter and summer. (Note the elevation of the rooted marsh (Site 3) remained at .3 m throughout the study interval.)

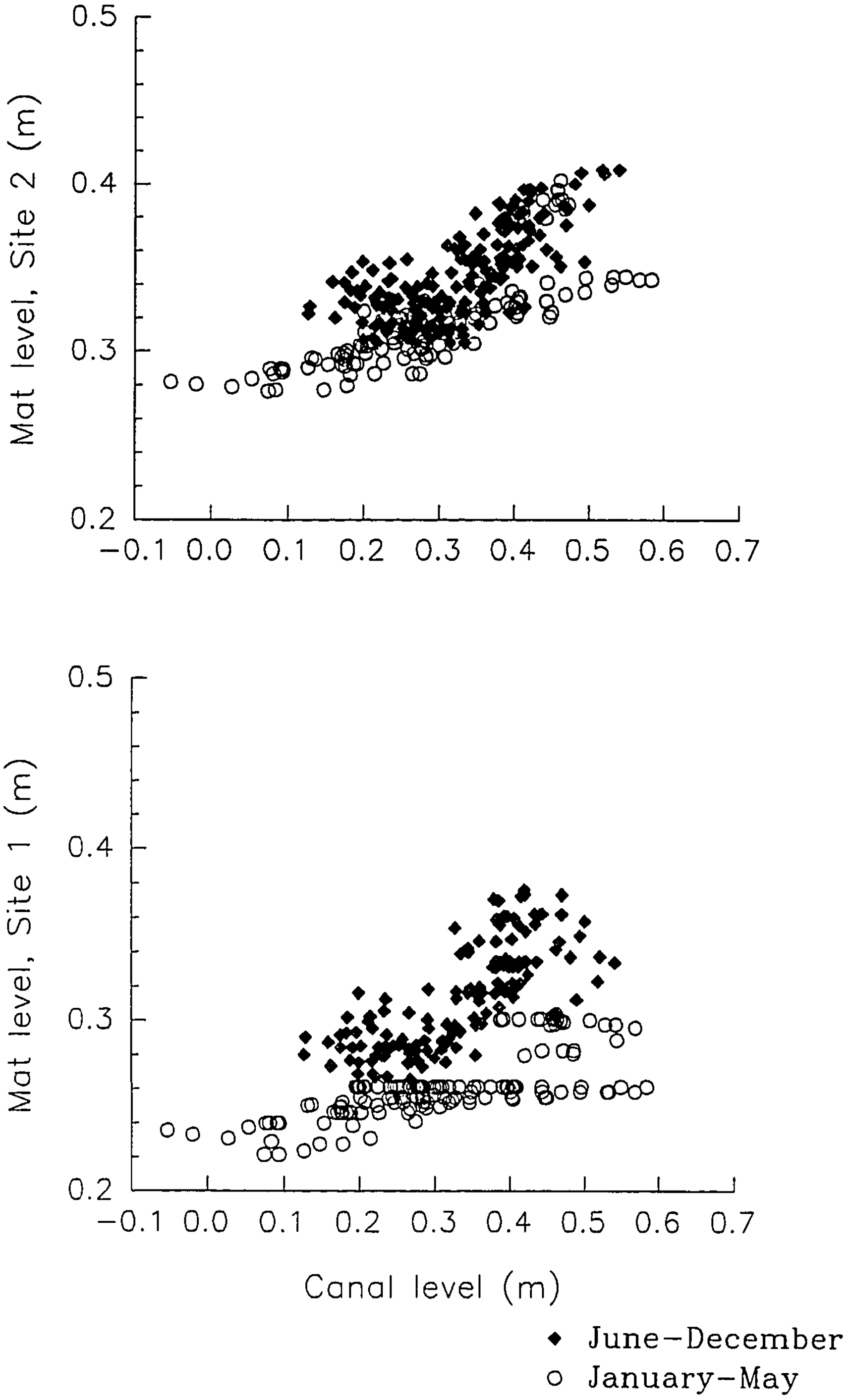
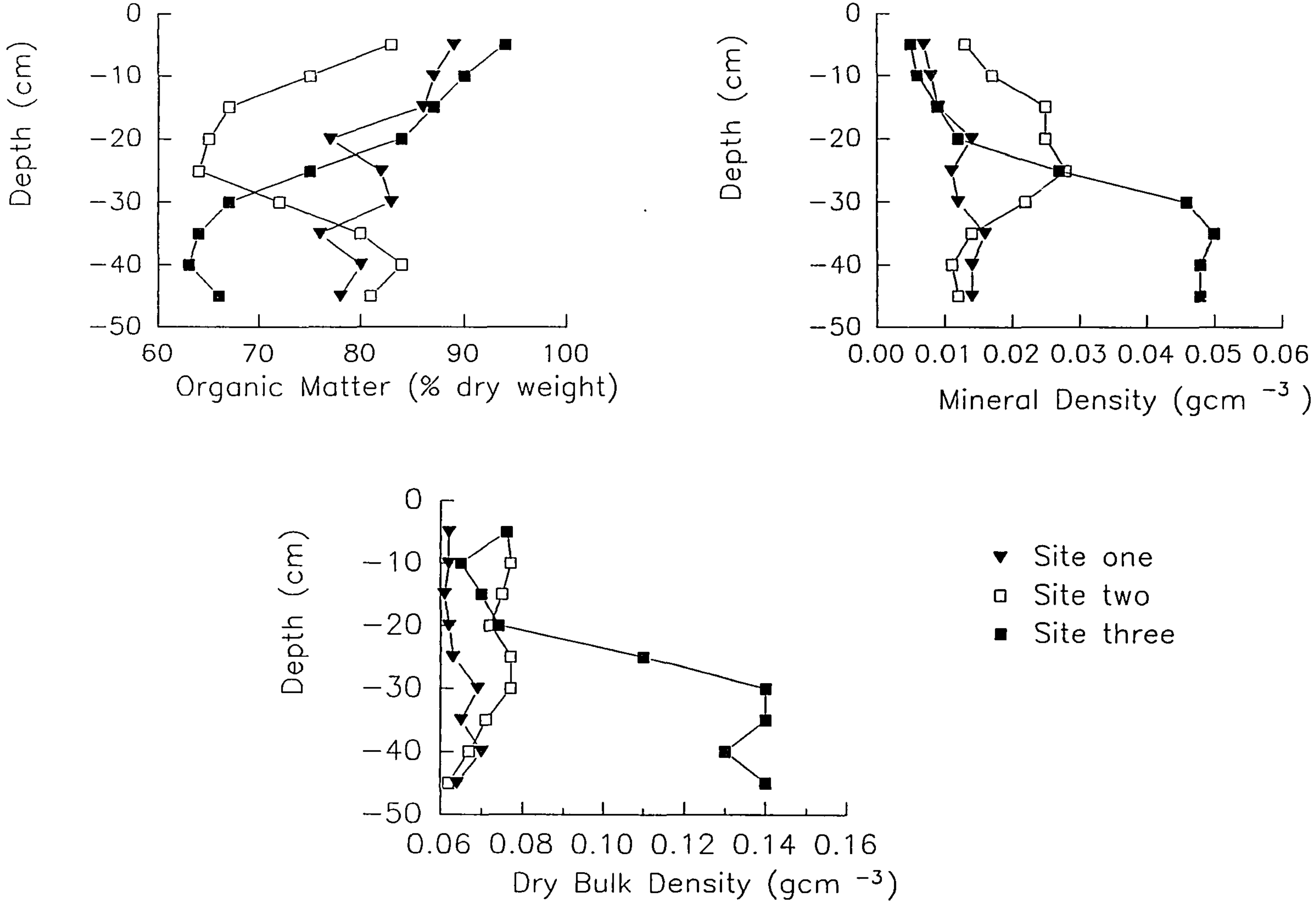

Mat level, Site 2 (m)
0.5
0.4
0.3
0.2
−0.1 0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
Mat level, Site 1 (m)
0.5
0.4
0.3
0.2
−0.1 0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
Canal level (m)
◆ June−December
○ January−May

FIG. 5. Organic matter content (% dry weight), mineral density and bulk density distribution with depth at the floating marshes (Sites 1 and 2) and the rooted marsh (Site 3) near Lake Salvador, Louisiana. Values are means of 4 to 5 measurements.


Depth (cm)
0
−10
−20
−30
−40
−50
60
70
80
90
100
Organic Matter (% dry weight)
Depth (cm)
0
−10
−20
−30
−40
−50
0.00
0.01
0.02
0.03
0.04
0.05
0.06
Mineral Density (gcm −3)
Depth (cm)
0
−10
−20
−30
−40
−50
0.06
0.08
0.10
0.12
0.14
0.16
Dry Bulk Density (gcm −3)
▼ Site one
□ Site two
■ Site three

organic matter content remained around 80% to a depth of 45 cm. At Site 2, organic matter in the upper 30 cm of soil was as low as 60% of dry weight, but increased to over 80% below 30 cm.

The soil below 25 cm was significantly heavier at Site 3 than at Sites 2 or Site 1 (Table 1) and organic matter content was lowest at these depths at Site 3. In the upper 25 cm of substrate, organic matter content was significantly lower than at Sites 1 and 3.

2.3.3 Subsurface characterization

At all three sites the mat layer consisted of fibric tightly intertwined root material. Below this well-structured mat layer the amounts of clastic and organic sediment differed from site to site (Fig. 6).

At Site 1, the mat layer was 17-23 cm thick from 50 m inland to the edge of the canal. There was no difference in mat thickness from inland to the marsh edge. Immediately below this layer was similar but slightly softer and more decomposed material, extending to about 29 cm below the surface. Below this layer the material was very decomposed and soft. Some finely divided organic matter was mixed in with the plant fragments. This layer, extending to about 45 cm below the surface, lost its shape upon removal from water. Most free water drained out of the soil upon removal from the water. Below this layer was soft, very loose and finely divided organic material which consolidated into a fine brown muck below 80 cm. Small clay lenses (5-10 cm) were present at 130-155 cm below the surface and again from 168-175 cm.

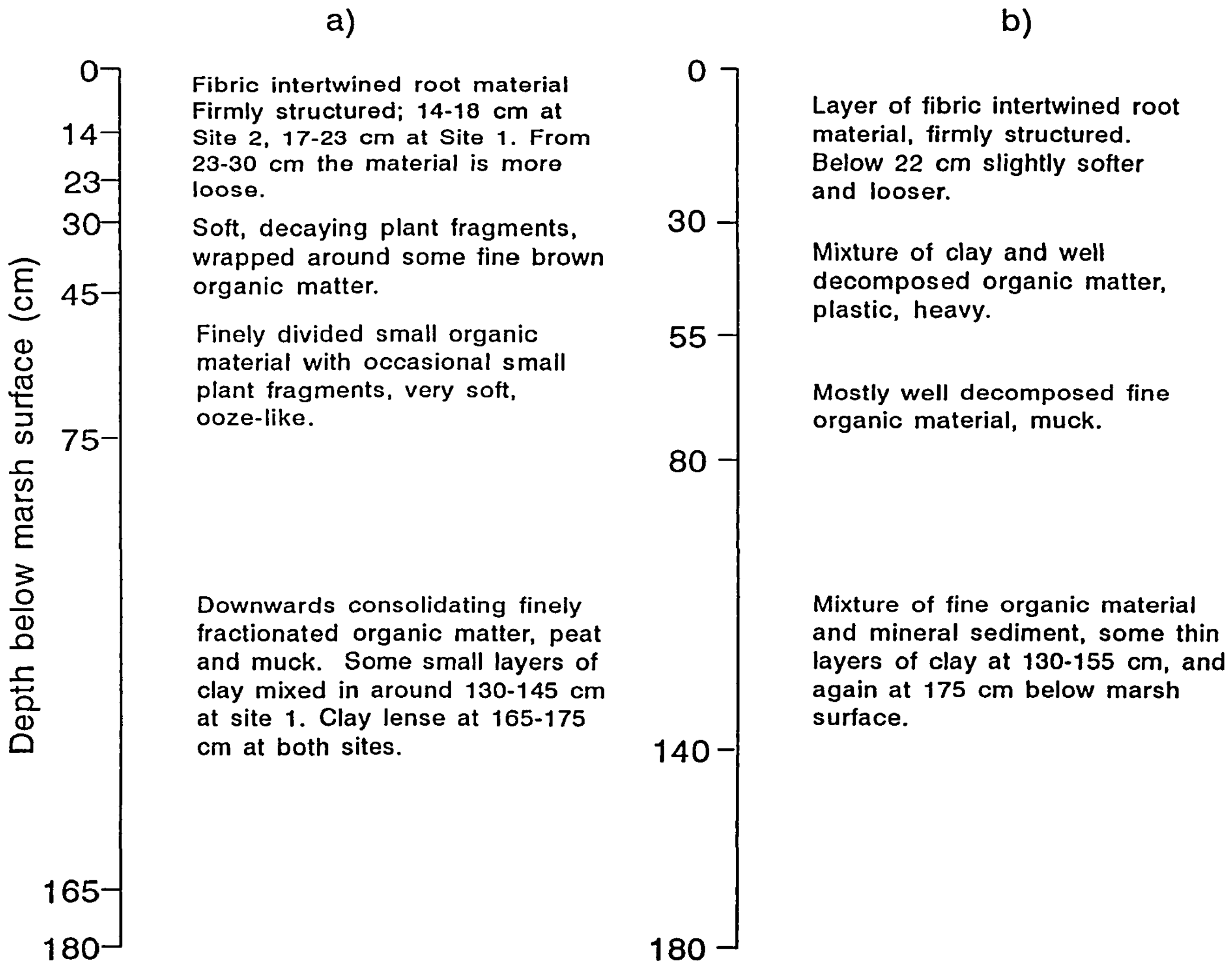
At Site 2, the mat layer was 14-18 cm thick. Again there was no gradient in thickness with distance from the water's edge. The slightly looser layer under the mat extended to 24 to 30 cm below surface. Below this layer was fragmented plant material

TABLE 1. Mean bulk densities and organic matter content (± 1 s.d.) of the shallow substrate at the floating marshes (Sites 1 and 2) and the rooted marsh (Site 3) near Lake Salvador, Louisiana[1/].

	SITE 1		SITE 2		SITE 3	
Depth (cm)	Bulk Density g cm^{-3}	Organic Matter Content (% dry weight)	Bulk Density g cm^{-3}	Organc Matter Content (% dry weight)	Bulk Density g cm^{-3}	Organic Matter Content (% dry weight)
-5	0.002±0.009^a	89±03^a	0.076±0.003	83±02^a	0.076±0.007	94±02^a
-10	0.062±0.007	87±01	0.071±0.004	75±50^a	0.065±0.007	90±02
-15	0.061±0.006	86±02	0.075±0.015	67±04^a	0.070±0.010	87±03
-20	0.067±0.006	77±07	0.072±0.008	65±04^a	0.075±0.011	84±04^a
-25	0.063±0.007	82±02	0.077±0.011	64±04^a	0.110±0.017^a	75±08
-30	0.069±0.012	83±04^a	0.077±0.013	72±02	0.140±0.026^a	67±09^a
-35	0.065±0.005	76±12	0.071±0.010	80±05^a	0.145±0.045^a	64±06^a
-40	0.071±0.026	80±08	0.067±0.010	84±02	0.134±0.016^a	63±01^a
-45	0.064±0.008	78±05	0.062±0.016^a	82±04^a	0.143±0.049^a	66±04^a

[1/] ^{a} indicates significant difference ($p<0.05$) among sites for the depth and parameter indicated.

FIG. 6. Visual characterization of the upper 180 cm of substrate for a) the floating and b) the rooted marsh type near Lake Salvador, Louisiana.



a)

Fibric intertwined root material Firmly structured; 14-18 cm at Site 2, 17-23 cm at Site 1. From 23-30 cm the material is more loose.

Soft, decaying plant fragments, wrapped around some fine brown organic matter.

Finely divided small organic material with occasional small plant fragments, very soft, ooze-like.

Downwards consolidating finely fractionated organic matter, peat and muck. Some small layers of clay mixed in around 130-145 cm at site 1. Clay lense at 165-175 cm at both sites.

b)

Layer of fibric intertwined root material, firmly structured. Below 22 cm slightly softer and looser.

Mixture of clay and well decomposed organic matter, plastic, heavy.

Mostly well decomposed fine organic material, muck.

Mixture of fine organic material and mineral sediment, some thin layers of clay at 130-155 cm, and again at 175 cm below marsh surface.

with some fine organic matter. From 45 cm to about 75 cm finely divided organic material, sometimes with plant fragments, was present. Twenty five to 50% of the core volume was lost with each sample during retrieval. From 75 to at least 180 cm the organic material consolidated. There was a clay layer at 165 to 175 cm below the marsh surface.

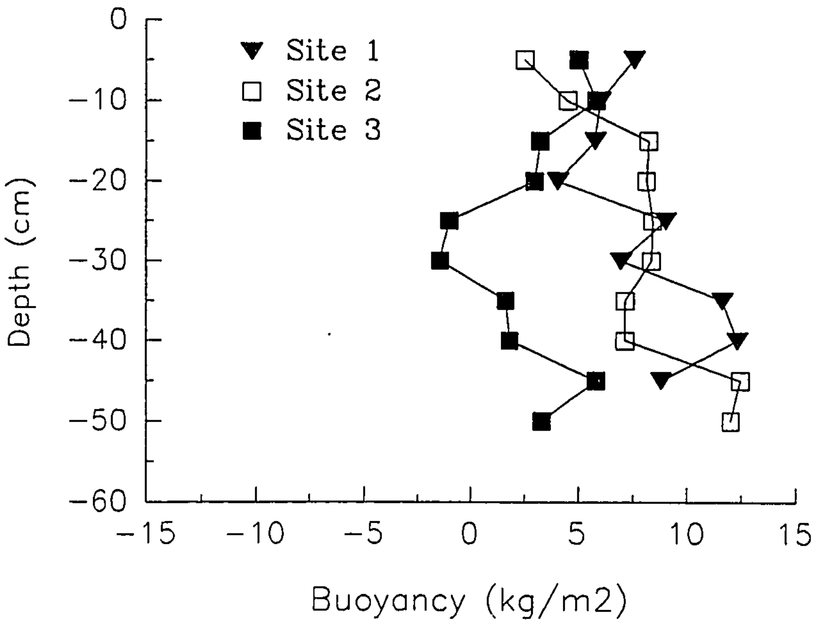
Fifty m inland at Site 3, the mat layer was 22-24 cm thick. From 25-31 cm the organic material was slightly softer and looser. Below this organic layer was a mixture of heavy mineral and well decomposed organic matter to about 55 cm. The clayey layer started at 24 cm and 18 cm below the marsh surface at distances 25 and 5 m meters, respectively, from the canal edge. Below this clayey layer was a mixture of peat amd muck to about 80 cm, and below this depth to at least 180 cm was a mixture of mineral and organic deposits. The proportions of each varied, with more clay occurring in the interior of the marsh.

Root growth into the empty bottles buried at 45 cm depth was 0.162 mg cm^{-3} at Site 3 and 0.048 mg cm^{-3} at Site 1. These results are the average of four samples, but because they were weighed together, an estimate of variability was not possible. No samples were recovered from Site 2.

2.3.4 Contribution of substrate to buoyancy

Buoyancy was similar in the upper 25 cm at Sites 1 and 3 and decreased slightly with depth. At Site 2 buoyant force was higher (Fig. 7). At depths greater than 25 cm, buoyancy at Site 3 was substantially less than at the two floating sites. From 25 to 35 cm, values were negative at Site 3, indicating a non-buoyant layer with a net downward force. At Sites 1 and 2 the contribution below 25 cm was somewhat comparable.

FIG. 7. Buoyancy of the substrate at the floating marshes (Sites 1 and 2) and the rooted marsh (Site 3) near Lake Salvador, Louisiana.


▼ Site 1
☐ Site 2
■ Site 3
0
−10
−20
−30
−40
−50
−60
Depth (cm)
−15
−10
−5
0
5
10
15
Buoyancy (kg/m2)

2.4 Discussion

The mat moved freely in response to open-water fluctuations at Site 1, at least during part of the year, was restricted in vertical oscillations at Site 2 and did not float at all at Site 3, where the mat was firmly anchored to the non-buoyant substrate. The response of the mat to water-level fluctuations was seasonal at both floating marshes. Differences in soil structure and bulk soil parameters correlated with the degree of mat movement exhibited at each marsh.

The seasonal change from a non-buoyant to a fully buoyant mat at Site 1 and from a less buoyant to a more buoyant mat at Site 2 was likely caused by increased rates of gas production and root growth caused by the higher temperatures in summer. Seasonal buoyancy of the marsh at Site 1 had been previously measured, but at a different location (Swarzenski et al. 1991). The present study provides evidence that the seasonality of mat movement is a recurring feature of this marsh. The authors suggested that the roots of the dominant emergent vegetation at this site cannot develop a sufficiently buoyant mat to maintain the buoyant condition of the mat during the winter months, when gas production is limited by low temperatures. Krusi and Wein (1988) have shown how gas generation through anaerobic decomposition is temperature-limited. Swarzenski et al. (1991) hypothesized that the root system of the emergent vegetation plays a key role in mat buoyancy during those times when the rates of anaerobic metabolism and gas generation are reduced.

Differences in the bulk properties in the upper 45 cm of soil resulted in differences in mat movement at all three sites. The ability to float was correlated with the presence or absence of a heavy non-buoyant soil layer at depths greater than 25 cm below the marsh surface. Differences in mineral density and perhaps dominant emergent vegetation influenced the degree of mat response to open-water fluctuations.

The major differences among sites in the measure of buoyancy used in this study occurred at depths greater than 25 cm. At Site 3, the buoyant tendencies of the soil were mostly near zero at this depth, and even negative from 25 to 35 cm. In the floating marshes, buoyancy is still positive. This measure of buoyancy is an approximation of the buoyant forces. It is unclear how much of the water contained in the soil pores weighs down or contributes to mat buoyancy. It was assumed in this study that all of the water that did not freely drain was weighing the mat down. Our experience has shown that the peat layer of the floating marshes cannot support much downward force; the mat contains most of the buoyant force which supports a person's weight for short periods of time. While taking the soil cores, the lower portions of the peat at the two floating marsh sites lost water rapidly, and at least some of the apparently high buoyant force at these depths at Sites 1 and 2 was due to the excessive loss of water during sampling. Water loss was not a problem in the soil near the surface in the two floating marsh sites, and along the whole depth interval at Site 3. This measure of buoyancy provided a useful comparison of buoyant tendencies among the three sites.

The upper 25 cm of substrate at Sites 1 and 3 both had similarily low mineral densities. Site 3 was slightly more organic than Site 1. The vegetation at Sites 1 and 3 was dominated by the same vegetation, namely *Sagittaria falcata*. Thus, neither vegetation nor soil characteristics could account for differences in mat movement between the two sites. At Site 3, mineral and bulk density increased to 3-5 times greater than at Site 1 at depths below 25 cm. The increase in mineral density corresponded roughly to the decrease in buoyancy at this site. It appears that this non-buoyant layer is important in determining whether or not a highly organic, buoyant vegetation mat becomes detached. The denser layer affects mat movement at Site 3 by providing a non-buoyant substrate that can anchor the buoyant vegetation mat. Almost 4 times more root production was measured at 45 cm depth at Site 3 than at the floating marsh at Site 1. The dense soil provides a medium for roots to penetrate and counter the buoyant tendencies of the highly organic mat, which is very similar in structure and content to the mat at Site 1. The more clayey substrate at Site 3 may also be a less suitable substrate for the microbial community to decompose, and gas generation may also be reduced at this site.

At Site 2, as at Site 1, the layer from 25-45 cm was mostly organic and this layer was insufficient to anchor the mat against buoyant uplift. However, the top 20 cm was heavier and contained more mineral sediment than at Site 1. The heavier mat likely accounted for the dampened response to water-level fluctuations at Site 2. However, the difference in seasonal buoyancy compared with the Site 1 mat was more likely attributed to the different dominant species growing at Site 2. Site 2 contained, in addition to *Sagittaria falcata* , abundant growth of *Spartina patens.* The mat at Site 2 remained more buoyant than the mat at Site 1 in the winter months. Any weight effect due to the heavier mat at Site 2 would have reduced buoyancy in the winter months even more at this site. Vegetation type in addition to substrate conditions will affect mat buoyancy in a given marsh.

The mat at all three sites was comparable in terms of physical structure and consisted of a well-structured mass of intertwined root material. The mat layer at Site 3 increased in thickness with increasing distance from the canal. There was no lateral gradient in mat thickness in the floating marshes. Streamside accretion rates are greater than in the marsh interior in rooted marshes (Hatton et al. 1983). A similar relation has not been established for floating marshes. The difference in physical structure between floating and rooted marshes was most evident at depths of 25 to 80 cm below the marsh surface. In the rooted marsh there was a layer of mineral sediment at depths of 25 to about 50 cm. Organic matter in this layer was finely fractionated and contained within the clastic sediment. At the same depth, organic matter in the two floating marshes consisted of decomposing large plant fragments with little clay or finely divided organic material. From about 45 cm to 80 cm the floating marshes consisted of very fluid finely decomposed organic material. At this depth the substrate at the rooted marsh had a much thicker consistency. Recovery with a coring tube was almost 100 %.

In the floating marshes it was the mat and peat layers which moved vertically in response to changes in ambient water levels. Most of the buoyant force was contained in the mat layer. The peat layer could not support much downward force imposed on it. Instead, the decomposing organic material at this depth shrank and expanded as water levels rose and fell.

The shallow sediments at all three sites fall into the organic-rich or true peat categories, with 35%-75% and >75% organic material respectively (Kosters et al. 1987). The authors described the distribution of these organic deposits in the Barataria Basin. The primary shallow organic depositional sequences in BB occurred in two stages, from 2300 yr to 1000 yr before present, and from roughly 500 yr before present to the present time. This latter stage is still ongoing in the upper parts of the basin, but marine transgression caused by regional subsidence has halted organic deposition further gulfwards. An intervening episode of clastic sedimentation shows up in cores of Kosters (1989) but was not distinguished at the three marshes of this study.

2.4.1 Environmental Setting

The widespread occurrence of floating marshes in the MRDP was originally reported by Russell (1942) and O'Neil (1949). The origin and distribution of floating marshes in the MRDP was thought to be mostly a recent phenomenon, brought on by the introduction of water hyacinth to coastal Louisiana and subsequent rapid infilling of shallow water bodies with the resultant organic debris (Russell 1942), or alternately involved the gradual detachment by buoyant uplift of highly organic freshwater marshes because of regional subsidence (O'Neil 1949). It is likely that both mechanisms of floating marsh formation can and do occur, even simultaneously. They have vastly different implications in terms of the evolution and dynamics of the wetland landscape in the fresher parts of the MRDP and it is a valuable exercise to consider the proposed modes of formation within the context of the regional setting.

Through deltaic processes such as progradation of the river mouth downstream, and in recent times as a consequence of the leveeing of the riverbanks, clastic sedimentation in the upper reaches of interlobe basins is minimal. In these areas, marsh accretion is primarily through organic matter derived from the emergent vegetation itself. Site 3 provides evidence of the scarcity of mineral sediment here. Even though this marsh is anchored, and thus exposed to regular surface flooding from the adjacent canal, the substrate in the upper 20-30 cm is almost exclusively organic. Surface mineral densities are comparable to those at Site 1.

Concurrent with the organic accretion in the marshes, the MRDP is also experiencing subsidence of about 1 cm yr^{-1} (Hatton et al 1983). Mineral layers deposited through overbank flooding in earlier times are subsiding below zones of active root growth. As subsidence proceeds, the mineral layer moves down and is replaced by the highly organic and buoyant mat which can no longer be held down by root growth into a non-buoyant substrate.

Finally, the physiography of the upper reaches of interlobe basins also contributes to the occurrence of floating marshes. Natural slopes in the basin are very small. When water levels along the Gulf of Mexico are high, as is usual during the summer, water inside the basin does not drain. Periods of prolonged deep water may result in the interlobe basins (e.g continuous flooding for more than 60 days at Site 3). When the marsh is flooded, the root-substrate connection is stressed by the buoyancy inherent in the organic mats. Eventually, marshes in the fresh areas detach. Erosion of peat through wind-induced water table fluctuations may facilitate the severing of the root-substrate connection. Lateral movement of water above the interface between a more permeable and less permeable layer (e.g mat and heavier layer at Site 3) is greatly enhanced (Miller 1973).

Under these conditions, the development of many floating marshes in the MRDP through buoyant detachment from a non-buoyant substrate seems probable. Gradual infilling of shallow water bodies as a mechanism for the formation and observed widespread occurrence of floating marshes in Louisiana seems less probable. Buoyant uplift has also been described for the formation of the floating marshes in the Danube Delta (Rodewald-Rodescu 1974) and for the buoyant detachment of a vegetation mat subsequent to flooding reported by Kruesi and Wein (1988) for a northern reed marsh. Taken within the context of the regional setting and what has been learned about the Mississippi Delta Plain in the past 40+ years (e.g. that floating marshes can be identified in stratigraphic record of prior delta-building sequences, Yi-ih 1988) O'Neil's original hypothesis seems to me the stronger of the two proposed mechanisms for the formation of floating marshes.

2.5 Summary

I examined the relation between buoyancy and the shallow substrate of two floating marshes and one rooted marsh in the low-salinity marshes of MRDP. The upper 25 cm at all three marshes was low density, mostly organic material, with buoyant properties. A non-buoyant layer of more mineral sediment below 25 cm at the rooted marsh kept this mat from detaching when it was flooded, possibly by providing a non-buoyant medium for roots of emergent vegetatio to anchor in. In the two floating marshes, the soil at 25 cm and deeper was more organic than at the rooted marsh, and was not able to anchor the mat against buoyant uplift. A large portion of the floating marshes in the MRDP appear to evolve from what were formerly rooted marshes. They appear to be a recurring feature of the MRDP wetland landscape, part of the delta cycle of seawards progradation and landwards marine transgression that has been occurring in coastal Louisiana since stabilization of sea level at current levels some 8,000 years ago.

Chapter III

SOIL SALINITY FLUCTUATIONS IN FLOATING AND ROOTED MARSHES

3.1 Introduction

Soil salinity is one of the principle factors determining patterns of vegetation zonation and productivity in a wetland landscape (Odum 1988). Plant response varies depending on length of exposure to, and absolute concentrations of, soil salinity (McKee and Mendelssohn 1989, Smart and Barko 1980, Liefers and Shay 1982). Plant community structure is often determined by long-term patterns in the ambient salinity regime (Zedler and Beare 1986). This parameter is mostly controlled by hydrological and climatological factors (Casey and Lasaga 1987), although vegetation may exert influence on salinities directly through secretion (Rozema et al., 1981 Smart and Barko 1980) and indirectly by influencing the water balance in the soil through evapotranspiration. Nevertheless, it is the physical environment which is most critical in determining salt concentrations in the soil.

Sources of salt in a marsh are primarily the adjacent surface waters (Adam 1990) but may in some instances be of relict origin (Price and Woo 1988). Salinity levels in marsh substrate are affected by advection and molecular diffusion. Salts may be carried in the water and move in response to pressure gradients. Where such pressure gradients are small, vertical gradients in salt concentration may be sufficient for molecular diffusion to be the dominant transport mechanism (Price and Woo, 1988). Topography and climate also affect salt levels in the marsh. Topography controls the hydrological gradient and leaching potential in the soil, whereas the water balance of the soil is controlled by the ratio of precipitation to evaporation. The interplay of these processes results in a spatial and temporal pattern of salt distribution in a given wetland.

Where the marsh is frequently and regularly flooded, soil salinities reflect the salinity of the flooding water (Beeftink 1977). As the frequency and duration of flooding decrease, soil salinities become more variable, reflecting an excess or scarcity of precipitation by the resulting dilution or hypersalinity (de Leuw et al. 1991). During periods of low rainfall, this may lead to higher soil salinities in a marsh that is located inland from, and at higher elevations, than a marsh fringing the fresh upper reaches of an estuary (Adam 1991). Typically, salinities increase with depth in the upper meter of soil, but in areas where there is groundwater discharge an upward increasing gradient of salinity may result (Lindberg and Harriss 1979). Seasonal variations in salinity were limited to the upper 25 cm in a study of a salt marsh (Casey and Lasasga 1987). These authors found relative constant values below this depth. Price et al. (1987) and Earle and Price (1988) provided interesting examples of how these processes may interact to produce localized characteristic soil salinities in Canadian coastal wetlands.

The purpose of this research was to examine the dynamics of soil salinity with respect to depth and distance from the adjacent surface water in shallow marsh substrate in coastal freshwater marshes. Frequent measurements of salinity were made over a three-year period to study the interaction of surface-water salinities with soil salinities in the marsh substrate. Two hydrologically distinct marsh types, one floating and the other firmly anchored, were used for this study. An understanding of soil salinities and how they relate to open-water salt concentrations is critical to understanding the patterns of vegetation distribution and productivity of coastal wetlands.

3.2 Methods

Samples (5 ml) for measurement of salinity were collected in triplicate 1 m (berm) and 50 m (inland) from the adjacent canal, at 5 cm depth intervals to 25 cm, and at depths of 50, 75 and 100 cm. Samples were also collected in the adjacent canal 50 cm below the surface of the water. Samples were collected from October 15, 1987 until May 8, 1990, initially at approximately monthly intervals and every 60 to 90 days after July 15, 1988. From May 19 to August 30, 1989 the sampling frequency was every 14 days. After August 14, 1989, a third location at each site, 15 m from the berm, was added to the sampling regime.

Salinities were calculated from chlorinity values (Strickland and Parsons 1982) measured with a Hakke-Buchler chloridometer. Values are given in ppt, and are assumed equivalent to g of total salts per kg of water. Soil salinity and soil salt content refer to values obtained in this manner.

Pore waters were collected using PVC well points (1.5 cm i.d.), perforated over 2 cm at the appropriate depth to allow entry of water. Dedicated well points were used for each depth. To collect samples, the well points were pushed into the marsh, and allowed to fill.

For some analyses, samples from 5 to 25 cm were averaged to obtain mat salinities and samples from 50 to 100 cm were averaged to obtain sludge salinities. Analysis of variance (Sokal and Rohlf, 1988) was used to test for significant differences between mat and sludge at a given site and location, for significant differences of the comparable horizon between locations within a site and among sites at corresponding locations. Site refers to a particular marsh, location refers to position within a site relative to the canal, and horizon refers to the depth below marsh surface where the sample was taken.

Mean summary statistics were computed for each depth interval for both horizons at all locations and sites.

Canal salinities were correlated with mat and sludge salinities at the berm and 50 m inland at all three sites using a linear model to calculate Pearson correlation coefficients (SAS, 1985). The non-parametric Kendall Tau statistic (Hirsch et al. 1982) with a block for season was used to test for significant monotonic trends in mat and sludge salinities with time.

3.3 Results

3.3.1 Mean conditions

There was considerable range in salinities for both horizons at all locations during the period of study (Table 2). Mat salinities in the two floating marshes (Sites 1 and 2) ranged respectively from 0.1-1.9 ppt and 0.3-2.5 ppt, and in the firmly anchored marsh from 0.4-3.4 ppt. In the sludge, salinities at Site 3 ranged from 1.1-5.0 ppt, with highest values found in the inland location. In the floating marshes, sludge salinities ranged from 0.4 to 3.8 ppt, with highest values obtained at the berm.

Berm salinities at a given horizon and site were significantly lower than corresponding inland salinities ($p < 0.05$, Table 2.) The exception was the sludge at Site 1, where there was no significant difference between the berm and the interior location. Within a given site and location, mat salinities were significantly lower than sludge salinities ($p < 0.05$). Finally, salinities at Site 3 were significantly higher than those at Site 2 (1.91 vs. 1.20 ppt in the mat inland at Sites 3 and 2 respectively) which were higher than those at Site 1 (1.07 ppt) for horizons at corresponding locations. The exception was the berm, where mat salinities at Site 1 and Site 2 were not statistically different (0.87 and 0.86 ppt respectively); sludge salinities were significantly higher at Site 1 (1.29 ppt) than at Site 2 (1.10 ppt, $p < 0.05$).

3.3.2 Mat and sludge salinities

Mat and sludge salinities varied in response to open-water salinity at all three sites (Fig. 8).

At Site 1, open water salinities were mostly less than 1 ppt except for several weeks in the winter of 1987-1988. Mat and canal salinities closely paralleled each other

TABLE 2. Mean (± 1 s.d.) and range of salinities in the mat (5-25 cm depth) and sludge (50-100 cm) at the floating marshes (Sites 1 and 2) and rooted marsh (Site 3) near Lake Salvador, Louisiana. Values are pooled for the complete study interval.

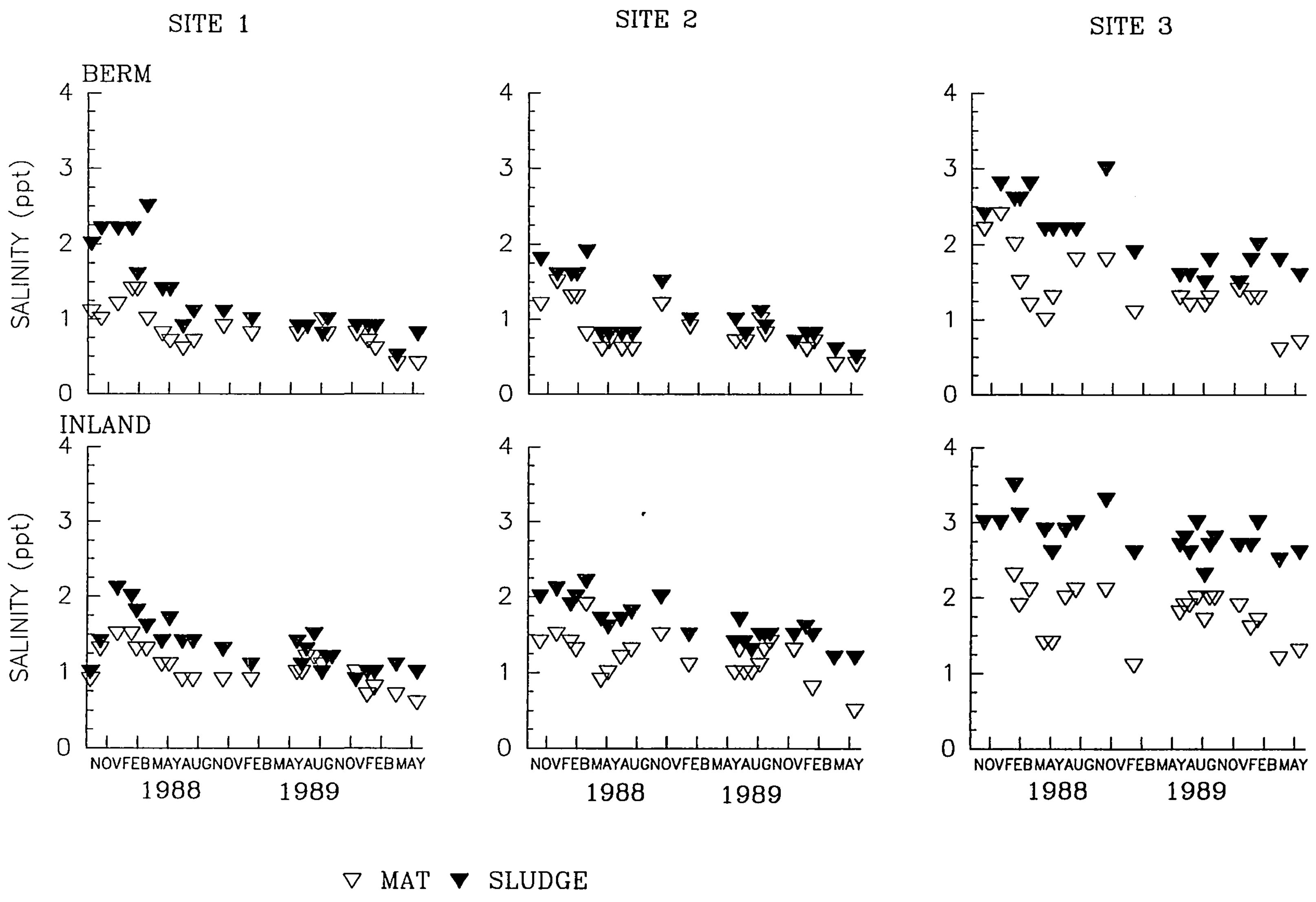
		BERM			INLAND		
		n	mean±s.d.	range	n	mean±s.d.	range
Site 1	mat	182	0.87±0.31	0.1-1.8	239	1.07±0.29	0.4-1.9
	sludge	144	1.29±0.65	0.4-3.8	169	1.32±0.40	0.7-3.3
Site 2	mat	171	0.86±0.35	0.3-1.7	241	1.20±0.41	0.2-2.5
	sludge	147	1.10±0.41	0.4-3.7	179	1.65±0.41	0.7-3.3
Site 3	mat	157	1.43±0.41	0.4-3.4	224	1.91±0.52	0.7-3.4
	sludge	129	2.07±0.55	1.1-4.4	159	2.90±0.52	2.0-5.0

1) Significant differences ($p<0.001$) between mat and sludge salinities at all locations at all sites

2) Significant differences ($p<0.001$) between mat values at all three sites and bewteen sludge values at all three sites at all locations except for berm mat salinities at Sites 1 and 2.

3) Significant differences ($p<0.001$) of mat values and of sludge values between locations at all three sites except at Site 1.

FIG. 8. Mean (± 1 s.d.) salinities in the porewaters of the mat (5-25 cm depth) and sludge (50-100 cm) at the floating marshes (Sites 1 and 2) and rooted marsh (Site 3) near Lake Salvador, Lousiana (by sampling date).


SITE 1
SITE 2
SITE 3
BERM
INLAND
SALINITY (ppt)
SALINITY (ppt)
0
1
2
3
4
NOVFEBMAYAUGNOVFEBMAYAUGNOVFEBMAY
1988
1989
▽ MAT ▼ SLUDGE

(r=0.88, Table 3), although mat salinities were slightly higher than canal values. At the beginning of the study, sludge salinities at the berm were high, but these values decreased rapidly once canal salinities dropped (after April 1988). The gap between mat and sludge was greatest in the first six months of the study. Fifty m inland, mat salinities also tracked open-water salinities (r=0.76), but the response to canal salinities was slower than at the berm. Initially, salinities increase in the mat, but after canal salinities decreased, mat salinities also decreased here, although at a slower rate than at the berm. The sludge values inland decreased the slowest at Site 1, but correlated better with canal salinities (r=0.76) than did the berm values (r=0.58).

At Site 2, open-water salinities were marginally higher than at Site 1 and followed the same trends. At the berm, mat and sludge salinities tracked open-water salinities very closely (r=0.85). The difference between mat and sludge was small. At the inland location, mat and sludge salinities were higher, and the difference between mat and sludge values was greater than at the berm. Mat salinities correlated poorly with canal salinities (r=0.42). Differences in mat and sludge salinities were greater in late winter and smaller in the summer months.

At Site 3, salinities in both horizons at the berm decreased gradually as canal salinities decreased. The difference between mat and sludge here was greater than at any of the locations at the other two sites. There was a seasonal increase in this difference during the winter months, when mat salinities dropped. The highest salinities during this study were found 50 m inland at this site. Salinities showed only a very slight decrease over the course of the study in response to the low canal salinities prevailing during the last two years of the study. Mat salinities at the berm and 50 m inland tracked canal salinities equally well (r=.60), but it was the sludge layer which correlated well with open-water salinities at the berm (r=0.79). Sludge salinities in the marsh interior correlated poorly with canal salinities (r=0.42).

TABLE 3. Correlations[1/] between canal salinities and marsh salinities and trend analyses[2/] at the respective horizons at the floating marshes (Sites 1 and 2) and rooted marsh (Site 3) near Lake Salvador, Louisiana.

SITE	HORIZON	BERM				INLAND			
		Trend	p	r	p	Trend	p	r	p
1	mat	(-)	0.016	0.88	0.000	(-)	0.096	0.76	0.000
	sludge	(-)	0.000	0.58	0.007	(-)	0.007	0.76	0.000
2	mat	(-)	0.041	0.85	0.000	(-)	0.014	0.42	0.076
	sludge	(-)	0.008	0.75	0.001	(-)	0.000	0.73	0.000
3	mat	(-)	0.001	0.59	0.012	(-)	0.001	0.60	0.005
	sludge	(-)	0.003	0.79	0.000	(-)	0.007	0.42	0.065

[1/] Pearson's correlation coefficient.

[2/] Kendall's non-parametric Tau statistic (Hirsch et al. 1982) (H_o: slope is equal to zero).

3.3.3 Depth distribution of salinity

Isohalines (0.5 ppt intervals) were mapped at approximately two to three month intervals from August of 1989 to May 1990 (Fig. 9). During this period and for the six prior months canal salinities varied from 0.5 to 1 ppt. A record of canal water levels as well as precipitation during this time are given in Fig. 10.

At Site 1 most of the substrate between open water and 50 m inland was approximately 1 ppt until March of 1990. In March and May of the following year salinities increased slightly; a 1.5 ppt isohaline developed near the 100 cm depth inland. Salinities were mostly low and homogeneous in the shallow substrate.

At Site 2 salinities were slighly higher. The 1.0 ppt isohaline vertically split the area in half at the beginning, then was pushed farther inland in the next sampling period. From November to January, during a period of continously low water levels, the 1.0 ppt isohaline moved towards the canal. Most of the inner shallow substrate increased to greater than 1.5 ppt. As water levels rose, the 1.0 isohaline moved farther inland and deeper. By March of the following year, the highest salinities (1.5-2.0 ppt) were found along the inland bottom.

Salinities at Site 3 were higher than at the other two sites. Salinities in the substrate were greater than 2.5 ppt except near the berm. In November, the 2.5 ppt isohaline moved deeper near the berm. In the marsh interior and along the surface, conditions remained as before. After the low period of low water, the 3 ppt isohaline moved towards the canal and a 3.5 ppt isohaline developed in the interior of the study area. The area of salinity greater than 3.5 ppt increased from January to March 1990 along the bottom of the substrate. Finally, the substrate freshened again in May of 1990, with the 2.5 to 3 ppt band being pushed to the lower interior of the marsh. Near the berm and near the surface, salinities dropped considerably.

FIG. 9. Lines of equal salinity for the top 100 cm of substrate (0.5 ppt intervals) at the floating marshes (Sites 1 and 2) and rooted marsh (Site 3) near Lake Salvador, Louisiana.

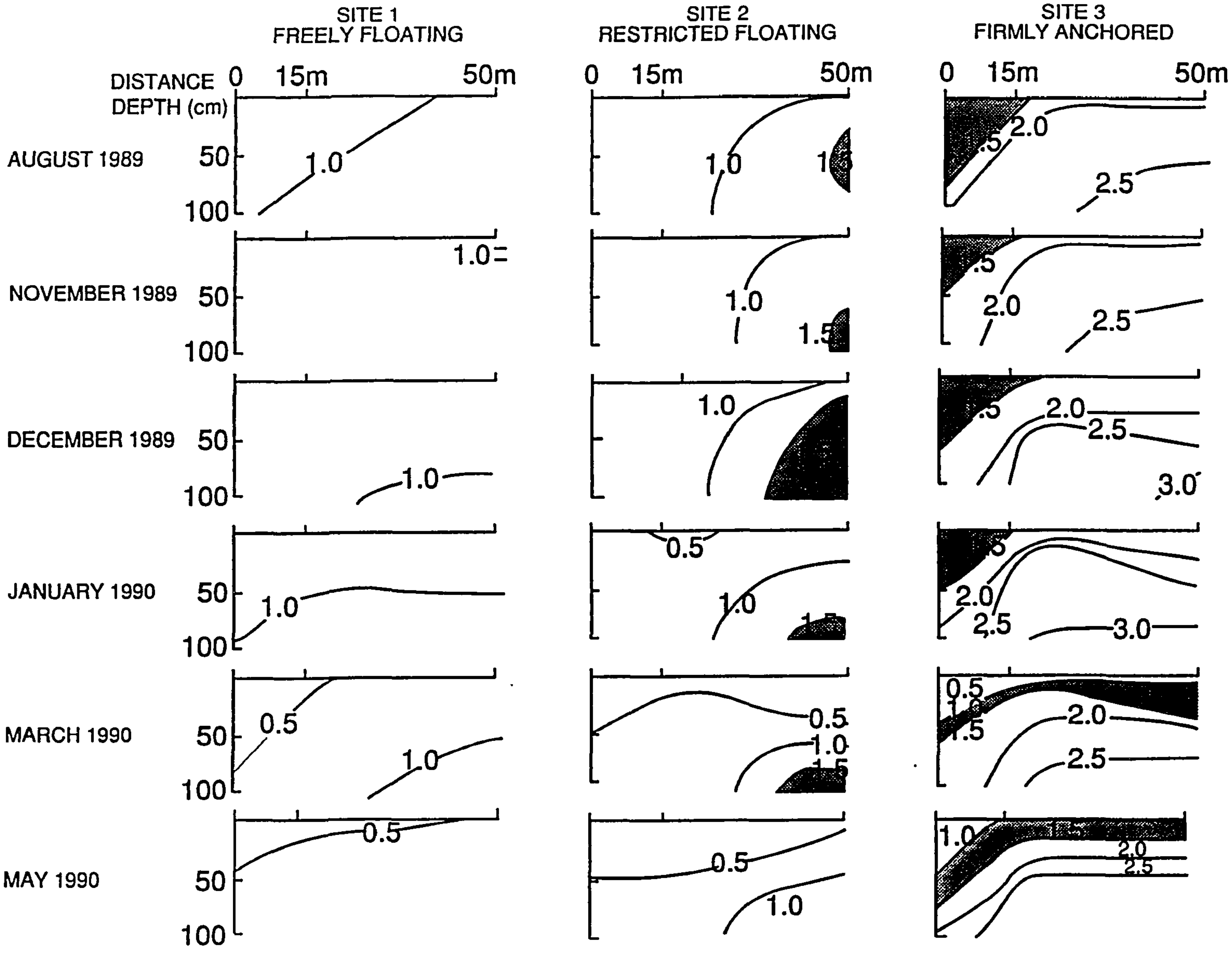
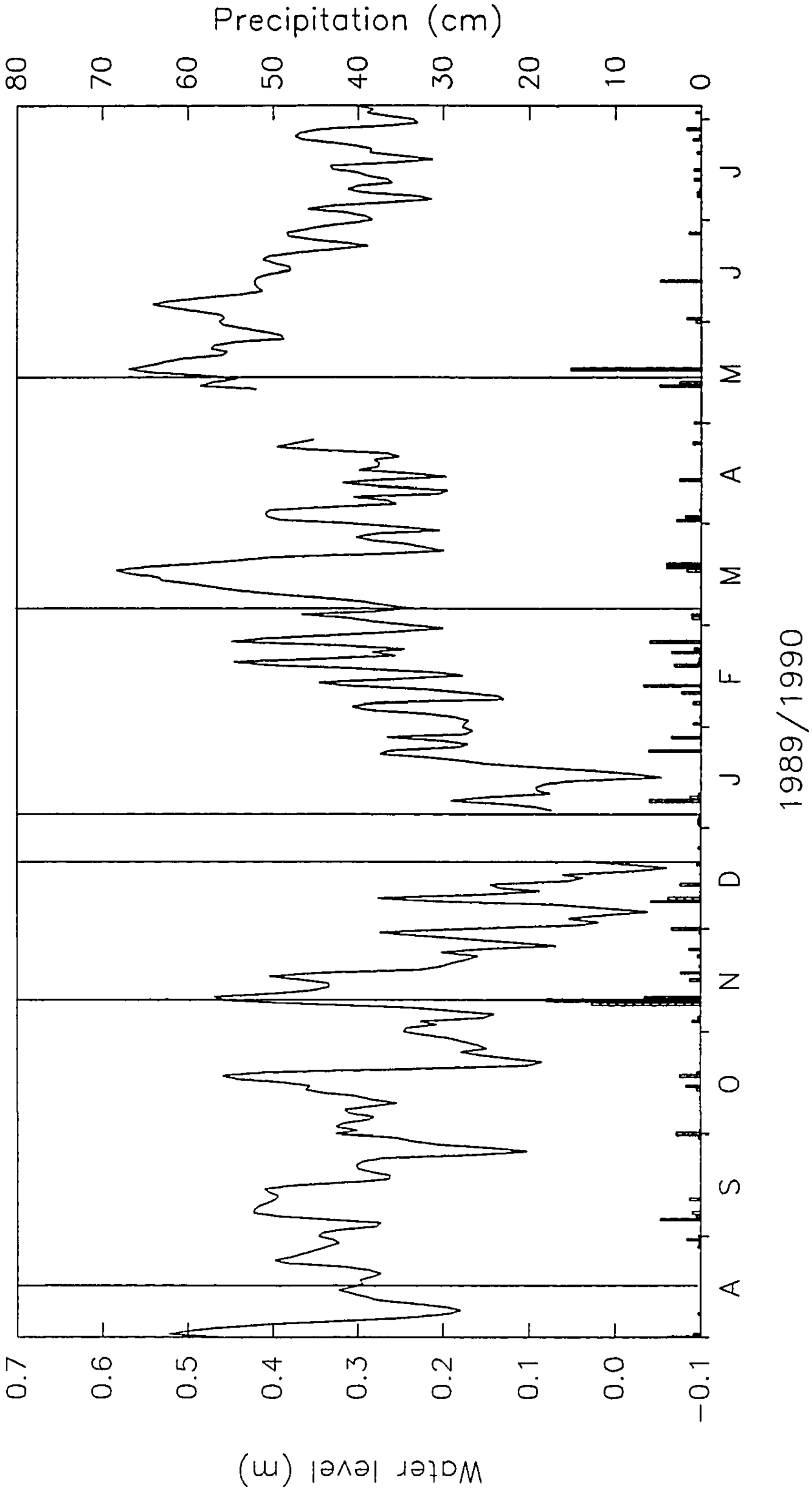

SITE 1
FREELY FLOATING
SITE 2
RESTRICTED FLOATING
SITE 3
FIRMLY ANCHORED
DISTANCE
DEPTH (cm)
0
15m
50m
50
100
AUGUST 1989
NOVEMBER 1989
DECEMBER 1989
JANUARY 1990
MARCH 1990
MAY 1990
0.5
1.0
1.5
2.0
2.5
3.0

FIG. 10. Record of open waterlevels and precipitation at Lake Salvador, Louisiana for the period August 1989 to July 1990. Water levels were measured in the canal at Site 1; precipitation was recorded by the National Park Service at Jean Lafitte National Historic Park, 8 km from the study area.


Precipitation (cm)
80
70
60
50
40
30
20
10
0
Water level (m)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
A
S
O
N
D
J
F
M
A
M
J
J
1989/1990

3.4 Discussion

Soil salinities followed the salinities of the surface water more closely in the two floating marshes than in the firmly anchored marsh, and more closely in the freely floating marsh than in the restricted-floating marsh. There was considerable variability in the data from one sampling period to the next and from one year to the next at each marsh. Salinity profiles were subject to rapid and complete change in the upper meter of soil in the two floating marshes. Salinities in the anchored marsh responded more gradually to changes in the ambient salinity regime.

Under the prevailing, mainly low, canal salinities, the freely floating marsh had the lowest overall salinities, whereas the firmly anchored marsh experienced the highest salinities. Soil salinities generally increased from the water's edge to 50 m inland, and also increased with depth at a given site and location. Only at Site 1 did berm salinities exceed inland values, and then only at the beginning of the study period, when canal values were at their highest levels.

The pattern of soil salinities in the study marshes appears to be chiefly a function of how rapidly and readily pore-waters mix with adjacent canal waters: the more complete the mixing, the closer pore-water salinities follow open-water salinities. The degree of mixing is affected by the degree of buoyancy, that is whether and how much a marsh is floating. In the firmly anchored marsh, there was belowground exchange of surface water with pore-water only along the edge of the canal. For the most part, water movement in the interior of such a marsh is restricted to the vertical direction in response to pressure gradients (Harvey et al. 1987). Salt enters or leaves the substrate in this way, or through diffusion across concentration gradients. The below-ground lateral transport between marsh and creek bank is very limited (Nuttle 1988). In the floating marshes lateral movement of water between canal and marsh was much greater as indicated by the degree of mixing. As water levels rose and fell, the vegetation mat moved up and down and canal water moved in under and through the mat to take up space or marsh water moved out from under the mat into the adjacent canal. Lateral advection was the dominant transport mechanism for porewater constituents; there was more rapid and complete mixing of interstitial and surface waters in buoyant marshes.

In the two floating marshes, pore-water salinities reflected the prevailing low salinities. Mat and to a lesser degree sludge salinities paralleled canal salinities near the canal/marsh edge. Farther inland salinities were slightly higher than open-water salinities. In the anchored marsh, salinities were much higher than those in the canal. The berm gradually freshened over the three-year study period, in response to near fresh conditions prevailing in the adjacent canal throughout the study period. Salinities decreased only very slowly at this site.

In the floating marshes there were fewer lines of equal salinity near the canal's edge to 50 m inland. The gradient near the surface was less pronounced than in the anchored marsh. For example, in the mat of the freely floating marsh salt concentrations were between 0.5 and 1.5 ppt. In the restricted floating marsh, salinities varied from 0.5 to less than 2.0 ppt. In the firmly-rooted marsh salinities varied as much as from 0.5 ppt to nearly 3.0 ppt within a given sampling period. The distribution of salt in the substrate at the floating marshes was more homogeneous than in the rooted marsh, likely reflecting lateral advection as the dominant transport mechanism of salt. The greater lateral below-ground flow in the floating marshes reduces the impact precipitation and evapotranspiration have on pore-water salt concentrations. In the rooted marsh, the water balance, and with it it salt concentrations, were impacted more immediately by evaporation and precipitation. For example, the range in salinities in the mat 50 m inland at Site 3 was from less than 1.0 ppt to 3.4 ppt. In the floating marsh across from the canal, mat salinities never reached beyond 2.5 ppt.

Inland salinities were invariably higher than berm salinities at Sites 2 and 3. This trend also held at Site 1 except for the early stages of the study, when there was a reversal of this gradient in response to high open-water salinities. This reversal of gradient again demonstrates the potential for rapid mixing of pore and canal water in a marsh with a buoyant mat.

The data also appeared to show a seasonal trend in the distribution of salinity with depth that was most pronounced in the marsh with the least direct connection between pore and canal waters. During summer, when evapotranspiration rates were highest, mat salinities were higher than in the winter, and the difference between mat and sludge salinities was small. In late winter/early spring, when there was an excess of water and only small evapotranspiration rates, mat salinities were lower than in the summer, and differences between mat and sludge were generally greater. This is noticeable for Site 3, and also inland at Site 2 whenever the sampling was frequent enough. This trend occurred regardless of canal salinity. Salinities in the canal were high in the winter of 1987-88, but not two years later. The winter drop in marsh mat salinities occurred regardless of canal salinity levels.

Exposure to the same external forcing (canal salinity) resulted in contrasting and interpretable salinities in the floating and rooted marsh types. Open-water salinities in this area of the MRDP vary seasonally and from year to year and it is the long-term patterns of open-water salinities, together with the distinct response of the two marsh types which will at least partially control which kind of plant species grow in the floating and rooted marshes.

Salinities in this part of the MRDP generally fall in the 0.5 to 5 ppt range with an annual variability of 1-2 ppt (Byrne et al. 1976). Surges in salinity that occur every 3-8 years may raise ambient salinities to 6-10 ppt for periods of weeks to several months.

The differences in hydrology between the floating and the rooted marsh type affect the marsh response to these surges. Data from this study indicate that through its more direct connections to canal waters, the floating marsh mat will be immersed in the higher salinity water. The anchored marsh will be affected by the high salinities mainly through vertical diffusion of salt into the substrate by overlying water, occurring only when water levels are high enough to flood the marsh. Salinities in the floating marshes will generally be low, but increase in response to any surge in open-water salinities. The anchored marsh will usually have higher salinities than the floating marsh during fresh conditions, but the soil will be buffered from events of high canal salt. The canal salt enters the marsh mainly through diffusive processes, only when there is overland flow.

Salinities in rooted marshes respond to changes in surface-water salinity only very gradually. Thus, levels measured in this marsh type reflect long-term average conditions rather than short-term conditions. Even after more than two years of continuously fresh open water, the marsh 50 m inland from the canal barely showed a decrease in salinities in the rooted marsh in this study and this marsh-type will be affected by long-term trends of increasing salinity in a different manner than the floating marsh type. Salinities will slowly increase in the anchored marsh. Mean salinities in the floating marsh would also increase, but periods of low salinity would still occur in this marsh type.

Periodic surges in canal salinities, as a quasi steady-state process, and long-term trends in salinity, a transient phenomenon, impact the plant species growing in this area. Brewer and Grace (1990), Zedler and Beare (1986) and Beare and Zedler (1987) emphasized the long-term interaction between species occurrence and salinity conditions. Salt-tolerant species may be able to persist in a fresh habitat with only occasional periods of high salinity. Brewer and Grace (1990) suggested that pulses of high salt may control the plant community in a low-salinity marsh of the MRDP. In their system, plant distribution was thought to occur in response to zones of soil salinity corresponding to distance from the edge of a lake subject to periodic storm surges and high salinity. The more salt-tolerant species persisted in their system even though salinities were fresh most of the time. In floating marshes conditions may shift from one where a salt-tolerant species is able to persist because of infrequent high salinities to a condition where a fresh species persists because of infrequent low salinities. In contrast, in an anchored marsh, salinities will follow the long-term conditions: eventually the fresh species will be replaced by the salt-tolerant species if there is a trend of increasing salinity.

3.5 Summary

Data from this study show salt concentrations in intermediate marshes of coastal Louisiana were variable with depth and distance from open water, from month to month and from year to year. Floating marshes tracked canal salinities closely and salt was distributed homogeneously throughout the upper 100 cm of substrate. Anchored marshes were buffered from short-term variations in canal salinity. Several years are needed to alter salinities in the marsh interior even slightly just 50 m from the canal edge. Along the canal marsh interface, canal salinity levels affected marsh salinity levels more noticeably. Seasonally varying rates of evapotranspiration were more important in changing porewater salinity levels in the marsh interior at the rooted marsh site.

The different marsh types resulted in distinct soil salinities occurring in an area subject to the same forcing conditions. The result may be plant species with different salt tolerances dominating in the respective marsh types, even though external conditions are the same. The response of these marshes to long-term trends in salinity will also depend on the marsh type. It is probable that changes in plant community will again reflect the unusual, but predictable conditions occuring in the two marsh types.

Chapter IV

EFFECT OF HYDROLOGY AND VEGETATION ON MARSH NUTRIENT LEVELS

4.1 Introduction

Nitrogen and phosphorus contribute to the high productivity for which wetlands are well known (Mitsch and Gosselink 1986, Howard-Williams 1985). These and other plant nutrients occur in the soil, water and organic matter in various inorganic and organic forms. The inorganic forms are directly available to the plants for uptake and incorporation into organic production. The biogeochemical transformations and movement of the nutrients within and between these compartments, as well as across the boundaries of a particular landscape are important functional attributes of a wetland and constitute a significant area of research in wetland ecology. Hydrology plays a central role in this "cycling" of nutrients. It is the surface flow which primarily transports the nutrients and other materials to and from the marsh surface. Lateral below-ground water movement is generally limited to near the creek bank (Nuttle 1988) and consequently there is little transport of materials here. Floating marshes are an exception. These marshes adjust vertically to changes in ambient water levels. There is at least the potential for more extensive below-ground water flow than in the rooted marshes (Chapter III). Nutrient cycling may be expected to differ as a result of this marsh buoyancy (Verhoeven 1986, Howard-Williams 1985).

This potential for extensive belowground movement of dissolved and particulate nutrients is a distinguishing feature of floating marshes. The net transport depends largely on the prevailing hydrologic regime (Gaudet 1982). Whether the system is relatively more open (on top of or fringing a river) or closed (e.g. marshes fringing the shoreline of a lake) is of prime significance (Gaudet 1982). In the former, river stage (Koerselmann 1989)and/or discharge (Gaudet 1979) control the movement of materials. If the flow rate is fast enough, the mat and vegetation may be relatively isolated from the through-flowing water (Bowden 1987, Howard-Williams and Gaudet 1985). Materials sedimented from the overlying mat may be transported out of the system (Gaudet 1979). In the floating marshes fringing a shoreline, as for example in a bog, the ratio of precipitation to evapotranspiration will drive the exchange of water between marsh and and the adjacent surface water (Hopper and Morris 1982). In this latter system, the contact time between the below-ground water and the marsh substrate is much longer and the physical marsh environment will play a greater role in the cycling of nutrients. Buoyancy of the marsh in and of itself will also influence the movement of nutrients. In some floating marshes, the marsh surface is rarely if ever inundated (e.g. Swarzenski et al. 1991). Here, aboveground plant material will decompose in place and the nutrients released during the senescence of the plant tissue will for the most part sink into the substrate. Another type of floating marsh is inundated even as the mat moves vertically in response to open-water oscillations (e.g. Swarzenski et al. 1991). In this instance overland water flow may also serve as a conduit for nutrients.

Detailed studies of nutrient cycling in floating marshes have been reported (Gaudet 1977, 1979, 1982) for papyrus swamps in East Africa and by Sasser et al. (1991) in coastal Louisiana. Both studies indicated downwards increasing levels of inorganic nitrogen and phosphorus, with highest levels in the free water beneath the floating portion of the mat. Sasser et al. (1991) suggested plant absorption in the root mat (near the surface) sets up this gradient. Sasser et al. (1991) also found concentrations of TKN in the soil increasing with depth, suggestive of N enrichment. Gaudet (1979) showed that the particulate and detrital compartments contained by far the largest proportions of nutrients in the papyrus swamps. The particulate and detrital fraction is for the most part mobile, and may represent either a considerable loss from circulation (through sedimentation and burial) or transport off site, where it could support secondary productivity. Studies of nutrient cycling in other floating marshes are not uncommon, but often the buoyant nature of the mat has been incidental to the primary objectives of those studies.

In this study I compared and contrasted N and P movement in the porewaters and sediment of minerotrophic rooted and floating marshes. All three marshes studied occurred within 2 km of each other, and were subject to essentially the same forcing conditions from the adjacent surface water. Inorganic and organic N and P were measured in shallow and deep porewaters and sediments over the course of one year, with the frequency of sampling higher during the growing season. Through this direct comparison, an assessment of the impact of two hydrologically contrasting systems on N and P movement was possible. One surprising result of this study was the importance of dominant vegetation in controlling at least the inorganic levels of nitrogen and phosphorus in the porewaters of these marshes.

4.2 Methods

Porewater was sampled at all three sites at depths of 18 and 48 cm below the marsh surface 50 m inland from the closest canal for one year. The shallow depth was in the zone of active root growth, the 48 cm depth was chosen in order to sample the layer just beneath the decomposing peat and above or in the free water layer. Five replicate samples were taken at each depth using a 60 cc syringe and 0.5 cm diameter clear plastic pipe with openings for water entry pushed to the appropriate depth. The marshes were sampled once in January, March, May (twice), July, August September, November and December of 1990. During the same time interval the canal separating Sites 2 and 3 was sampled every two weeks 50 cm below the water surface. Samples were immediately stored on ice, and frozen upon return to the laboratory until analysis, up to a maximum of six months. Ammonium samples were analyzed within 48 h of sampling. Unfiltered water samples were used for colorimetric determinations of ammonium, nitrate+nitrite and soluble reactive phosphorus (SRP) as well as total kjeldahl nitrogen (TKN) and total phosphorus using an automatic flow-through system (Scientific Instruments, Hawthorne, NY, USA) following appropriate U.S. Environmental Protection Agency procedures (US EPA 1979). The sample was allowed to settle for 30 minutes prior to analysis. Total organic nitrogen values were calculated by subtracting the inorganic nitrogen fractions (nitrate+nitrite and ammonium) from TKN. Organic phosphorus was calculated as the difference between total phosphorus and inorganic phosphorus (SRP). The color of the water sample (humics) interfered with the nitrate-nitrite analysis, and absorbance values obtained without the color reagent were subtracted from the original readings. For the other parameters, interference was less than the detection limit. Table 1 lists the methods used and the detection limits for each analysis. The accuracy of the analyses was checked using samples of known concentration.

TABLE 4. Techniques and detection limits used for the analysis of nitrogen and phosphorous in water and soil samples [1]/.

	SPECIES	TECHNIQUE	DETECTION LIMIT ($mg\ l^{-1}$)
WATER	Ammonium (NH_4)	Salicylate hypochlorite	0.0056 NH_4-N
	Nitrate (NO_3+NO_2)	Copper cadmium reduction	0.0025 NO_3-N
	Total Kjeldahl Nitrogen (TKN)	block digestion with 5% sulfuric acid and mercuric oxide, salicylate hypochlorite	0.025 NH_4-N
	Total Phosphorous (TP)	block digestion with 5% sulfuric acid and mercuric acid catalyst, phosphomolybdate	0.025 PO_4-P
	Soluble Reactive Phosphorous (SRP)	phosphomolybdate	0.005 PO_4-P
SEDIMENT			
	Total Nitrogen (TKN)	block digestion with concentrated sulfuric acid and mercuric oxide catalyst, salicylate hypochlorite	0.025 NH_4-N
	Total Phosphorous (TP)	block digestion with concentrated sulfuric acid and mercuric oxide catalyst, phosphomolybdate	0.025 PO_4-P

[1]/ U.S. EPA 1979

Sediments were sampled at the same depth as the porewaters, in August and November of 1989, and in January and May of 1990 (to coincide with distinct periods of the growing cycle). Total nitrogen (TKN) and total phosphorus were determined on oven-dried (75 C, constant weight) samples ground through a #40 mesh Wiley mill. About 0.25 g of sediment were digested with concentrated sulfuric acid using mercuric acid as a catalyst. Orchard leaves of known concentration were used to check for accuracy of the sediment analyses. Nitrogen and phosphorus levels in the sediment are given on a volume basis (g N or P per volume of soil) instead of the more common weight by weight basis. Volumetric expression provides a clearer indication of the nutrients available to the emergent vegetation (Rainey 1979).

For all block digestions the samples were selected at random from the whole pool of available samples to avoid bias that might be introduced, for example, if digestions were grouped by date or site.

4.2.1 Winter-summer comparison

Analysis of the porewater nutrient data suggested that vegetation influenced inorganic nutrient levels. During the comprehensive sampling program, water samples at Site 2 were obtained randomly from either of the two dominant vegetation stands. In February amd June of 1991 ammonium levels were measured at all three marshes at both depths. Samples were purposely taken in monotypic stands of each dominant species at both the floating marsh at Site 2 and in the rooted marsh at Site 3. Five replicates were taken at each depth. This was done to investigate the unusual pattern in porewater nutrients observed at Site 2.

4.2.2 Statistical Analyses

One-way analysis of variance (SAS 1982) was used to test for differences in the mean values of chemical parameters among sites at each depth, and between depths at each site. When a significant difference was indicated ($p < 0.001$), a post-Anova multiple comparison test (Tukey hsd) was used to test for differences among the means. Detection limit values substituted for real numbers in those instances when the concentrations fell below the detection limit for a given parameter.

4.3 Results

4.3.1 Interstitial Water

Mean nitrate+nitrite levels were highest in the canal, but did not differ among sites, nor with depth at a particular marsh (Table 5). The dominant inorganic nitrogen form in the marshes was ammonium. Mean levels were higher in the floating marsh at Site 2 at both depths than in the remaining two marshes and the canal. There levels were not significantly different. Ammonium levels did not differ with depth at any of the marsh sites. TKN was highest in the rooted marsh at Site 3, at both depths. Values decreased from Site 2 to Site 1 and the canal. There was no TKN gradient with depth at any of the marshes.

There were also seasonal fluctuations of nutrient levels in the marshes and canal. Inorganic nitrogen species behaved similarily at 18 and 48 cm depth (Fig. 11). Levels increased slightly during mid-summer. In the canal ammonium levels also increased at this time, but nitrate-nitrite levels were very low. In the canal, nitrate-nitrite levels were highest during the winter months. TKN levels did not show any obvious seasonal trends.

There were clear seasonal trends in reactive phosphorus (SRP) (Fig. 12). At sites 1 and 3, a floating and a rooted marsh respectively, levels increased sharply after the August sampling. At Site 2, a similar trend was less pronounced. In the canal, SRP levels remained low throughout the summer but were higher in the intervening time. Total phophorus levels did not exhibit obvious seasonal trends at 48 cm depth. Levels were similar at all three sites. This pattern held for the marshes at Sites 1 and 3 at 18 cm depth as well. At the floating marsh at Site 2, TP levels were elevated during the summer months, but were lower prior to and after mid-summer.

TABLE 5. Mean porewater concentrations (± 1 s.d.) of phosphorus and nitrogen species at the two floating marshes (Sites 1 and 2) and the rooted marsh (Site 3) near Lake Salvador, Louisiana.

PARAMETER (mg/l)	Depth (cm)	SITE			
		CANAL	SITE 1	SITE 2	SITE 3
TP	18	0.07±0.02	0.06±0.02	0.14±0.08^{a,b}	0.06±0.02
	48		0.06±0.02	0.09±0.02^{a,b}	0.05±0.03
SRP	18	0.027±0.016	0.026±0.020	0.063±0.026^{a}	0.027±0.027
	48		0.025±0.018	0.044±0.020^{a}	0.033±0.034
TKN	18	1.15±0.28^{a}	1.64±0.42^{a}	2.02±0.51^{a}	3.42±0.71^{a}
	48		1.57±0.38^{a}	1.88±0.47^{a}	3.22±0.71^{a}
NO_3+NO_2	18	0.112±0.163^{a}	0.005±0.003	0.006±0.003	0.009±0.008
	48		0.006±0.004	0.007±0.003	0.010±0.017
NH_4	18	0.105±0.131	0.046±0.031	0.500±0.327^{a}	0.084±0.092
	48		0.052±0.043	0.528±0.264^{a}	0.107±0.125

[1/] a indicates significant difference ($p<0.05$) among sites at a given depth, b indicates significant difference ($p<0.05$) between depths at a given site (ANOVA).

FIG. 11. Seasonal variation (mean ± 1 s.d.) in total Kjeldahl nitrogen (TKN), ammonium and nitrate+nitrite in the porewaters at the floating marshes (Sites 1 and 2) and the rooted marsh (Site 3), and in the canal near Lake Salvador, Louisiana.

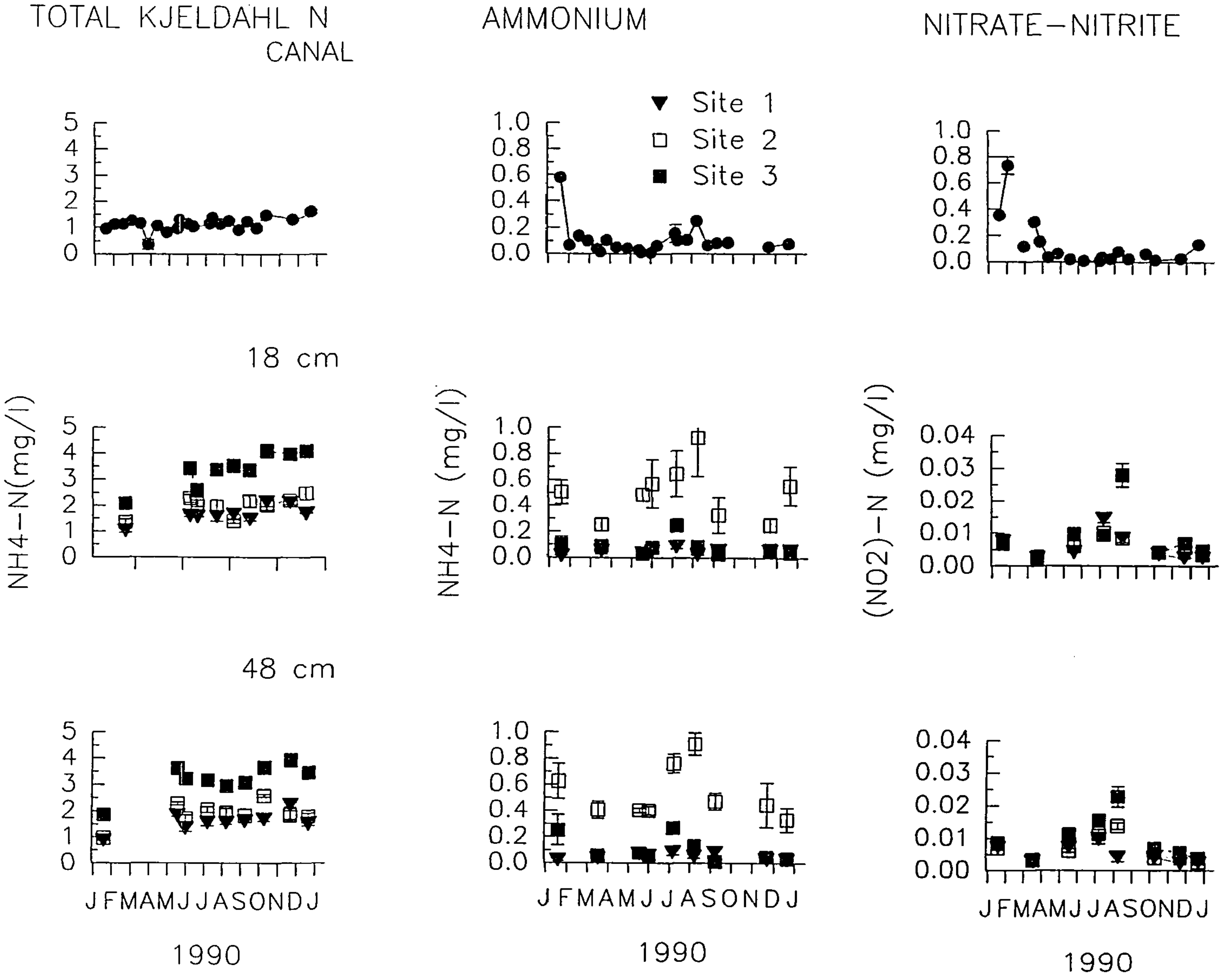
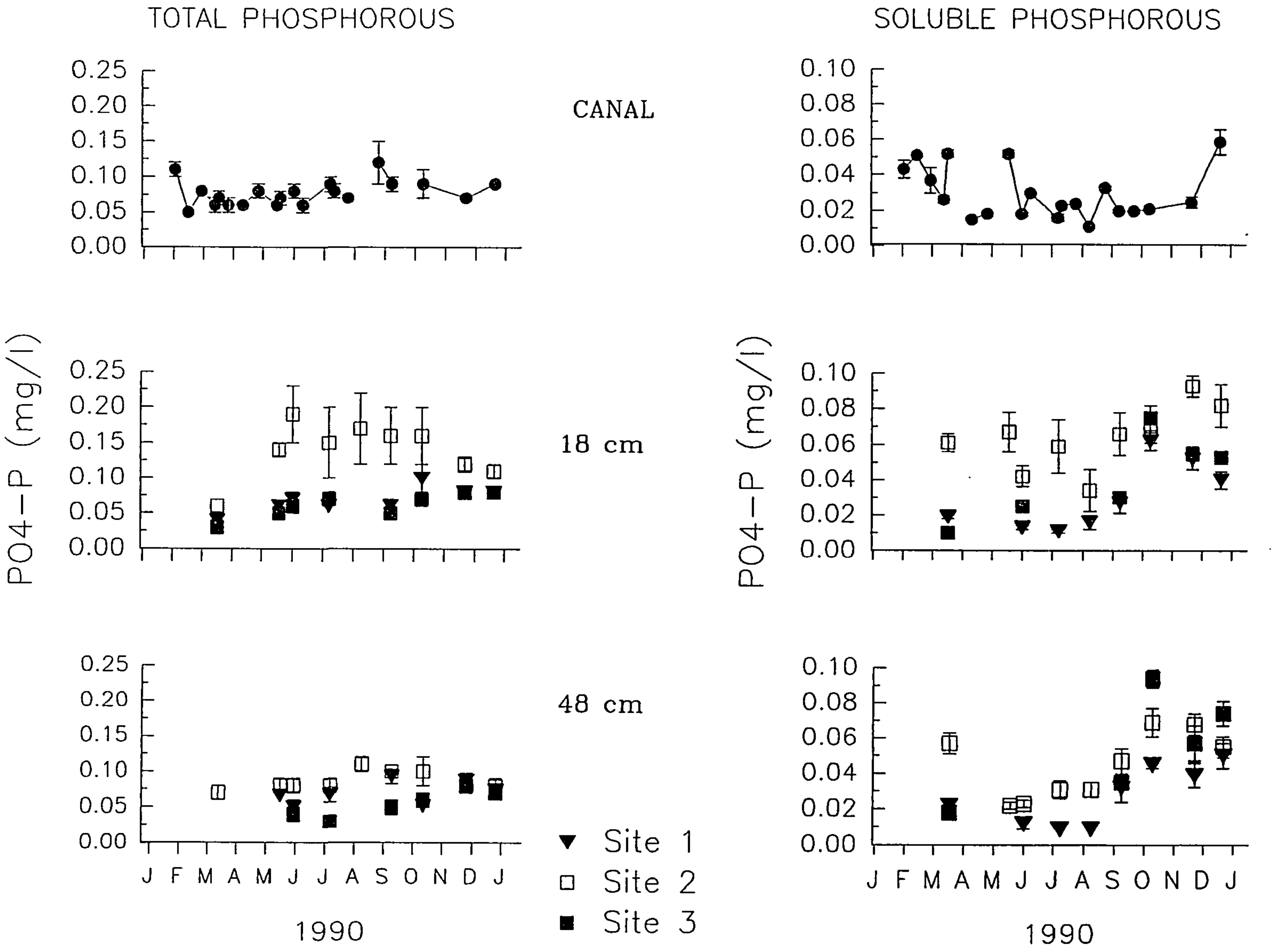

TOTAL KJELDAHL N
CANAL
AMMONIUM
NITRATE–NITRITE
▼ Site 1
□ Site 2
■ Site 3
18 cm
48 cm
NH4–N(mg/l)
NH4–N (mg/l)
(NO2)–N (mg/l)
0
1
2
3
4
5
0.0
0.2
0.4
0.6
0.8
1.0
0.00
0.01
0.02
0.03
0.04
J F M A M J J A S O N D J
1990

FIG. 12. Seasonal variation (mean ± 1 s.d.) in soluble reactive phosphorus (SRP) and total phosphorus (TP) in the porewaters at the floating marshes (Sites 1 and 2) and rooted marsh (Site 3), and in the canal near Lake Salvador, Louisiana.


TOTAL PHOSPHOROUS
SOLUBLE PHOSPHOROUS
CANAL
18 cm
48 cm
PO4−P (mg/l)
0.25
0.20
0.15
0.10
0.05
0.00
0.08
0.06
0.04
0.02
J F M A M J J A S O N D J
1990
▼ Site 1
□ Site 2
■ Site 3

4.3.2 Sediment

ANOVA did not detect any significant seasonal differences in soil nitrogen and phophor¢s at any site at either depth. Results were therefore pooled by depth and location for all subsequent analyses (Table 6).

Total nitrogen in the two floating marshes was higher at 18 cm than at 48 cm, although at Site 1 this difference was not significant. TP was significantly higher at 18 cm than at 48 cm in both floating marshes. In contrast, TKN and TP levels at the rooted marsh (Site 3) increased with depth. At 18 cm, TKN was significantly lower than in the floating marshes. At 48 cm TKN was the highest of the three marshes, intermediate at Site 1 and lowest at Site 2. TP concentrations at Site 1 were significantly lower than at Sites 2 and 3, which did not differ from each other. At 48 cm, TP levels were significantly lower in the two floating marshes than in the rooted marsh at Site 3.

4.3.3 Winter-summer nutrient comparison

Ammonium levels were not different among sites nor between vegetation types at either depth during the February 1991 sampling of porewaters (Table 7). In June, ammonium levels were significantly higher in the stands of *S. patens* than in stands of *Sa. falcata.*

TABLE 6. Total nitrogen and phosphorus (± 1 s.d., per g dry soil and per wet volume) in the shallow and deep soils at the floating marshes (Sites 1 and 2) and the rooted marsh (Site 3) near Lake Salvador, Louisiana[1/].

SITE	DEPTH (cm)	ORGANIC MATTER CONTENT (% dry weight)	TOTAL KJELDAHL NITROGEN (TKN)		TOTAL PHOSPHORUS (TP)	
			dry weight (mg g^{-1})	wet volume (mg cm^{-3})	dry weight (mg g^{-1})	wet volume (mg cm^{-3})
1	18	84	26.9±2.2	1.72±0.14	0.67±0.07	0.042±0.004[a,b]
	48	83	24.7±2.7	1.58±0.17[a]	0.59±0.07	0.037±0.004[b]
2	18	67	21.1±1.5	1.54±0.11[a,b]	0.75±0.06	0.054±0.005[b]
	48	81	19.3±2.4	1.20±0.15[a,b]	0.64±0.06	0.039±0.004[b]
3	18	85	25.2±4.1	1.81±0.29	0.77±0.07	0.055±0.005[b]
	48	64	15.4±1.9	2.19±0.26[a]	0.55±0.05	0.078±0.007[a,b]

[1/] a indicates significant difference ($p < 0.05$) at a given depth among sites, b indicates significant difference between depths within a site.

TABLE 7. Comparison of porewater ammonium levels (mg/l) in distinct stands of *Sagittaria falcata* and *Spartina patens* growing in the floating marshes (Sites 1 and 2) and in the rooted marsh (Site 3) on 14 February (winter) and 6 June (summer) of 1991 [1/]. ANOVA with vegetation as the main factor indicated that there were significant differences between the means of the vegetation types in the summer ($p < 0.05$), but not in the winter.

		WINTER		SUMMER	
SITE	DEPTH (cm)	*Sa. falcata*	*S. patens*	*Sa. falcata*	*S. patens*
1	18	0.46±0.19	-	0.08±0.03	-
	48	0.20±0.04	-	0.08±0.04	-
2	18	0.18±0.07	0.16±0.13	0.09±0.03	0.51±0.31
	48	0.28±0.09	0.20±0.11	0.09±0.04	0.32±0.13
3	18	0.15±0.04	0.24±0.11	0.08±0.02	0.69±0.32
	48	0.18±0.03	0.26±0.20	0.12±0.02	1.79±1.13

[1/] There was no *Spartina patens* at Site 1; each value is the mean of five samples.

4.4 Discussion

The differences in the two marsh types appeared to affect the levels of at least one of the nutrients, but surprisingly the type of dominant vegetation also appeared to control nutrient levels in these marshes.

4.4.1 Interstitial waters

Inorganic forms of nitrogen and phosphorus in porewaters exhibited two distinct patterns, depending primarily on which species of emergent vegetation was dominant. In the two marshes dominated by *Sa. falcata* levels of ammonium and soluble reactive phosphorus were very low during the summer growing season. Inorganic nutrients remained high in the floating marsh at Site 2 during this same time period. Water samples from this site had been collected indiscriminately in both *Sa. falcata* and *S. patens* patches. The role of vegetation type in determining inorganic nutrient levels was confirmed by the additional porewater sampling the following year in monotypic stands of both species in the floating and rooted marshes (Table 6). During peak growing season, ammonium levels were much higher in stands of *S. patens* regardless of whether these stands were located in the buoyant or rooted marsh. In the winter there were no significant differences among the sites. It is noteworthy that in the stands of *S. patens* that porewater ammonium levels were much higher in the rooted marsh than in the floating marsh. This is likely because of the more extensive lateral below-ground water movement in the floating marshes, which would disperse any accumulations of materials. The higher levels of TKN would also contribute towards this effect.

The low summer inorganic nutrient levels in the porewaters at Sites 1 and 3 are probably the result of uptake by *Sa. falcata* in the production of organic matter. Uptake of inorganic nutrients from water during the growing season has been frequently reported for freshwater marshes (Grant and Patrick 1970, Klopatek 1978, Simpson et al. 1983). Uptake of nitrogen and phosphorus can be rapid during the early parts of the growing season (Simpson et al. 1984). Peak growth of *Sa. falcata* is during the mid-summer in coastal Louisiana marshes (Brewer and Grace 1990, Hopkinson et al. 1978). After July, the fleshy tissues senesce, with rapid intial decay rates (Hopkinson et al. 1978). Release from the decomposing tissue as well as reduced demand by the vegetation should account for the observed increase in SRP levels in the fall. However, corresponding ammonium levels did not exhibit the clear pattern of SRP.

In the porewaters beneath the stands of *S. patens* inorganic N and P was produced in larger amounts than the plants could take up. This resulted in comparatively large pools of available nutrients there, during peak growing season. This pattern was not unique to Site 2. The concentrations of inorganic nutrients at any given instance represent the balance of inputs and outputs. Vegetation could influence this balance in any of several ways. The substrate of *Sa. falcata* marshes, consisting mostly of organic matter derived from this same species may mineralize ammonium in greater quantities than the substrate of *Sa. falcata* stands. *S. patens* may have lower nutrient requirements and/or nutrient utilization by this species may be suboptimal here, perhaps due to environmental stress. In terms of the ecology of the marshes in the current study, the interesting result is that there were comparatively large pools of inorganic nutrients going unused by the emergent vegetation there, and adjacent to vegetation that is drawing down porewater nutrient levels. This has implications both in the way nutrients are being cycled, and for plant dynamics.

Mineralization of organic matter generally supplies a large portion of the inorganic nutrients required by the emergent wetland vegetation (Bowden 1987, Verhoeven 1986). This holds especially for nitrogen (Mineral sediment may be a significant source of phosphorus, however). Inorganic nutrients are then mostly recycled back into organic production (Delaune et al. 1986). In areas where S. *patens* dominates, some inorganic nutrients mineralized may not be cycled back into organic matter production. The excess ammonium and SRP at Site 2 may leave the marsh through diffusive and advective transport, and to a lesser extent volatilization for ammonium. To what extent this will occur depends on biogeochemical reactions in the substrate, the prevailing hydrological regime and whether the transport carries the nutrients across areas where there is only *Sa. falcata*. In these latter areas there is not such a large amount of nutrients available for transport during the summer growing season. It appears that most of the mineralized nutrients are being incorporated into the production of organic matter instead.

Having two stands of vegetation with such different nutrient regimes growing side by side in a mosaic of patches is intriguing. An excess of available nutrients positioned adjacent to areas where they are scarce should introduce an element of instability . All other factors being equal, and given enough time, one might reasonably expect *Sa. falcata* to encroach on stands of S. *patens*, where inorganic nutrients are plentiful, especially since at least some *Sa. falcata* grows mixed in with the stands of S. *patens*. Yet through experience gained working in the marshes of the MRDP, it seems the mosaic of these two species is common, and persists over time. What prevents this displacement from happening is an important biological question which could lead to insight into the occurrence and distribution of the two species in the marshes of the MRDP.

A large portion of the N and P in these and most wetlands is not immediately available to the emergent vegetation as nutrients, but is bound in the dissolved or particulate fraction of the porewaters. The bound nitrogen and phosphorus in the porewaters exhibited contrsting behaviors. Porewater TKN levels seemed to be determined primarily by differences in below-ground hydrodynamics between floating and rooted marshes rather than differences in emergent vegetation among the three sites or interactions with the substrate. At the rooted marsh, TKN concentrations were much higher than in the two floating marshes and in the open water. Moreover, seasonal patterns were not in evidence from any of the three marshes. The observed patterns are best explained by the greater porewater exchange with the adjacent surface water that occurs in the floating marshes compared with the rooted marsh (Chapter III). Biogeochemical reactions which contrast in the floating marsh and the rooted marsh would need to be inferred to explain the observed disparity in TKN concentrations between the rooted and floating marshes. At 48 cm depth, there is almost 50% more organic matter in the rooted marsh than in the two floating marshes. Nitrogen mineralization of the substrate is strongly dependant on the supply of organic matter (Mitsch and Gosselink 1986, Bowden 1987). An argument could also be made that this caused the observed elevated TKN levels at Site 3. However, TKN concentrations in the upper 18 cm zone are also much greater in the rooted marsh even though there is no more organic matter here than in the floating marshes. Non-reactive, conservative substances tend to disperse rather quickly in floating marshes, as I demonstrated with fluoroscein dye for these same three marshes (Swarzenski, unpublished data) and also with chloride distributions here (Chapter III). It appears that TKN behaves like a conservative substance in these marshes. Such behavior suggests that floating marshes may supply a considerable amount of nitrogen to the adjacent surface waters.

The bound phosphorus behaved somewhat differently than TKN. There was no accumulation of total phosphorus at the rooted marsh, as would be expected based on differences in hydrodynamics between the floating and rooted marshes. At Site 3 there was much more mineral sediment at 48 cm than in the two floating marshes. It is possible that phosphorus is accumulating in the particulate fraction at this site (see Richardson 1985). At 18 cm depth, bound phosphorus was much higher at the floating marsh at Site 2 during mid-summer. It is possible that some of the SRP, which is present at high concentrations at Site 2 only, and only at 18 cm, was being immobilized during this time interval. Phosphorus forms complexes and binds with other substances rather easily under certain physico-chemical conditions (e.g. Sinke et al. 1990). Hopper and Morris (1982) presented data on the fate of phosphates applied to the surface and to porewaters of a northern marsh. The phosphorus applied to the surface was mostly converted to an unreactive form, but not the phosphorus applied to the porewaters. Phosphorus moves between a reactive and a labile phase in response to a variety of physico- chemical cues; the behavior is complicated (Verhoeven et al. 1990).

In this study unfiltered porewaters which had been allowed to settle for 30 minutes were analyzed. This was termed the "dissolved" fraction. Ammonium values obtained in this way were not consistently higher or lower than values obtained after filtering samples with Whatman GF/C filter papers (Charles Sasser, Louisiana State University, personal communication). The values from this study should be a reasonable approximation of the dissolved nutrient concentrations in the marshes. The particulate fraction was deliberately not measured as part of this study, for lack of a standarized technique. The amount of particulate material introduced into the water sample by the syringe suction method used in this study was highly variable. An attempt was made to measure sedimentation of particulates under the floating marsh, but consistent results were elusive. As much as >90% of nutrients may be contained on the particulate fraction (Gaudet 1979) and it is clear is that the movement of particulates and the nutrients contained therein through the soil matrix will disproportionately affect any budgets and descriptions of nutrient cycling. It is essential to establish appropriate sampling procedures which define and measure the movement of particulate matter, especially in floating marshes, if the objective is to develop a realistic nutrient budget for a given marsh system especially in floating marshes.

4.4.2 Sediment

The largest amounts of nitrogen and phosphorus in marshes are generally found in the soil, and are usually orders of magnitude larger than found in the interstitial waters (Mitsch and Gosselink 1986, Verhoeven 1986). In the current study this relation held.

Nutrient density at 48 cm in the rooted marsh was relatively higher than at 18 cm in this marsh, and than at both depths in the two floating marshes. This was largely a function of the higher soil bulk density at 48 cm in the rooted marsh. As a result there is a much larger store of nitrogen and phosphorus in the rooted marsh than in the floating marshes. In floating marshes most root production occurs in the upper mat layer (the upper 25 to 30 cm in the marshes of this study; Swarzenski 1992). Beneath the mat there is a layer of decaying, increasingly fragmented organic matter (Gaudet 1979). As the organic decays, it may settle out beneath the buoyant marsh (Gaudet 1982) or it may be transported off site through lateral below-ground flow (Howard-Williams and Gaudet 1985, Crisp 1966). Either way there is a net loss of material. In the rooted marsh, in contrast, root growth occurs throughout at least the upper 45 to 50 cm of substrate (Swarzenski 1992). During the annual cycle of root production and decay, organic matter, and with it the nitrogen and phosphorus, is continously incorporated into the substrate and accumulates.

Whether there has been an overall accumulation or loss of nitrogen and phosphorus is however largely determined by how the floating marshes formed. If the floating marshes formed through infilling of what used to be open-water (Russell 1942), then a net increase in stored nutrients is occurring in the floating marshes. If these marshes formed through buoyant detachment of a formerly rooted marsh (O'Neil 1949), then a considerable amount of organic material, and with it nutrients has been lost from the marsh during buoyant detachment.

Soil nutrient concentrations based on volume of soil space (density) follow the physical differences in the soil substrate. Comparing nutrient contents of the soil with the amount of organic matter provides a more biological perspective on nutrient cycling in these marshes. Table 6 presents carbon to nitrogen ratios at both depths among the three marshes. At 18 cm, these ratios were remarkably similar among all three sites considering the physical and vegetation differences among them. At 48 cm the floating marsh at Site 2 and the rooted marsh at Site 3 had similar C:N ratios. These were higher than at Site 1. The differences between the floating marshes may be expected based on species-specific structural differences in the decomposition of the organic matter and also on the differences in utilization of ammonium between the two sites. The differences between Sites 1 and 3 suggest instead some effect based on whether the marsh floated or not.

TABLE 8. Carbon:nitrogen ratios in shallow (18 cm) and deep (48 cm) sediments at two floating (Sites 1 and 2) and one rooted (Site 3) marsh near Lake Salvador, Louisiana.

Depth (cm)	Site		
	1	2	3
18 cm	18.96	19.28	20.48
48 cm	20.47	25.49	25.36

4.5 Summary

I measured nitrogen and phosphorus in the porewater and sediments of two floating and one rooted marsh. Despite the contrasting porewater hydrodynamics of floating and rooted marshes, it was the above-ground vegetation which appeared to control the observed patterns of porewater inorganic nutrient levels at 18 and at 48 cm. Inorganic nutrient levels were much lower in porewaters in stands of *Sa. falcata* than *S. patens* during the summer growing season. This relation held even though there was a much greater potential supply of nutrients in the rooted marsh compared with the floating marshes. The patterns of dissolved TP in porewaters followed those of phosphates. The greatest amounts were found at Site 2 during the growing season. This pattern suggested to me that SRP, perhaps through microbial action, was being converted to a bound form at this site.

Total Kjeldahl nitrogen was the only nutrient whose distribution followed initial expectations of differences based on the differing porewater hydrodynamics of floating and rooted marshes. I attributed the significantly higher concentrations of TKN in the rooted marsh to the reduced rate of exchange of porewaters in this marsh type with adjacent open water. Such an interpretation suggests that floating marshes may contribute nitrogen to the adjacent surface waters.

The most pronounced differences in nutrients occuring in the soil were at 48 cm. There was much nitrogen and phosphorus in the rooted marsh here than in the floating marshes. This difference was related to the physical differences in soil structure between floating and rooted marshes.

Chapter V

INFLUENCE OF ABIOTIC FACTORS ON EMERGENT VEGETATION

5.1 Introduction

The frequent zonation of emergent vegetation into distinct and recurring communities in the otherwise apparently featureless marsh landscape has stimulated much research attempting to correlate observed patterns of vegetation distribution with abiotic (Earle and Kershaw 1988) and biotic factors (e.g. Grace and Wetzel 1981). Marsh flooding patterns (depth, duration and frequency) as well as salinity of the flooding waters are the most common sources of stress to the marsh vegetation. Flooding creates a strongly reducing, anoxic environment (Ponnamperuma 1972) which alone and in combination with salts and reduced sulphates carried in seawater adversely affects the emergent vegetation. Seed germination rates (Ungar and Riehl 1980, Gallinato and van der Valk 1986), seedling recruitment (van der Valk 1986, Gaudet 1976, Welling et al. 1988) and growth rates of mature plants (Liefer and Shay 1982, Shay and Shay 1986) may be affected differently by flooding and salinity characteristics, and plant species may in turn segregate based on their tolerances at the various growth phases. Biotic interactions such as competition also play a role in structuring marsh plant communities (Grace and Wetzel 1981, Bertness and Ellison 1987). The less competitive species is frequently displaced into the harsher physical environment (Gosselink 1984, Bertness 1991).

In Louisiana, the marshes of the Mississippi River Deltaic Plain (MRDP), comprising roughly 40% of the coastal marshes of the contiguous U.S.A., occur in a continuum from fresh at the upland interface to salt marsh along the coast of the Gulf of Mexico. The marshes have been divided into fresh (< 1 ppt), intermediate (0.5-5 ppt), brackish (5-18 ppt), and saline (> 18 ppt) vegetative units (Penfound and Hathaway 1938, Chabreck 1972), with characteristic species associated with each unit. The fresh marsh contains the most species (> 90 spp), but this number drops rapidly in a gulfward direction, as soil salinities increase. Gosselink (1984) suggests that although salt-tolerant species can grow well in fresh water environments they often are competitively displaced from the fresher areas by other species. Some species are abundant in more than one vegetative unit. Within a vegetative unit, sub-groupings of vegetation occur which may be related to differences in elevation, and hence inundation (Sasser 1977). Especially in the intermediate salinity area, vegetation zonation can be very complex (e.g. Gosselink 1984) with the simultaneous occurrence of several overlapping communities. Interpreting patterns of vegetation along environmental gradients likely involves considerations of temporal as well as spatial variability in flooding and salinity regimes. A thorough description of the physical environment where the emergent vegetation occurs is a necessary first step to understanding the patterns of occurrence and distribution.

The objective of this study was to describe the co-occurrence of two dominant plant species with differing salt and flooding tolerances in terms of the temporal and spatial variability of the salinity and marsh flooding regimes. The unique role of mat movement in shaping soil salinities and marsh flooding characteristics was of particular interest, as was the long-term record of ambient open water salinities in this intermediate region of the MRDP. I hypothesized that in floating marshes, inundation is reduced, and the marsh is more susceptible to periodic episodes of elevated salinity than the rooted marsh. Thus the more salt tolerant and less flood tolerant grass *S. patens* would more likely be found in the floating habitat than the less salt tolerant but more flood tolerant *Sa. falcata* in areas where both species co-occur.

5.2 Methods

5.2.1 Marsh flooding

Movement of the marsh mat was measured hourly 50 m inland at all three sites using punch chart recorders (Fisher-Porter, Warminster, PA, USA), with a dog-leash anchor twisted 20 cm into the marsh in place of a float. At Site 1, open-water levels were recorded in the same fashion, but using a float and counter-weight. Marsh-water movement was measured continuously with Stevens Type-F strip chart recorders (Leupold & Stevens, Beaverton, Oregon) adjacent to the mat gages at Sites 2 and 3. All parameters were measured for the calendar year 1990. Occasional gaps in the record from any one gage were filled using comparable data from another gage, or through interpolation based on the record before and after the interrruption. Daily averages were then obtained for all parameters. At Sites 2 and 3, mat values were subtracted from marsh-water levels to get marsh flooding durations. At Site 1, the adjacent open-water gage was used in place of a marsh-water gage, and mat values were subtracted from open-water values. This was feasible since only flooding events were counted. Marsh-water and open-water levels are identical when the marsh is flooded.

The data were divided into flooding classes starting with days flooded less than 2.5 cm. For the purposes of the study, this category was equivalent to an exposed marsh. Days the marsh was flooded greater than 2.5 cm to 32.5 cm were tabulated in 5-cm increments for each marsh on a monthly basis. In addition, the maximum number of days the marshes were consecutively flooded for each depth class was counted.

5.2.2 Salinity

Data on daily chloride levels at Bayou Barataria at Lafitte collected since October 1955 were obtained from the U.S. Army Corps of Engineers (New Orleans District), and loaded onto an IBM mainframe computer for analysis using the statistical program SAS (SAS, 1985). The chlorides were converted to salinity using the following equation:

$$\text{Salinity (ppt)} = 1.805 * \text{chlorides } (\text{g l}^{-1}) - 0.030 \text{ (Kinne, 1971)}$$

Lafitte is located approximately 15 km from the study site, across Lake Salvador. The number of days that salinity was equal to or greater than 6, 8 and 10 ppt was tabulated for each year of record. In addition, salinities were averaged into monthly values for two types of year: those years when salinities reached 4 ppt for at least one hundred days out of the year (n=9), and those years when salinities did not reach the same levels for an equal length of time. Through 1986, the record is remarkably complete. Missing values were few. The lower of the two values bracketing the gap was used to fill these gaps.

Above-ground standing biomass was measured by clipping the vegetation using 0.25 m^{-2} quadrats at five random locations about 50 m inland at all three sites in June and September of 1990. In June, samples were taken in pure stands of *Sa. falcata* only. In September, samples were taken in pure stands of *Sa. falcata* at all three sites, and in stands of S. *patens* at Site 2. In February of 1991, the vegetation growing in a 50 m by 50 m area, centered on the mat and water gages, and parallel to the adjacent canal, was classified as either S. *patens* or *Sa. falcata* every 2.5 m within the plot.

5.3 Results

5.3.1 Marsh flooding

The period of record for this study was January through November. In December, there was not enough data recovery to make valid comparisons among the sites.

Marsh flooding at Site 3, the firmly rooted marsh, and at Site 1, the freely floating marsh, were similar in terms of depth and duration (Fig 13). The marsh at Site 2 was flooded less often and less deeply than the other two marshes. For example, the marsh at Site 3 was flooded at depths greater than 2.5 cm for 172 total days, and 60 consecutive days during the period of study. At Site 1 the total duration was 176 days, and the longest the marsh was flooded was 59 consecutive days. In contrast, the marsh at Site 2 was flooded for a total of 105 days, and consecutively for only 14 days.

There was a seasonal difference in flooding characteristics between Site 1 and Site 3 (Fig. 14). In winter and through early summer, flooding at Site 1 was greater than at Site 3. This pattern was reversed during late summer and fall. Marsh flooding was greatest during the early summer and intermittent throughout the rest of the year.

5.3.2 Salinity

Salinity increased to above 6 ppt in 24 of the 31 years of observations and in 17 of those years values remained above this level for at least 10 days (Fig. 15). In the two years salinities remained above 8 ppt for prolonged periods of time. There were seven other years during which salinities remained at levels greater than 4 ppt for at least 100 days (Fig. 15). The monthly average salinities during these years exhibited a much different pattern than the values averaged during the remaining years (Fig. 16). Values started to diverge in March, and continued to remain high through late fall. Salinities were distributed in a bimodal pattern over the year, with peaks in spring and autumn.

FIG. 13. Days the marsh is flooded at the two floating marshes (Sites 1 and 2) and the rooted marsh (Site 3) near Lake Salvador, Louisiana. Flooding durations were tabulated separately for 5 cm depth classes, starting with the category < 2.5 cm.

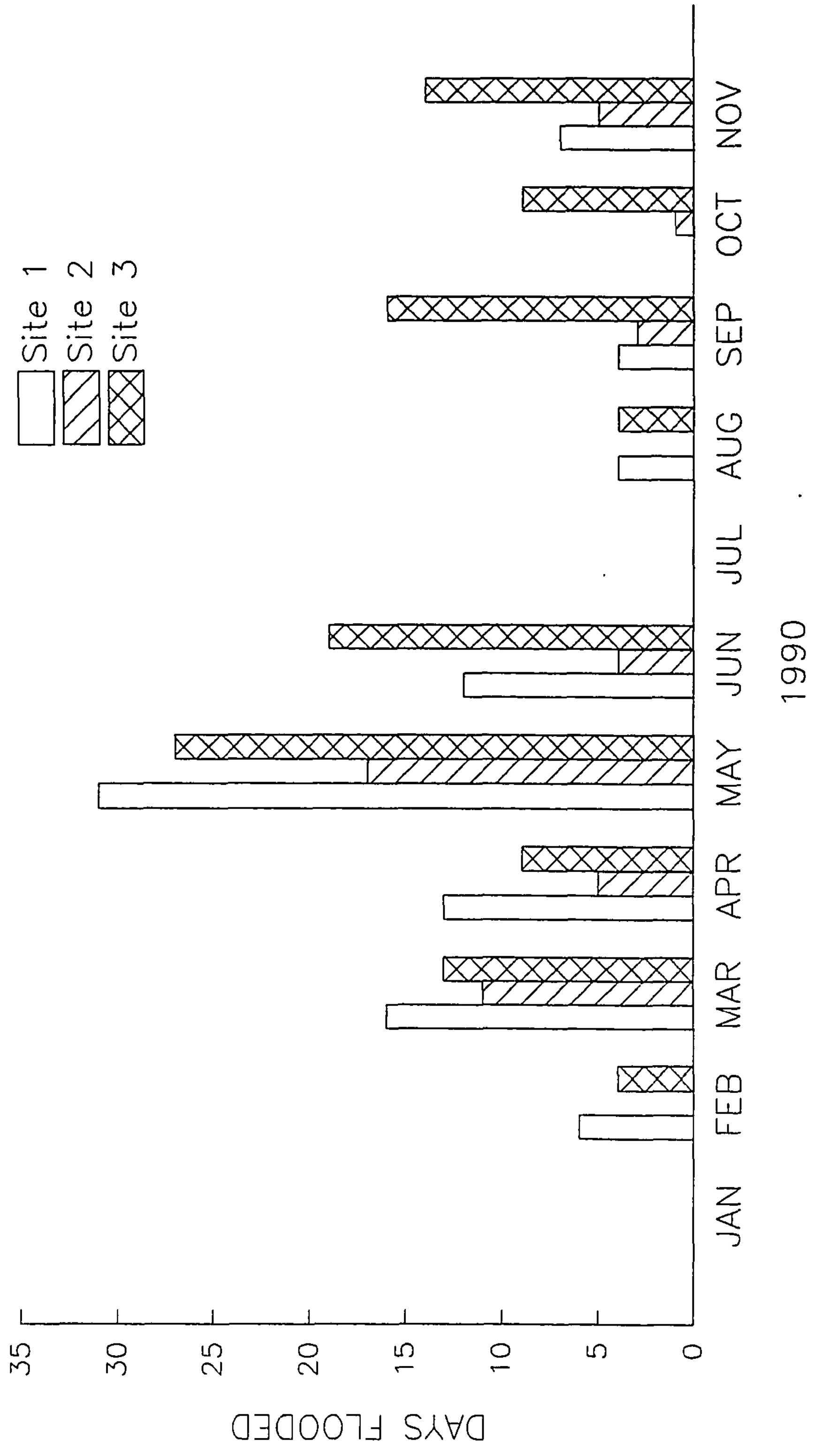

Site 1
Site 2
Site 3
DAYS FLOODED
0
5
10
15
20
25
30
35
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
1990

FIG. 14. Comparison of days the marsh is flooded deeper than 7. 5 cm (by month) at two floating marshes (Sites 1 and 2) and a rooted marsh (Site 3) near Lake Salvador, Louisiana.

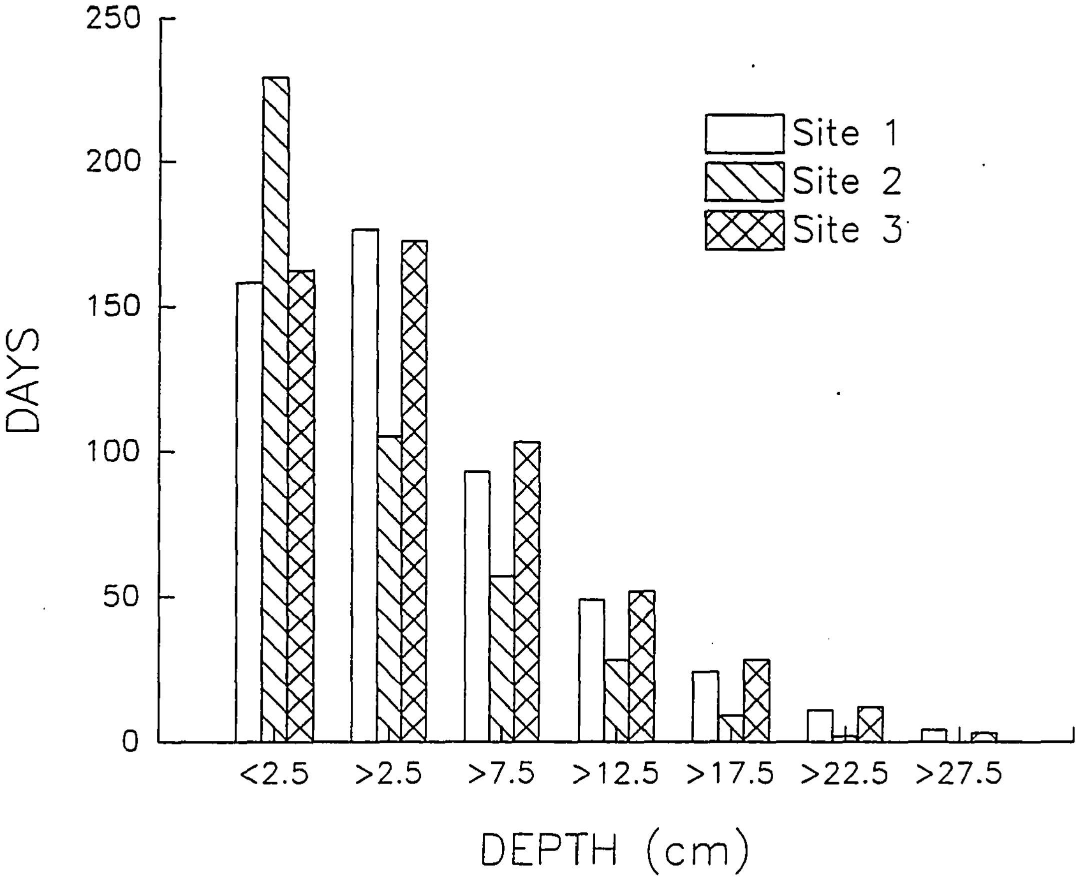

250
200
150
100
50
0
DAYS
Site 1
Site 2
Site 3
<2.5
>2.5
>7.5
>12.5
>17.5
>22.5
>27.5
DEPTH (cm)

FIG. 15. The number of days (by year) salinities reached at least 6, 8 and 10 ppt at Bayou Barataria at Lafitte, Louisiana (1956-1987).

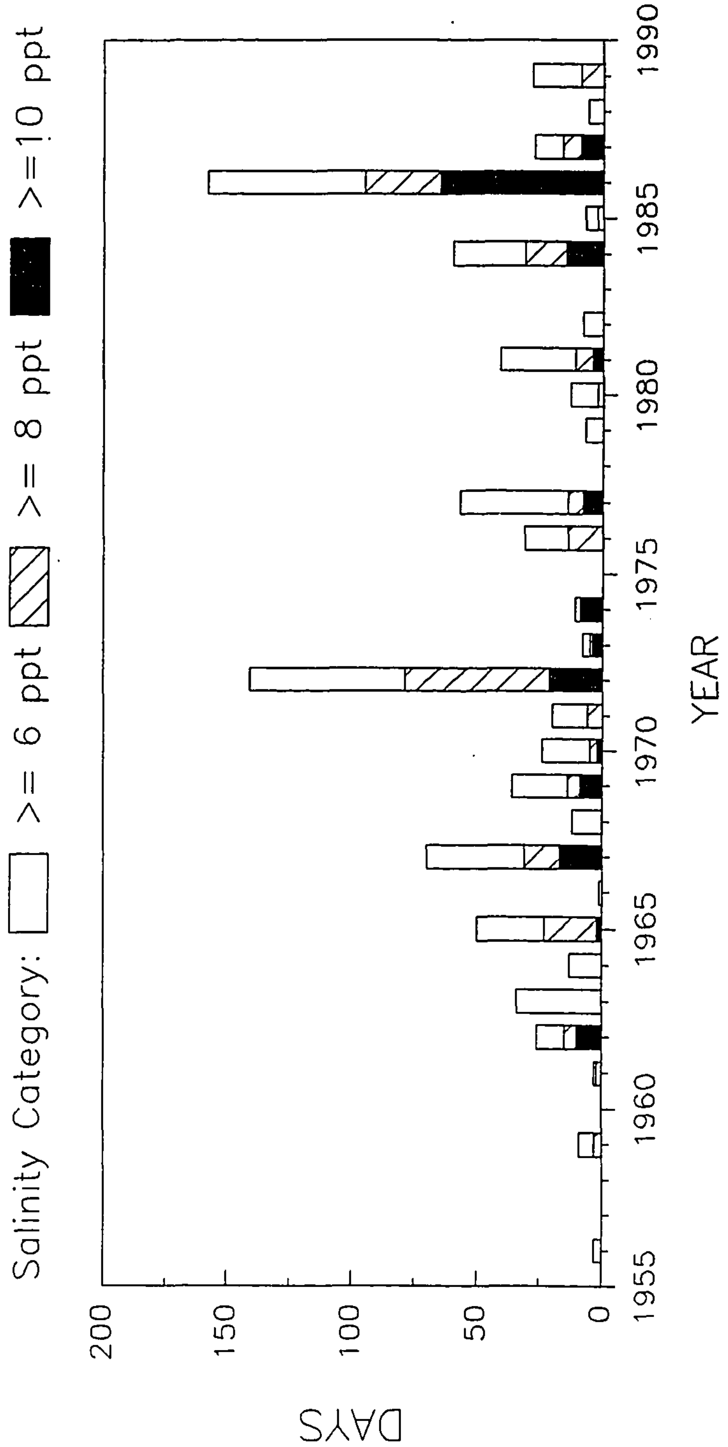
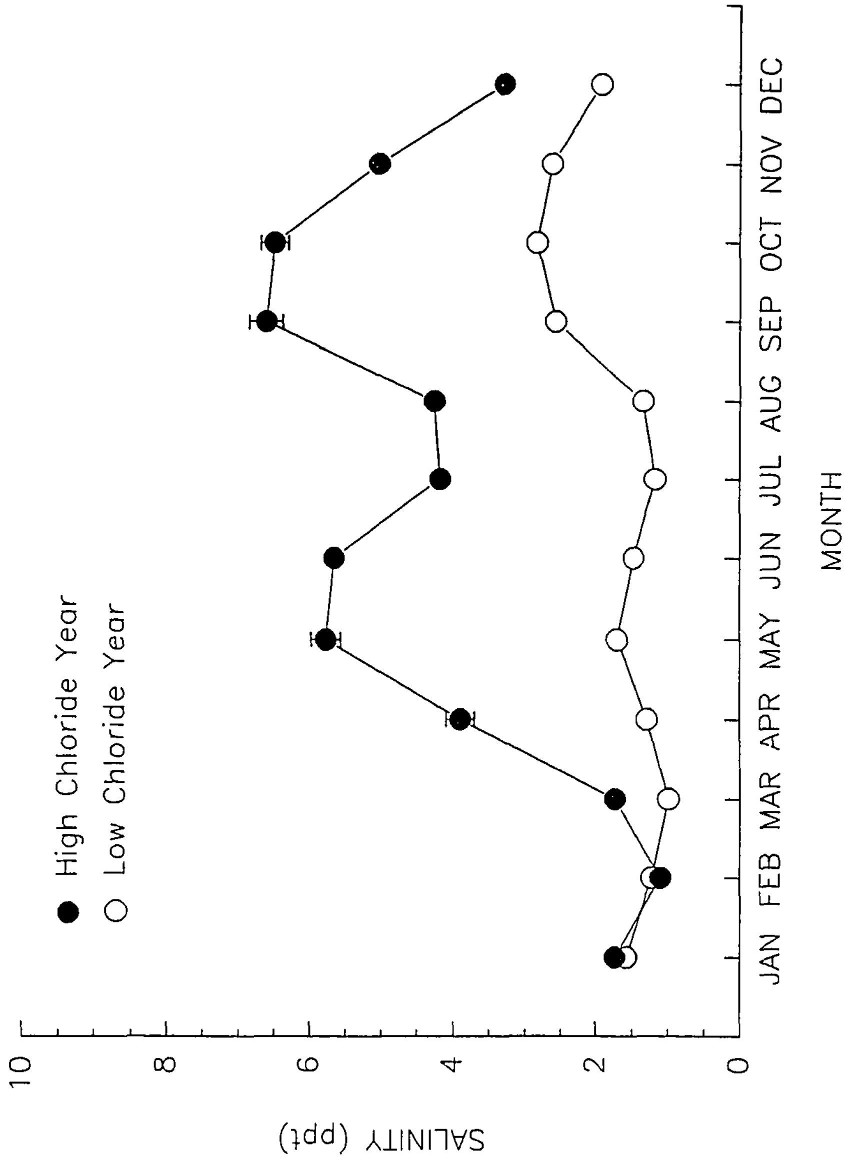

Salinity Category:
□ >= 6 ppt
▨ >= 8 ppt
■ >= 10 ppt
DAYS
0
50
100
150
200
YEAR
1955
1960
1965
1970
1975
1980
1985
1990

FIG. 16. Monthly averaged salinities for those years when salinities at Bayou Barataria at Lafitte reached 4 ppt for at least 100 days (high chloride years) and for the remaining years (low chloride years).


● High Chloride Year
○ Low Chloride Year
SALINITY (ppt)
0
2
4
6
8
10
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH

5.3.3 Vegetation

Live above-ground biomass in June in the stands of *Sa. falcata* was highest at Site 3 (about 700 g m^{-2}) (Table 9) and comparable at Sites 1 and 2 (552 g and 510 g m^{-2}, respectively). In September, live standing biomass decreased at all three sites, but proportionately less at Site 1. Most of the biomass was associated with *Sa. falcata*, but *Eleocharis* spp were also well represented. There was no *S. patens* found in this association.

In September, the stands of *S. patens* were also sampled and above-ground living and dead biomass were higher in these stands than elsewhere. Standing biomass was almost 1000 g m^{-2}, to which *S. patens* contributed almost 75%. *Sa. falcata* was intermixed with *S. patens*.

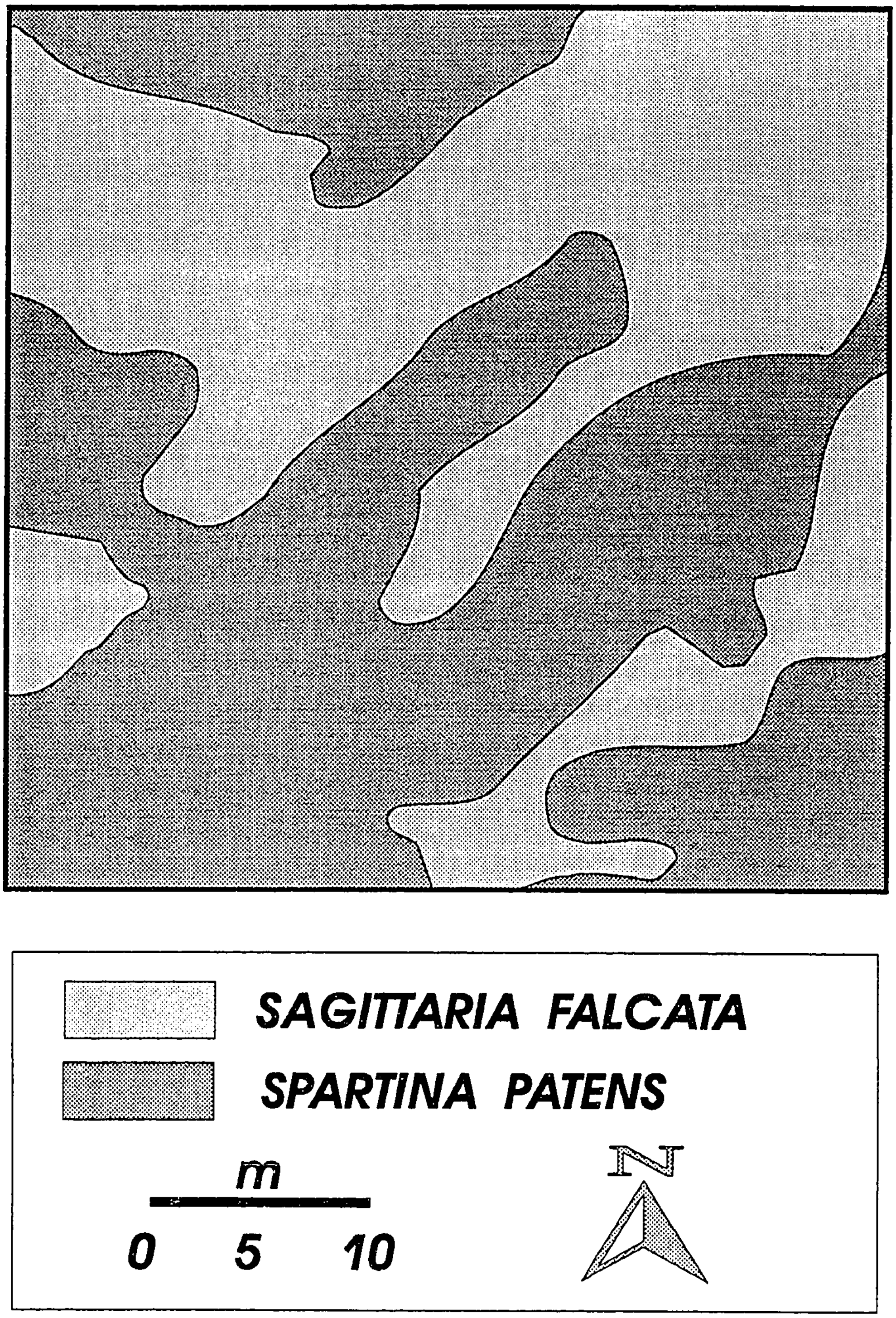
The spatial distribution of the stands of *S. patens* and *Sa. falcata* at Site 2, where both species were abundant, is shown in Fig. 17. At Site 3, only two 4-m diameter patches of *S. patens* grew in the marsh; the edge of one patch fell within the boundary of the 50 by 50 m study grid. At Site 1, several swards of *S. patens* grew in the marsh, but none fell within the sample grid.

TABLE 9. Live above-ground biomass in June and September of 1990 at the floating marshes (Sites 1 and 2) and the rooted marsh (Site 3) near Lake Salvador, Louisiana [1].

Species	Site 1		Site 2			Site 3	
	June (g m^2)	September (g m^2)	June (g m^2)	September (g m^2) a	b	June (g m^2)	September (g m^2)
S.falcata	453.3	310	316	165.7	(124.1)	540.8	99.98
S. patens	0	0	0	0	(732.1)	0	0
Eleocharis spp	48.6	38.8	97.4	58.6	(62.3)	138.9	104.0
Live	552.1	364.6	510.4	228.0	(992.1)	700.7	206.3
Dead	139.8	335.2	195.8	169.3	(664.5)	270.2	322.1
# species	15	7	7	7	(5)	7	2

[1] At Site 2 in September, column a repesents measurements in stands of *Sa. falcata*, column b are samples .taken in stands of *S. patens*.

FIG. 17. Distribution of *Sagittaria falcata* and *Spartina patens* stands at the floating marsh at Site 2. Stands were visually categorized every 2.5 m in a 50 m by 50 m area starting 25 m inland from the adjacent canal. (Note: at the rooted marsh (Site 3) there was a very small patch of *S. patens* that fell on one border of the sampling area; at the other floating marsh (Site 1), there was only *Sa. falcata*).


SAGITTARIA FALCATA
SPARTINA PATENS
m
0 5 10
N

5.4 Discussion

In coastal marshes, the observed pattern of emergent vegetation distribution often follows variability in local salinity and inundation regimes, in response to differential tolerances to the stresses by different plant species. In the MRDP, *S. patens* is common in the intermediate and brackish salinity zones, whereas *Sa. falcata* is limited to the fresh and intermediate salinity areas (Chabreck 1972). Thus, on a regional scale, salinities appear to control the distribution of these two species. The two species differ in their tolerance to stress from salinity and flooding. Based on laboratory and field studies, *S. patens* is the more salt tolerant, while *Sa. falcata* grows more effectively in fresh, deeply flooded marshes. Tissue damage occurred in *Sa. falcata* growing in the greenhouse at concentrations greater than 4.8 ppt (Mendelssohn and Mckee 1987). *S. patens* was not affected by salinity below 12 ppt. The consensus of workers in Gulf Coast marshes is that the latter species is more salt tolerant than *Sa. falcata.*

Flooding stresses *S. patens*. In brackish marshes not only higher salinities but also increased flooding limits the occurrence of *S. patens* in favour of *Spartina alterniflora* (Sasser 1977). In a study to measure the response of Gulf Coast dominants to global sea level rise, Pezeski and Delaune (1989) showed inhibition of root elongation with increased levels of flooding. Belowground biomass of *S. patens* decreased with increasing durations of flooding (Mendelssohn and McKee 1987). In a marsh transect from creek edge to the marsh interior the largest standing biomass of *S. patens* was found growing in the least flooded location (Burdick et al. 1989). Together these studies suggest *S. patens* is sensitive to marsh flooding. There is little data comparing the biomass and production of *Sa. falcata* to levels of inundation. Flooding within the range of values experienced within Gulf Coast marshes has not been shown to limit growth of this species. How do the observed patterns of occurrence of these two species at the present study sites fit with the known tolerances to flooding and salinity?

Although flooding characteristics differed among the three sites, *Sa. falcata* was common at all three marshes. At the rooted marsh (Site 3) and the floating marsh at Site 1, this species was the single dominant and *S. patens* occurred only in two small patches at Site 3. At Site 2, the two species were co-dominants. Since the marsh at Site 2 was flooded much less than the other two marshes, the distribution of the two species followed expectations. Soil salinities were highest in the rooted marsh in a three-year study of this parameter at the same three sites (Chapter III). According to measurements made during the short time period, the occurrence of the two species did not match predictions. *S. patens*, which is the more salt-tolerant of the two species, was common only in the fresher marsh at Site 2. However, interactions between salinity and emergent vegetation may occur at longer time scales (e.g. Beare and Zedler 1983, Brewer and Grace 1990) than the three years of the soil salinity study. The infrequent years when ambient salinities remained high for much of the time may be signficant in this respect. Brewer and Grace (1990) suggested salt pulses, possibly associated with infrequent storm events (i.e. hurricanes) structured another intermediate Gulf Coast marsh dominated by the same two species.

What role does mat movement play in determining soil salinities and flooding regimes in the intermediate marshes in the MRDP? As shown by this study, marsh inundation is not necessarily reduced in floating marshes. Whether the marsh floats seasonally or on a continuous basis is important, as is the resting elevation of the floating marsh. At Site 1, the seasonally buoyant marsh rested about 8 cm lower than the non-moving marsh at Site 3. Marsh flooding durations were similar in the two physically differing marsh systems as a consequence. However, the floating state may significantly reduce flooding provided base elevation is similar to that of a rooted marsh (e.g. Site 2 and Site 3).

The study of soil salinities (Chapter III) showed that soil salinities tracked open water salinities more closely in the floating marshes than in the rooted marsh. Below-ground lateral exchange of water between canal and marsh is presumed to be more rapid in floating marshes compared to rooted marshes, because of the mat movement. During periods of low salinity, the floating marshes had lower salinities than the rooted marsh. The behaviour of soil salinities during high salinity years was not clearly demonstrated, primarily because a high salinity year did not occur during the sampling interval. Nevertheless, some of the data suggest that salinites in the floating marshes responded more directly to increases in open water salinities than rooted marshes. The significance to this is that floating marshes may respond to the high chloride years more directly than the buffered rooted marsh. However, in and of itself, this property of floating marshes may not be sufficient to allow the occurrence of *S. patens* . The floating marsh at Site 1 did not have much of this latter species. Perhaps there is a threshold of marsh flooding beyond which the occurrence of this salt-tolerant species is not possible no matter how saline the habitat may occasionally get.

It is hypothesized that salinity is nevertheless important in permitting *S. patens* to persist in the generally low-salinity areas of this study, and that without the periodically occurring high-salinity years, this species would not occur in abundance here. Pools of inorganic nutrients (available to plants for direct uptake) remained at high levels in the stands of S. *patens* throughout the growing season, but not so in the adjacent *Sa. falcata* dominated stands (Chapter IV). These excess pools represent a nutrient source to those plants that can make use of them. *Sa. falcata* is one such species and grows mixed in with S. *patens*. Under continually fresh conditions, *Sa. falcata* could eventually displace the other species. Periodic salt surges may provide a mechanism for the salt-tolerant species to persist, perhaps by injuring proportions of the *Sa. falcata* population during these events. Under this scenario, the relative proportions of the two populations may switch back and forth in a type of dynamic equilibrium. Floating marshes, through their more direct and extensive exchange of interstitial waters with adjacent canal waters, may be affected more strongly than rooted marshes by the high salinity events.

This study has shown the variabilty that occurs in flooding regimes within a localized area of the MRDP, based in part on the buoyant characteristics of a given marsh. Even slight buoyancy can significantly reduce the amount of flooding and thus waterlogging and associated reduced soil conditions. In this respect, floating marshes of the MRDP may have a short-term advantage over the rooted marshes in the rapidly subsiding delta plain. Predictable variability of annual salinity patterns was also evident from the long-term record. Flooding and salinity may interact to produce some observed patterns of emergent vegetation in this part of BB.

Chapter VI

SUMMARY AND CONCLUSIONS

The purpose of this work was to increase understanding of the importance of floating marshes in the Mississippi River Deltaic Plain by contrasting behavior of this marsh type with the better understood rooted marsh.

There was not much difference between organic matter content and mineral density in the upper 25 cm of substrate between the floating and the rooted marshes. In both types there was very little mineral sediment there and the substrate consisted almost entirely of organic matter from below-ground root production of the marsh vegetation. This upper mat layer appeared to be equally buoyant in both marsh types. However, from 25 - 45 cm depth, the rooted marsh contained far more mineral sediment than did the floating marshes. Data suggested that the roots in the former reached into this non-buoyant layer to act as an anchor for the buoyant mat. In the floating marshes there was nothing for the roots to attach to at that depth.

Based on chloride profiles taken frequently over the three year study interval, it was shown that the belowground exchange of water between marsh and adjacent surface water was much greater in the floating marsh than in the rooted marsh. Salinities in the floating marsh tracked open-water salinities much more closely than they did in the rooted marsh. Since open-water salinities were fresh through-out the study period, the floating marshes averaged significantly lower salinities than the rooted marshes. In the rooted marsh, porewater salinities were buffered from short-term variations in openwater salinities. In the rooted marsh salinities in the mat layer experienced considerable seasonal variation due to the seasonally varying effects of evapotranspiration. Mat salinity levels increased nearly to levels found at greater depths during the summer growing season. This effect was less apparent in the two floating marshes. Rooted marsh salinities seem to integrate several years of ambient conditions, and also are somewhat higher than long-term averages. As ambient salinites continue to rise, albeit gradually, rooted marsh salinities will follow suite. I have argued in this work that the vegetation community consists mainly of fresh-water species, and that more salt-tolerant species may persist because of infrequent years of higher than average salinities (e.g.when preciptation levels are below average during the critical spring and fall peaks in salinity). I expect that the inverse will happen as ambient salinities continue to increase, and that occasional years of exceptionally high rainfall will occur with sufficent frequency These will depress salinity levels to a greater extent in the floating marshes and allow some fresher species to continue to persist there.

Nitrogen and phosphorus distribution in porewaters and sediment did not exclusively follow differences in hydrodynamics of floating and rooted marshes. The effect of dominant emergent vegetation appeared to override any hydrological differences between marsh types in determining inorganic porewater nutrient levels: in areas dominated by *Sa. falcata* levels dropped to near or even below detection limits. In areas where *S.patens* was dominant, levels of ammonium and soluble reactive phosphorus remained high during this same time frame. Total phosphorus also followed the same pattern. I think that some of the elevated SRP may be undergoing microbial immobilization during mid-summer and become unavailable. Only total Kejldahl nitrogen followed expectations: highest levels were found both at 18 and 48 cm depth at the rooted marsh. Dispersion of non-reactive, conservative substances is extremely slow away from the creekbank in rooted marshes. In the floating marshes, TKN levels were much lower and closer in concentration to open-water values. Such an interpretation suggested that floating marshes contribute substantial amounts of organic nitrogen to the surrounding open water. In the sediments, nitrogen and phosphorus were substantially higher in the rooted marshes at depth than in the floating marshes. This was due to the significantly greater amount of sediment there in the former.

I hypothesized that the more salt-tolerant, but flooding sensitive S. *patens* would be more likely to grow in the floating habitat than the flooding-tolerant, but salt-intolerant *Sa. falcata* . I reasoned that because of their mat movement, floating marshes would experience less inundation. Also, because of their better belowground connection to the adjacent surface water, they would be more susceptible to the occasional episodes of salt-intrusion. Data indicated that the floating condition did not automatically confer an advantage to the marsh in terms of reducing flooding. The relative elevation of the marsh when it was resting on the substrate (during periods of low water) and the seasonality of mat movement were equally important in determining marsh inundation characteristics. S. *patens* grew best in the marsh which was flooded the least. However, open-water salinities were low throughout the period of study. Hence, I was unable to determine the response of both marsh types to periods of increased open water salinity. I was able to show that there are recurring times when open water salinities become elevated for much of the year. I hypothesize that these episodes are important in enabling S. *patens* to persist in this part of the MRDP. It remains to be tested whether the high salinities affect both marsh types equally, or whether the floating marsh responds to these events more directly.

In looking at the different elements of this study, and the behavior of these marshes, I put together the following story. Through regional subsidence and organic accretion, formerly rooted marshes detach and become buoyant. Mat movement creates salinity regimes and patterns of inundation in this marsh type different from those in rooted marshes. Such differences allow species with differing tolerances to these stresses to co-occur in areas exposed to the same forcing from salinity and water levels. Finally, inorganic nutrient levels are affected by the type of emergent vegetation, rather than hydrologic type. Plant vigour and productivity will depend heavily on nutrient availability and levels of salinity and flooding. Species distributions will represent a dynamic balance between short- and long-term variability in flooding and salinities, and competition for available nutrients.

6.1 Future directions

The contrasting hydrologies of floating and rooted marshes can be the basis of any number of interesting ecological problems, as for example the vegetation and nutrient dynamics. Nevertheless, it is within the context of the regional setting of the MRDP, with associated high rates of subsidence and gradual landwards encroachment of saline waters, that this marsh type becomes extremely important. Understanding how floating marshes respond to these stresses will underlie any succesfull attempts to manage this area of the MRDP against deterioration and landloss.

An early attempt to map the occurrence of floating marshes in Louisiana was largely descriptive (O'Neil 1949). Currently, attempts to map the distribution of floating marshes is proceeding (Charles Sasser, personal communication, Coastal Ecology Institute, Louisiana State University, Baton Rouge, Louisiana) using helicopter surveys and marsh level recorders.

Open water salinities are gradually increasing in this part of the MRDP. What effects will this have on mat movement, and on floating marshes? Increased salinities may reduce the amount of methane generated during anaerobic decomposition (Bartlett et al. 1978). A controlled dose study should be performed to measure the effect of increasing salinities on mat movement The type of vegetation also determines the extent of buoyancy of the mat. As vegetation shifts to more salt-tolerant species the ability to form a structured root mat capable of mat movement should be studied. *S. patens* a species likely to increase in areal extent as salinities increase may be less of a floater than the species it replaces. Based on current knowledge, a reasonable hypothesis might be that mat movement will decrease as ambient salinities increase at a given location.

A controversial issue is to what extent organic matter beneath floating marshes is being eroded out into the open water. The floating marshes consist almost entirely of organic matter. Peats are susceptible to erosion; for example piping occurs in sloping peatlands in Wales. Macropores form preferential flowpaths and gradually become enlarged as the peat erodes. It is not unreasonable to envision a similar process occurring under floating marshes, except that the hydraulic gradient is caused by water level fluctuations due to wind tides. A technique favored by marsh managers to prevent the possibility of this lateral erosion from occurring is erection of levees at the boundary between open water and marsh. Studies of the magnitude of the organic transport in floating and in rooted marshes, as well as the effects leveeing has on marsh viability and productivity should be implemented as soon as possible.

Fresh and intermediate salinity marshes flank the Louisiana upland/ wetland interface. It is possible that a large portion of these marshes are floating, having formed in response to subsidence and subsequent organic marsh accretion. The currently debated freshwater diversions and proposed sediment enhancements should be designed with an understanding of what marsh types are on the receiving end of such projects.

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