SEDIMENT DEPOSITION AND AVAILABILITY IN THE RIPARIAN WETLANDS OF THE CAPE FEAR RIVER

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ABSTRACT

Tidal riparian wetlands serve as buffers between upland areas and the adjacent river channel. The ability of these swamps and marshes to keep up with changes in sea level depends on a combination on several factors including: sediment availability, hydrologic regime, deposition rates, and below ground productivity, that control surface elevation. This study examines sediment availability, deposition, and elevation change across different types of tidal wetlands in the Lower Cape Fear River Estuary, North Carolina. The study used marsh and swamp sites as well as sites along two different stream types, black and brown-water, within the estuary. Marshes and wetlands along the brown-water river exhibited significantly greater and more variable deposition rates than swamps and wetlands located along the black-water river (0.720 ± 1.310 gm^2day^{-1} and 0.710 ± 1.270 gm^2day^{-1}). The brown-water marsh site exhibited significantly greater rates of deposition than any of the other sites. Organic content of deposited material was highest at the black-water swamp site and lowest at the brown-water marsh site.

Total suspended solids measured once a month over a single flood tide were highest at the black-water marsh (33.01 ± 43.54 mgL^{-1}) and lowest at the black-water swamp (3.07 ± 10.62 mgL^{-1}). Measurements of surface water flow during a single ebb tide at each site were examined along with the mean grain size of available material. Results showed vertical flow speed and grain size were the dominant controls on deposition in this system. Measurements of surface elevation at each wetland showed a loss of elevation at the marsh sites and very slight increases at the swamp sites. When compared to current rates of sea-level rise for the area, it appears that these wetlands are not able to maintain their elevation in the face of rising sea-level.

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INTRODUCTION

Background

Increasing concern over coastal flooding and rising sea level has lead to numerous studies examining sediment transport and deposition in coastal wetlands (ORSON, 1998; LEONARD, *et al*., 1995; HACKNEY and YELVERTON, 1990). In coastal plain estuaries, these wetlands may also include riparian buffers which are important systems that filter upland toxins and particulates originating from storm water run-off before these waters reach estuarine and inland waterways (PASTERNACK and BRUSCH, 1998).

The ability of tidal wetlands to maintain their elevation in the face of rising sea level is dependant on several factors including: sediment availability, hydrologic regime, deposition rates, and below ground productivity (ORSON, 1998; LEONARD, *et al*., 1995). Riparian systems may be better positioned to keep up with rising sea level due to greater sediment input from adjacent rivers; however, these systems also are subject to greater anthropogenic influences that complicate accretion patterns (REED, 1990).

Sediment deposition rates are controlled by a combination of biological, physical, and hydrological process (LEONARD, 1997) which can influence both spatial and temporal patterns in deposition within a wetland. One key factor influencing deposition is sediment availability. The amount and type of available sediment can be affected by distance from, and type of, source material (FREIDRICHS and PERRY, 2001; FRENCH, *et al.*, 1995; LEONARD *et al.*, 2002). In tidal and/or riparian systems, the proximity of a wetland to a tidal creek or river (horizontal distance from marsh or swamp edges) increases the likelihood that sediments will be available for deposition on the wetland surface when it is flooded. Numerous studies have shown that deposition generally decreases with distance from such sources (CAHOON *et al.*, 1996; CHILDERS and DAY, 1990; FRENCH *et al.*, 1995; FRIEDRICHS and PERRY, 2001; HEIMANN and ROELL, 2000; HUPP and MORRIS, 1990; LEONARD, 1997; LEONARD, *et al.*, 2002; YANG, 1999) in tidal systems. Other studies (LEONARD, 1997; REED *et al.* , 1999; CHRISTIANSEN, *et al.*, 2000) have found that sediment availability is enhanced by physical processes such as waves, currents, and storm activity

The duration and frequency of inundation is another important influence over deposition on wetland surfaces. In general, a positive correlation exists between sediment deposition and length and/or frequency of inundation. As a result, differences in elevation across the marsh surface also influence depositional patterns. Marsh areas with higher elevations are usually flooded less frequently and for shorter periods of time, therefore the potential for deposition is decreased (KLEISS, 1996; HEIMANN and ROELL, 2000; REED *et al.*, 1999). The geomorphology of a wetland can determine local tidal range and the length of time that a wetland surface is inundated (CAHOON and REED, 1995; CHILDERS and DAY, 1990; FREIDRICHS and PERRY, 2001; HACKNEY and YELVERTON, 1990; LEONARD, 1997; REED, 1992; YANG, 1999). Because studies have shown wetland hydrology to be easily influenced by human activities such as channel dredging, dams, and the construction of other structures such as weirs along a waterway (HACKNEY and YELVERTON, 1990; REED, 1992), the combined effects of microscale topography and surface hydrology can strongly control spatial and temporal deposition patterns (LEONARD, 1997).

Biological factors also exert control over deposition in wetland systems. In many systems, higher rates of deposition occur during the growing season when plant densities are greatest (DARKE and MEGONIGAL, 2003; HEIMANN and ROELL, 2000; LEONARD, *et al.*, 2002; PASTERNACK and BRUSH, 2001). One reason for this pattern is that the presence of vegetation tends to baffle flow velocities and promote conditions conducive to increased deposition (FRIEDRICHS and PERRY, 2001; HUPP and MORRIS, 1990). Increased deposition in the summer, however, may also be associated with a general increase in biological activity within wetlands. Benthic invertebrates that reside in the sediments can resuspend material into the water column which is then transported to elsewhere in the wetland (ZEDLER and CALLAWAY, 2001) leading to greater sediment availability and increased deposition.

Characteristics of Tidal Marshes and Riparian Swamps

This study looks specifically at the depositional rates of several tidal marshes and riparian swamps. Tidal marshes are commonly found along macro-tidal coastlines with low energy regimes, such as estuaries or lagoons (FREIDRICHS and PERRY, 2001; MISCHT and GOSSELINK, 2000). They range from the temperate to high latitudes, but occur only where the coastal plain is wide and gently-sloping (FREIDRICHS and PERRY, 2001; MISCHT and GOSSELINK, 2000).

Tidal salt marshes are adapted to saline conditions and vegetation zones within the marsh are determined by the tolerance levels of different plant species to salt water (MISCHT and GOSSELINK, 2000). A common vegetation pattern for a tidal salt marsh in North Carolina consists of tall *Spartina alterniflora* along tidal creek levees and short *Spartina alterniflora* just behind in low, ponded areas. The high marsh is dominated by *Juncus roemerianus* (LEONARD, 1995; MISCHT and GOSSELINK, 2000).

Riparian swamps occur adjacent to river systems and serve as transition zones between the river and uplands (MISCHT and GOSSELINK, 2000). These swamps are strongly dependant on their location within the river or estuarine continuum and are dominated by fluvial processes (HEIMANN and ROELL, 2000; KLIESS, 1996; MISCHT and GOSSELINK, 2000). Riparian zones can exhibit several features based on river morphology such as natural levees, meander scrolls, oxbow lakes, and sloughs (MISCHT and GOSSELINK, 2000). Riparian swamps in the southeastern United States are commonly bottomland hardwood forests. They are vegetated by hydrophilic trees such as bald cypress, tupelo, sweet gum, and green ash (MISCHT and GOSSELINK, 2000). These species of tree are adapted to waterlogged conditions of a swamp and serve a similar function as tropical mangroves.

Previous research in sediment deposition in tidal wetlands is extensive, however little work has been done within the Cape Fear River of southeastern North Carolina (OLIVOLA, 2005; RENFRO, 2004). The estuary presented a unique research opportunity for comparing depositional rates across wetland types and hydrologic regimes within the same system. Also, there are few documented studies in the literature on sedimentation in swamps. For those that exist, the results indicate that the location of a swamp within the river continuum as well as proximity to large channels are two factors that most strongly impact deposition (HEIMANN and ROELL, 2000; HUPP and MORRIS, 1990; and KLEISS, 1996).

The goal of this study was to quantify short-term depositional rates and elevation change in two types of tidal wetlands and to relate these patterns to surficial processes that include surface hydrology and sediment availability. The study objectives were:

- To compare depositional rates between marshes and swamps.
- To compare depositional rates between brown- and black-water rivers.
- To examine temporal trends in deposition.
- To examine both surface deposition and overall elevation change using several methodologies.

These objectives were established to test two primary hypotheses:

1) Marsh sedimentation will exceed that of swamps; and 2) Depositional rates at sites along a brown-water river will be higher than rates along a black-water river. The data also will help address a larger research question which is: Are these wetlands keeping up with sea level rise?

Study Area

The Cape Fear River Estuary is part of the largest river basin that lies entirely within the state of North Carolina. The estuary contains a wide variety of hydrologic regimes and habitats. The river system is composed of several main tributaries with their own distinct properties. The Northeast Cape Fear River is a coastal plain tributary with headwaters dominated by coastal swamps. It is classified as a black-water river due to the high dissolved organic content of the water. The Cape Fear River tributary drains the piedmont region of North Carolina. This branch of the river is classified as a brown-water river due to its greater suspended sediment load. However this branch has a major black-water tributary, the Black River, which potentially impacts sediment load and type within the study area.

Four sites were selected from an existing and ongoing study of the Lower Cape Fear River. The sites (shown in red on Fig. 1) were installed as part of a monitoring program to evaluate changes in water level associated with the dredging of Wilmington Harbor by the U.S. Army Corp of Engineers. All four sites are affected by semi-diurnal tides with tidal ranges of 0.96 m to 1.31 m. In general, tidal ranges decrease with distance upstream and are strongly influenced by periods of high rainfall that tend to suppress tidal range but may increase overall water level (HACKNEY, *et al*., 2001; HACKNEY, *et al*., 2004).

Site Descriptions

Two sites (P6 and P8) are located along the main branch of the Cape Fear River. It is fed by both the Black River coastal plain stream (a black-water stream) and the piedmont derived Cape Fear River (a brown-water stream). P6 is a tidal marsh with a

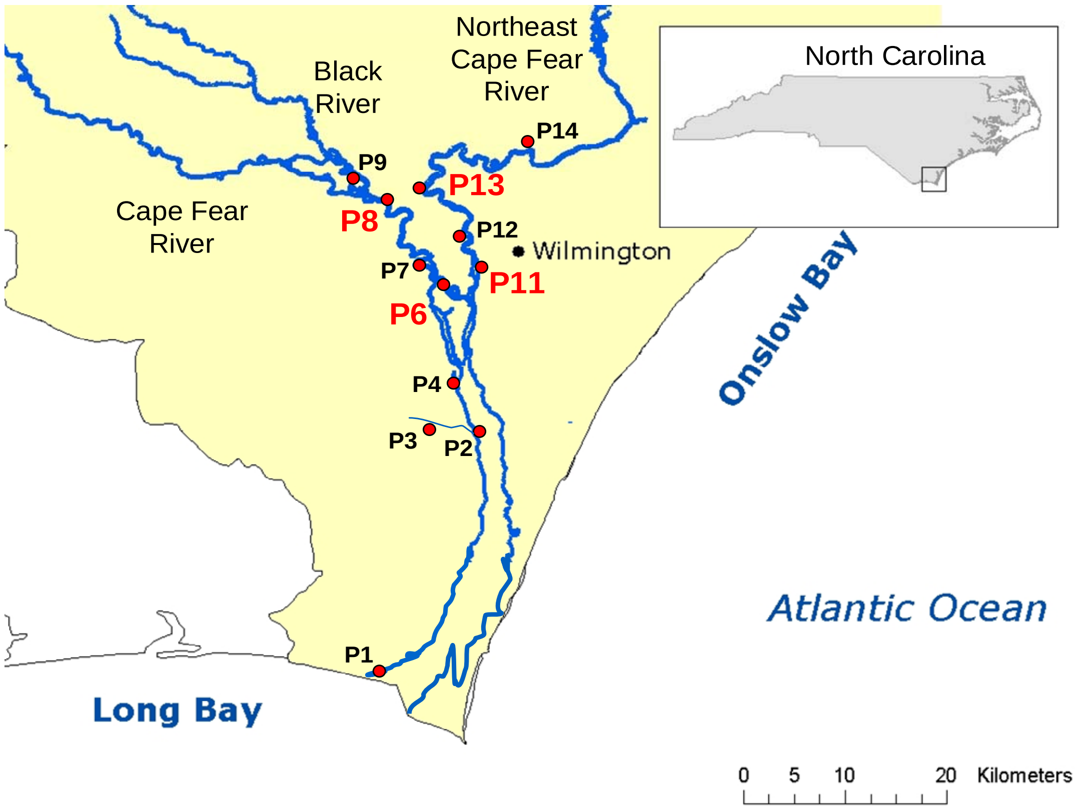

Figure 1. Map of the Lower Cape Fear River watershed showing the sites used in this study. Sites labeled in red were used in this study. The remaining sites are sites established as part of a US Army Corps of Engineers project to monitor changes in water level associated with harbor dredging activities in Wilmington.

relative surface elevation of -0.155 m. The immediate sampling area was located within a dense stand of giant cord grass (*Sacciolepis striata*) and saw grass (*Cladium jamaicense*) (RENFRO, 2004). During the winter season, this area has little vegetative cover. By May, the vegetation has grown back. This site was also subject to a large amount of boating traffic in the adjacent river, which periodically affected sampling attempts. Beginning in 2007, major construction began just up-river, potentially influencing the amount and type of sediment available at this site. Site P8 is a tidal swamp, with a relative surface elevation of 0.390 m. The sampling area was vegetated with a mix of bald cypress (*Taxodium disichum*), lizards tail (*Saururus cernuus*), halberd-leaf tearthumb (*Polygonum arifolium*), and green ash (*Faxinun pennsylvanica)* (RENFRO, 2004).

The other two sites (P11 and P13) are located along the Northeast Cape Fear River. This is a black-water river that has lower levels of suspended inorganic particulates and higher levels of suspended and dissolved organic material. Site P11 is a tidal marsh site with a relative elevation of -0.390 m. Local vegetation was similar to P6 with the addition of the common reed (*Phragmites australis*) (RENFRO, 2004). This site was regularly affected by barge traffic between the Progress Energy Power Plant and the Port of Wilmington. There also is a small creek which enters the river immediately adjacent to the site, potentially impacting the site's hydrology. P13 is a tidal swamp with plant species similar to P8 but with greater vegetation density. It has a relative elevation of 0.020 m.

METHODS

Sediment Tiles

Ceramic tiles (10 cm^2) were placed directly on the wetland surface, glaze side up to determine monthly and seasonal depositional rates (Fig. 3A). These tiles, made by American Olean, are of a standard make by the company. All were bought from the same lot number to ensure consistency and vary only in glaze color for the purpose of field identification. Tiles were placed within a 1 m^2 plot located within 2 m of the site's surveyed benchmark (Fig. 2). A total of 20 tiles were left in place at each site over four (10 white tiles) and twelve (blue and red tiles) week periods. Sampling began in November 2004 and continued until June 2007.

Sediment deposited on the tiles was scraped off into sample bottles (Fig. 3A) using a rubber scrapper and de-ionized water. The tiles were then returned to the marsh surface within the defined plot. Sample bottles were transported to the laboratory and emptied into pre-weighed and pre-combusted metal tins (Fig. 3A). Samples were dried to a constant weight at 80°C in an oven, after which they are combusted at 450°C for four hours in a furnace to determine percent organic content of the sediment. Surface deposition was calculated in g m^2 day^{-1}.

Total Suspended Material (TSM)

Sediment availability at each site was measured by determining the total suspended solids concentrations at each site during rising tide. Plastic sample bottles were fitted with rubber caps with two lengths of copper tubing in them (Fig. 3B).

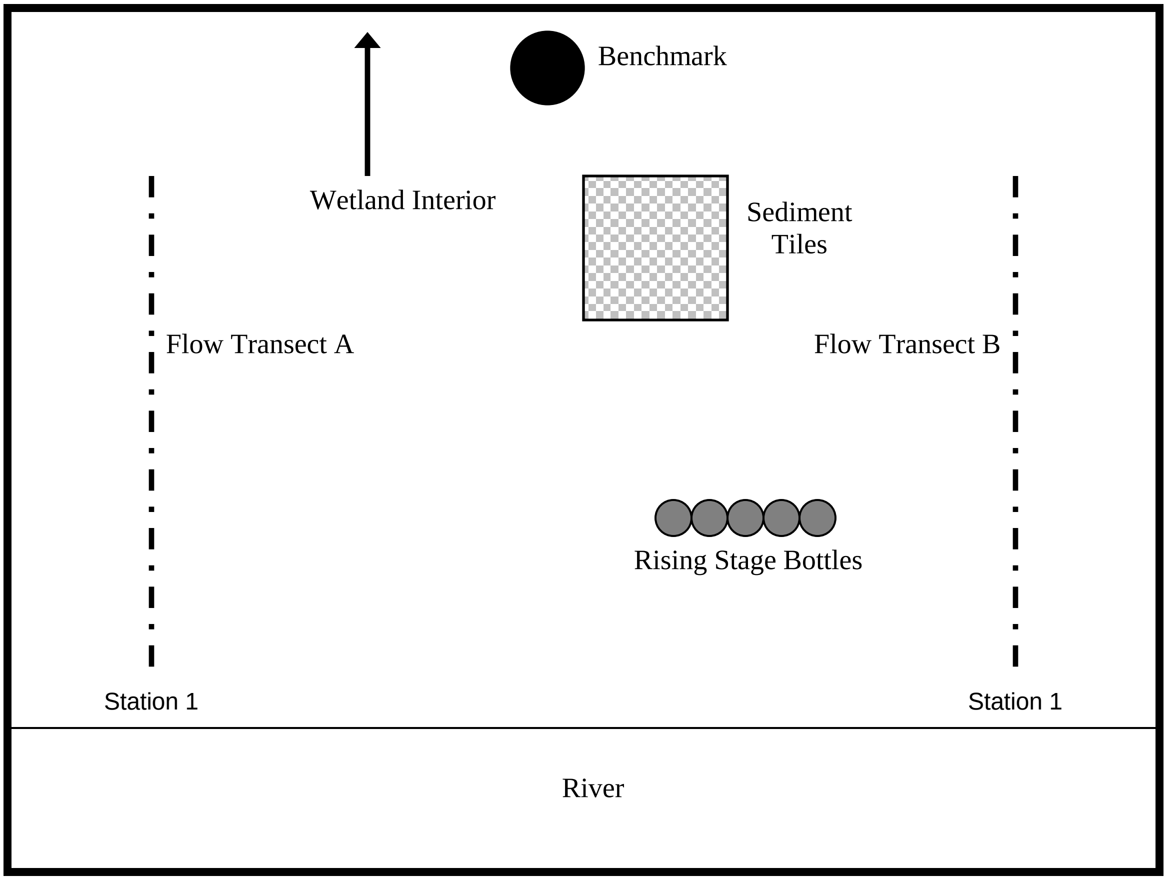

Figure 2. Generalized site diagram showing placement of sampling equipment and transects used in this study. The benchmark was surveyed to NAVD88 by the U.S. Army Corps of Engineers.

Figure 3A

Figure 3B

Figure 3C

Figure 3A-C. Pictures of field instrumentation used in this study. A) Sediment Tiles, sample bottle, and drying tin. B) Rising-stage bottles deployed in the field. C) SET deployed in the field.

One tube rises directly up from the stopper and serves as a release for trapped air as the bottle fills (Fig. 3B). The other bends down towards the wetland surface (Fig. 3B This creates a vacuum as the tide rises, forcing air out the top of the tube and pulling water into the sample bottle. A total of five bottles were deployed at each site for one tidal cycle each month beginning in June 2006 and continuing until June 2007 (Fig. 3). Sample bottles were collected and filtered in the laboratory using pre-weighed 2-um filter papers. The filter papers were dried to a constant weight and combusted at 450°C for four hours to determine the percent organic and inorganic of the suspended material.

Additional water samples were collected from the adjacent river channel when the rising stage bottles were deployed. These data were used to determine the potential source of sediments making their way onto the marsh surface. Finally, TSM data from nearby sites in the river were provided (LEONARD pers. comm.) for additional comparisons.

Flow Measurements

Flow speed of water ebbing off the marsh surface was measured to examine the potential for re-suspension of deposited sediment. The measurements were taken using a pair of 3D Sontek acoustic Doppler velocemeters (ADV). The sensors were mounted on metal rods for easy height adjustment. Measurements were taken at one-half depth in the water column at stations spaced 1 meter apart along two transects at each site (Fig. 2). Collection began at high tide and continuing until the water level became too shallow to collect reliable measurements. Data were collected in 30 second sampling bursts that were then averaged to a single data point for each station along the transect. These measurements were collected over four sampling days in January and February of 2008.

Sedimentation-Erosion Table (SET)

The SET method was used to measure overall changes in marsh surface elevation. Where as the sediment tiles recorded only surface deposition, this method also accounted for subsurface processes and erosion. The SET instrument consisted of a metal arm with an array of 9 rods on one end attached to the site's benchmark (Fig. 3C). The benchmark was installed at each site by the U.S. Army Corps and referenced for the placement of sampling equipment relative to the NAVD88 datum. The array of rods allowed for measurements of the elevation of the wetland's surface relative to the elevation of the benchmark. Measurements of surface elevation were taken in four directions around the benchmark every three months (Fig. 2). Changes in surface elevation were compared to deposition rate at each site.

Water-level Data

Discharge data for the Cape Fear River was available online from the U.S. Geological Survey (http://nwis.waterdata.usgs.gov/nwis/dv/?site_no=02105769& agency_cd=USGS). Water level data is acquired from instruments affixed to data collection platforms adjacent to each site. These stations were installed as part of an on-going effort to monitor the effects of the Wilmington harbor dredging project on water levels in the river (reference). Water levels were recorded every 3 minutes and telemetered to UNCW's Center for Marine Science weekly. All water level data are referenced to NAVD88 datum.

Data Analysis

Statistical analysis of data was completed using MINITAB software. Sediment tile data was normalized to g m^2 day^{-1}. Totals suspended solids were normalized to mg

L^{-1}. Data were tested for normality by both the Anderson-Darling and Ryan-Joiner tests and found to be normal. Both 2 sample t-test and ANOVA were used to examine differences between sample means as a function of study site, stream, and wetland type.

RESULTS

Deposition

Temporal Variations in Deposition

Mean sediment deposition, as measured by sediment tiles, varied over the course of the study at all four sites. The brown-water marsh (P6) exhibited the greatest variation over the study period, ranging from a sample period mean of 0.103 ± 0.052 to 7.376 ± 2.193 g m^2 day^{-1}. The other sites exhibited considerably less variation (Fig. 4). Deposition at the brown-water marsh (P6) usually exceeded deposition at any of the other sites during the study (Fig. 4 and Table 1). With the exception of the black-water marsh (P11), all of the sites exhibited higher rates of deposition during the summer than during the winter (Table 1A). Deposition patterns in the brown-water marsh (P6) exhibited the clearest seasonality while deposition patterns in the black-water marsh (P11) exhibited the least (Fig. 4A and 4C). All four sites showed high deposition rates and greater variability during September 2005 (Fig. 4).

Site Comparisons of Deposition

When deposition rates were averaged over the study duration, the brown-water marsh (P6) had the highest and most variable mean deposition of 1.146 ± 1.762 g m^2 day^{-1} for this study (Fig. 5 and Table 1B). This rate is significantly higher than the rate observed at any of the other three sites at $P < 0.001$ (Table 1B).

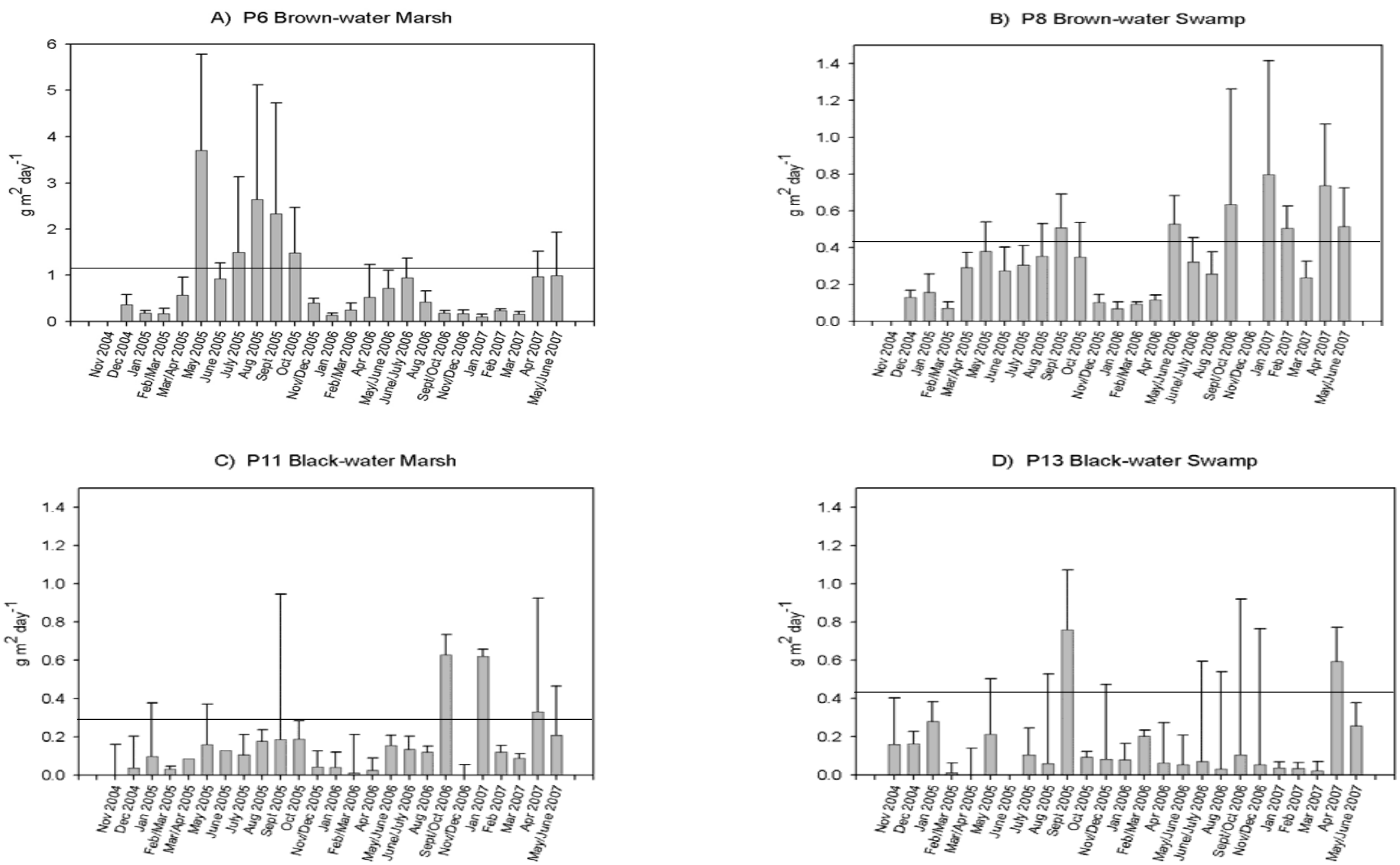

Figure 4A-D. Mean deposition in g m^2 day^{-1} by site for each sampling period during the study. A blank space at a sample period indicates missing data. Error bars denote one standard deviation from the mean for that sample period. The horizontal line represents the study mean at each site.

A	Mean Summer Deposition (g m^2 day^{-1})	Mean Winter Deposition (g m^2 day^{-1})
P6 Brown-water Marsh	1.467 ± 1.662 **(A)**	0.781 ± 0.201 **(B)**
P8 Brown-water Swamp	0.402 ± 0.249 **(C)**	0.298 ± 0.334 **(D)**
P11 Black-water Marsh	0.336 ± 0.302 **(E)**	0.327 ± 0.344 **(E)**
P13 Black-water Swamp	0.548 ± 0.449 **(F)**	0.310 ± 0.297 **(D)**

B	Mean Deposition (g m^2 day^{-1})	N
P6 Brown-water Marsh	1.15 ± 1.76 **(A)**	173
P8 Brown-water Swamp	0.35 ± 0.30 **(B)**	205
P11 Black-water Marsh	0.33 ± 0.32 **(B)**	188
P13 Black-water Swamp	0.42 ± 0.39 **(B)**	197

C	Mean Total Deposition (g m^2 day^{-1})	P - value	DF
Brown-water v. Black-water	0.710 ± 1.270 **(A)** 0.375 ± 0.361 **(B)**	P < 0.001	436
Marsh v. Swamp	0.720 ± 1.310 **(A)** 0.382 ± 0.348 **(B)**	P < 0.001	405

Table 1A-C. Mean deposition in g m^2 day^{-1}. A) Mean seasonal deposition in g m^2 day^{-1} for each site over the study period. B) Mean sediment deposition in g m^2 day^{-1} at each site over the study period. Significance determined by ANOVA. C) Mean deposition in g m^2 day^{-1} by river type and wetland type. Significance determined by 2-sample t-test. Within each panel, values with the same letter within a panel were not significantly different at $p < 0.05$.

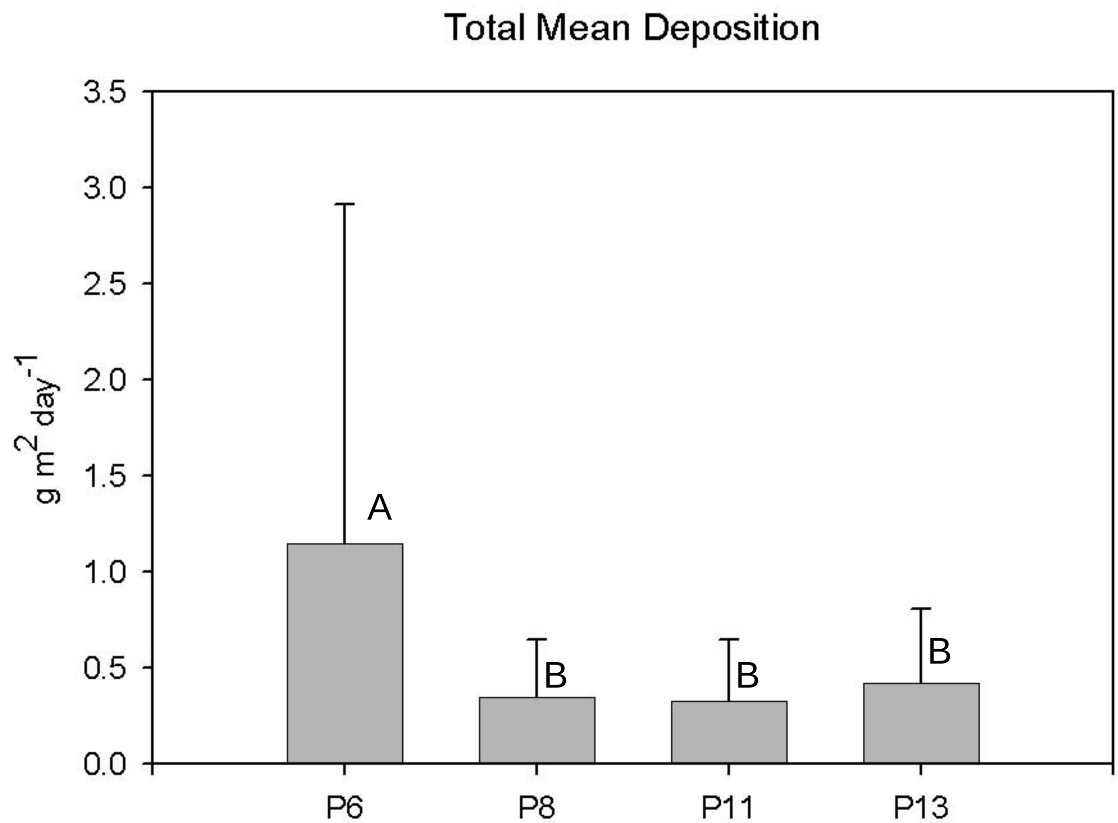

Figure 5. Total mean sediment deposition over the study period in g m^2 day^{-1} at each site. Error bars denote one standard deviation from site mean. Bars with the same letter were not found to be significant at $p < 0.001$.

The lowest deposition occurred at the black-water marsh (P11), of 0.331 ± 0.324 g m^2 day^{-1} (Fig. 5 and Table 1B). There was no significant difference in deposition between P8, P11, and P13 (Table 1B).

Depositional Comparisons between River and Wetland Types

Sites along the brown-water river (i.e. Cape Fear River mainstem) had significantly higher rates of deposition than sites located along the black-water (i.e. Northeast Cape Fear) river (Table 1C). When comparing the two different wetland types, deposition rates at the marsh sites were significantly higher than deposition rates at the swamp sites (Table 1C).

Temporal Variations in Percent Organic Content of Deposited Material

The percent organic content of the sediment deposited on the tiles showed no consistent temporal pattern (Fig. 6A-B). Although a seasonal pattern of increased organic content in the summer was expected, such a pattern was not evident. In fact, some of the highest percent organic values occurred in winter or late fall. When the summer percent organic means were compared to winter means, there was no significant difference (Table 2A).

Site Comparisons for Percent Organic Content

The material deposited on tiles placed at the black-water swamp (P13) site consistently exhibited higher percent organic contents than the deposited material at other sites. In fact, mean percent organic content was significantly higher than any of the other sites at 42.10 ± 10.56 % (Table 2B). Samples taken from the brown-water marsh (P6) and swamp (P8) had the lowest percent organic content means of 22.70 ± 10.45 and 25.66 ± 12.87 %, respectively (Table 2B). The percent organic content of sediments deposited on the black-water marsh (P11) was significantly higher than the percent organic content at the two brown-water sites, but significantly lower than organic content at the black-water swamp (Table 2B). Overall, Percent organic content of deposited material was significantly higher at the black-water wetland sites compared to the brown-water wetland sites (Table 2C). The sediment deposited at swamp sites also had a significantly higher percent organic content then material deposited on the surface of the marsh sites (Table 2C).

Total Suspended Material

The concentration of total suspended material available for deposition (TSM) varied widely across this study. Greater variation was seen in water samples collected from the wetland surface during rising tide compared to samples taken from the adjacent channel on the same day (Figs. 8A-D and 9A-D). For both data sets, the location with the highest mean TSM for any deployment usually also had the greatest variability among replicates (Figs. 8A-D and 9A-D).

Temporal Variations in Suspended Solids

Wetland surface samples exhibited reasonably consistent concentrations of suspended sediment over the study period, with the exception of a few distinct peaks at each site (Fig. 8A-D). Suspended sediment concentrations were significantly higher than the overall site mean in April, May, or June of 2007 for both marsh sites (P6 and P11) (Fig. 8A-D). Elevated TSM occurred during January 2007 at both swamp sites, as well as during April and May of 2007 (Fig. 8A-D). Some of the lowest TSM concentrations were measured in November and December at all four sites (Fig. 8A-D).

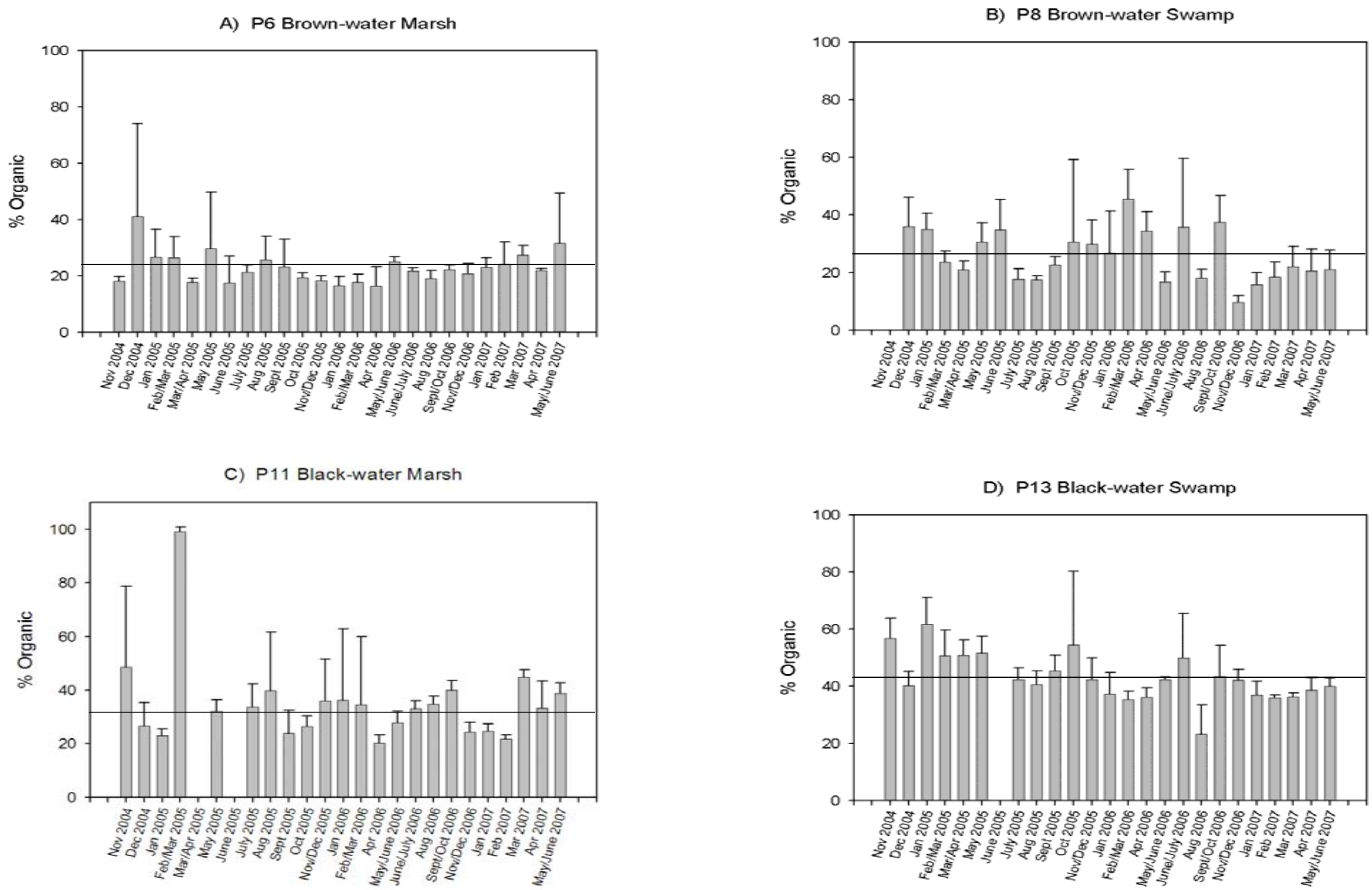

Figure 6A-D. Mean percent organic for each sampling period during the study at each site. Error bars denote one standard deviation from the mean. The horizontal line represents the study mean at each site.

A	Mean Summer Percent Organic Content	Mean Winter Percent Organic Content
P6 Brown-water Marsh	23.56 ± 10.46 **(A)**	21.72 ± 10.41 **(A)**
P8 Brown-water Swamp	25.60 ± 14.01 **(B)**	25.71 ± 11.82 **(B)**
P11 Black-water Marsh	33.18 ± 10.05 **(C)**	32.79 ± 19.97 **(C)**
P13 Black-water Swamp	42.65 ± 12.34 **(D)**	41.66 ± 8.96 **(D)**

B	Mean Percent Organic Content	N
P6 Brown-water Marsh	22.70 ± 10.45 **(A)**	170
P8 Brown-water Swamp	25.66 ± 12.87 **(A)**	210
P11 Black-water Marsh	32.98 ± 16.00 **(B)**	185
P13 Black-water Swamp	42.10 ± 10.56 **(C)**	198

C	Mean Percent Organic Content	P - value	DF
Brown-water v. Black-water	24.3 ± 11.9 **(A)** 37.7 ± 14.2 **(B)**	P < 0.001	740
Marsh v. Swamp	28.1 ± 14.5 **(A)** 33.6 ± 14.4 **(B)**	P < 0.001	744

Table 2A-C. Mean percent organic content of the sediment deposited on tiles. A) Mean seasonal percent organic content for each site over the study period. B) Mean percent organic content at each site over the study period. Significance determined by ANOVA test. C) Mean percent organic content by river type and wetland type. Significance determined by 2-sample t-test. Within each panel, values with the same letter were not significantly different at $p < 0.05$

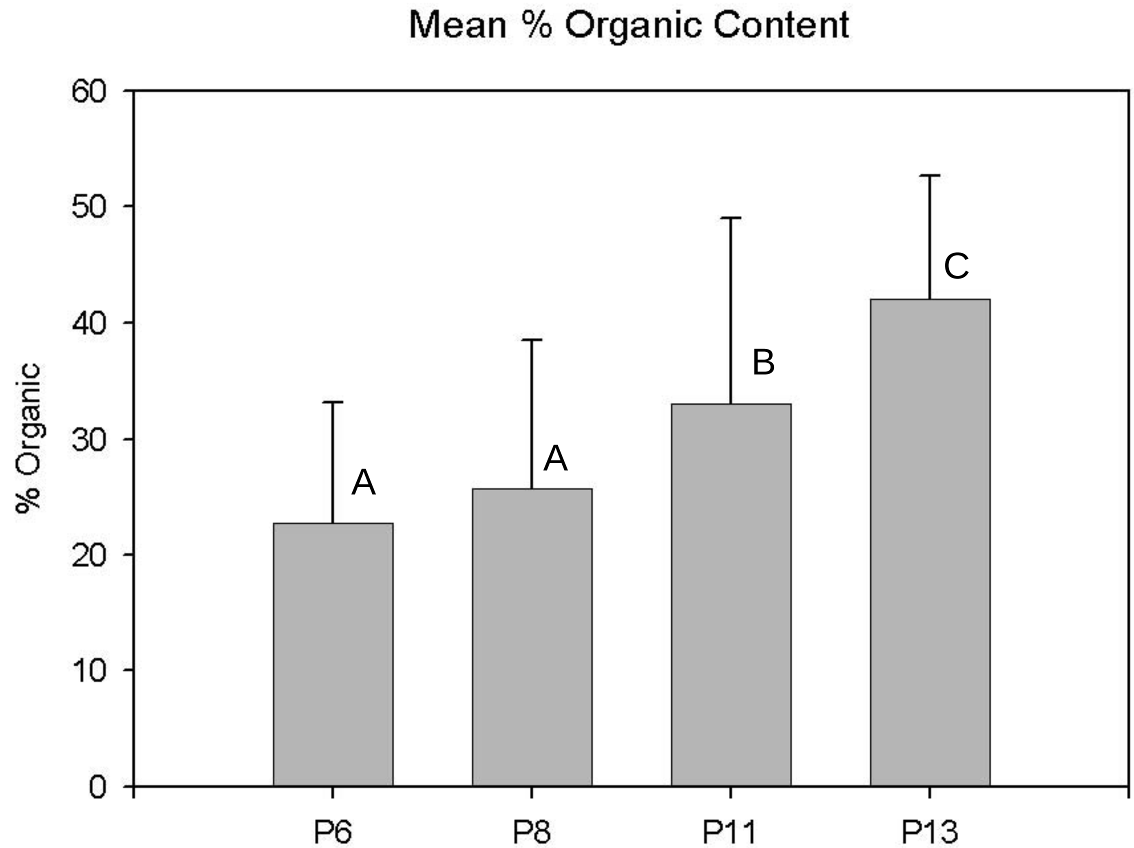

Figure 7. Mean percent organic content of material deposited on sediment tiles over the study period. Error bars denote one standard deviation from site mean. Bars with the same letter were not found to be significant at $p < 0.001$.

River channel TSM concentrations were also relatively consistent throughout the study period at each site (Fig. 9A-D). Only a slight peak during April 2007 was seen at the brown-water swamp (P8) and black-water marsh (P11) (Fig. 9A-D). The brown-water marsh (P6) exhibited higher peaks during April and May of 2007 (Fig. 9A-D). The black-water swamp (P13) exhibited peaks during February and May of 2007 (Fig. 9A-D).

Site Comparisons of Suspended Material

The black-water marsh (P11) exhibited the highest mean concentration of suspended material on the wetland surface, while the black-water swamp (P13) had the lowest mean concentration (Fig. 10 and Table 3A). The concentrations at all four sites were significantly different from each other (Table 3A). When the TSM concentrations of all brown water sites were compared to the mean concentration at black water sites, there was no significant difference (Table 4A). However, when TSM concentrations were examined by wetland type, marsh site concentrations were significantly higher than swamp site concentrations, 29.9 ± 39.8 mg L^{-1} and 11.4 ± 15.7 mg L^{-1}, respectively (Table 4A).

The river channel adjacent to the brown-water marsh site (P6) exhibited significantly higher mean TSM concentrations during this study (18.0 ± 12.9 mg L^{-1}). There was no significant difference in TSM between the other three sites. There was also no significant difference in mean TSM concentration between sites along the brown- and black-water rivers (Table 4B). However, comparisons between marsh and swamp sites showed a significant difference in TSM. Marsh sites had significantly greater TSM concentrations then the swamp sites.

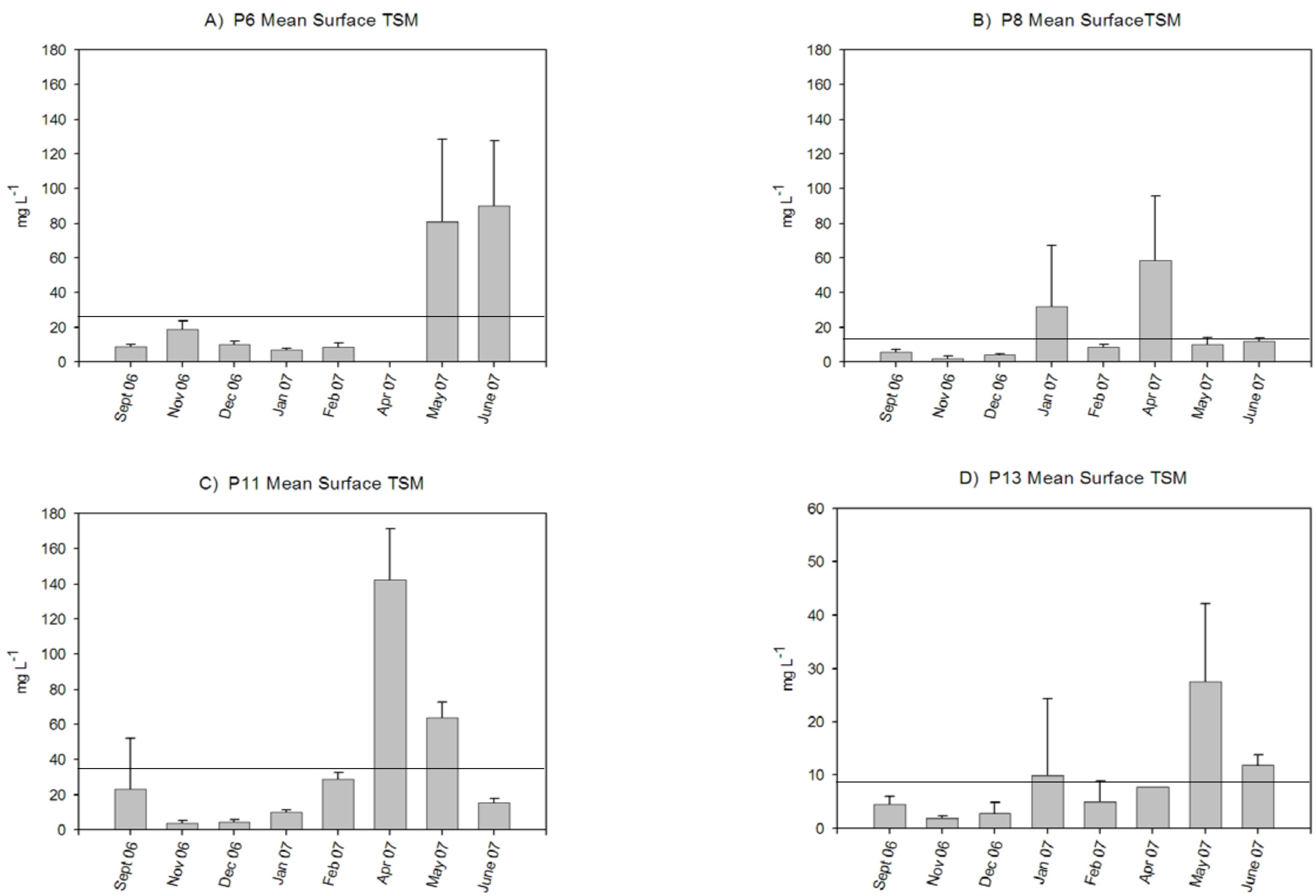

Figure 8A-D. Mean TSM for each deployment of the rising stage collection bottles. Error bars denote one standard deviation from the mean. The horizontal line represents the study mean at each site.

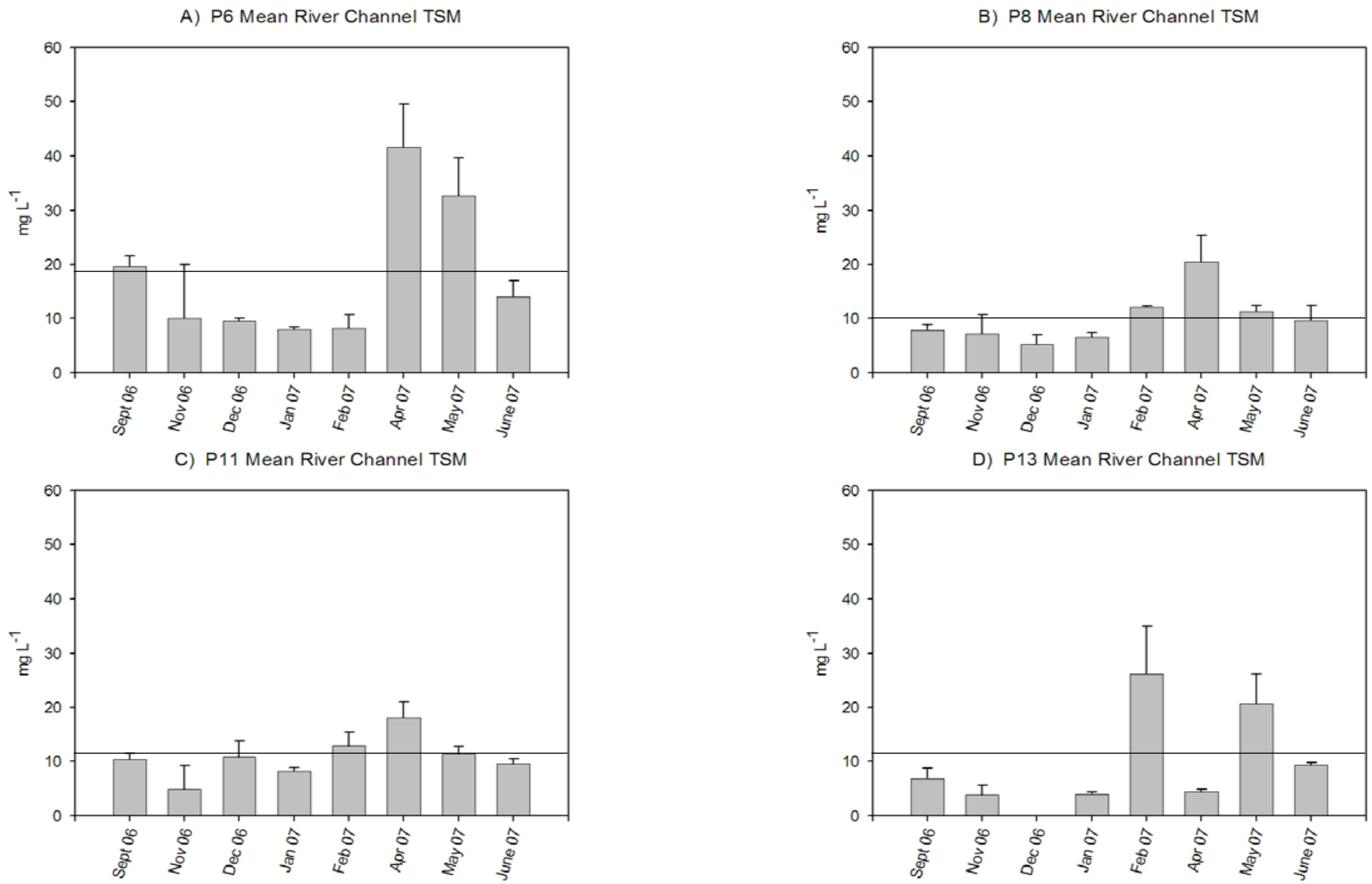

Figure 9A-D. Mean TSM in the river channel adjacent to each study site. Error bars denote one standard deviation from the mean.

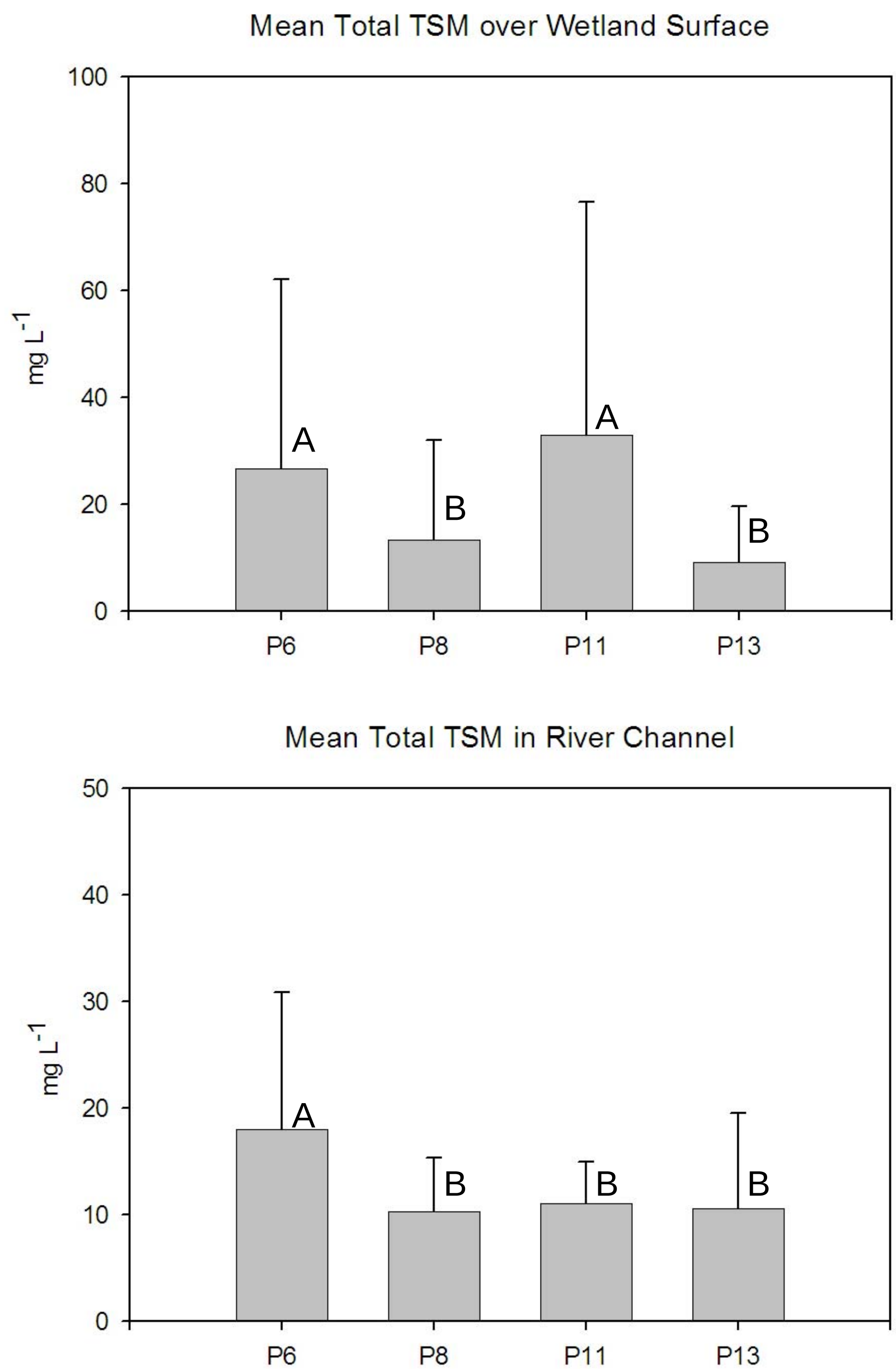

Figure 10A-B. Mean TSM measured in mg L^{-1} at each site. A) Mean TSM over the wetland surface during a single high tide event. B) Mean TSM in the river channel adjacent to each site. Wetland surface and river channel samples collect on the same day for each site. Error bars denote one standard deviation from the mean.

A	Mean Wetland Surface TSM (mg L^{-1})	N
P6 Brown-water Marsh	26.58 ± 35.52 **(A)**	43
P8 Brown-water Swamp	13.25 ± 18.79 **(B)**	40
P11 Black-water Marsh	33.01 ± 43.54 **(C)**	47
P13 Black-water Swamp	9.07 ± 10.62 **(D)**	32

B	Mean River Channel TSM (mg L^{-1})	N
P6 Brown-water Marsh	17.98 ± 12.89 **(A)**	24
P8 Brown-water Swamp	10.27 ± 5.02 **(B)**	23
P11 Black-water Marsh	11.05 ± 3.95 **(B)**	23
P13 Black-water Swamp	10.52 ± 9.03 **(B)**	22

Table 3A-B. Mean total suspended material in mg L^{-1}. Significance determined by ANOVA test at $P < 0.05$. Significance denoted by letter. A) Mean wetland surface TSM for each site over the study period. B) Mean river channel TSM at each site over the study period. Values with the same letter within a panel were not significantly different at $p < 0.05$

A	Mean Wetland Surface TSM (mg L^{-1})	P - value	DF
Brown-water v. Black-water	20.2 ± 29.3 **(A)** 23.3 ± 36.1 **(A)**	P = 0.543	150
Marsh v. Swamp	29.9 ± 39.8 **(A)** 11.4 ± 15.7 **(B)**	P < 0.001	121

B	Mean River Channel TSM (mg L^{-1})	P - value	DF
Brown-water v. Black-water	14.2 ± 10.5 **(A)** 10.8 ± 6.8 **(A)**	P = 0.067	79
Marsh v. Swamp	14.6 ± 10.1 **(A)** 10.4 ± 7.2 **(B)**	P = 0.024	82

Table 4A-B. Statistical comparisons between river and wetland types. A 2-sample t-test was used to determine significance at $p < 0.05$. Tests that resulted in a p – value of less then 0.0001 will simply be noted as $p < 0.001$. Significance denoted by letters. A) Mean total suspended sediment concentrations over the wetland surface. B) Mean total suspended sediment concentrations in the river channel adjacent to each study site. Within each panel, values with the same letter were not significantly different at $p < 0.05$.

These results indicate that suspended sediment availability in the channel differs between sites lower in the estuary and those higher up river, but not between river types.

Temporal Variations in Percent Organic Content

The percent organic content of total suspended material (TSM) contained within water flooding the wetland surface and in the river channel varied over time, however, there was no apparent seasonal trend (Fig. 11A-D and 12A-D). The percent organic content of TSM in wetland surface water generally decreased over the study period at all sites except the brown-water marsh (P6) (Fig. 11A-D). The percent organic content of TSM in adjacent river water did not show a similar pattern. For the river samples, the only consistent pattern was slightly higher TSM organic content values at most sites in September, 2006, December 2006 and January 2007 (Fig. 12A-D).

Site Comparisons of Percent Organic Content

The percent organic content of TSM in wetland surface water was highest at the black-water swamp site (52.16 ± 26.90 %) and lowest (31.20 ± 12.65) at the brown-water marsh (Fig. 13 and Table 5A). Of the river TSM samples, the black-water swamp (P13) again exhibited the highest percent organic content (41.39 ± 21.68 %). Further, P13 was the only river channel site that had a percent organic content that was significantly different from the other river sites (Table 5B). The organic content of TSM taken from both the river channel and the water over the wetland surface at both swamp sites was significantly higher than the levels measured at the two marsh sites (Table 5A). When the percent organic content of TSM in the river channel was compared to the organic content of TSM in wetland surface waters, the river values were slightly lower and less variable.

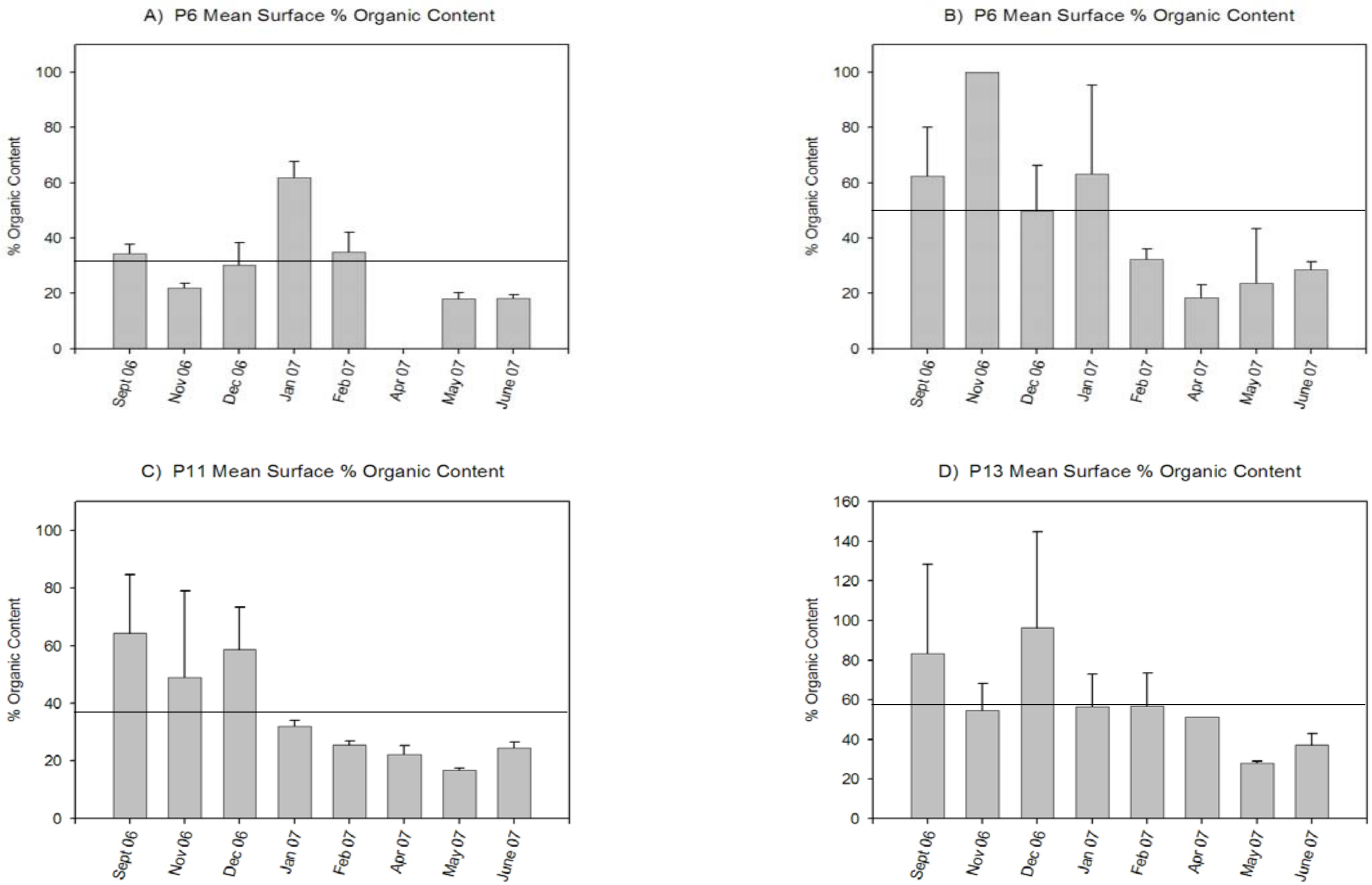

Figure 11A-D. Mean % organic content of TSM over the wetland surface at each study site. Error bars denote one standard deviation from the mean. The horizontal line represents the study mean at each site.

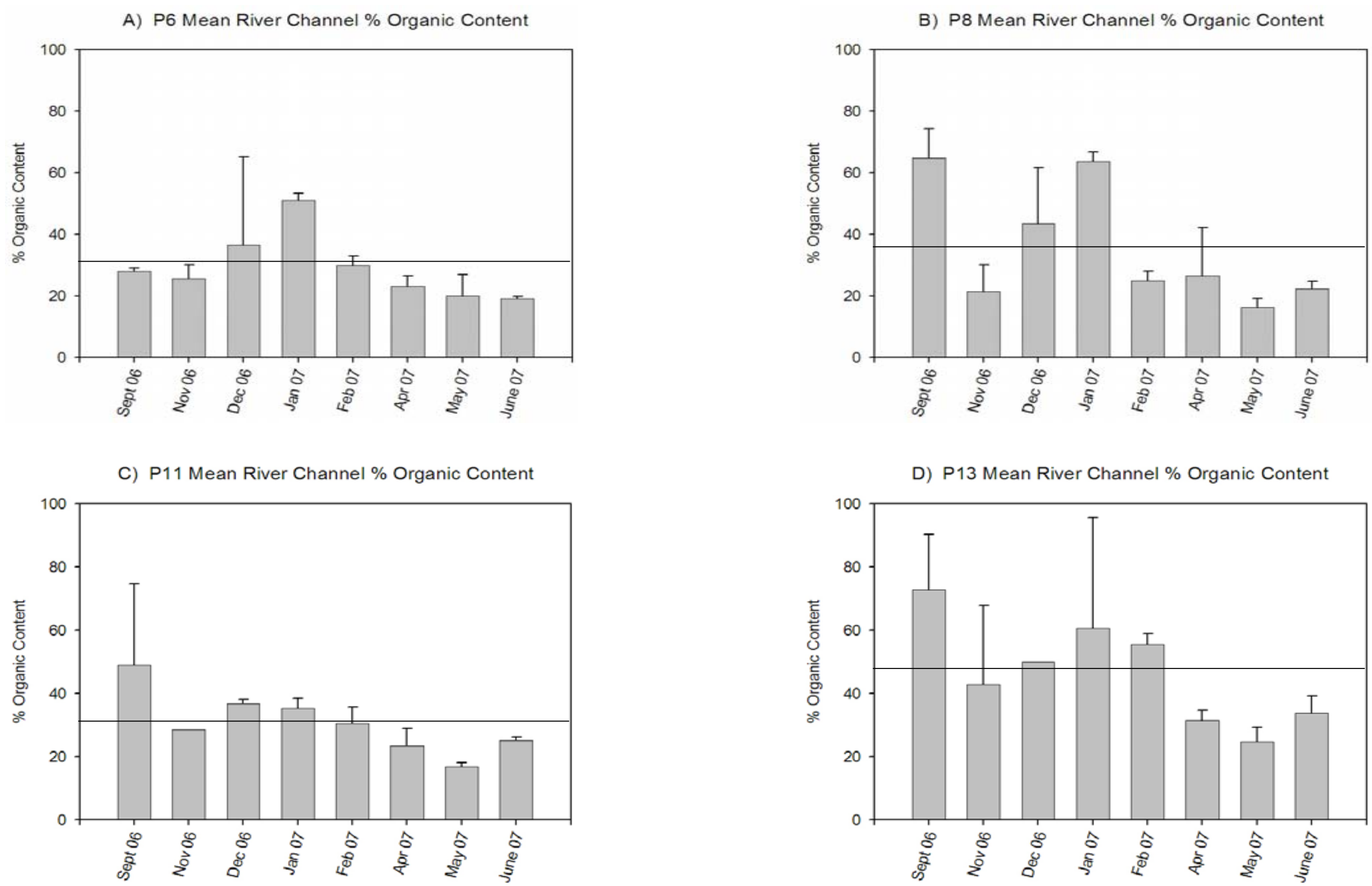

Figure 12A-D. Mean % organic content of TSM in the adjacent river channel at each study site. Error bars denote one standard deviation from the mean. The horizontal line represents the study mean at each site.

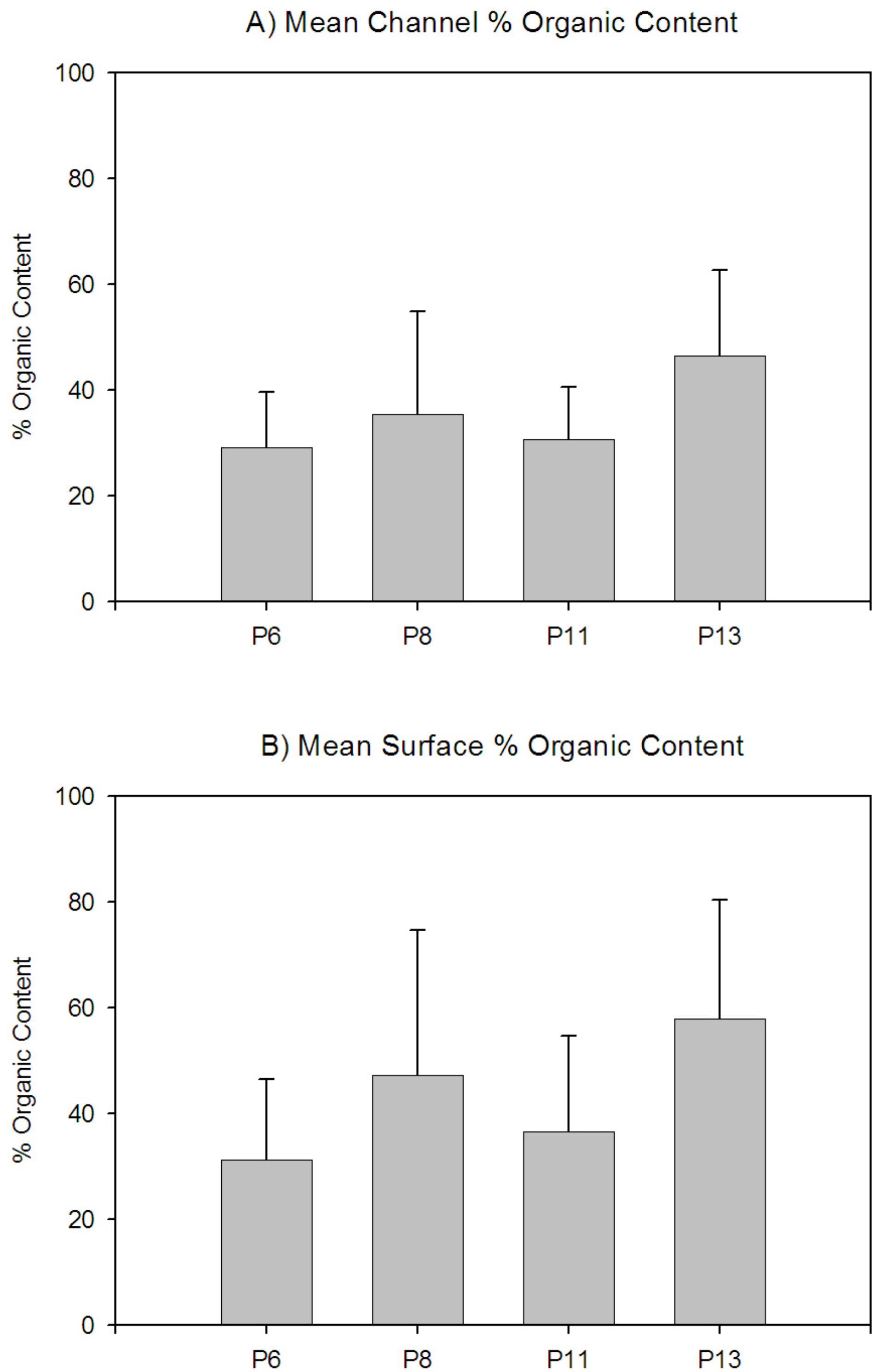

Figure 13A-B. Mean percent organic fraction of TSM at the study sites. A) Mean percent organic content of TSM in the river channel adjacent to each site. B) Mean percent organic content of TSM over the wetland surface at each site. Wetland surface and river channel samples collect on the same day for each site. Error bars denote one standard deviation from the mean.

A	Mean Wetland Surface TSM % Organic Content	N
P6 Brown-water Marsh	31.20 ± 12.65 **(B)**	43
P8 Brown-water Swamp	47.53 ± 27.78 **(A)**	40
P11 Black-water Marsh	35.93 ± 19.67 **(B)**	47
P13 Black-water Swamp	52.16 ± 26.90 **(A)**	31

B	Mean River Channel TSM % Organic Content	N
P6 Brown-water Marsh	29.15 ± 13.38 **(B)**	24
P8 Brown-water Swamp	33.42 ± 20.32 **(B)**	23
P11 Black-water Marsh	29.53 ± 11.82 **(B)**	23
P13 Black-water Swamp	41.39 ± 21.68 **(A)**	22

Table 5A-B. Mean percent organic content of TSM. Significance determined by ANOVA test at $P < 0.05$. Significance denoted by letter. A) Mean wetland surface percent organic content for each site over the study period. B) Mean river channel percent organic content at each site over the study period. Within each panel, values with the same letter were not significantly different at $p < 0.05$.

A	Mean Wetland Surface TSM (mg L^{-1})	P - value	DF
Brown-water v. Black-water	39.1 ± 23.0 **(A)** 42.4 ± 23.0 **(A)**	P = 0.374	157
Marsh v. Swamp	33.7 ± 17.1 **(B)** 49.6 ± 27.3 **(A)**	P < 0.001	111

B	Mean River Channel TSM (mg L^{-1})	P - value	DF
Brown-water v. Black-water	31.2 ± 17.1 **(A)** 35.3 ± 18.2 **(A)**	P = 0.269	89
Marsh v. Swamp	29.3 ± 12.5 **(B)** 37.3 ± 21.1 **(A)**	P = 0.032	70

Table 6A-B. Statistical comparisons between river and wetland types. A 2-sample t-test was used to determine significance at $p < 0.05$. Tests that resulted in a p – value of less then 0.0001 will simply be noted as $p < 0.001$. Values with the same letter were not significantly different at $p < 0.05$. A) Mean percent organic content of suspended material over the wetland surface. B) Mean percent organic content of suspended material in the river channel adjacent to each study site.

Comparisons between River and Wetland Types

There was no significant difference due to river type in the percent organic content of TSM contained in either the river water samples or the surface waters of brown- versus black-water wetlands (Table 6A). For both wetland surface and river channel samples, the percent organic content of TSM at swamp sites was significantly higher than the percent organic content at marsh sites (Table 6A).

Flow Measures

Flow over the wetland surface was measured during falling tide at each of the study sites. Due to low water levels, flow speed was measured at only one location at P6. With the exception of the marsh edge at site P11, the mean flow speed (x and y components of velocity) did not exceed 2 cm s^{-1} (Fig. 14). The highest flow speeds measured during the study were seen at the edge station (Station 1) in the black-water marsh (P11) (Fig. 14C). Mean flow speed across the wetland surface was fairly consistent at most sites (Fig. 14A-D). However, the speeds measured at locations closer to the river were higher than speeds measured in the wetland interior at both the brown-water swamp (P8) and the black-water marsh (P11) sites. These locations also exhibited the most variability in flow speed during the inundation events that were sampled (Fig. 14B-C). No significant difference in mean flow existed between sites.

Vertical variations in flow speed (z component of total velocity) were recorded as part of the velocity transects (Table 7). The z-component of velocity was much lower than the x and y components. This result indicates there was little vertical turbulence in the flows moving across the wetland surface. The highest mean vertical velocity of 0.33 cm s^{-1} occurred at the brown-water marsh (P6) site. This was the case at most of the

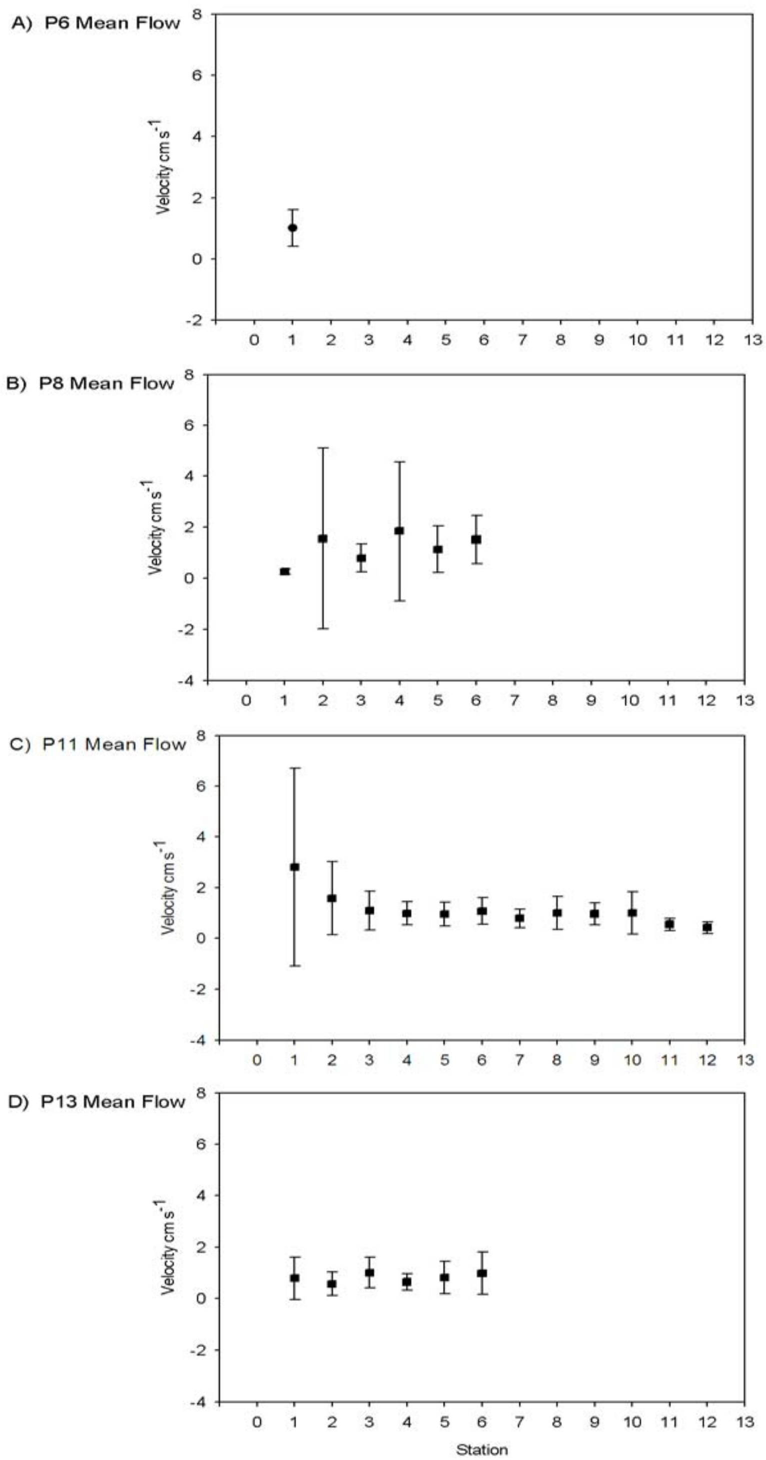

Figure 14A-B. Mean flow velocities in cm s^{-1} at each station along the site transect. Stations begin with 1 at the wetland edge and are spaced at 1 meter intervals to the interior. Error bars denote one standard deviation from station mean. A) Due to extremely low water conditions only one station was used at site P6. B) Stations 7-12 were not used due to low water conditions. D) Stations 7-12 were not used due to low water conditions.

Site	Mean Z Component (cm s^{-1})
P6 Brown-water Marsh	0.33
P8 Brown-water Swamp	0.16
P11 Black-water Marsh	0.01
P13 Black-water Swamp	0.08

Table 7. Mean vertical velocity at each study site.

sites. The lowest mean z-velocity was measured at the black-water marsh (P11) site. At this location, the z-component was close to the minimum resolution of the probe.

Settling Velocity

To determine if the measured flow velocities were able to hinder deposition of available material, mean grain size of material deposited on wetland surface was measured. The brown-water marsh (P6) was found to have the largest mean grain size of material deposited of 0.385 mm, while the brown-water swamp (P8) had the smallest of 0.043 mm, respectively (Table 8). Using Stoke's Law, the settling velocity of particles equal to the mean grain size observed at each site was calculated. The brown-water marsh (P6) was found to have the highest potential for settling with a velocity of 9.88 cm s^{-1} and the brown-water swamp had the lowest of 0.12 cm s^{-1} (Table 8).

SET

Base line SET (sedimentation-erosion table) measurements were taken in June and July of 2006. At this time, the elevations of both marsh sites were found to be below zero relative to the NAVD88 datum (Table 8). The elevation of the surface of the brown-water swamp (P8) was slightly over zero elevation, while the black-water swamp surface was almost right at zero elevation (Table 8). At the end of the one year elevation monitoring period, the two marsh sites (P6 and P11) showed a negative change in elevation (Table 8). The brown-water marsh (P6) lost 0.017 m of elevation and the black-water marsh (P11) lost 0.011 m of elevation. In contrast, the brown-water swamp (P8) showed the greatest change in elevation, an increase of 0.07 m (Table 8). The black-water swamp (P13) also exhibited an increase in elevation (0.007m), but it was minimal.

The SET method of measuring surface elevation change is usually accompanied by marker horizon measurements. This combination allows for the differentiation between subsurface and surface contributions to elevation change. Unfortunately, the marker horizons were too highly degraded during this study to be useful. However, the marker horizons provided anecdotal information consistent with the surface elevation data. These results indicate that the marsh sites are losing elevation, while the swamp sites are either increasing in elevation or at least maintaining their current elevation.

	Mean Grain Size (mm)	Settling Velocity (cm s^{-1})
P6 Brown-water Marsh	0.385	9.88
P8 Brown-water Swamp	0.043	0.12
P11 Black-water Marsh	0.076	0.38
P13 Black-water Swamp	0.132	1.17

Table 8. Mean grain size of material deposited on the wetland surface at each site. Settling velocity calculated using Stoke's Law.

	Baseline Elevation	Mean Elevation Change	Final Elevation
P6 Brown-water Marsh	-0.138 m	-0.017 ± 0.013 m	-0.155 m
P8 Brown-water Swamp	0.383 m	0.07 ± 0.08 m	0.390 m
P11 Black-water Marsh	-0.348 m	-0.011 ± 0.020 m	-0.359 m
P13 Black-water Swamp	0.019 m	0.007 ± 0.085 m	0.020 m

Table 9. SET (sedimentation-erosion table) elevations. Elevations relative to the NAVD88 datum.

DISCUSSION

The goal of this study was to examine differences in surface deposition and elevation change across wetland types within the Cape Fear River Estuary as defined by differences in sediment availability and hydrologic regimes. Previous work has shown that the type and amount of available material can affect the rate and composition of deposited material (TEMMERMAN, *et al*., 2003; REED, 1989; RENFRO, 2004). Additional studies have shown that the deposition of this material is strongly influenced by hydrologic parameters such as river discharge, frequency and length of inundations, and flow velocities (MITSCH and GOSSELINK, 2000; FRIEDRICHS and PERRY, 2001; CAHOON and REED, 1995; REED, 1989; TEMMERMAN, *et al*., 2003). My study found that a combination of availability, grain size, and flow speed over the wetland surface, most strongly influenced patterns of deposition and elevation change in the riparian wetland systems of the Cape Fear River Estuary. Further, this study found that although the brown-water wetlands experienced significantly higher deposition rates than their black-water counterparts, the results were likely skewed by extremely high values measured at the brown-water marsh site.

Quantifying the Sediment Available for Deposition

One of the original hypotheses of this study was that deposition in the wetlands along the brown-water river would exceed deposition in the black-water wetlands due to relatively higher sediment availability in the brown-water system. Previous research has documented a significant correlation between sediment availability and deposition (LEONARD, 1997). The presumed source of sediment to be deposited in this system was the adjacent river channel. However, in this study there was no difference in sediment availability among the sites. This lack of difference between river types may have been due to the fact that drought conditions existed during much of this study. Under these conditions, the potential for sediment loading to the CFR is greatly reduced and the potential for dilution of TSM concentration by black-water tributaries increased. However, even if there was no difference in availability, the question remains as to whether or not the TSM in the river is in fact transported onto the wetland surface during inundation events.

For the most part, the temporal patterns evident in the river TSM concentrations mirrored temporal changes in TSM of waters on the wetland surface. When river TSM was compared to surface TSM, river TSM was positively and significantly correlated with surface TSM at the brown-water swamp (P8), the black-water marsh (P11) and the black-water swamp (P13) sites (Fig. 16A-B). Further, a significant positive correlation existed between the percent organic content of river TSM and the organic content of surface TSM at all sites except the brown-water swamp (P8) site (Fig. 17A-C).

While these results support my assumption that TSM in the river is available for deposition on the wetland surfaces, there is no apparent difference in the amount of material available to the brown- or black-water wetlands. No significant difference was found between the brown- and black-water wetlands for TSM and percent organic of TSM in either wetland surface waters or the river channel (Tables 4A-B and 5A-B). Therefore, my hypothesis for differences in TSM across different river types was found to be unsupported.

Spatial and Temporal Patterns of Deposition

After determining that river TSM is transported onto the surfaces of these wetlands and is therefore available for deposition, the next question is where and when are these sediments deposited? Previous studies have linked high TSM availability to increased deposition on the wetland surface but have noted that sediment deposition can vary widely, both temporally and spatially (LEONARD and LUTHER, 1995).

During this study, temporal variations in deposition existed primarily as seasonal trends with higher deposition rates in the summer and lower deposition rates in the winter (Fig. 4A-D and Table 1). This result is consistent with previous depositional studies conducted in temperate tidal marshes (LEONARD, 1997; CAHOON AND REED, 1995; HUTCHINSON, *et al*., 1996; and YANG, 1999) that reflect increased deposition in summer and decreased deposition in the winter. This pattern was most pronounced at the brown-water marsh (P6) site and least pronounced at the black-water marsh (P11). The brown-water marsh (P6) was also the only site where river TSM was not correlated with surface TSM. However this site did exhibit the only significant correlation between surface TSM and deposition (Fig. 15).

One possible explanation for the observed differences in the seasonal depositional signal is variation in type of vegetation and variation in the degree of seasonal die-back between these sites. Previous research has shown strong seasonality reflected in deposition rates due to a combination of greater sediment trapping by vegetation and increased biological activity during the summer (LEONARD and LUTHER, 1995; HUTCHINSON, *et al*., 1996; and YANG, 1999). For my study sites, the greatest winter die-back of vegetation occurred at the brown-water marsh (P6). As a result, the potential

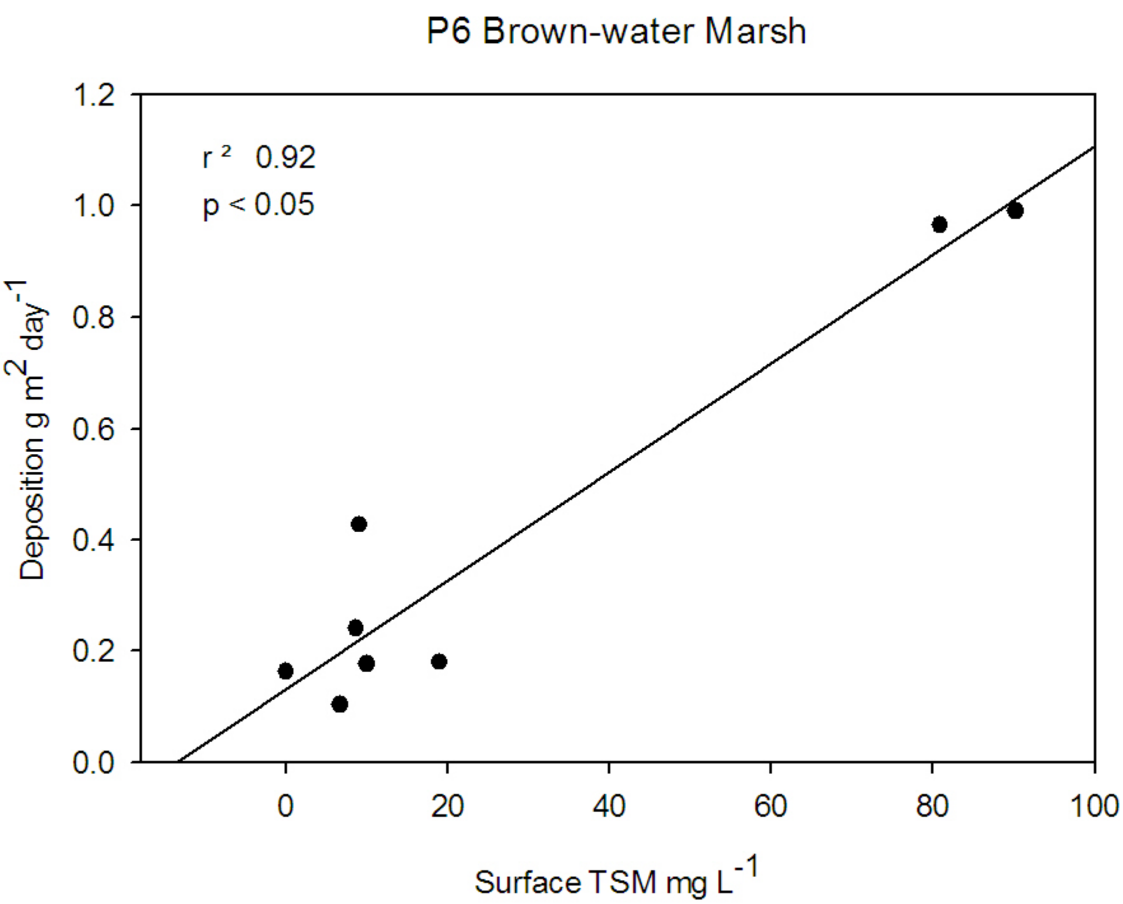

Figure 15. The relationship between wetland surface TSM concentration and surface deposition rate.

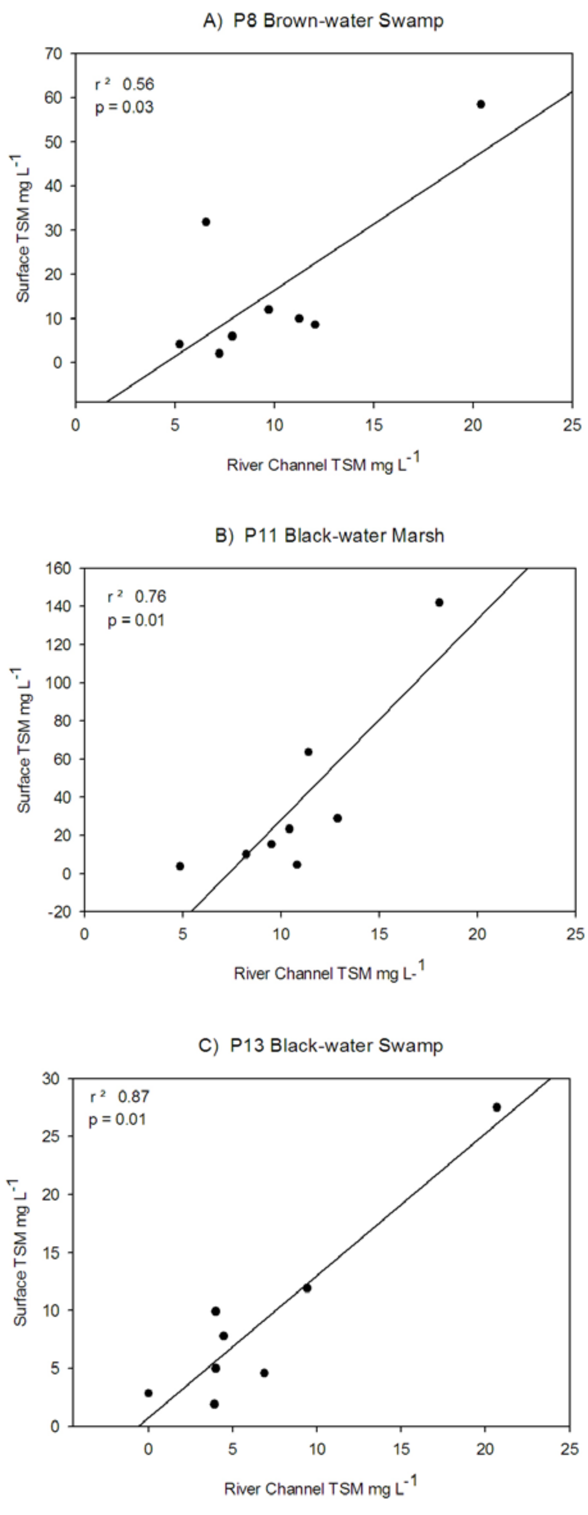

Figure 16A-B. The relationship between river channel TSM and wetland surface TSM concentrations. A) The brown-water swamp (P8) site. B) The black-water marsh (P11) site. C) The black-water swamp (P13) site.

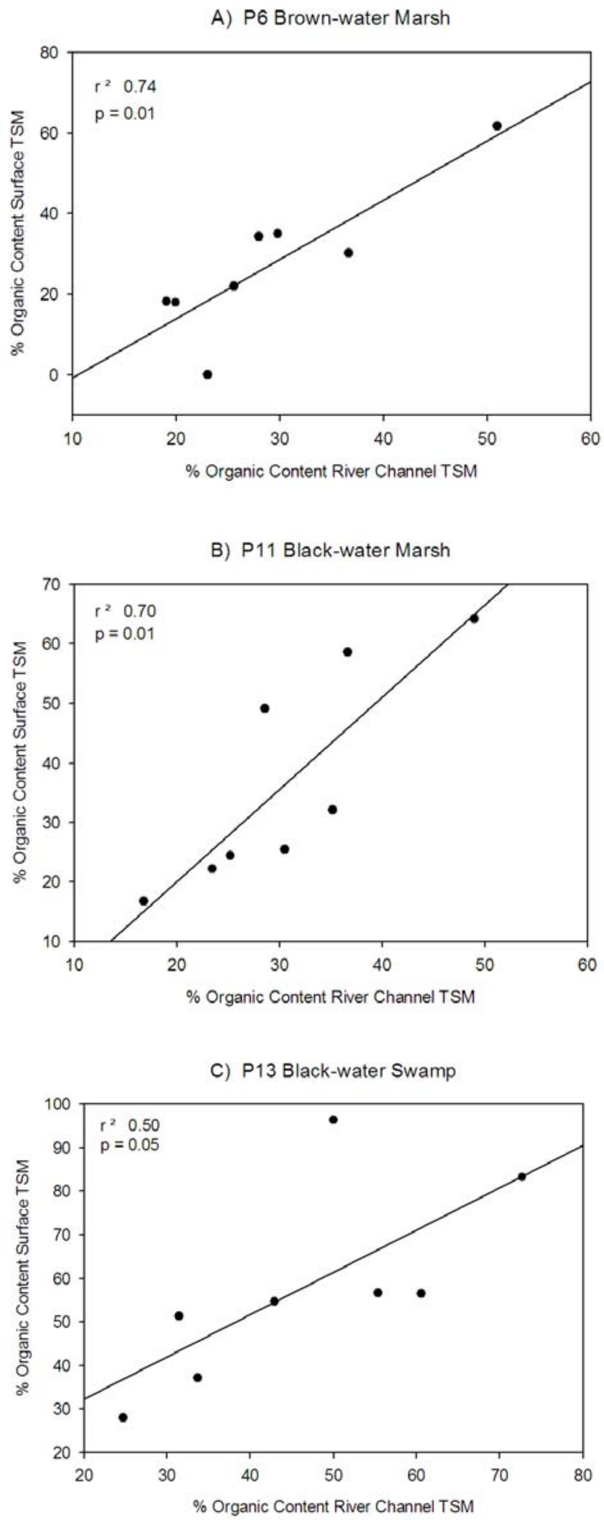

Figure 17A-C. The relationship between the % organic content of river channel TSM and the % organic content of wetland surface TSM. A) The brown-water marsh (P6) site. B) The black-water marsh (P11) site. C) The black-water swamp (P13) site.

for sediment trapping and retention by plants was greatly reduced in the winter at this site.

Another mitigating factor is seasonal changes in sediment availability which also can vary over both spatial and temporal scales. Studies of sediment transport in tidal wetlands have shown increased TSM concentrations in the summer compared to the winter (LEONARD, 1997). Although TSM concentrations were frequently elevated in late spring/summer surface TSM was significantly correlated with deposition rate at only one site, the brown-water marsh (P6) (Fig. 15). Suspended sediment availability did not significantly affect deposition rate at any other site. I also looked for a relationship between the percent organic content of TSM and percent organic content of material deposited on the wetland surface. However, no significant relationship between percent organic content of TSM and that of deposited material was found for any of the sites. There also appeared to be no relationship between high TSM events and deposition rate over individual sample periods during the study.

One very interesting result of this study was that the brown-water marsh (P6) was observed to have significantly greater deposition despite there being no significant difference in TSM availability among the sites. These results indicate that while TSM can potentially impact deposition rate, it does not appear to be the primary control on deposition within this particular system. Further, these results indicate that other processes are mediating deposition in these systems. Thus these results are only somewhat consistent with previous studies of deposition in temperate tidal wetlands that have linked TSM to deposition (DARKE and MEGONIGAL, 2003; DAY, *et al.,* 1998; LEONARD, 1997; FRENCH, 1993).

Effects of Hydrology on Deposition

In the tidal wetlands of the Cape Fear Estuary, there are additional factors that may influence the delivery of material to the wetland surface and its ultimate deposition. One such factor is changes in river discharge, where increased discharge may result in higher sediment loads in the river and greater inundation of the wetland surface (SIMMONS, 1993). Other factors include differences in the frequency and length of tidal inundation between sites (FRIEDRICHS and PERRY, 2001); and differences in surface hydrology between sites (LEONARD *et al.*, 1995; LEONARD and REED, 2002; CHRISTIANSON, *et al.*, 2000).

River Discharge

Discharge data from stations up-river of study sites on each river branch was plotted against mean surface deposition and TSM to determine possible relationships between these factors. However, no significant correlation existed between river discharge and mean surface deposition at any of the study sites. Further, even though periods of elevated deposition sometimes coincided with periods of higher river discharge, there was no consistent pattern (Figs. 18A-B and 19A-B). There was also no significant correlation ($p > 0.05$) between the magnitude of river discharge and the concentration of TSM in the river (Figs 20A-B and 21). This finding refutes the assumption that increased discharge resulted in greater sediment delivery to the wetland surfaces in the study area. Further, these results indicate that deposition is not controlled by river discharge in this particular system.

Frequency and Length of Tidal Inundations

Previous work suggests that increases in hydroperiod or frequency of flooding leads to increased deposition (CAHOON and REED, 1995; LEONARD, 1997). The number of potential high tide inundation events for each site, as well as the number of low tides events that did not fall below the elevation of the wetland surface, were compiled. From these data the percentage of total possible inundation events and percent of total tides that did not recede from the wetland surface was calculated. All of the sites were inundated during every possible high tide, except for the brown-water marsh (P8) which was flooded only 92% of the time (Table 9). There was no significant difference in the number of inundations among the sites (Table 9).

In terms of events where the water did not drop off the marsh surface, the black-water marsh site (P11), the site with the lowest surface elevation, had the greatest number of these events (7.8% of all low tides). Given the lack of appreciable difference in flooding among the sites, frequency of inundation does not appear to be a primary control on deposition at these particular sites. This finding is supported by the additional observation that the site with the lowest elevation (P11) also had the lowest deposition rate.

Influence of Surface Flow Characteristics and Grain Size

Fine scale differences in surface flow dynamics are known to affect particle settling in tidal wetland environments (CAHOON, *et al.*, 1995; LEONARD and LUTHER, 1995). These differences may be expressed in the horizontal plane (x-y components of velocity) and affect spatial variations in deposition or in the vertical

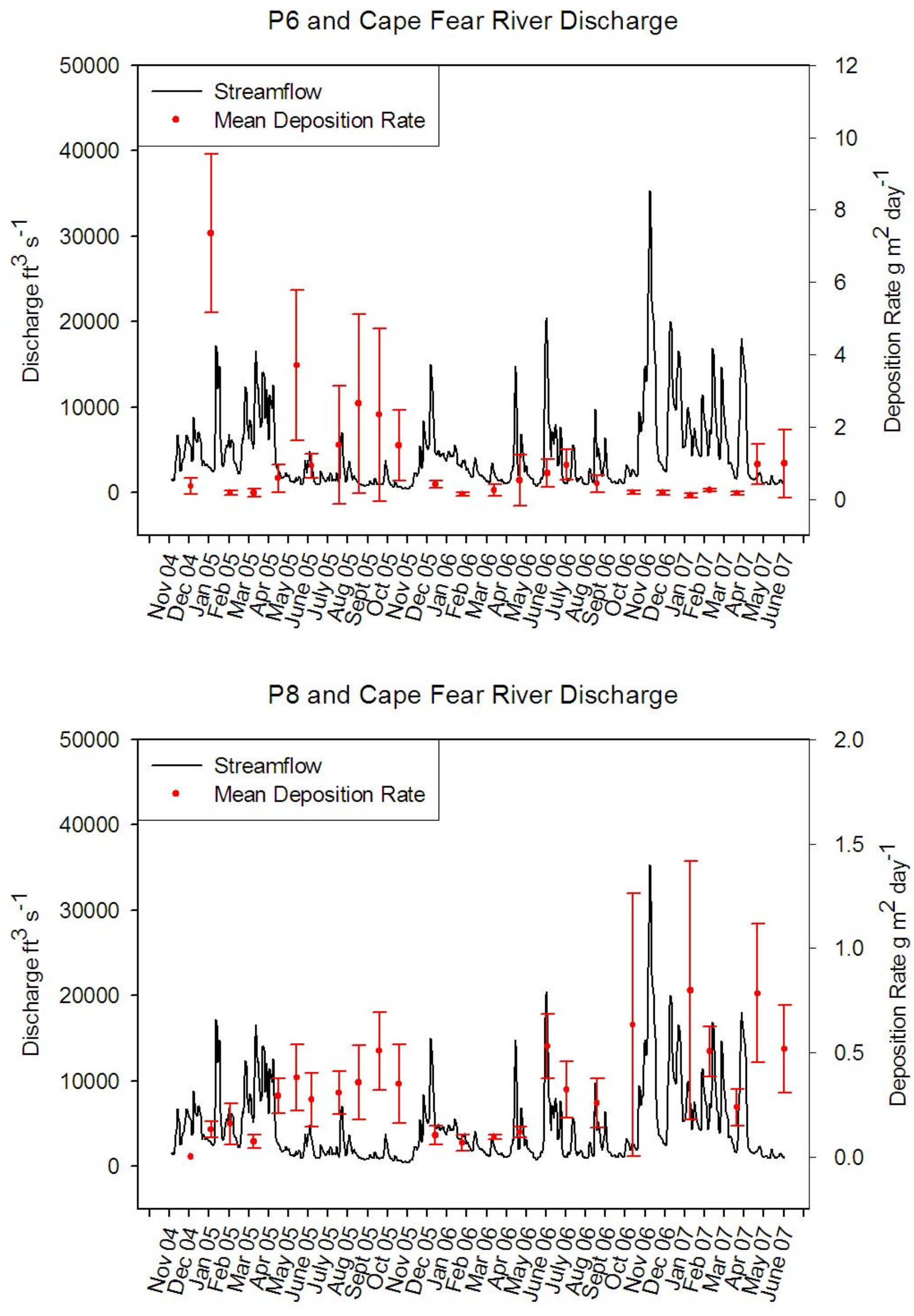

Figure 18A-B. Mean daily discharge for the Cape Fear River in $ft^3\ s^{-1}$ plotted with sample period means for each study site. A) Mean sample period deposition for the brown-water marsh (P6) and river discharge. B) Mean sample period deposition for the brown-water swamp (P8) and river discharge.

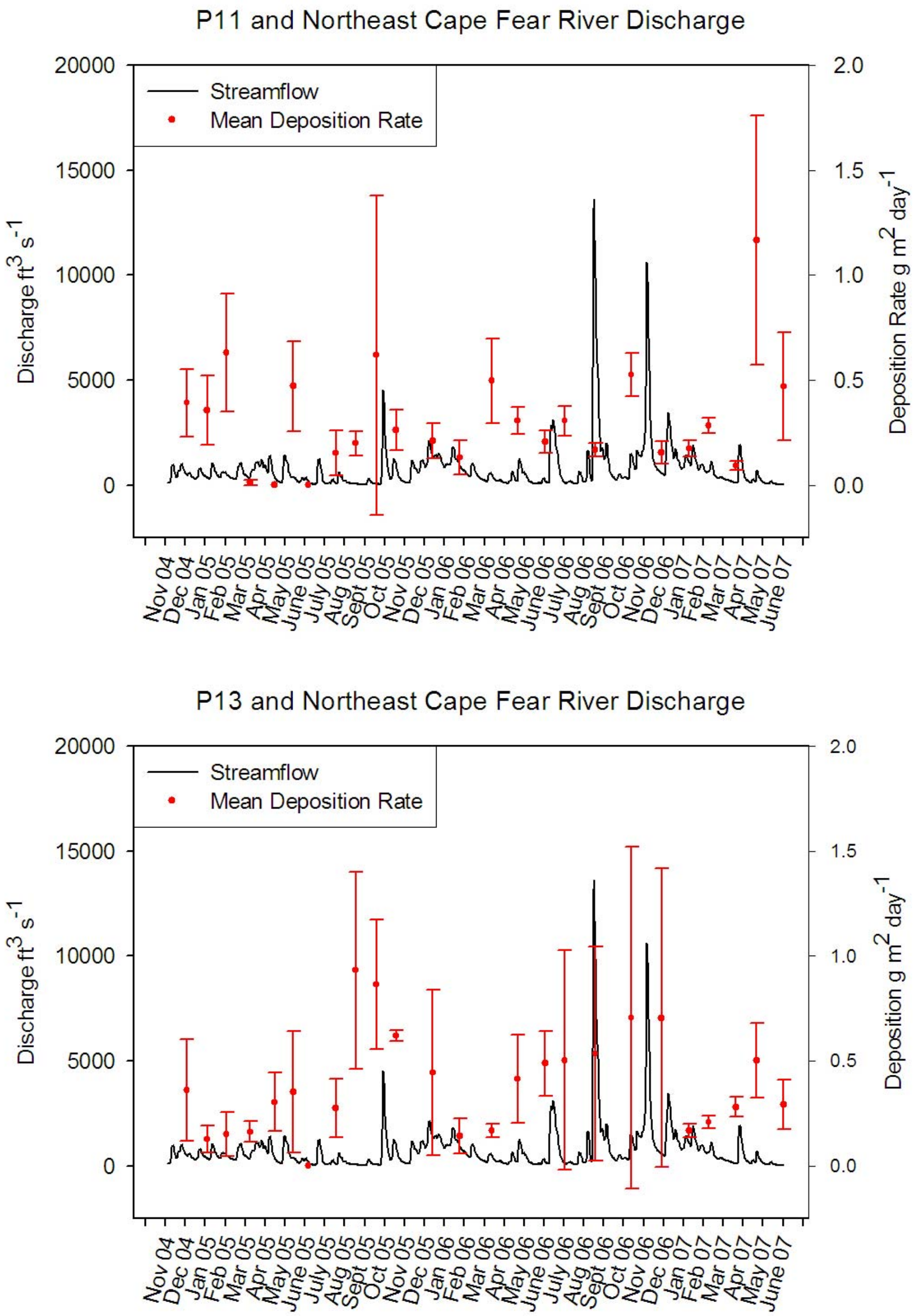

Figure 19A-B. Mean daily discharge for the Northeast Cape Fear River in $ft^3\ s^{-1}$ plotted with sample period means for each study site. A) Mean sample period deposition for the black-water marsh (P11) and river discharge. B) Mean sample period deposition for the black-water swamp (P13) and river discharge.

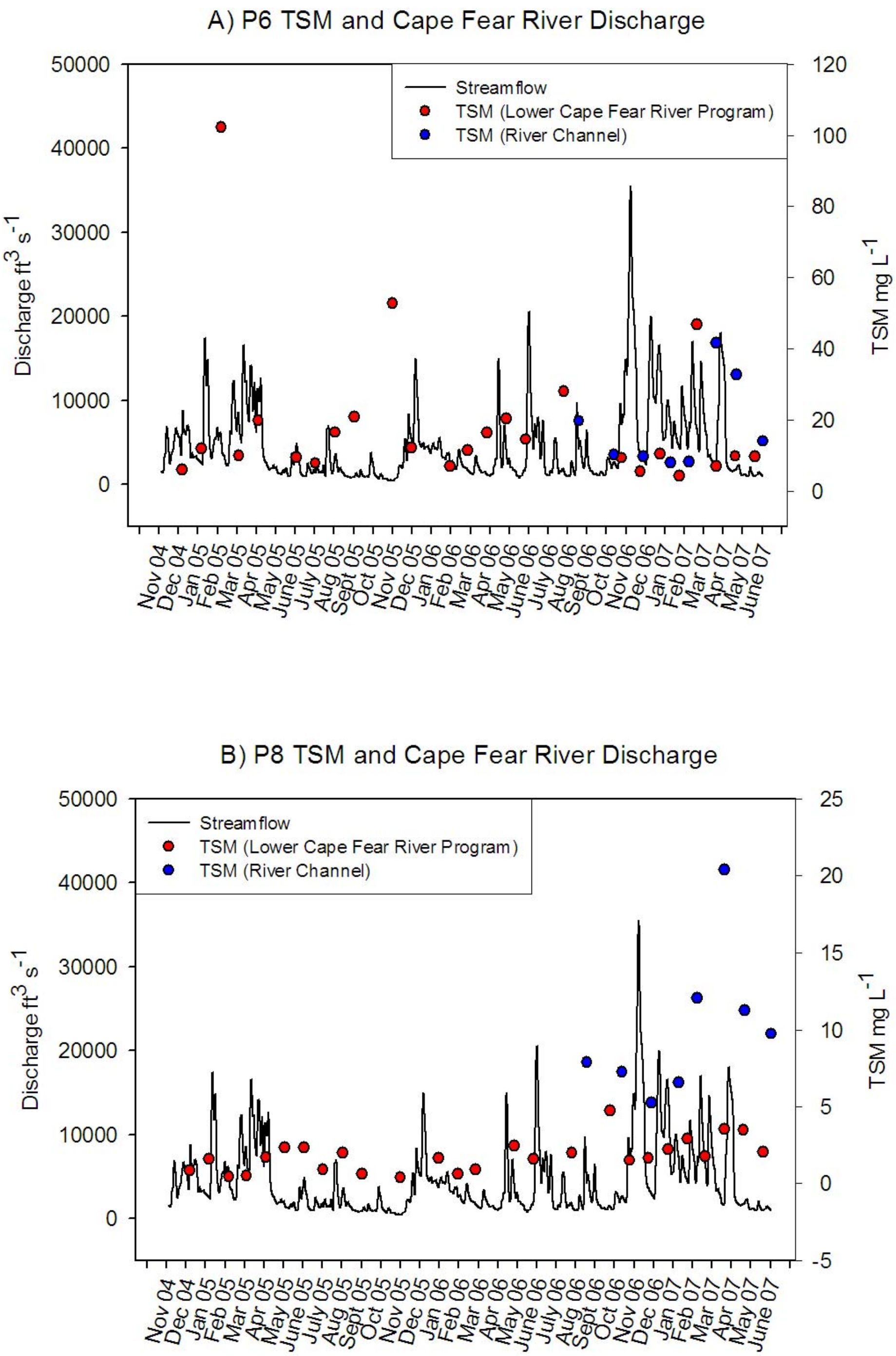

Figure 20A-B. Mean daily discharge for the Cape Fear River in ft^3 s^{-1} plotted with TSM in mg L^{-1} sample period means for each study site. Red points represent TSM from another study in the Cape Fear River Estuary with a longer record. Blue points represent river channel TSM observed in this study. A) Mean sample period TSM for the brown-water marsh (P6) and river discharge. B) Mean sample period TSM for the brown-water swamp (P8) and river discharge.

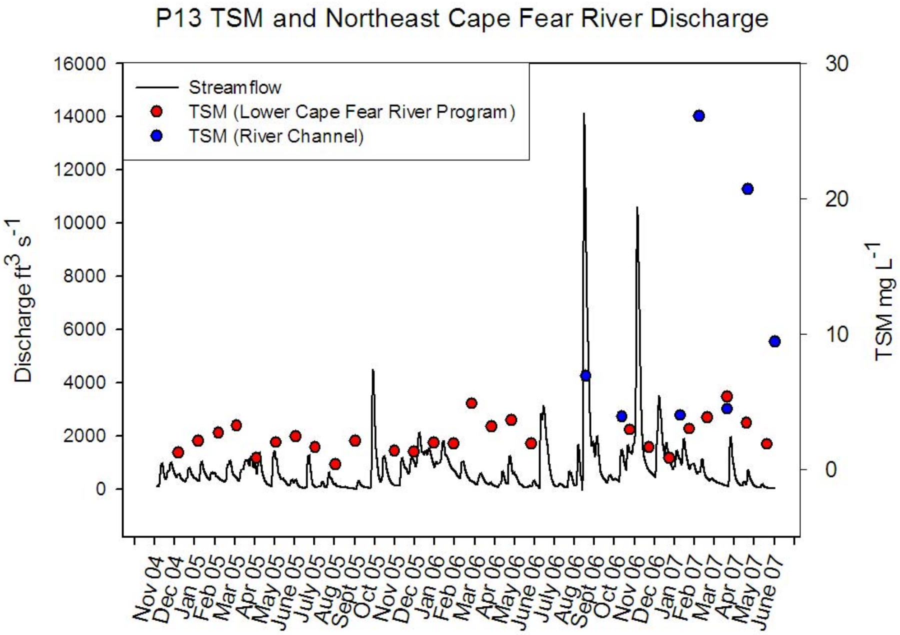

Figure 21. Mean daily discharge for the Northeast Cape Fear River in ft^3 s^{-1} plotted with TSM in mg L^{-1} sample period means for the study site. Red points represent TSM from another study in the Cape Fear River Estuary with a longer record. Blue points represent river channel TSM observed in this study.

(z-component of velocity) which affects rate of deposition. Both horizontal and vertical variations in surface velocity were examined to determine the extent to which differences surface flow characteristics among the sites influenced sediment deposition.

No significant difference in horizontal flow velocity existed among the study sites. Horizontal velocities were comparable among the sites and generally too low to result in erosion of the substrate. Vertical flow velocities were much lower than horizontal velocities, but did show some variation among the study sites (Table 7). In order to assess the potential effect of these velocity variations on deposition, I compared each mean vertical velocity to the Stoke's settling velocity of the mean grain diameter of sediment collected from the tiles.

The brown-water marsh (P6) had the largest mean grain size (0.385 mm) and a Stoke's settling velocity of 9.87 cm s^{-1}. This site also had the highest mean vertical velocities (0.33 cm s^{-1}), but this value was one order of magnitude lower than the Stoke's settling velocity. This combination of large particles with high settling velocities and low vertical velocities may explain the higher deposition rates observed at P6. The black-water swamp (P13) had the second greatest potential for settling with a Stoke's value of 1.17 cm s^{-1} compared to a vertical velocity of 0.08 cm s^{-1}. This site also had the second highest rate of sediment deposition among the study sites, even though this difference was not significant. The Stoke's settling velocity at the brown-water swamp (P8) was 0.124 cm s^{-1} and this value was comparable to the mean vertical flow velocity of 0.16 cm s^{-1}. These conditions suggest that surface flows may impede settling at this site and this may account for the lower deposition rate observed during this study.

	Number of Inundations	% of Possible Inundations	Number of Low Tide Events that were not Dry Events	% of Possible Dry Events
P6 Brown-water Marsh	1723	100 %	16	0.9 %
P8 Brown-water Swamp	1221	92 %	20	1.5 %
P11 Black-water Marsh	1327	100 %	139	7.5 %
P13 Black-water Swamp	1856	100 %	69	3.7 %

Table 10. The number of high tide inundation events that occurred over the study period at each site. The data sets used did not contain every possible high and low tide at each site due to various equipment or software malfunctions.

Stoke's settling velocity at the black water marsh (P11) was 0.38 cm s^{-1}; an intermediate value among the sites. The vertical velocity, however, was close to the resolution of the probe thereby complicating the interpretation of data from this site. It is likely that the effect of vertical fluctuations in flow on settling was greater than observed at P6 and intermediate to the other sites. These results demonstrate that, over the time scales examined here, flow characteristics and the grain size of available material exerted greater influence over deposition in this system than river or wetland type.

Elevation Change and Sea-level Rise in the Cape Fear River Estuary

The last question this study posed was whether these wetlands are able to keep up with current and/or future rates of sea-level rise? The current rate of sea-level rise for southeastern North Carolina is 2.12 mm yr^{-1} (www.noaa.gov). Based on the results of this study, only one site, the brown-water swamp (P8) appears to be maintaining its elevation relative to current sea-level (Table 9). The other sites are either losing elevation or appear unable to keep pace with sea-level (Table 9). In spite of the availability of material and positive rates of deposition even the brown-water marsh (P6) which had the highest deposition rate is losing 0.017 m of elevation per year.

Another study conducted in the Cape Fear River Estuary (RENFRO, 2004) corroborates the trends in deposition that I observed. RENFRO (2004) used alternative methods (i.e. sediment traps, ISCO water samplers, and radioisotope dating) but found similar deposition and sediment availability patterns. Her results, however, varied in magnitude from this work. Further, RENFRO (2004) observed that the wetlands should be gaining surface elevation, not losing it.

The loss of elevation at the marsh sites in spite of net deposition suggests that other processes, such as changes in below ground inputs and subsurface decomposition are important. One way to account for the subsurface contribution to elevation in SET studies is to calculate the differences in total elevation change in conjunction with accretion over a marker horizon. During this study I deployed marker horizons but they were too quickly degraded to determine the below ground contribution to accretion. Where short-term back of the envelope calculations were possible, the below ground changes accounted for up to 95% of elevation change.

Changes in pore water salinity can also affect the accumulation of below ground organic material, thereby influencing changes in surface elevation (MENDELSSOHN, *et al.*, 1999). Organic material is consumed by different types of bacteria at varying rates (HACKNEY, *et al.*, 2004). Changes in pore water salinities can cause shifts in the bacterial community of the wetland soil, altering the rate organic material is decomposed (HACKNEY, *et al.*, 2004). This process can result in significant losses in elevation due to compaction of the substrate.

CONCLUSIONS

This study examined the differences in deposition between marshes and swamps. It was hypothesized that deposition at marsh sites would exceed that of swamp sites due to a combination of greater sediment trapping by marsh vegetation and the location of the two marshes lower in the estuary. I observed that the marsh sites did exhibit significantly higher rates of deposition then the swamps, however, this result may have been skewed by high rates of deposition at the brown-water marsh (P6) site.

Differences in deposition rate between sites along the brown-water Cape Fear River and the black-water Northeast Cape Fear River were also examined. It was hypothesized that the sites along the brown-water CFR would exhibit greater rates of deposition then sites along the black-water NECFR with its theoretically lower TSM load. However, this study found no difference in TSM between the two river types. Despite this, the deposition at brown-water sites was significantly higher than deposition rates at black-water sites. However, given the lack of difference in TSM availability between the two river types, it is again possible that this result is skewed due to the influence of the brown-water marsh (P6) site.

In Conclusion:

1. Deposition rates at marsh sites were greater than rates at swamp site.
2. Deposition rates at brown-water sites were greater than rates at black-water sites.
3. The brown-water marsh (P6) exhibited the highest mean deposition. This was attributed to coarser grain sizes of available material with settling velocities high enough to overcome vertical variations in flow.
4. Results from the brown-water marsh (P6) may have skewed the river and marsh type comparisons.
5. There is no correlation between river discharge and either sediment deposition or TSM availability.
6. Grain size and settling velocity were the primary controls on deposition.
7. These wetland systems do not appear to be keeping pace with sea-level.

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