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SEDIMENT AND NUTRIENT ACCUMULATION WITHIN LOWLAND BOTTOMLAND ECOSYSTEMS: AN EXAMPLE FROM THE ATCHAFALAYA RIVER BASIN, LOUISIANA

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ABSTRACT

Sediment and nutrient deposition, storage, and transformations are important environmental functions of riverine forested wetland ecosystems, yet documentation and interpretation of sedimentation/nutrient processes remain incomplete. Our studies located in the Coastal Plain of southeastern USA, including the Atchafalaya Basin, La. (a distributary of the Mississippi River) serve as example for detailed discussion of sediment and nutrient accumulation in lowland systems. The Atchafalaya Basin is the largest contiguously forested riparian wetland in North America and is incurring high sediment loads and hypoxic zones in backswamp settings. We established several floodplain transects, located to reflect major depositional environments within the Basin, to monitor general and local sediment deposition patterns over a multi-year period. Deposition rate and loss on ignition (LOI) data were collected above artificial markers (clay pads) at multiple stations along each transect. Mean floodplain sedimentation rates ranged from about 2 to 42 mm/yr and mean percent organic material ranged from about 7 to 28 percent. The transects were categorized into statistically different deposition groups based on sedimentation rate; most of these groups could be coherently interpreted based on a suite of parameters that includes hydroperiod (elevation), source(s) of sediment-laden water, hydraulic connectivity, flow stagnation, and location in transect (levee versus backswamp). Low elevation (long hydroperiod), high hydraulic connectivity to multiple sources of sediment-laden water, and hydraulic damming (flow stagnation) lead to the highest amounts of sediment trapping; the converse in any of these factors may diminish sediment trapping. Based on aerial extent of deposition groups, the study area (about 500 km^2) potentially traps $6.72 \cdot 10^9$ kg of sediment, annually, of which 12 percent or $8.20 \cdot 10^8$ kg are organic material. This accumulated sediment contains a coarsely estimated 5% and 27% of the annual nitrogen and phosphorus loads to the Atchafalaya Basin, respectively, and $3.7 \cdot 10^8$ kg C. Thus, the Atchafalaya Basin plays an important role in sediment storage, including the sequestration of carbon, nitrogen, and phosphorus.

KEYWORDS: floodplain sedimentation, nutrients, fluvial geomorphology, riparian zone, biogeochemical cycling, Atchafalaya Basin, carbon sequestration

INTRODUCTION

The Coastal Plain Physiographic Province of the United States lies almost entirely in the southeast and covers an area of about 1.2 million square kilometers. The bottomlands of meandering rivers in the Coastal Plain typically are broad, alluvial features with low gradients, most of which terminate downstream in tidal estuaries. Coastal Plain river systems have received noticeably less hydrologic study than higher gradient Piedmont and montane river systems. The floodplains of Coastal Plain rivers are typically inundated every year for prolonged (months in some cases) periods. Sediment accretion rates on these floodplains may be among the highest of any physiographic province in the U.S (Hupp, 2000). The forests (Bottomland Hardwood systems including southern Deep-Water Swamps) have received considerable ecological study, yet the linkages between the fluvial geomorphic processes, forest ecology, and biogeochemical processes remain poorly understood (Hupp et al. 2005). Recent studies have shown that coastal

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lowlands may be an important sink for carbon (Raymond and Bauer, 2001; Ludwig, 2001) and associated nutrients (Noe and Hupp, 2005), which may be stored in these systems as organic rich sediment (nitrogen) or mineral sediment (in the case of phosphorus). This organic material presumably is from both autochthonous and allochthonous sources. Investigation of lowland fluvial systems may be critical towards our understanding of global carbon cycling, nutrient accumulation, and biogeochemical processes which in turn have direct implications for natural remediation, aquatic "dead zones", and global climate change.

The purposes of the present paper are to describe and interpret sediment and nutrient (specifically nitrogen and phosphorus) accumulation patterns in lowland bottomlands using the central part of the Atchafalaya Basin for detailed investigation. This paper reports on a smaller aspect of a much larger study on the Atchafalaya Basin. Specific purposes include the interpretation of sediment deposition rates as related to elevation or hydroperiod (bank height), patterns of flow during the hydroperiod, and degree of connectivity between a sampling point and sediment-laden streamflow.

Vertical accretion, the "slow" accumulation of overbank sediment without appreciable later channel migration, is the primary process by which most lowland floodplains develop (Middlekoop and Van der Perk, 1998; Nanson and Croke, 1992; Walling and He, 1998). Discharges that occur about10 percent of the time or less frequently may be responsible for from 50 to 90 percent of suspended sediment transport in alluvial river systems (Meade, 1982). With minimal erosion caused by lateral migration and little remobilization and export of floodplain sediments, particulate storage could be long (decades or longer) in the Coastal Plain (Meade, 1982; Walling et al., 1996; Raymond and Bauer, 2001). Coastal Plain riverbanks are relatively low and once overbank flows occur, the inundated width extends across the entire floodplain, significantly limiting flow competence. Natural levees, usually dominated by sand, frequently form adjacent to the channel where relatively coarse suspended load sediments are deposited (Hupp, 2000; Pizzuto, 1987). Elevations typically vary only a few meters within the floodplain, such that small differences in flood stage or groundwater elevation can substantially affect inundation frequency and hydroperiod across large areas. These floodplains may be inundated multiple times a year, often for extended periods, particularly during the winter and spring.

Like many Coastal Plain riparian areas, the Atchafalaya Basin is the last place for significant storage of riverine sediments before reaching saltwater. Approximately 25 percent of Mississippi River flow on an annual basis and all of the Red River flow passes through the Basin. The entire suspended- and bed- sediment load of the Red River and as much as 35 percent of the suspended and 60 percent of the bed sediment load of the Mississippi River (Mossa and Roberts, 1990) is now diverted through the Atchafalaya Basin. As a result, the Basin suffers simultaneously from exceptionally high sedimentation rates at sites with high connectivity to the main river and from hypoxia in stagnant areas with little connection to the main river. Both of these results may be detrimental to socially and economically important crawfish and fin-fish fisheries. There is currently a major effort by the state and federal governments to devise a management plan to maximize freshwater inflows into stagnant areas while simultaneously minimizing sedimentation.

The Atchafalaya Basin wetland (5670 km^2) is about 70 percent forested and the remainder is marshland and open water. Most of the generally North-South trending Basin is bounded by flood-protection levees on the East and West sides separated by 20 to 30 kilometers. The Basin extends for about 160 kilometers separating the Louisiana cities of Baton Rouge and Lafayette (Fig. 1). This broad floodplain supports a complex and dynamic system of meandering bayous

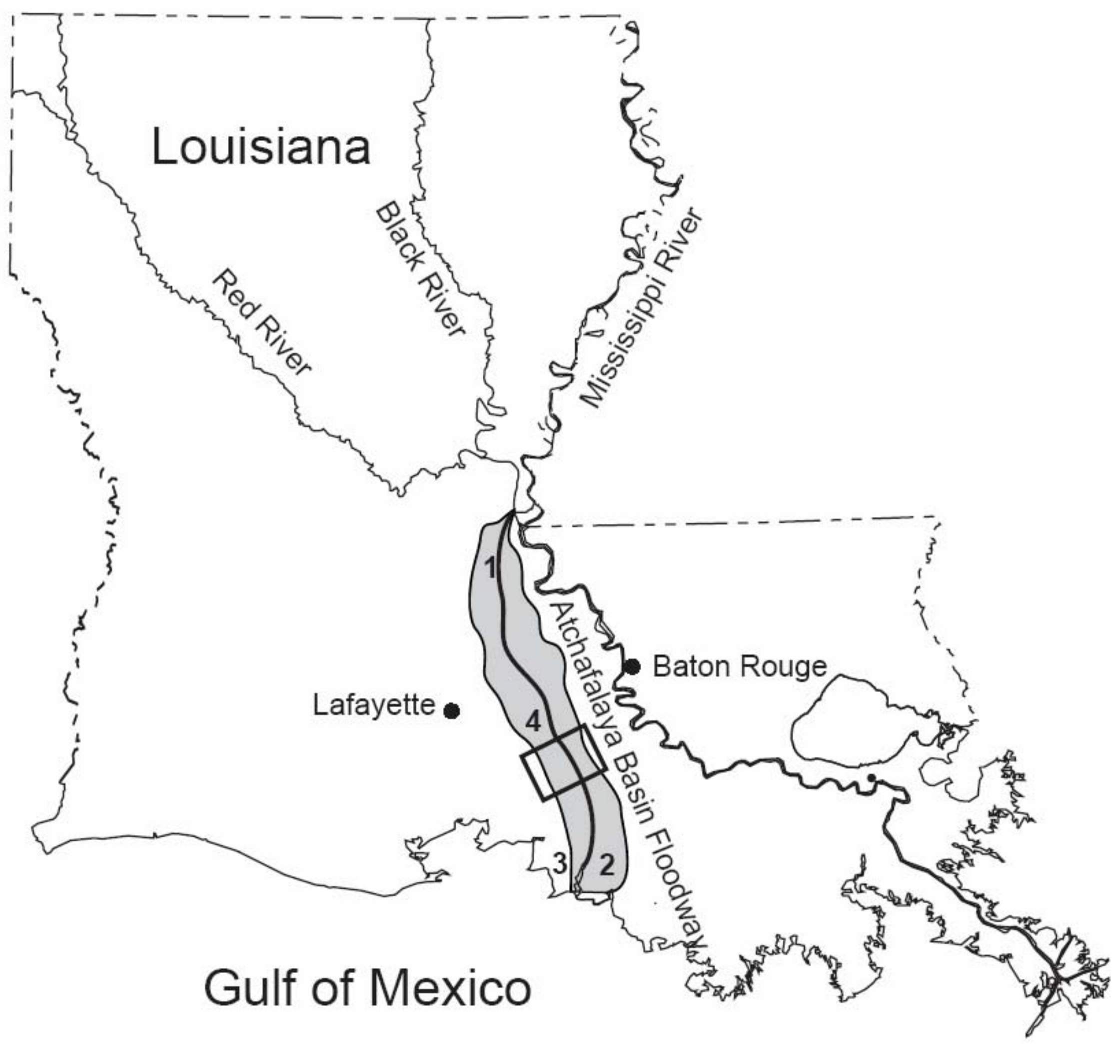

Figure 1. Map of Louisiana indicating the location of the Atchafalaya Basin (shaded), study area (rectangle), and location of gaging stations; 1, Atchafalaya River at Simmesport; 2, Atchafalaya River at Morgan City; 3, Wax Lake Outlet at Calumet, LA; 4, Butte La Rose (stage only).

and lakes that have been altered by natural processes and human impacts, especially from channel construction for oil and gas exploration and transmission, timber extraction, flood control, and navigation. The mouth of the Basin empties into Atchafalaya Bay, part of the Gulf of Mexico, and one of the few aggrading areas on the otherwise eroding Louisiana coastline. The Atchafalaya River flowing through the Basin has an average annual discharge of about 6410 m^3/s, among the top five in the U.S (Demas et al., 2001). The general study area lies near the center of the Atchafalaya Floodway between the Bayou Sorrel boat ramp and the Bayou Benoit boat ramp (Fig. 2). This area is typical of most of the central part of the Basin with a network of numerous meandering natural bayous, constructed channels, and occasional relatively small lakes. Much of this area was open water, particularly on the west side prior to about 1917, and now is part of the largely sediment filled Grand Lake (Roberts et al., 1980; McManus, 2002). Sedimentation of the Basin here and downstream has been substantial and continues today.

The forested wetlands are generally of three major types: 1) typical bottomland hardwoods (Sharitz and Mitsch, 1993) on levees and higher floodplains, 2) cypress-tupelo swamps on low backswamp floodplains, and 3) young stands of predominantly black willow that have developed on recently aggraded point and longitudinal channel bars (silt and sand). Most of the relatively young forests (70 years or less) have grown since lumbering of old growth cypress and

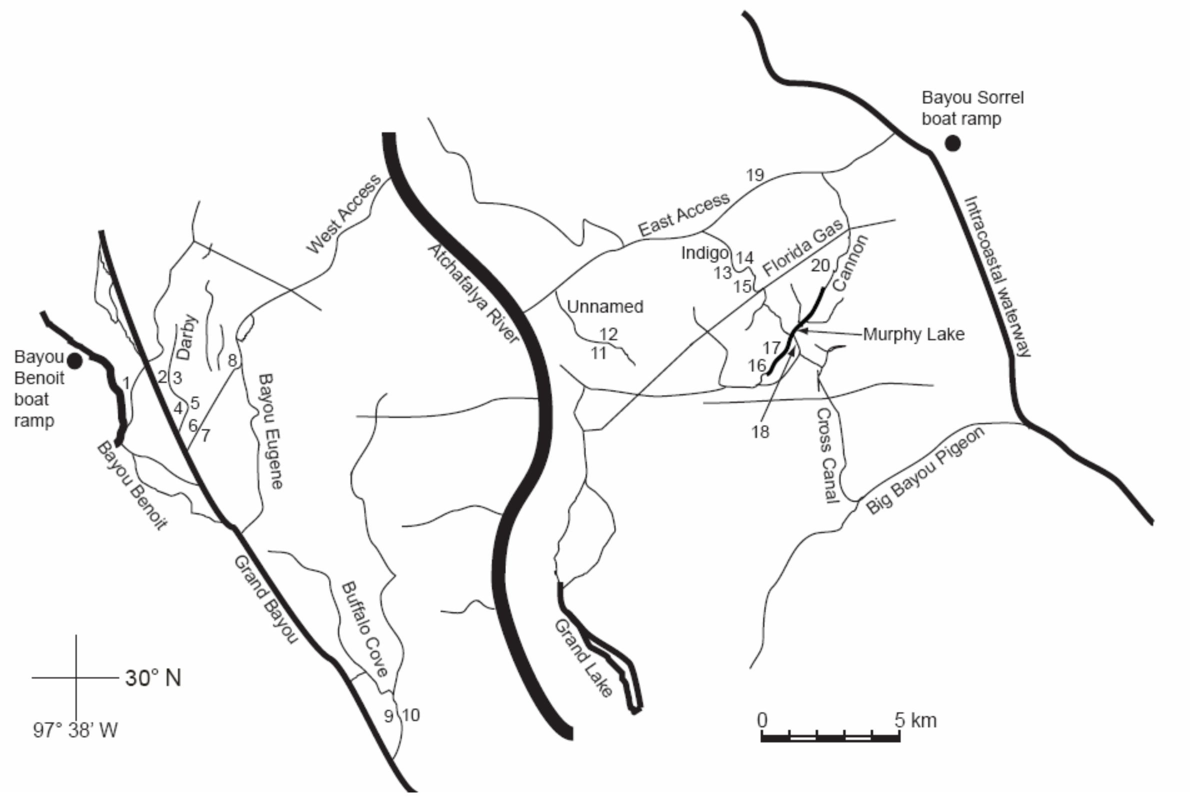

Figure 2. Map of study area showing pertinent canals and bayous, west and east access points (boat ramps), and location of sites (transects). From west to east sites are: 1- BB, 2- BD2W, 3- BD2E, 4- BD1W, 5- BD1E, 6- WADN, 7- WADS, 8- WABE, 9- BCN, 10- BCS, 11- UNBW, 12- UNBE, 13- IBW, 14- IBO, 15- FGI, 16- MLPB, 17- MLDH, 18- MLCC, 19- BS, 20- FGBC (full names are provided in Table 1).

bottomland hardwoods completed by the early 1930s. Additionally, the filling of open water areas since the middle of the last century (Roberts et al., 1980) has created numerous and extensive surfaces for forest establishment. All flow within the Basin is regulated by structures upstream operated by the Corps of Engineers. Much of the flow in all of the waterways has been altered through various activities (opening cuts, blocking channels) to divert water through the system for various management options (typically for access, pipeline construction, or channel maintenance). Flow in many of the bayous and canals may carry high sediment loads resulting from the ambient alluvial nature of the both the Mississippi and Red Rivers and, in some cases, due to substantial resuspension of channel sediment. Discharge and suspended sediment delivered to the basin has been measured at the Atchafalaya River at Simmesport, LA (Fig. 1) gaging station since 1963 with an average water discharge of 6115 cms (218,400 cfs). The gaging stations for the Lower Atchafalaya River at Morgan City (1995 to present) and Wax Lake Outlet at Calumet, LA (1986 to present) record discharge and suspended sediment leaving the basin (Fig. 1); average water discharge for these respective stations are 3510 cms (125,370 cfs) and 2325 cms (83,030 cfs). Additionally, two other stage-only gages (Butte La Rose and Buffalo Cove) operate in or near the study area.

METHODS

We selected 20 sediment monitoring sites and established transects (aligned normal to a canal or bayou) that began on the channel edge (usually a levee) and continued for a few hundred meters into the low backswamp area; each site was sampled using a single transect. Each transect typically had four to six sampling points along the transect, where periodic measurements were made of deposition rate, texture, and composition; these sampling points were numbered consecutively starting with the lowest number nearest the channel. Selection of transects was based on known problematic areas (management interests), potential impacts from sedimentation, and property ownership. We used aerial photography in combination with existing GIS information to select a stratified range of sites (in terms of probable deposition

Table 1. Mean deposition rate, bulk density, percent organic material (LOI), percent sand (>63 microns), and bank height for 20 sites in the central Atchafalaya Basin.

Site	Deposition mm/yr	Bulk Density	LOI	Percent > 63 microns	Bank Height ft.
Bayou Sorrel (BS)	1.8	0.95	28.2	15.4	13.79
Florida Gas canal off Indigo (FGI)	2.2	1.08	24.15	13.3	
Unnamed Bayou, West (UNBW)	2.2	1.12	14.9	16.5	12.8
Indigo Bayou, Old (IBO)	2.4	1.10	21.4	16.0	
West Access near Bayou Eugene (WABE)	6.4	0.80	13.8	6.9	13.88
Bayou Benoit (BB)	7.3	0.38		4.7	4.26
Indigo Bayou, West (IBW)	7.4	0.97	18.6	16.2	11.75
West Access Dog Beat, North (WADN)	7.9	1.00	14.2	16.6	10.74
Murphy Lake, Daniel Hoover (MLDH)	9.9	0.59	13.8	14.1	5.46
West Access Dog Beat, South (WADS)	10.1	1.12	8.8	10.1	10.14
Bayou Darby, 1 West (BD1W)	13.6	0.99	7.1	10.2	9.51
Bayou Darby, 2 West (BD2W)	14.1	1.11	1.8	40.7	7.51
Murphy Lake, Cross Canal (MLCC)	14.5	0.84	7.9	10.6	7.07
Murphy Lake, Point Bar (MLPB)	14.9	0.92	10	32.0	2.97
Buffalo Cove, South (BCS)	19.2	0.88	9.1	7.5	7.91
Bayou Darby, 1 East (BD1E)	19.3	1.02	7.2	17.8	9.99
Bayou Darby, 2 East (BD2E)	20.7	1.00	5.7	9.2	7.25
Unnamed Bayou, East (UNBE)	26.3	1.31	2.4	43.6	12.06
Florida Gas at old Bayou Canon (FGBC)	36.5	1.02	15.8	12.3	
Buffalo Cove, North (BCN)	42.0	1.11	7	4.9	6.81

rates) so that our results would be representative of the general area. The basic sampling strata included relatively high in elevation levee areas, intermediate transition areas, and low elevation backswamp areas; these strata are based on forest cover types, clearly visible in aerial photography, that have been verified on the ground to reflect the named surfaces. A GIS map developed from the photography indicates that approximately 22 percent, 34 percent, and 24 percent of the study area is in levee, transitional, and backswamp areas, respectively; the remaining area is largely open water or developed natural gas fields. The portion of the total combined length of transects cover approximately 30 percent levee, 40 percent transitional, and 30 percent backswamp, thus providing accurately divided sampling strata. This breakdown of land types roughly equals the Basin in general; although more area is of the levee type north of our study area, this shift is balanced by more backswamp area south of our study area. We believe this non-random sampling design allows for a reasonably unbiased estimate of sedimentation rates in the Basin. Each transect was differentially leveled using a laser level. Bank heights were measured near the beginning of most transects from the top of the bank (usually levee) to the low water elevation; all bank height measurements were corrected for water stage using the stage-only gage at Butte La Rose as datum for the given date of measurement. Datum for the Butte La Rose gage is sea level, e.g. 1 m on the gage is 1 m above sea level (NGVD of 1929). All leveled transects were corrected relative to the Butte La Rose gage.

Artificial marker layers (clay pads) were placed at each sampling point, typically spaced along transect by about 50 meters. These markers are made by placing powdered white feldspar clay approximately 2 cm in thickness over an area of about 0.5 m^2 on the soil surface that has been cleared of coarse organic detritus. This clay becomes a fixed plastic marker after absorption of soil moisture that permits accurate measurement of short-term net sediment deposition (Bauman et al., 1984; Kleiss, 1996; Hupp and Bazemore, 1993; Ross et al., 2004). The clay pads were examined annually and measured for depth of burial during the course of study. Whole transect mean sediment deposition rates were statiscally analyzed using hierarchical clustering methods

(Ludwig and Reynolds, 1988), which places similar transects into groups or clusters. An ANOVA among the groups using the Tukey HSD method was performed to test for statistical difference.

Sediment samples were taken near each clay pad at both the beginning and end of the study. The last sample was taken from the soil surface to a depth matching that above the clay pad in order to study deposition so that only current, net (past three years) processes are reflected in the sediment analyses. Sediment sample analyses included: 1) bulk density, by taking a known sample volume, which was then dried and weighed, 2) size clast composition by dry sieving with various screen sizes in a vibratory sieve shaker, and hydrometer analyses for size classes less than 0.063 mm (Guy, 1969), and 3) organic fraction of the sample through standard "loss on ignition" (LOI) procedures. The carbon, nitrogen, and phosphorus content of the deposited sediment was estimated from mean nutrient concentrations of recently deposited floodplain sediments from other southeastern USA Coastal Plain rivers (Chickahominy, Mattaponi, and Pocomoke Rivers, Noe and Hupp 2005; Roanoke River, Noe and Hupp unpublished data). Average (+/- one s.e.) carbon, nitrogen, and phosphorus concentrations among these four river systems were 12.4 +/- 3.3 %C, 0.66 +/- 0.16 %N, and 0.872 +/- 0.117 mg P/g of sediment. Given the strong correlation between organic sediment and C and N concentrations, and mineral sediment and P concentration in floodplain sediments (Noe and Hupp, 2005), this can be expressed as 450 +/- 13 mg C/g and 24.5 +/- 0.8 mg N/g of organic sediment and 1.27 +/- 0.27 mg P/g of mineral sediment.

RESULTS

Within the present study area, mean annual sediment deposition rates for an entire site/transect ranged from 2 mm/yr on high levees to 42 mm/yr at low elevation sites with substantial hydraulic connection to sediment-laden water (Table 1). All rates are based on net cumulative deposition during the three-year period (2000 to 2003). Sediment deposition rates measured within the central Atchafalaya Basin exceed the 2 -5 mm/yr range typical of other floodplains in the Lower Mississippi region (Hupp, 2000). Rates for individual clay pads ranged from trace amounts in stagnant areas with no hydraulic connection to 65 mm/yr in rapidly filling locations. Bulk density did not vary significantly among transects. However, LOI percentages ranged from 2.4 to 28.2 percent and generally varied inversely with deposition rate; that is, soils from low deposition rates tended to have high LOI and vice versa with one notable exception (FGBC, Table 1). No clear relation was found between sediment size and sedimentation rate, as evidenced at our three highest transects for deposition rate where sediment greater than 63 microns ranged from 4.9 to 43.6 percent.

When arrayed in ascending order (Fig. 3) deposition rates for each transect appear to be separated into relatively distinct groups. Statistical cluster analysis (a classification technique for placing similar entities into groups or clusters, Ludwig and Reynolds, 1988) independently sorted the mean transect deposition rates into several univariate clusters or groups (Fig. 4). An ANOVA of the means for each of five clustered groups with multiple sites, using the Tukey HSD method, revealed that all five significantly differ at less than the 0.002 level. These groups can be described and distinguished largely by their degree of hydraulic connectivity to sediment laden flow and the patterns of suspended sediment sources; most sites have been affected by human altered flow through the basin. It is beyond the scope of the present paper to describe in detail each of these groups.

Sampling points (clay pads) along each of the 20 transects demonstrated variable deposition both along transect (channel edge to backswamp) and temporally over the three year period. Three sites BS, FGI, and UNBW with the lowest mean deposition rates (A Group, Fig. 4) show weak

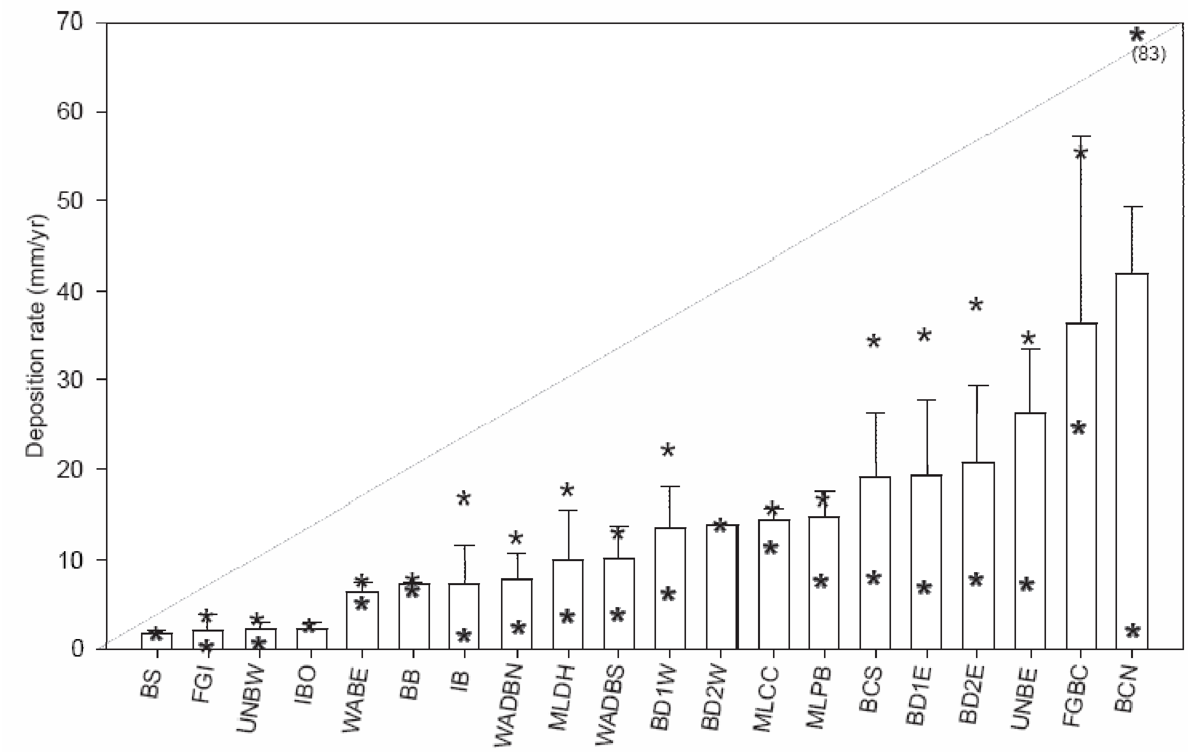

Figure 3. Mean deposition rate (mm/yr) for whole sites in increasing order. Range is indicated by asterisks, positive standard error is indicated by whisker.

spatial deposition patterns and are located on relatively high constructed levees. Conversely, B Group including WABE, WADN, MLDH, and WADS (Fig. 4) show a relatively distinct pattern of decreasing deposition from the levee toward the backswamp. Sites in the C Group (Fig. 4), although tightly related statistically in terms of deposition rate, are functionally dissimilar. The pattern shown in the B Group is continued in the relatively high deposition rate D Group (Fig. 4) where the greatest amounts of deposition clearly occur near the channel and diminish toward the

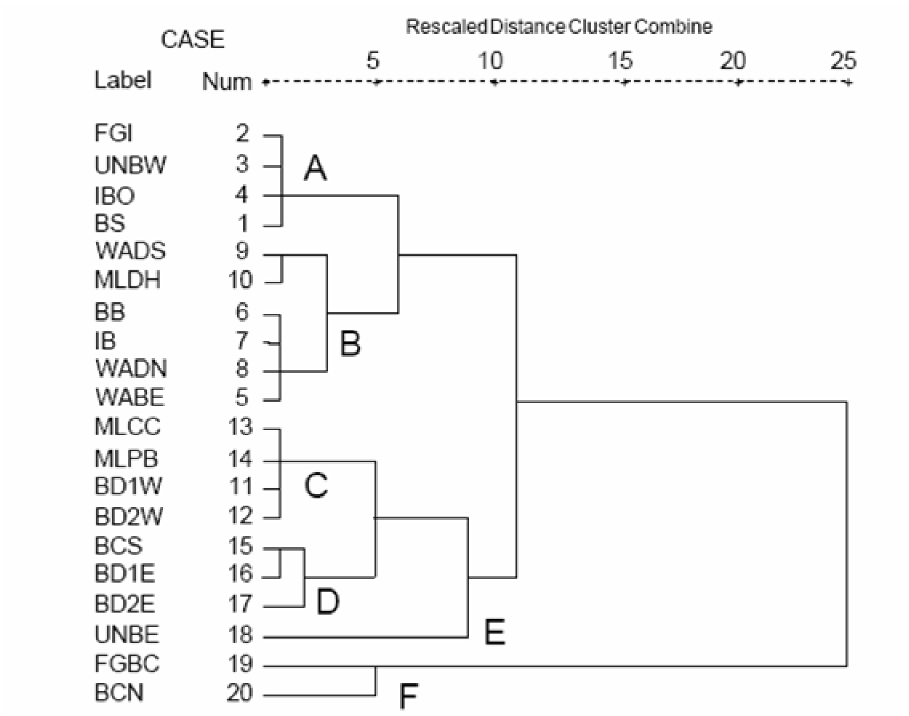

Figure 4. Dendrogram (using average linkage between groups) from hierarchical cluster analysis of mean site deposition rates.

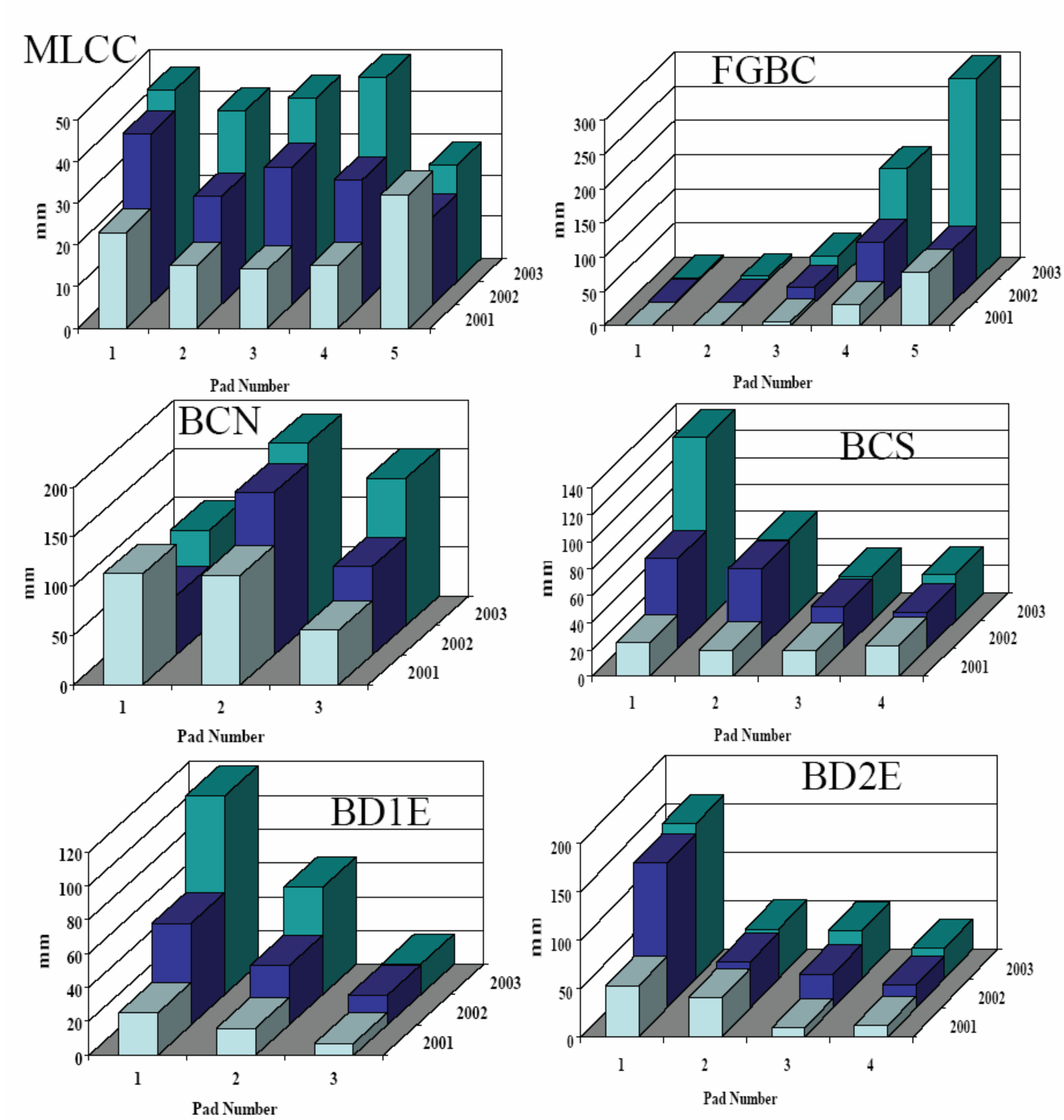

Figure 5. Cumulative deposition above clay pads in transect for selected sites showing spatial (along transect) and temporal sedimentation trends for three years ending in 2001, 2002, 2003. Pads are numbered from nearest the channel to farthest.

backswamp (Fig. 5). This suggests that the sediment source is from the adjacent channel. The highest deposition amounts occurred at UNBE, FGBC, and BCN (E and F Groups, Fig 4; UNBE is affected by a crevasse in the levee upstream and will not be discussed further). BCN and FGBC may receive substantial sediment from other sources in addition to the adjacent channel (Fig. 5). There are no strong temporal patterns over the study period except that sampling dates in 2001 (calendar year) include part of the previous drought year 2000; sampling dates in 2002 and 2003, during near normal years, tend to show higher deposition at most sampling locations than 2001.

Our sites reflect a range of hydrologic (Fig. 6) and geomorphic conditions within the study area (central Atchafalaya Basin, Fig. 2). Some sites are relatively high in elevation (about 4 m above sea level, e.g. UNBW, BS, Table 1), have a relatively short hydroperiod (between 18 and 30 percent exceedance, Fig. 6) with very low sedimentation rates (<3mm/yr, Table 1), and relatively high amounts of organic material (average about 20 percent LOI, autochthonous). Some sites are stagnant, low wet sites (e.g. BB, Fig. 6) with relatively low sedimentation rates

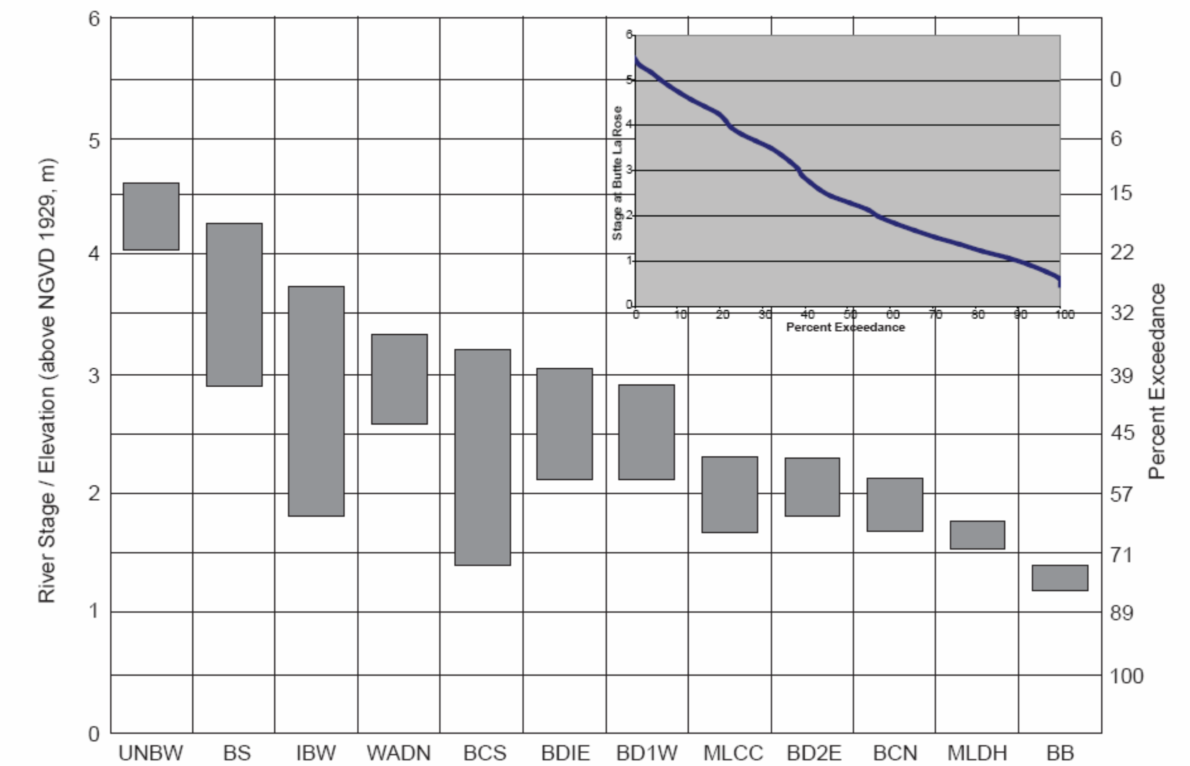

Figure 6. River stage/elevation above sea level (NGVD 1929) and percent exceedance (annual flow duration) for 12 sites. Top of bars are the leveled maximum elevations of transects (typically top of levee), bottom of bars equals the elevation of transect in backswamp. Stage data are from the Butte La Rose gage from which, all leveled transects are referenced (datum equal sea level).

and high percentages of organic material. Many sites have moderate to relatively high rates of sedimentation particularly on the levee (e.g. BCS and all BD, Fig. 5) or sedimentation may be uniform (e.g. MLCC, Fig. 5). Two sites (FGBC, BCN) have mean floodplain deposition rates of 36.5 and 42 mm/yr, respectively that are in excess of any measured, to date, on the U.S. Coastal Plain (see Hupp 2000). The study area delimited in Figure 2 is approximately 500 km^2 and contains many examples of the conditions described above. Assuming that our sampling design reflects the spatial distribution (in area) of sedimentary environments in the study area, and using the site mean amount of sediment trapped (13.4 $kg/m^2/yr$) and mean percent organic material (LOI, 12%), the study area annually traps a net $6.72 \cdot 10^9$ kg of sediment, of which $8.20 \cdot 10^8$ kg are organic material.

DISCUSSION

Our discussion will focus largely on sites that experience high deposition rates and thus, may trap the greatest amount sediment, carbon, and nutrients (Groups D and F, Fig. 4). Variation in sources of sediment-laden flood water and the length of time a floodplain is flooded (hydroperiod) may explain much of the sediment deposition patterns observed in the central Atchafalaya Basin. In alluvial systems, the amount of suspended sediment in flood water at a given location on the floodplain may be a function of “connectivity” (Hupp, 2000; Noe and Hupp, 2005) of the location to sediment-laden river water. Locations along floodplain flow paths (sloughs) or those that are low and not blocked (typically by levees) and near the river tend to have higher sediment deposition rates than those that are less connected or distant from the over flowing banks (Ross et al., 2004). Some sloughs may have substantial flow that injects sediment relatively far across the floodplain and have an equal or greater effect on deposition than a more closely located channel.

The pattern of high levee sediment deposition diminishing into the backswamp is clearly evident in the high deposition-rate Group D (Fig. 5, sites BD1E, BD2E, and BCS). The adjacent channel

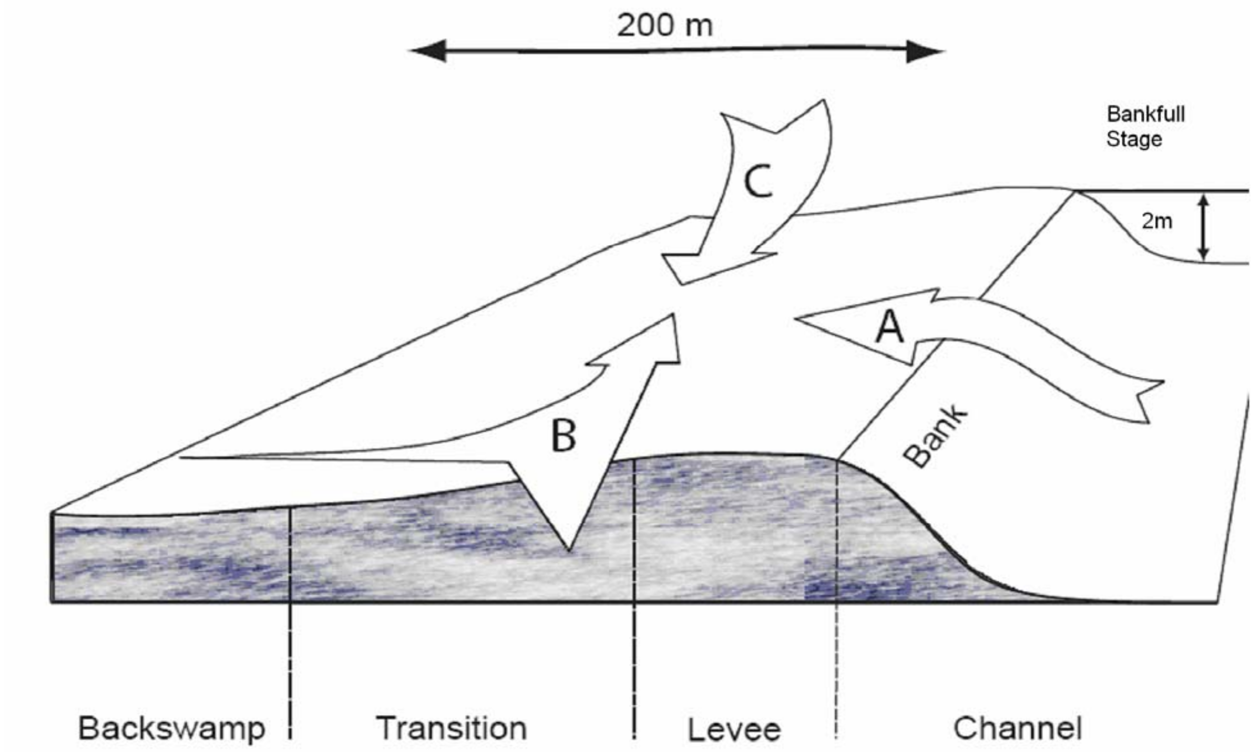

Figure 7. Generalized 3 dimensional floodplain, bank and channel looking upstream, illustrating potential sources of sediment-laden flow. A, flow from the adjacent channel overtopping the levee, B, opposing flow from downstream areas along channel and/or different channels, and C from upstream sloughs. Material may be delivered by B and C without over levee flow (A).

at these sites is the main source of sediment (A, Fig. 7). All are originally natural bayous with low floodplains that have been impacted by a severe increase in sediment load in the channel due to some human alteration in hydrology. When the adjacent channel is the dominant source of sediment it is expected that bank height would be an important factor as it would affect hydroperiod (Fig. 6). During overbank events, flow in these channels may become very slow, stop or reverse due to other water sources that become active during high stages and impede normal flow. This "hydraulic dam" in addition to high-suspended sediment may allow for significant sediment deposition. Deposition rate averages about 20 mm/yr at these sites, nearly 3 times the published highest rates; when mineral deposition is this high, percent organic material is usually relatively low (all sites <10% LOI). A feature associated with this sedimentary environment is the development of elongated bars that form on the channel edge. The bars grow in the downstream direction of the sediment source and appear to be associated with the moving “front” of high deposition-rate zones along these channels. These bars represent new terrestrial surfaces (BCN) and are rapidly colonized by black willow and other shrub species. Bars such as this may be seen throughout the study area (often expansive) along channels where suspended loads are high. Low sites without strong levee development typically experience rather uniform deposition (MLCC and BCN, Figs. 6 and 7).

FGBC and BCN form the final Group F (Figs. 3 and 4). These two sites appear to be functionally different (Fig. 5) but share two important factors conducive to high sediment deposition rates and amounts; a high degree of connectivity to sediment-laden water near the sedimentary front (see discussion above) supplied from at least two sources from different directions creating a hydraulic dam (Fig. 7). These two sites largely differ in their pre-deposition conditions or site history, FGBC has, at least since the channel was dug, been above the 2.75 m stage at the Butte La Rose gage (Fig. 6), meaning that most or all of the transect is dry during part of the year. Whereas, BCN prior to about 18 years ago (tree-ring data) was open water and

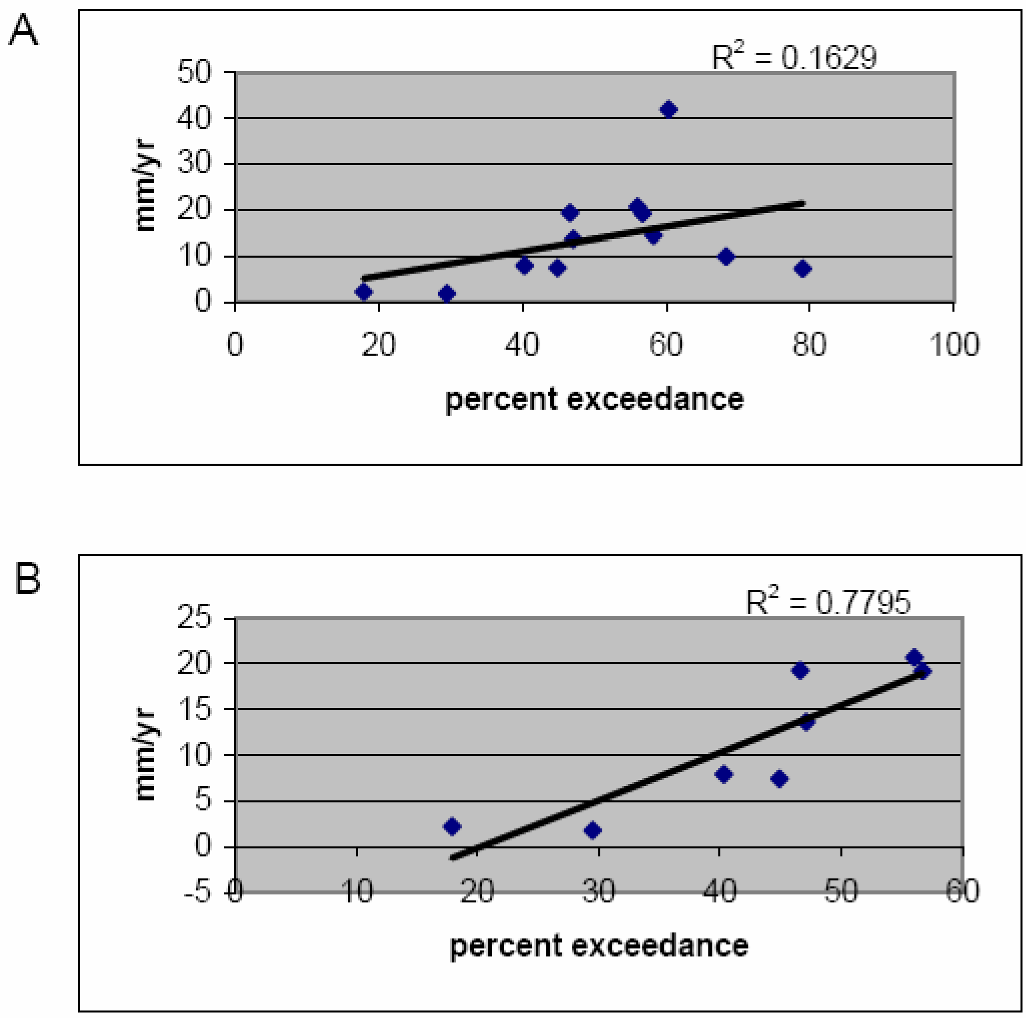

Figure 8. (A) Regression results plotting deposition rates for all sites shown in Figure 6 against percent exceedance; (B) after removal of low elevation sites (median percent exceedance <57, MLCC through BB, Figure 6) that may experience hydraulic damming.

part of the lake associated with Buffalo Cove that is now nearly filled. FGBC has relatively high banks and levee areas such that nearly all deposition is in the backswamp that receives water from two separate side channels (B and C, Fig. 7). BCN has the typical uniform pattern of deposition on low areas with multiple flow sources (A,B,C, Fig. 7). This site bears all of the conditions our study has found to facilitate sediment deposition; high connectivity to sediment-laden water, long hydroperiod (low banks), multiple sources of flow, and perhaps most importantly hydraulic damming.

On average, most of our sites experienced flooding in the backswamps when the stage gage at Butte La Rose was about 2.8 m (9 ft) and the banks were overtopped about the 3.7 m (12 ft) stage, representing the 40 and 30 percent flow durations (percent exceedance), respectively (Fig. 6). Temporally, the longer an area on the floodplain is inundated by sediment-laden water, the greater amount of sediment deposition; hydroperiod is generally inversely related to elevation (Hupp and Bazemore, 1993; Ross et al., 2004). Our results support this (regression r^2 = 0.78, Fig. 8) so long as similar sites are compared (well developed levees and median exceedance <57%). Inclusion of low sites that may have developed recently from open water (MLCC, BD2E, BCN, and BB, Fig 6) reduces the r^2 to 0.16 (Fig. 8) and suggests that factors other than simply elevation are responsible for deposition, namely multiple sources of sediment and hydraulic damming.

Organic material (LOI) generally decreases with increasing deposition rate regardless of location or rate at the sites (Table 1). A regression of LOI against whole site deposition rate yields an r^2 of 0.31, however if the two highest deposition rate sites (hydraulic dam areas) are removed from the analysis the r^2 increases to 0.72. Increased LOI at these two sites may suggest that where severe hydraulic damming occurs, the potential for trapping allochthonous (derived from outside the site) organic material increases.

The annual sediment trapping rates of mineral and organic sediment in the Atchafalaya Basin correspond to $6.4 \cdot 10^8$ kg C/yr, $2.0 \cdot 10^7$ kg N/yr, and $7.5 \cdot 10^6$ kg P/yr, estimated using average floodplain sediment nutrient concentrations in mineral and organic sediments from other Coastal Plain floodplain studies (Noe and Hupp, 2005, Noe and Hupp, unpublished data). These N and P accumulation rates represent 5% and 27%, respectively, of their annual loading rates to the Atchafalaya Basin (Turner and Rabalais, 1991; Goolsby, et al. 2001). It should be noted that these are coarse estimates that do not account for movement of sediment within the Basin, separate autochthonous from allochthonous sources of nutrients, or account for long-term biogeochemical processing of nutrients in deposited sediments (see Noe and Hupp, 2005), and relies on the assumption that Atchafalaya floodplain sediment nutrient concentrations are similar to other Coastal Plain floodplains.

CONCLUSIONS

The Atchafalaya Basin traps substantial amounts of suspended sediment annually; some areas have the highest documented sedimentation rates in forested wetlands of the United States. Sites that annually trap the least amount of sediment tend to be relatively high in elevation (short hydroperiod) and/or have a poor hydraulic connectivity to sediment-laden river water, and tend to be hypoxic. Sites that have the highest rates of sediment deposition tend to be low in elevation and receive sediment-laden water (high connectivity) from two or more sources, which may create slow velocities through hydraulic damming. The greatest percent organic material in the sediment tended to be in sites with low mineral-sediment deposition rates; this organic material is thus presumably autochthonous. However, in a few high-deposition rate sites LOI percents were also high, which suggests that some areas may be trapping large amounts of allochthonous organic material. Although the Atchafalaya Basin may no longer be a net sink for sediment, billions of kilograms of sediment and large amounts of P, N, and C are stored annually, which may allow for important biogeochemical transformations that potentially reduce contaminant, nutrient, and carbon inputs into the Gulf of Mexico.
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REFERENCES

1. Bauman, R., J. J.W. Day, and C. Miller. 1984. Mississippi deltaic wetland survival: sedimentation versus coastal subsidence. *Science* 224(6), 1093–1095.
2. Demas , Charles R., Brazelton, Sebastian T., and Powell, Nancy J. 2001. The Atchafalaya Basin- -River of Trees. *U. S . Geological Survey Fact Sheet* 021-02.
3. Goolsby, D.A., W.A. Battaglin, B.T. Aulenbach, and R.P. Hooper. 2001. Nitrogen input to the Gulf of Mexico. *J. Environmental Quality* 30:329-336.
4. Guy, H. P. 1969. Laboratory theory and methods for sediment analysis. U.S. Geological Survey Techniques of Water –Resources Investigations, book 5, chap.C1, 58p.

5. Hupp, C.R. 2000. Hydrology, Geomorphology, and Vegetation of Coastal Plain Rivers in the Southeastern United States. *Hydrological Processes* 14:2991-1010.
6. Hupp, C.R, and D.E. Bazemore. 1993. Temporal and spatial patterns of wetland sedimentation, West Tennessee. *Journal of Hydrology* 141:179-196.
7. Hupp, C.R., M.R. Walbridge, and B.G. Lockaby. 2005. Fluvial geomorphic processes and landforms, water quality and nutrients of Bottomland Hardwood forests of southeastern USA. In *Ecology and Management of Bottomland Hardwood Systems*, 37-56. L.H.Frederickson, S.L. King, and R.M. Kaminski, eds. University of Missouri, Gaylord Laboratory Special Publication No. 10, Puxico, MO, USA.
8. Kleiss, B.A. 1996. Sediment retention in a bottomland hardwood wetland in eastern Arkansas. *Wetlands* 16:321-333.
9. Ludwig, W. 2001. The age of river carbon. *Nature* 409:466-467.
10. Ludwig, J.A. and J.F. Reynolds. 1988. *Statistical Ecology: A Primer on Methods and Computing*. New York, NY: John Wiley and Sons.
11. McManus, J. 2002. The history of sediment flux to Atchafalaya Bay, Louisiana. In *Sediment Flux to Basins: Causes, Controls, and Consequences*, 210-226. S. J. Jones and L. E. Frostick, eds. The Geological Society of London, London, UK.
12. Meade, R.H. 1982. Sources, sinks, and storage of river sediments in the Atlantic drainage of the United States. *Journal of Geology* 90:235-252.
13. Middelkoop, H. and M. Van der Perk. 1998. Modelling spatial patterns of overbank sedimentation on embanked floodplains. *Geografiska Annaler* 80A:95-109.
14. Mossa, J. and H.H. Roberts. 1990. Synergism of riverine and winter storm-related sediment transport processes in Louisiana's coastal wetlands. *Gulf Coast Association of Geological Societies Transactions* 40:635-642.
15. Nanson, G.C. and J.C. Croke. 1992. A genetic classification of floodplains. *Geomorphology* 4:459-486.
16. Noe, G.B. and C.R. Hupp. 2005. Carbon, nitrogen, and phosphorus accumulation in floodplains of Atlantic Coastal Plain rivers, USA. *Ecological Applications* 15:1178-1190.
17. Pizzuto, J.E. 1987. Sediment diffusion during overbank flows. *Sedimentology* 34:301-317.
18. Raymond, P.A. and J.E. Bauer. 2001. Riverine export of aged terrestrial organic matter to the North Atlantic Ocean. *Nature* 409:497-500.
19. Roberts, H.H., R.D. Adams, R. Cunningham, G. P. Kemp, and S. Majersky. 1980. Evolution of sand-dominant sub-aerial phase, Atchafalaya Delta, Louisiana. *AAPG Bulleti*n 64:264-279.
20. Ross, K.M., C.R. Hupp, and A.D. Howard. 2004. Sedimentation in floodplains of selected tributaries of the Chesapeake Bay. *American Geophysical Union, Water Science and Application* V. 8, p. 187-208.
21. Sharitz, R.R. and W.J. Mitsch. 1993. Southern floodplain forests. In *Biodiversity of the southeastern United States, lowland terrestrial communities*, 311-372. W.H. Martin, S.G. Boyce, and A.C. Echternacht eds. John Wiley and Sons, Inc., New York.
22. Turner, R.E. and N.N. Rabalais. 1991. Changes in Mississippi River water quality this century and implications for coastal food webs. *BioScience* 41:140-147.
23. Walling, D.E. and Q. He. 1998. The spatial variability of overbank sedimentation on river floodplains. *Geomorphology* 24:209-223.
24. Walling, D.E., Q. He, and A.P. Nicholas. 1996. Floodplains as suspended sediment sinks. In *Floodplain Processes*, 399-439. M.G. Anderson, D.E. Walling, and P.D. Bates, eds. John Wiley and Sons, Chichester, UK.