PROFESSIONAL PAPER SJ2006-PP2

LITTORAL SEDIMENT CHARACTERISTICS: COMPARISONS WITH CHANNEL SEDIMENTS AND ASSOCIATION WITH SUBMERGED VEGETATION COVER

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by

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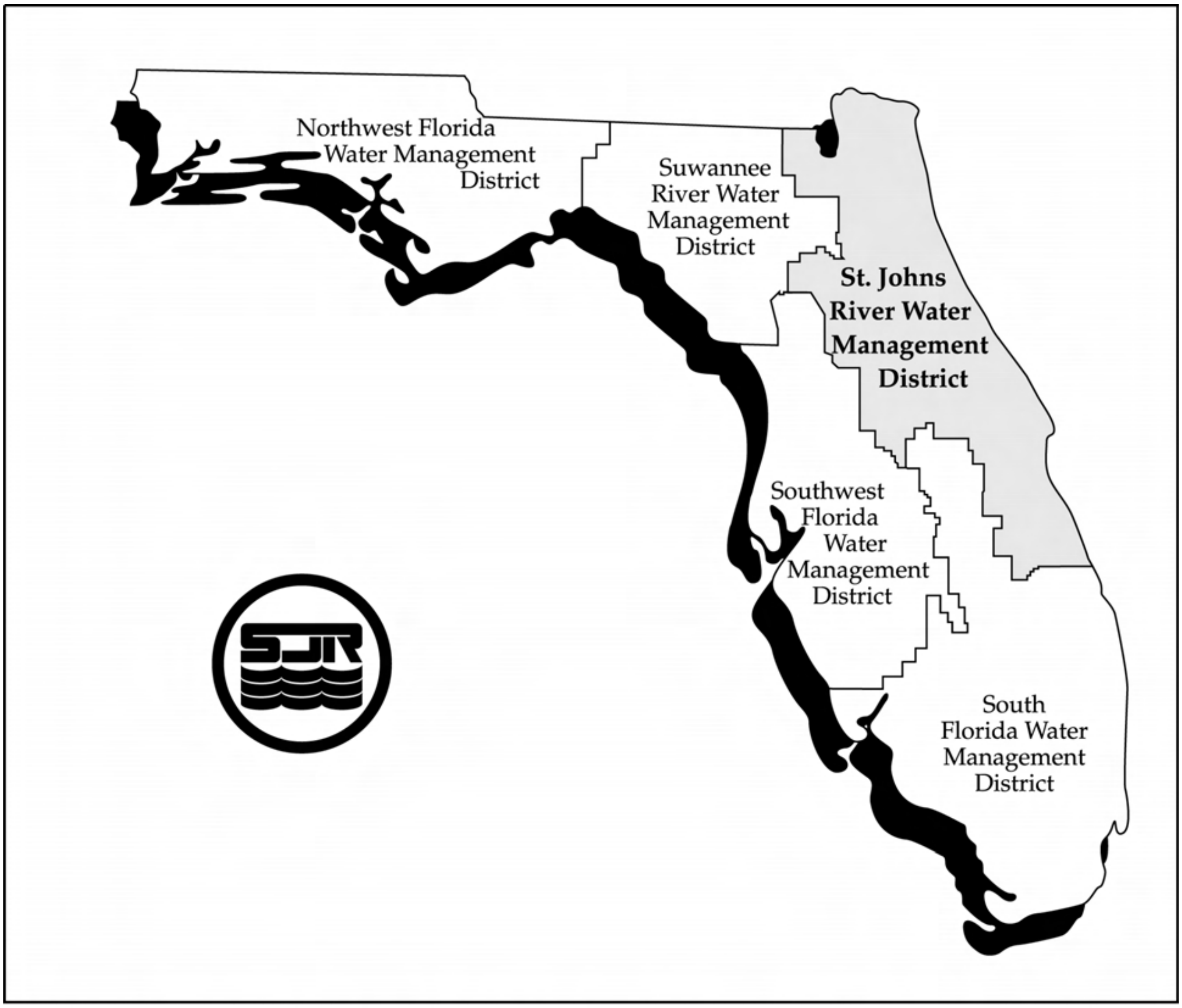

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ABSTRACT

Sediment samples were taken from littoral areas throughout the lower basin of the St. Johns River and from Doctors and Crescent lakes. Samples were used to (1) characterize littoral sediments, (2) compare littoral sediments to pelagic sediments, and (3) explore associations among submersed aquatic vegetation (SAV) and sediment quality. Cores were obtained along a transect from shore to the deep edge of the grass bed and separated into 0–10 cm and 10–20 cm horizons. Cores were analyzed for organic content, nutrient content, grain size, and extractable metals. Results showed that the freshwater-riverine section of the river had the lowest overall sediment quality, and the overall level of constituents was freshwater-riverine> Doctors Lake> oligohaline-lacustrine and freshwater-lacustrine> Crescent Lake. Littoral sediments had far lower concentrations of organic and nutrient constituents than did pelagic sediments, possibly due to sediment-focusing. This shows that it will be important in future modeling exercises to consider both the pelagic and the littoral areas of the rivers when considering sediment/water interactions. Finally, there was a negative exponential relationship among most sediment parameters and SAV coverage. Model fits suggested a ~40% SAV coverage threshold above which only good sediment quality was found.

INTRODUCTION

Sediments within the lower St. Johns River have been extensively sampled (Keller and Schell 1993, White et al. 2003). This sampling has largely been oriented toward determining sediment oxygen demand and nutrient fluxes for water quality modeling applications. In addition, the past sediment sampling has occurred mostly in the deeper pelagic areas of the river. However, littoral sediment characteristics could be substantially different because of increased wave energy, surficial groundwater inputs, benthic algal communities, and submersed aquatic vegetation (SAV) interactions. For example, SAV can modify sediment biogeochemistry through oxygenation of the sediments (Wigand et al. 1997). SAV colonization can also be constrained by sediment fertility (Barko et al. 1991, Rogers et al. 1994), type (Koch 2001, Harwell and Havens 2003), or toxicity (Carlson et al. 1994, Fairchild et al. 1998).

This project was undertaken to meet two objectives. First, sediment samples were obtained from nearshore littoral areas. These samples were used to complement the pelagic sediment data and to assess spatial heterogeneity of sediment characteristics within the river. Second, sediment samples were spatially and temporally congruent with SAV monitoring. Therefore, relationships among sediment characteristics and SAV community patterns could be explored.

METHODS

Site Description

The St. Johns River is the longest river in Florida, extending approximately 480 kilometers (km), flowing north through Jacksonville, and emptying into the Atlantic Ocean at Mayport, Fla. The headwaters of the St. Johns begin in freshwater marshes in St. Lucie and Indian River counties. The river has greater than 130 tributaries and drains approximately 22,790 km² of land (White et al. 2003).

The lower portion of the river is considered the northern 163 km between the mouth of the Ocklawaha River and the Atlantic Ocean. It is a shallow, blackwater river (Keller and Schell 1993), with an average gradient of 0.022 meters (m) / km, which causes the tidal effects in this section of the river to be strong. The lower St. Johns River (LSJR) is defined by three ecozones, which are characterized by salinity and morphology, with freshwater-riverine (FR) being the southernmost section with the lowest salinity. The freshwater-lacustrine (FL) zone extends from Palatka north to Green Cove Springs, and the oligohaline-lacustrine (OL) zone extends from Green Cove Springs to Jacksonville (White et al. 2003). For the purpose of this study, Doctors Lake (south of Jacksonville) and Crescent Lake (southeast of Palatka) have also been included as two separate zones.

Sediment Field Sampling

Ninety-nine cores were taken at 24 sites along the lower St. Johns River (Figure 1), using a 10 centimeter (cm) inner diameter polypropylene tube, from April 28 through May 29, 2003. Sampling dates, latitude, and longitude for each site are provided in the Appendix of this paper. Three cores were taken along a transect perpendicular to shore at each site, beginning at the near shore and up to l m in depth, with one core at the midpoint. At the permanent SAV monitoring sites, designated by three-letter abbreviations, two transects were sampled. In addition, triplicate cores were sampled (one site per sampling day) to assess sampling variability. The cores were then extruded in the field at 0–10 cm and 10–20 cm intervals and transported on ice to the laboratory at the University of Florida (UF). Analyses requiring wet sample were conducted within 28 days of collection, and those requiring dry sample were conducted within UF laboratory guidelines. Up to 10%—and no less than 5%—of the samples analyzed were replicated for quality assurance (see Appendix). Comparative data for pelagic sediment cores were used from 33 sites along the river (DePinto et al. 2005).

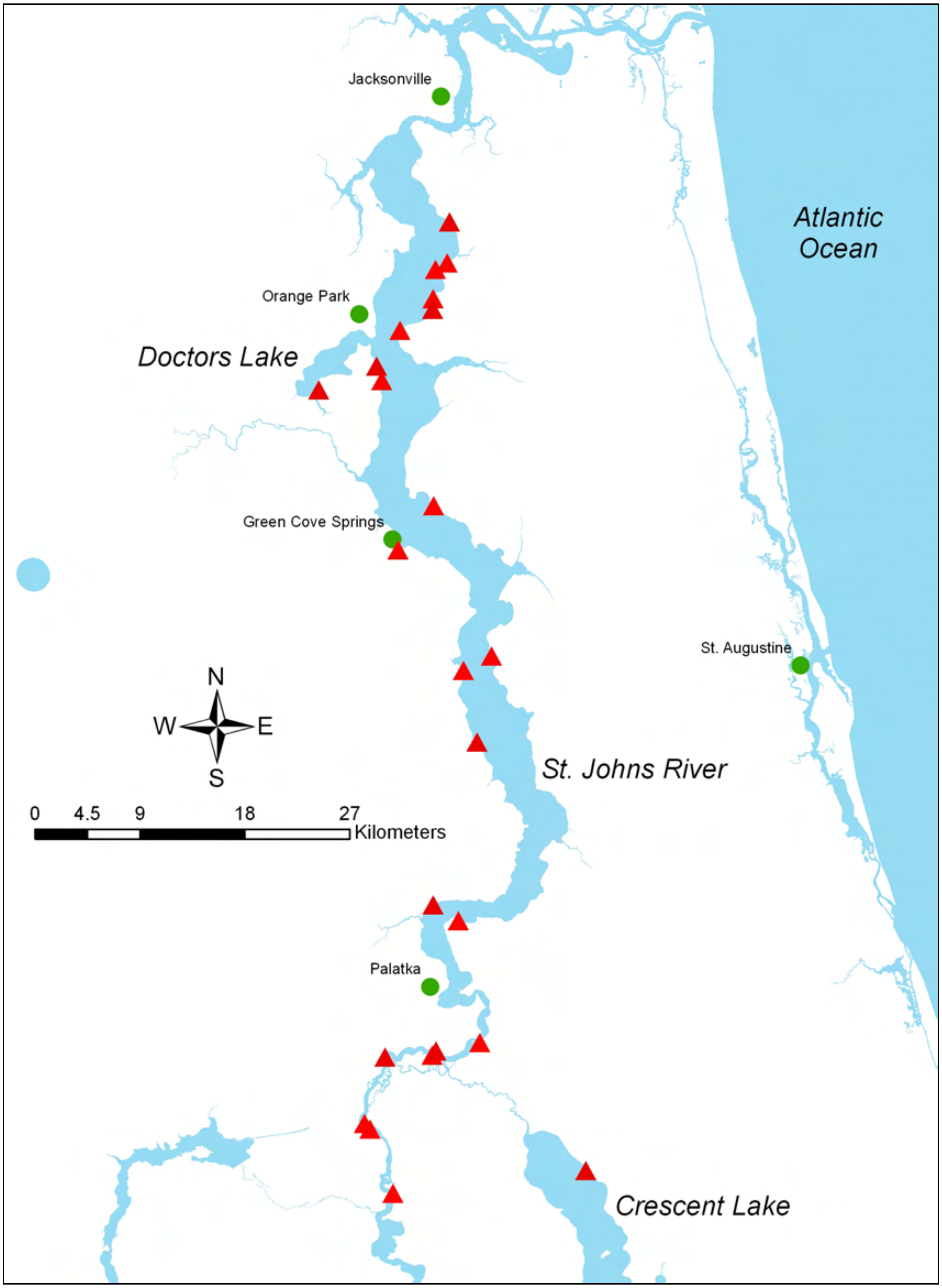


Figure 1. Locations of littoral sampling sites used in this study (coordinates listed in the Appendix)

Laboratory Analysis: Biogeochemical Parameters

Moisture content was determined by weighing approximately 35 gram (g) wet soil into an aluminum weigh dish and incubating at 70°C until a constant dry weight. Dry-weight bulk density was determined by calculating the known volume of soil collected. The total dry mass of the sediment and total weight of the sample was also calculated from this procedure.

Soil oxygen demand (SOD) was determined by weighing 7–10 g wet soil into dark bottles and filling the head space with O_2 saturated water. The bottles were shaken for 30 minutes prior to initial dissolved oxygen (DO) reading, using an Accumet AR40 DO meter (Fischer Scientific, 2001, Pittsburg, Pa.). Dissolved oxygen was measured again after 24 hours, and SOD was calculated based on weight of the soil, water volume, and initial reading minus final DO (APHA 1992).

Wet weight equivalent of approximately 0.5 g dry weight soil was placed in 50 milliliter (mL) centrifuge tubes to determine extractable soluble reactive phosphorus (SRP). Twenty-five mL 0.5 m $NaHCO_3$ was added to each sample and placed on a reciprocating shaker for 30 minutes (min). Samples were centrifuged for 10 min at 6,000 revolutions per minute (rpm) and vacuum filtered through a 0.45 micrometer (µM) membrane filter. A Technicon autoanalyzer was used to determine the SRP concentration of each sample, and the values were converted to a mass basis of parts per gram of dry weight soil (EPA Method 365.1.1993, Kuo 1996).

Ammonium-N was determined by an automated colorimetric technique according to EPA method 350.1.1993. Exchangeable ammonium-nitrogen (NH_4-N) was also analyzed using the Technicon autoanalyzer. Wet weight equivalent of approximately 2.5 g dry weight soil was weighed, placed in 50 mL centrifuge tubes, and 25 mL 2.0 mole (mol) KCl solution added. Samples were shaken for one hour on a reciprocating shaker and centrifuged for 10 min at 6,000 rpm, then filtered using Whatman #41 filter paper (Mulvaney 1996).

Total carbon and nitrogen (TC and TN) were analyzed by using dried ground samples and a Carlo-Erba NA-1500 C-N-S analyzer (Haak-Buchler Instruments, Saddlebrook, NJ) (DeBusk et al. 1994, Reddy and White 2000). Total phosphorus (TP) and loss on ignition (LOI) were measured during the same procedure. Approximately l.0 g dry ground soil was combusted at 550°C for 3 to 4 hours. The difference in weights of the pre- and post-combustedsamples was used to calculate the LOI. Twenty mL 6.0 mol HCl was added to the samples and evaporated until dry on a hot plate. After cooling, an additional 2.5 mL 6.0 mol HCl was added, and the samples were heated to just below boiling. The sample was passed through a Whatman #41 filter and brought to a 50 mL volume with distilled deionized water (Anderson 1976). Care was taken to ensure all samples were transferred, by rinsing the beaker and the filter no less than three times each. A Technicon autoanalyzer was again used to analyze TP concentration using the ascorbic acid method (Method 365.4, EPA, 1993).

Twenty-five mL 1.0 mol hydrochloric acid was added to approximately 1.0 g dry ground soil for metals analysis (extractable Ca, Mg, Fe and Al). The samples were shaken for 3 hours on a reciprocating shaker and centrifuged for 10 min at 6,000 rpm. Samples were then extracted by using Gelman 0.45 µM membrane filters, using a vacuum manifold (DeBusk et al. 1994, Reddy et al. 1998). Samples were analyzed by inductively coupled argon plasma spectrometry (model Spectro Ciros CCD, manufactured by Spectro Al, Inc. Fitchburg, Mass.), using EPA method 200.7 (1993) (Table 1).

Table 1. Median, upper and lower quartile values for littoral sediment constituents, pooled across river zone and depth horizon, measured in this study

Parameter	Median	Lower and Upper Quartiles
% LOI	0.94	(0.49, 2.12)
% Mud	2	(0.01, 0.03)
% Sand	98	(0.97, 0.99)
Bulk Density (g cm^{-3})	0.89	(0.76, 1.01)
Exchangeable NH4 (mg kg^{-1})	9.29	(5.10, 16.80)
Moisture Content (% wt)	25.55	(22.42, 29.76)
N:P (mol)	20.88	(1.34, 33.07)
pH	7.11	(6.91, 7.37)
SOD (mg $liter^{-1}$ h^{-1})	3.55	(2.07, 6.79)
SRP (mg kg^{-1})	6.91	(6.06, 9.23)
Total Al (mg kg^{-1})	122.62	(46.72, 338.22)
Total C (g kg^{-1})	3.50	(1.86, 7.72)
Total Ca (mg kg^{-1})	287.34	(136.48, 605.62)
Total Fe (mg kg^{-1})	89.53	(23.76, 196.57)
Total Mg (mg kg^{-1})	62.82	(19.97, 143.08)
Total N (g kg^{-1})	0.28	(0.01, 0.56)
Total P (mg kg^{-1})	31.28	(17.95, 65.85)

LOI = loss on ignition
SOD = soil oxygen demand
SRP = soluble reactive phosphorus

Grain Size Analysis

The samples collected by the Soil and Water Science (SWS) Department, UF, for particle-size analysis were processed according to standard practices of the U.S. Geological Survey (Poppe et al. 2000). Analysis objectives were to determine the relative mass fractions of sand (>63 µM particle diameter) and the fine-grained material (organic + inorganic <63 µM particle diameter) in surficial sediment of the lower St. Johns River.

The initial mass of each sample collected by SWS was several hundred grams, and samples were homogenized, and subsamples of ~100 g were removed and used for particle size analysis. A 2–4 g subsample of sediment and organic aggregates was transferred to a beaker, and 20 mL of a 1% Calgon solution was added to the beakers to aid in disaggregation, with the contents sonified in the water bath for 10 min to disaggregate clays and organic aggregates. The contents of the beaker were then passed and rinsed through a 4 Φ (63 µM) sieve, using deionized water, with the wash retained in an underlying beaker. The amount of material finer than 4 Φ generated during the sonification step was determined by two methods. In samples that visually appeared <10% fine fraction, the fine-fraction mass was determined by filtering a known volume of the wash suspension in a pre-weighed Nucleopore filter, determining net weight after distilled water-rinsing and air-drying. In samples that were >10% fines, the entire resultant wash suspension was placed in a pre-weighed beaker and brought to dryness. Calculating the total solids mass in the wash by both methods provided a measure of the operationally defined weight of fine-fraction organic-mineral aggregates in the sample.

The coarse-fraction sand mass was determined by transferring the >63 µM size fraction from the wet sieving process to a pre-weighed aluminum dish, and dried. Every fifth sample analyzed (38 samples total) was run in triplicate to monitor laboratory precision. With the exception of three outliers, the relative precision of the analyses ranged from 2% to 10% (e.g., 1.26% ± 0.05% mass percent fine-fraction) and was a function of the amount of fine-grain material present, with the highest relative error associated with the smallest amount of fine-grained material. From these 35 samples, the following linear error model was developed for the fine-fraction content:

relative % error of fine fraction = –0.029 × (% fine fraction) + 0.0351 ($r^2 = 0.6$).

SAV Field Sampling

The line intercept method was used for SAV sampling. Transects were established from the shore of the river beyond the end of the grass bed. Presence and absence of each species was recorded continuously along each transect. Distances for each species found along the transect were summed to obtain lineal cover. One transect was performed in 2003 for 15 of the sites (sites with numerical names in the Appendix). At nine sites, five transects were randomly placed within a 50 m study plot (sites with alphanumeric names in the Appendix). These latter sites were sampled either monthly or quarterly during 2003, and the percent SAV cover values for these sites were averaged over the five transects and over the different sampling dates.

Statistical Analyses

Nearly every sample constituent had a nonnormative distribution; therefore, nonparametric statistics were used. Comparisons among river zones and sediment horizons within the littoral samples were made using the Kruskal-Wallis one-way analysis of variance test. Comparisons between pelagic and littoral samples used the two-tailed Mann-Whitney test. The pelagic-littoral comparison was restricted to only the sediment parameters and river zones in common between the two studies. Values were pooled among sediment horizons for this comparison. Curves were fit to assess relationships between sediment characteristics and SAV coverage using the nonlinear curve-fitting module in Sigma Plot. Crescent Lake was omitted from this latter analysis because it has virtually no functional connection with the mainstem river and has a very different ecology. With the exception of bulk density, pH, percent sand, and percent mud, the best regression models were attained using the general equation,

$$y = a \cdot e^{(-b \cdot x)} \quad \textbf{(1)}$$

The bulk density curve was fit using the general equation,

$$y = a\left(1 - e^{(-bx)}\right) \quad \textbf{(2)}$$

RESULTS AND DISCUSSION

Littoral Sediment

Littoral sediment characteristics demonstrated a relatively wide range of values for most parameters measured (Table 1). When the data were sorted by river zone, large differences appeared (Table 2). The FR zone was found to have much higher amounts of nutrients, organic carbon, and percent mud (Table 2, Figure 2). As a result, SOD and bulk density were higher and lower, respectively, than the other zones in the river. Micronutrients were also higher in the FR zone (Table 2, Figure 2). It should also be noted that the FR zone had much more variability in most of the sediment parameters (Figure 2). The OL and FL zones generally had the lowest concentrations of nutrients, organic carbon, and micronutrients in the mainstem of the river (Table 2, Figure 2). Doctors Lake (DL), an off-line lake in the lower portion of the basin, had intermediate levels of nutrients, organic carbon, and micronutrients (Table 2, Figure 2). Crescent Lake (CL) was much different than the other zones in that sediments were highly mineral and had very low nutrients, organic carbon, and micronutrients (Table 2, Figure 2). In general, most parameters followed the order FR> DL> OL + FL> CL. Differences of all sediment characteristics were highly significant among river zones (Table 4).

There was much less variability in soil characteristics among soil horizons. Bulk density was significantly lower and moisture content was significantly higher, in the upper horizon (Tables 3 and 4, Figure 2), suggesting greater organic material. This was supported by significantly greater SOD in the upper horizon (Tables 3 and 4, Figure 2). However, total carbon was not significantly different among horizons (Table 4). Nutrients, both extractable and total, were significantly higher in the upper horizon (Tables 3 and 4, Figure 2).

The bathymetry characterizing each river zone may be responsible for the differences in sediment characteristics. The littoral shelves in the OL and FL zones are broad and support large areas of SAV. The combination of SAV and greater water exchange from waves, tidal movements, and possibly wind-driven currents likely promotes increased oxygenation of the sediments. In turn, this would increase rates of sediment metabolism and nutrient mineralization. In contrast, the FR zone has very narrow littoral shelves, mostly overhung with riparian canopy. This environment probably leads to lower sediment metabolism and nutrient mineralization and greater accrual of organic matter. High levels of organic material and nutrients in the FR zone (Table 2, Figure 2) support this hypothesis.

Table 2. Median (upper and lower quartiles) values for sediment constituents summarized by river zone

Parameter	Oligohaline-Lacustrine		Freshwater-Lacustrine		Freshwater-Riverine		Doctors Lake		Crescent Lake	
	N = 78		N = 66		N = 53		N = 12		N = 24	
% LOI	1.07	(0.69, 1.74)	0.88	(0.49, 1.46)	7.09	(0.77, 54.87)	1.57	(1.40, 2.38)	0.00	(0.00, 0.00)
% Mud	1.77	(1.14, 2.55)	0.71	(0.36, 1.44)	42.33	(1.52, 88.11)	3.27	(2.77, 3.37)	0.71	(0.64, 1.82)
% Sand	98.23	(97.45, 98.86)	99.29	(98.56, 99.64)	57.67	(11.89, 98.29)	96.73	(96.63, 97.23)	99.29	(98.18, 99.36)
Bulk Density (g cm^{-3})	0.90	(0.81, 1.00)	0.92	(0.80, 1.02)	0.50	(0.03, 0.91)	0.73	(0.66, 0.86)	1.02	(0.96, 1.12)
Exchangeable NH_4(mg kg^{-1})	9.05	(6.23, 12.23)	10.00	(5.43, 18.50)	23.51	(10.32, 47.42)	15.06	(11.64, 22.81)	3.81	(2.56, 5.15)
Moisture Content (% wt)	25.18	(23.12, 29.18)	24.53	(22.29, 27.39)	39.40	(24.96, 81.75)	31.32	(25.76, 34.71)	21.20	(20.20, 23.55)
N:P (mol)	21.54	(7.31, 33.08)	26.11	(20.88, 34.11)	16.67	(0.38, 56.48)	32.18	(29.53, 35.97)	0.90	(0.84, 1.03)
pH	7.25	(7.07, 7.52)	7.19	(7.01, 7.36)	7.01	(6.78, 7.11)	7.50	(7.41, 7.90)	6.94	(6.79, 7.10)
SOD (mg/L^{-1} hr^{-1})	3.86	(2.85, 6.29)	2.76	(1.37, 4.74)	10.80	(5.45, 34.76)	4.26	(3.24, 6.36)	1.60	(0.34, 1.95)
SRP (mg kg^{-1})	6.54	(5.70, 8.60)	7.13	(6.47, 8.79)	8.56	(6.72, 13.67)	7.86	(5.83, 10.50)	5.66	(5.15, 6.19)
Total Al (mg kg-1)	281.64	(189.44, 377.14)	64.70	(34.62, 100.25)	322.74	(65.16, 1061.54)	362.84	(317.76, 469.64)	29.81	(23.15, 39.38)
Total C (g kg^{-1})	3.80	(2.90, 5.79)	3.25	(1.83, 5.35)	19.98	(2.25, 250.23)	7.59	(6.17, 9.09)	0.77	(0.28, 1.14)
Total Ca (mg kg^{-1})	293.72	(194.31, 476.31)	253.29	(137.81, 363.68)	2520.26	(334.29, 14330.59)	406.86	(328.43, 755.05)	94.93	(76.38, 120.54)
Total Fe (mg kg^{-1})	152.11	(101.53, 264.93)	23.68	(12.90, 71.99)	144.22	(56.09, 570.68)	189.85	(140.32, 306.57)	13.09	(7.14, 46.94)
Total Mg (mg kg^{-1})	105.74	(76.81, 157.45)	30.30	(18.68, 48.84)	374.61	(38.46, 1665.87)	107.00	(87.46, 216.02)	8.79	(7.24, 11.92)
Total N (g kg^{-1})	0.31	(0.20, 0.46)	0.27	(0.20, 0.42)	1.04	(0.011, 1.98)	0.59	(0.50, 0.67)	0.01	(0.01, 0.01)
Total P (mg kg^{-1})	29.55	(19.69, 45.59)	25.71	(18.58, 42.73)	153.42	(73.77, 278.35)	39.03	(26.90, 54.16)	12.28	(10.74, 13.19)

LOI = loss on ignition
SOD = soil oxygen demand
SRP = soluble reactive phosphorus

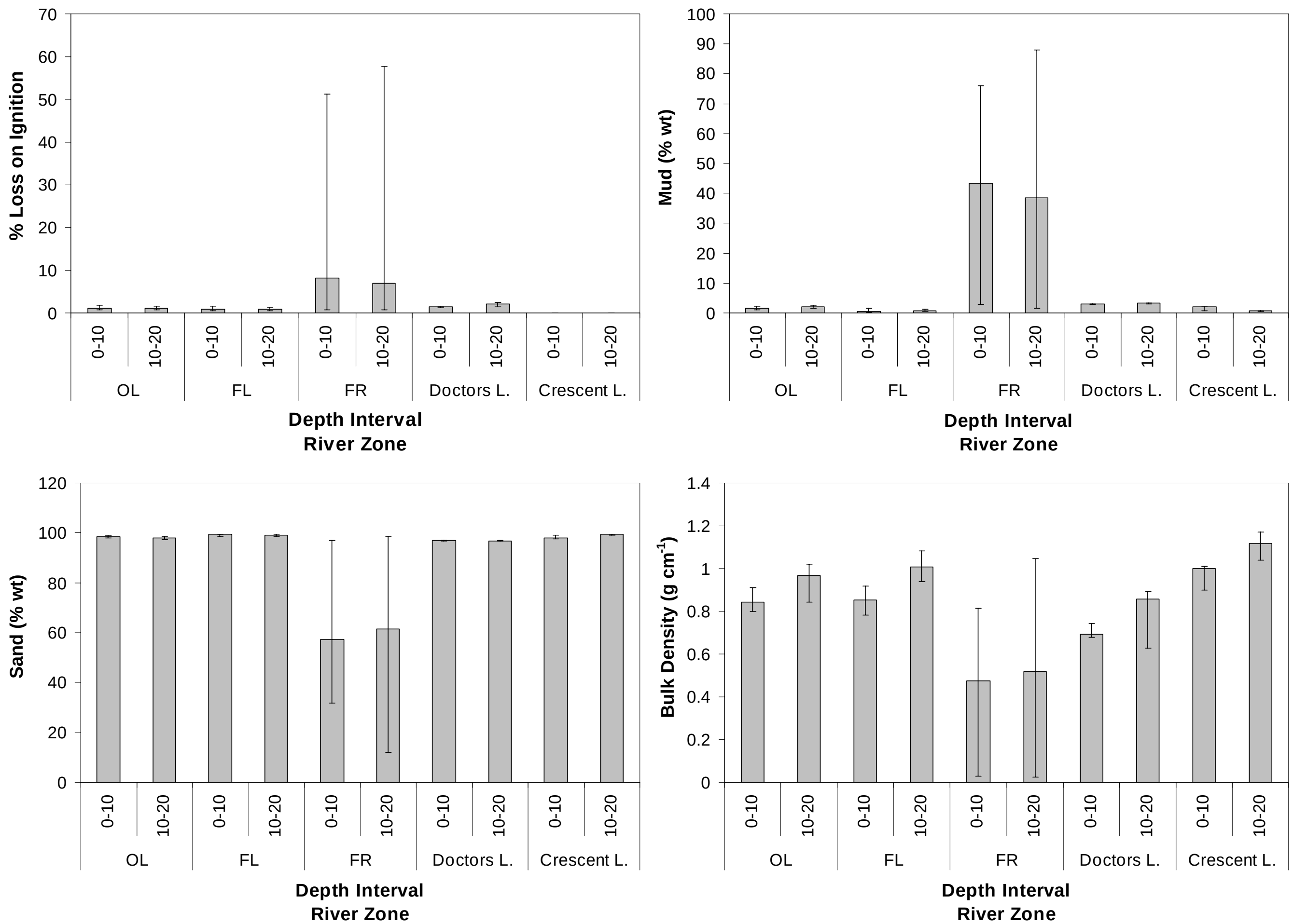
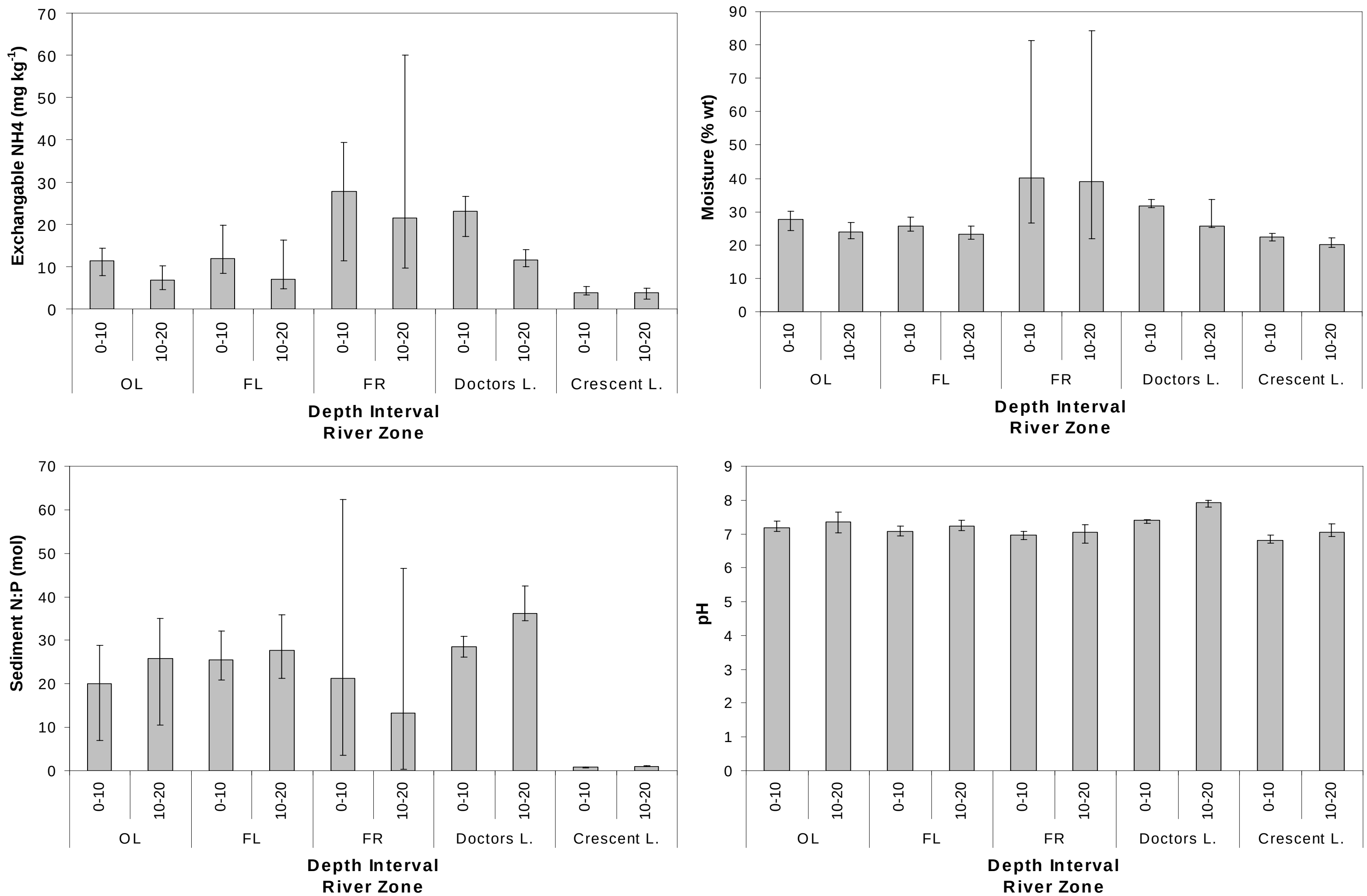


Figure 2. Median values for sediment constituents arranged by river zone and sediment depth, with error bars representing the upper and lower quartiles. OL, oligohaline-lacustrine; FL, freshwater-lacustrine; FR, freshwater-riverine.



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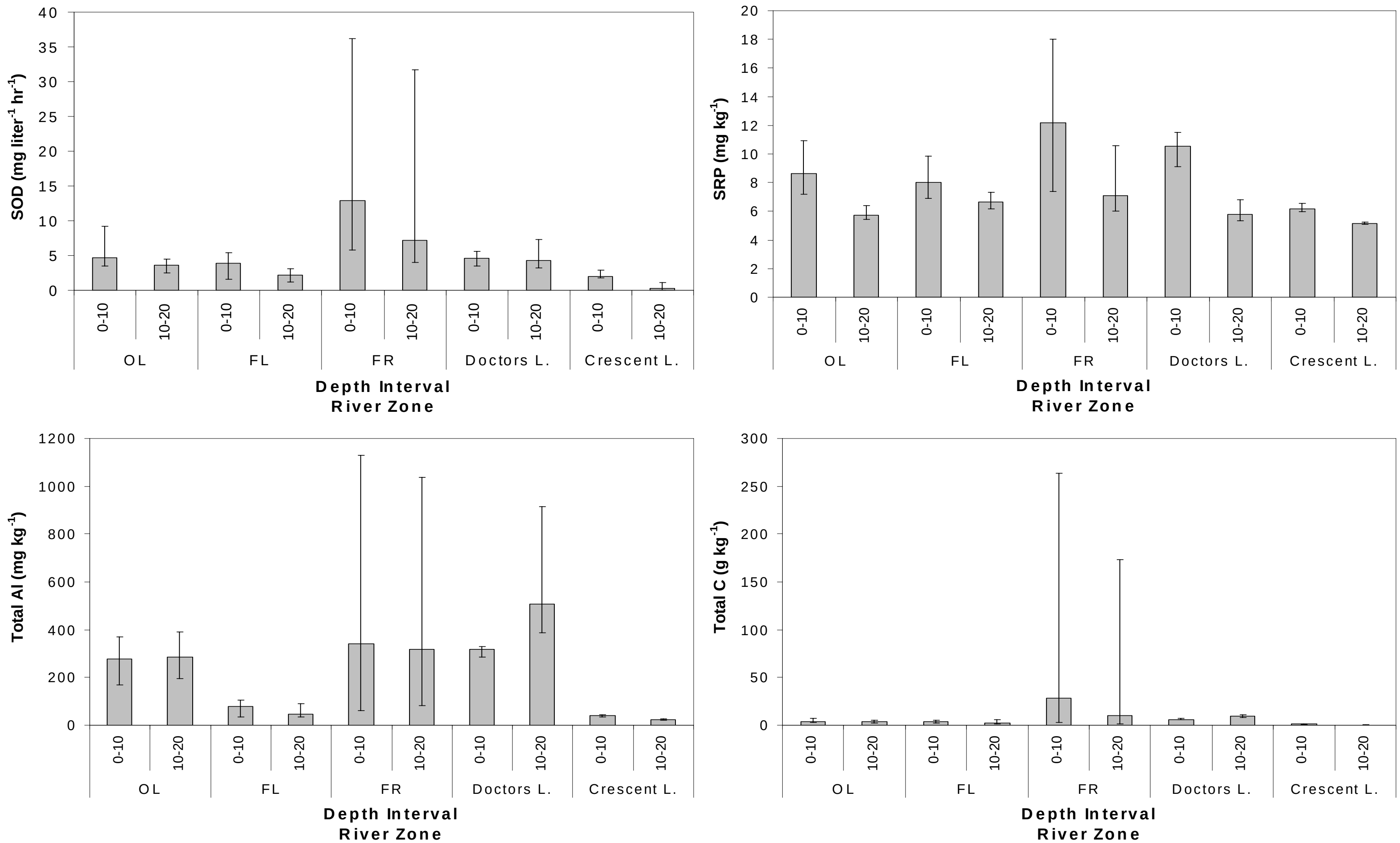

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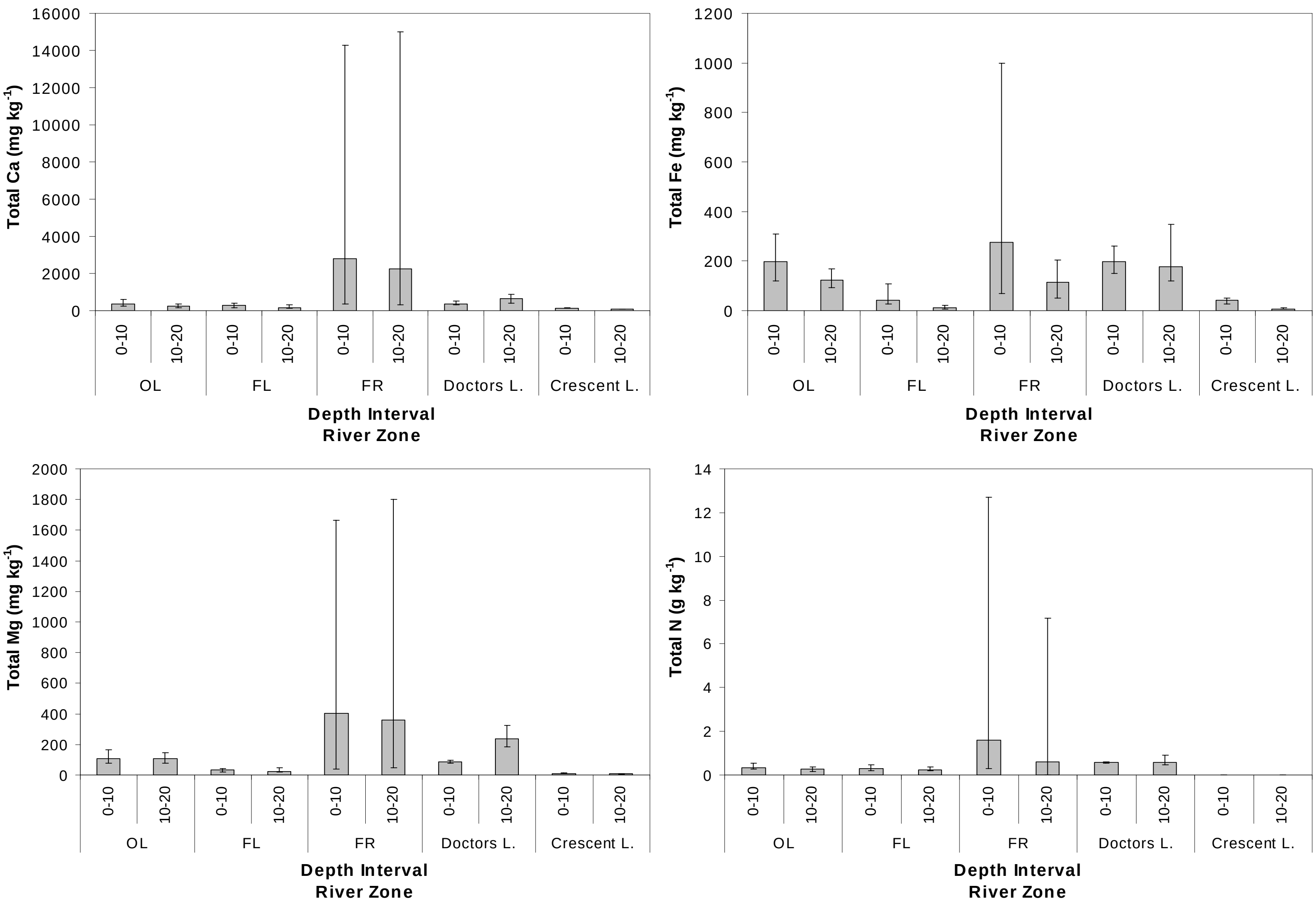

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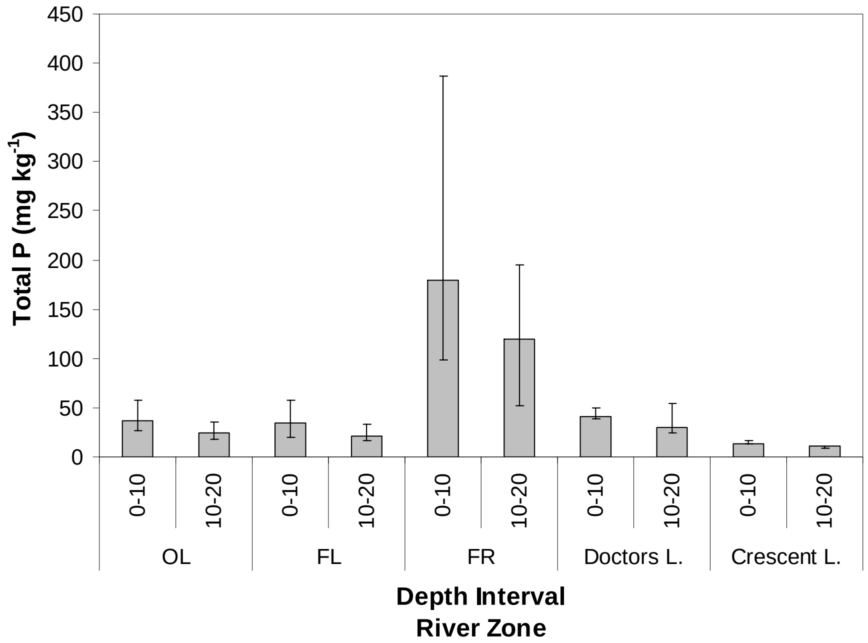

Figure 2—*Continued*

Table 3. Median values for sediment constituents grouped by river zone and depth horizon

River Zone	Oligohaline-Lacustrine		Freshwater-Lacustrine		Freshwater-Riverine		Doctors Lake		Crescent Lake	
Depth Interval (cm)	**0–10**	**10–20**	**0–10**	**10–20**	**0–10**	**10–20**	**0–10**	**10–20**	**0–10**	**10–20**
Sediment Parameter										
% LOI	1.05	1.08	0.88	0.89	8.19	6.90	1.37	2.20	0.00	0.00
% Mud	1.48	2.16	0.53	0.74	43.44	38.43	3.02	3.37	2.15	0.64
% Sand	98.52	97.84	99.47	99.26	57.11	61.57	96.98	96.63	97.85	99.36
Bulk Density (g cm^{-3})	0.84	0.97	0.85	1.01	0.48	0.52	0.69	0.86	1.00	1.12
Exchangeable NH4 (mg kg^{-1})	11.45	6.74	11.90	7.08	27.79	21.51	23.04	11.48	3.79	3.81
Moisture Content (% wt)	27.71	23.94	25.81	23.26	40.02	39.03	31.62	25.63	22.30	20.10
N:P (mol)	20.10	25.78	25.46	27.76	21.24	13.27	28.57	36.24	0.83	1.05
pH	7.18	7.37	7.08	7.24	6.96	7.05	7.40	7.92	6.82	7.05
SOD (mg $liter^{-1}$ hr^{-1})	4.74	3.56	3.90	2.22	12.87	7.24	4.57	4.26	1.96	0.25
SRP (mg kg^{-1})	8.64	5.74	8.03	6.65	12.20	7.07	10.53	5.76	6.19	5.15
Total Al (mg kg^{-1})	278.13	285.16	79.69	47.96	339.82	318.18	316.64	506.47	39.79	22.92
Total C (g kg^{-1})	3.93	3.72	3.69	2.35	28.47	10.25	6.13	9.12	1.17	0.27
Total Ca (mg kg^{-1})	369.85	238.45	277.13	172.79	2817.61	2237.15	356.34	642.78	121.46	75.54
Total Fe (mg kg^{-1})	198.82	123.24	41.00	12.96	276.59	112.97	197.73	176.37	41.16	7.10
Total Mg (mg kg^{-1})	106.74	104.73	32.89	25.04	402.32	361.42	85.19	239.39	11.78	7.38
Total N (g kg^{-1})	0.34	0.28	0.31	0.24	1.60	0.62	0.59	0.58	0.01	0.01
Total P (mg kg^{-1})	36.91	24.84	34.28	20.73	179.11	119.98	41.48	30.45	13.29	10.56

LOI = loss on ignition
SOD = soil oxygen demand
SRP = soluble reactive phosphorus

Table 4. Results of a Kruskal-Wallis test for sediment constituents among river zones and depth intervals. The test statistic (H) and the corresponding p-value are shown for each comparison

Parameter	River Zone		Depth Interval	
	H	p-value	H	p-value
% LOI	86.00	< 0.001	0.14	n.s.
% Mud	66.52	< 0.001	0.48	n.s.
% Sand	67.71	< 0.001	0.62	n.s.
Bulk Density (g cm^{-3})	50.47	< 0.001	19.66	< 0.001
Exchangeable NH4 (mg kg^{-1})	66.94	< 0.001	11.73	0.001
Moisture Content (% wt)	48.45	< 0.001	12.84	< 0.001
N:P (mol)	36.99	< 0.001	1.71	n.s.
pH	41.40	< 0.001	10.09	0.001
SOD (mg $liter^{-1}$ hr^{-1})	78.02	< 0.001	13.11	< 0.001
SRP (mg kg^{-1})	38.99	< 0.001	55.91	< 0.001
Total Al (mg kg^{-1})	96.55	< 0.001	0.21	n.s.
Total C (g kg^{-1})	70.00	< 0.001	2.28	n.s.
Total Ca (mg kg^{-1})	85.99	< 0.001	5.81	0.016
Total Fe (mg kg^{-1})	94.36	< 0.001	16.18	< 0.001
Total Mg (mg kg^{-1})	100.62	< 0.001	0.02	n.s.
Total N (g kg^{-1})	55.72	< 0.001	3.07	n.s.
Total P (mg kg^{-1})	119.37	< 0.001	9.14	0.002

LOI = loss on ignition
SOD = soil oxygen demand
SRP = soluble reactive phosphorus

Pelagic sediment

Pelagic sediment samples were substantially different and much greater, in concentrations of organic and nutrient constituents, than littoral samples (Table 5). Within the river's mainstem, nutrient and carbon contents in the pelagic were 22- to 68-fold greater than the littoral sediment (Table 6). Sediment properties such as LOI, moisture content, pH, and SOD were significantly higher, while bulk density was significantly lower (Table 6). Sediment N:P was not significantly different. Differences were not as great in Doctors Lake; though all sediment parameters, except pH and SOD, were significantly different (Table 6). These pelagic-littoral differences are likely caused by sediment-focusing. This focusing appeared to be greater in the mainstem of the river where tidal movement, flow, and possibly wind-driven effects may be greater than in Doctors Lake. These data also suggest that estimates of sediment water interactions within the river should include both the pelagic and the littoral areas.

Strong relationships existed among most sediment characteristics and SAV coverage. With the exception of a few, there were no significant relationships among grain size (e.g., percent mud and percent sand) and SAV coverage (Table 7, Figure 3). Neither was there a significant relationship between pH and

Table 5. Median (lower and upper quartiles) values for sediment constituents measured in the deeper pelagic areas of the St. Johns River

River Zone	Oligohaline-Lacustrine		Freshwater-Lacustrine		Freshwater-Riverine		Doctors Lake	
	n= 22		n = 38		n = 2		n = 4	
Bulk Density (g cm^{-3})	0.10	(0.09, 0.15)	0.14	(0.09, 0.19)	1.20	(1.18, 1.21)	0.07	(0.06, 0.08)
LOI (%)	26.79	(21.08, 28.79)	34.50	(25.85, 38.24)	2.18	(2.07, 2.30)	35.13	(34.39, 35.54)
Moisture Content (%)	82.34	(74.35, 83.62)	83.55	(80.00, 85.53)	31.89	(31.61, 32.16)	87.03	(85.61, 88.66)
pH	7.68	(7.60, 7.73)	7.36	(7.30, 7.48)	7.63	(7.56, 7.69)	7.53	(7.49, 7.56)
SOD (mg kg^{-1} hr^{-1})	4.71	(4.13, 5.07)	3.62	(3.24, 4.39)	7.05	(6.79, 7.31)	3.87	(3.75, 3.95)
SRP (mg kg^{-1})	498.76	(363.97, 578.55)	334.76	(244.95, 475.00)	208.30	(203.62, 212.97)	440.35	(422.08, 451.84)
TC (g kg^{-1})	105.34	(77.41, 114.13)	160.76	(124.57, 190.37)	6.50	(5.35, 7.65)	143.58	(142.47, 145.11)
TN (g kg^{-1})	7.71	(6.19, 8.84)	10.11	(7.55, 12.35)	0.46	(0.38, 0.55)	12.49	(11.89, 13.22)
TP (mg kg^{-1})	1237.81	(821.69, 1323.48)	873.69	(534.66, 1007.02)	265.52	(257.72, 273.32)	1575.07	(1469.62, 1698.44)

LOI = loss on ignition
SOD = soil oxygen demand
SRP = soluble reactive phosphorus
TC = total carbon
TN = total nitrogen
TP = total phosphorus

Table 6. Comparisons of channel and littoral sediment samples grouped by the river zones where common sampling occurred. Values shown are median values for each constituent and the p-value determined using a Mann-Whitney two-tailed test. Data were pooled across depth horizons. The FR zone was not included due to the low number of replicates.

	Oligohaline-Lacustrine			Freshwater-Lacustrine			Doctors Lake		
	Channel	**Littoral**	**p-value**	**Channel**	**Littoral**	**p-value**	**Channel**	**Littoral**	**p-value**
Bulk Density (g cm^{-3})	0.10	0.90	<0.001	0.14	0.92	<0.001	0.07	0.73	0.004
LOI (%)	26.79	1.07	<0.001	34.50	0.88	<0.001	35.14	1.57	0.004
Moisture Content (%)	82.3	25.2	<0.001	83.55	24.53	<0.001	87.03	31.32	0.004
pH	7.68	7.25	<0.001	7.36	7.19	<0.001	7.53	7.50	0.856
SOD (mg kg^{-1} h^{-1})	4.72	3.86	0.065	3.62	2.76	0.004	3.87	4.26	0.467
SRP (mg kg^{-1})	498.76	6.54	<0.001	334.76	7.13	<0.001	440.35	7.86	0.004
TC (g kg^{-1})	105.34	3.80	<0.001	160.76	3.46	<0.001	143.58	7.59	0.004
TN (g kg^{-1})	7.71	0.31	<0.001	10.11	0.28	<0.001	12.49	0.59	0.004
TP (mg kg^{-1})	1237.8	29.6	<0.001	873.69	25.71	<0.001	1575.07	39.03	0.004
N:P (mol)	15.21	21.54	0.210	26.21	27.52	0.524	17.58	32.18	0.015

LOI = loss on ignition
SOD = soil oxygen demand
SRP = soluble reactive phosphorus
TC = total carbon
TN = total nitrogen
TP = total phosphorus

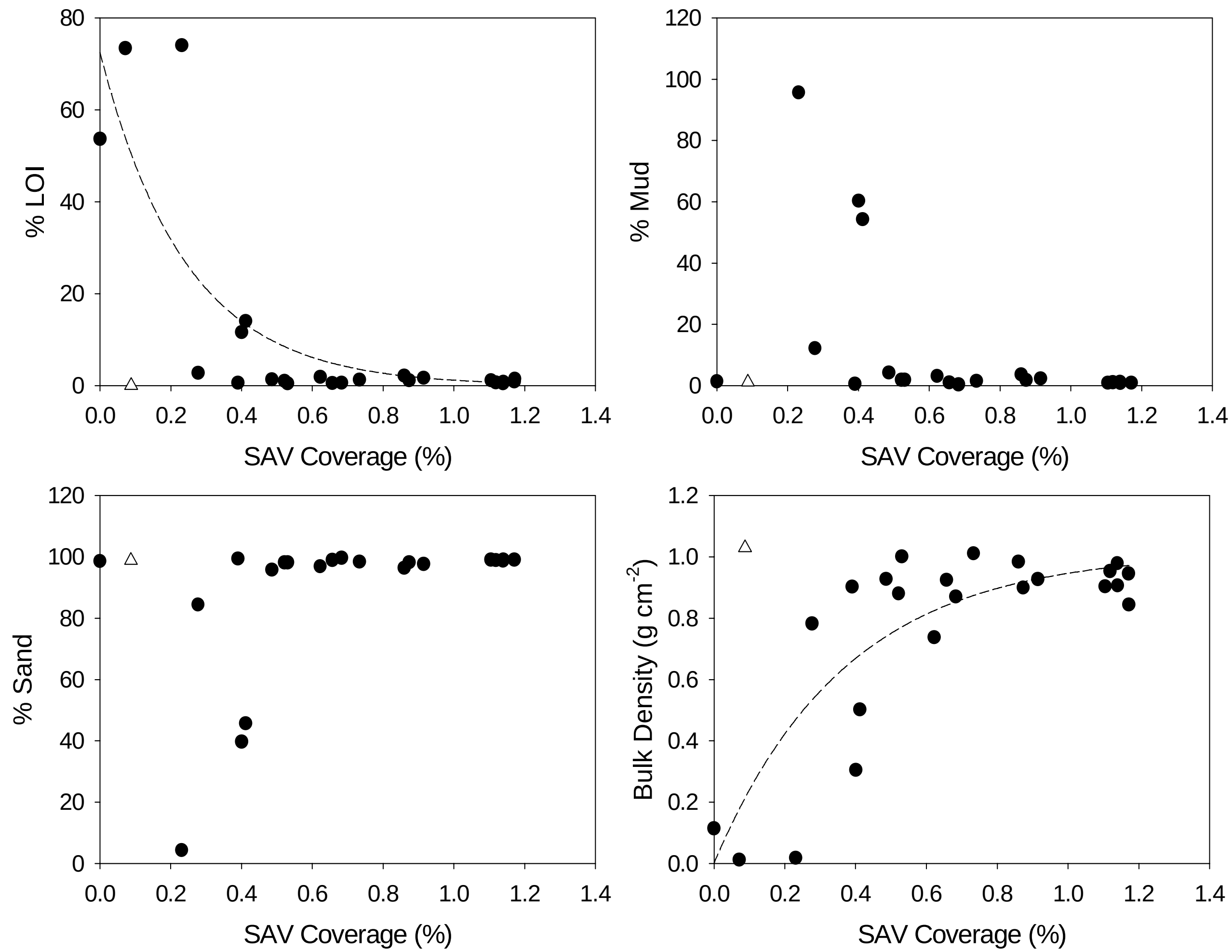

Figure 3. Best-fit regression relationships among sediment constituents and SAV percent coverage. Model parameters and statistics are shown in Table 7. Closed circles represent sites used in the analysis while the open triangles represent Crescent Lake (not used in this analysis).

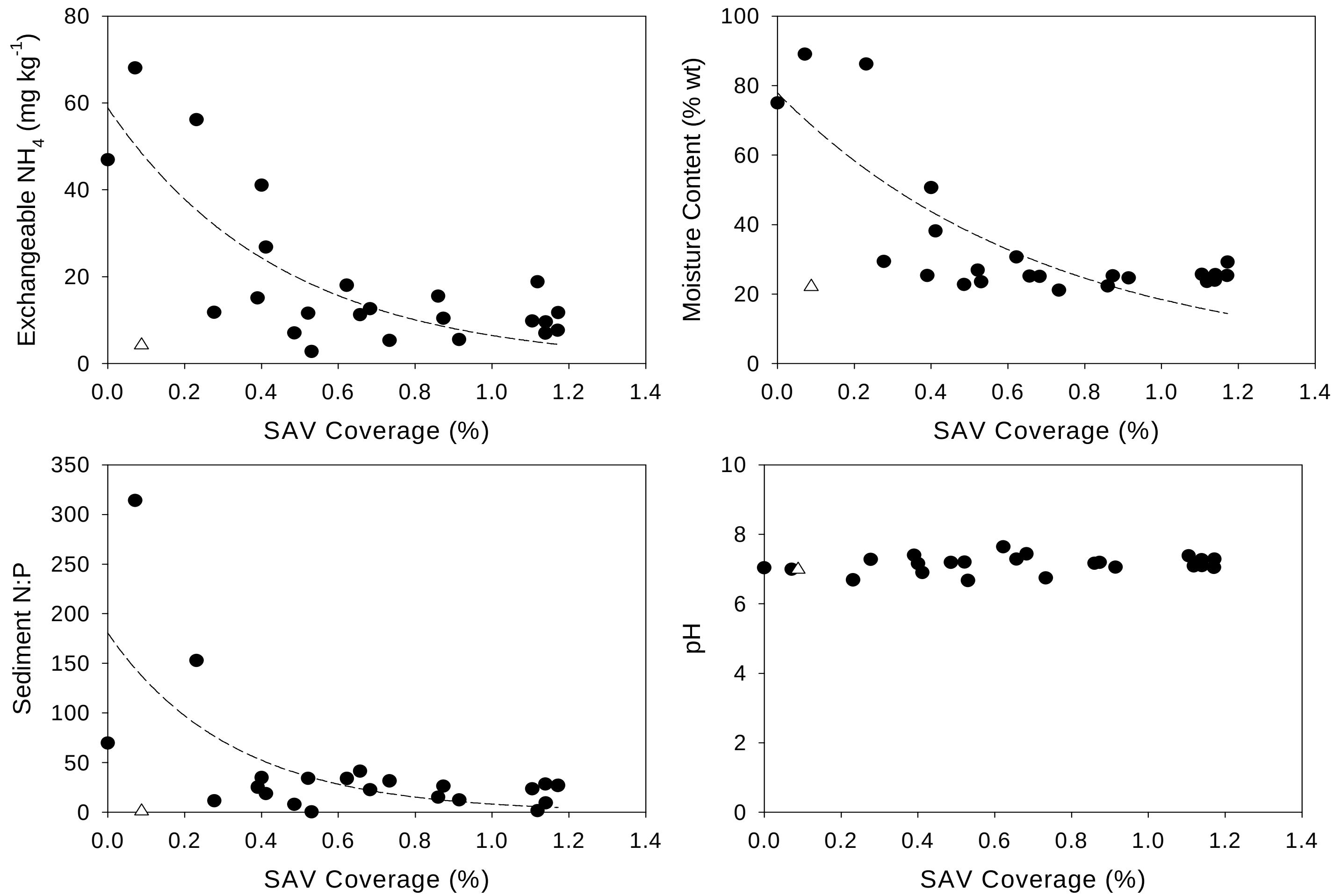

Figure 3—*Continued*

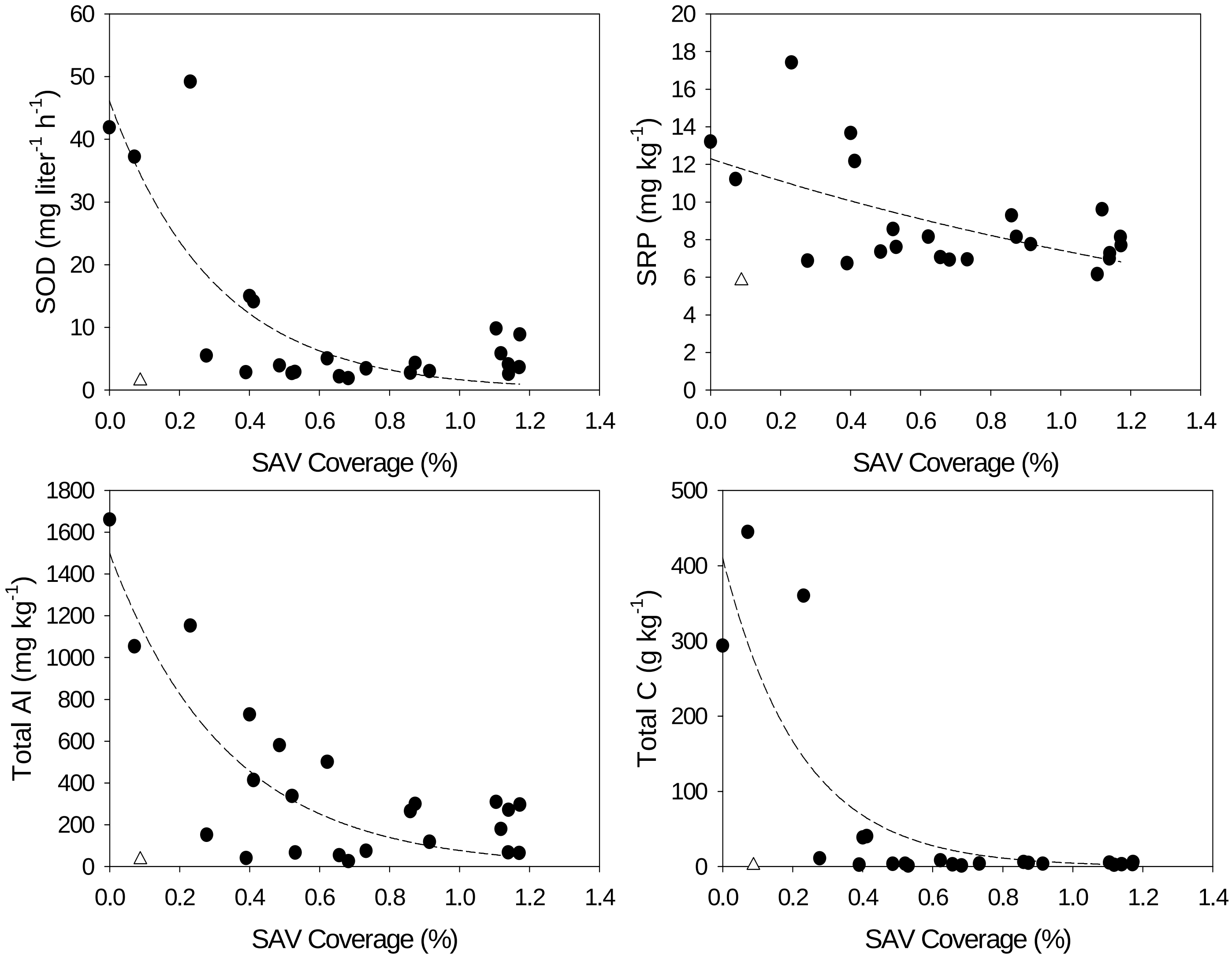

Figure 3—*Continued*

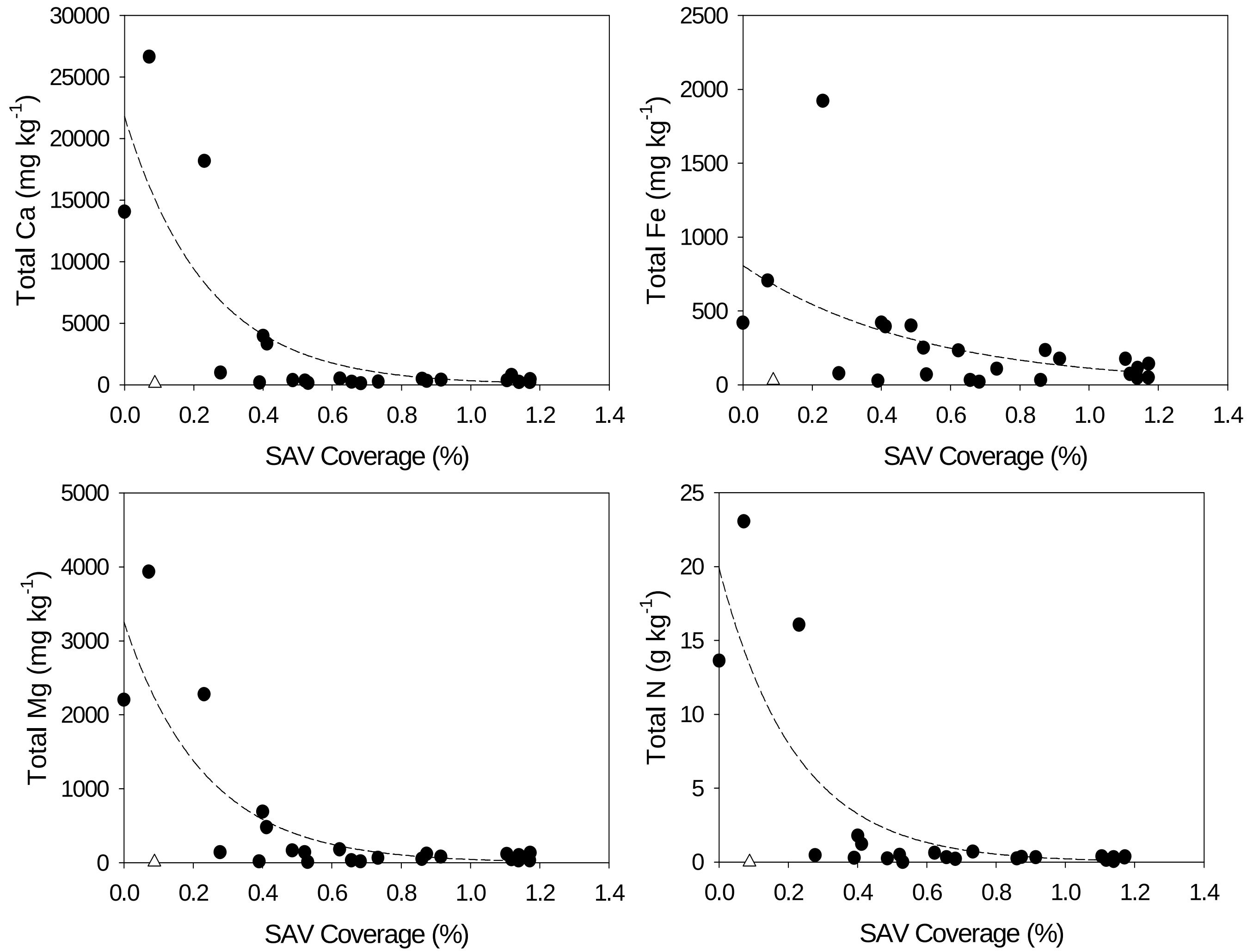

Figure 3—*Continued*

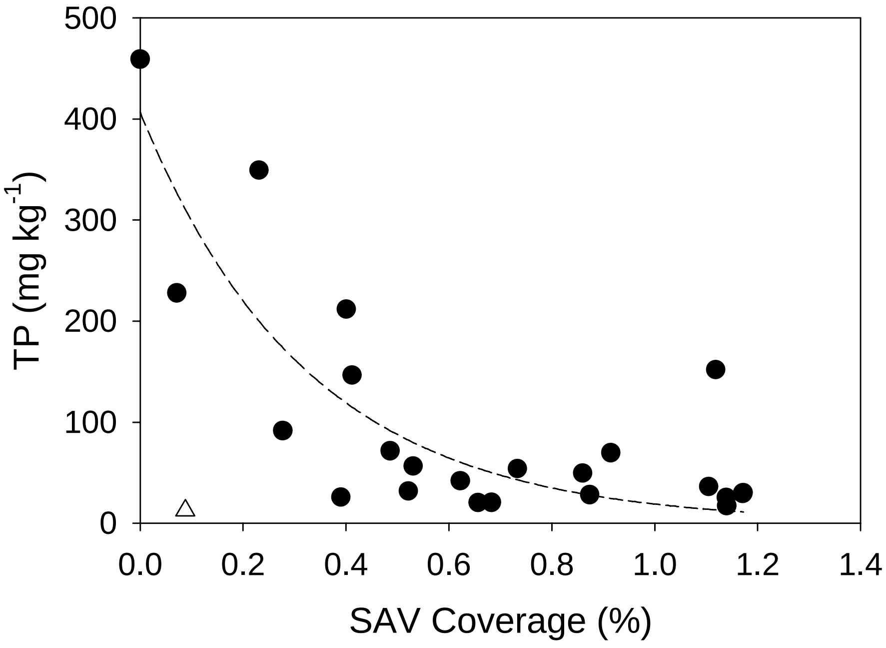

Figure 3—*Continued*

Table 7. Model parameters and statistics for regression curves fit to sediment parameters and SAV coverage data; all model fits used equation [1] except bulk density, which used equation. (2)

Variable	Model Parameters				
	a	b	r^2	F	p-value
% LOI	72.47	4.11	0.68	43.9	<0.0001
% Mud	n.s.				
% Sand	n.s.				
Bulk Density (g cm^{-3})	1.02	2.67	0.70	42.3	<0.0001
Exchangeable NH_4 (mg kg^{-1})	58.90	2.21	0.62	34.0	<0.0001
Moisture Content (% wt)	77.90	1.44	0.61	33.4	<0.0001
N:P (mol)	180.52	3.09	0.42	15.5	0.0008
pH	n.s.				
SOD (mg/L^1 hr^{-1})	46.16	3.33	0.67	41.7	<0.0001
SRP (mg kg^{-1})	12.30	0.50	0.32	9.9	0.0049
Total Al (mg kg^{-1})	1500.33	2.97	0.68	44.6	<0.0001
Total C (g kg^{-1})	410.27	4.49	0.70	49.1	<0.0001
Total Ca (mg kg^{-1})	21794.45	4.19	0.67	43.2	<0.0001
Total Fe (mg kg^{-1})	807.23	1.97	0.27	7.7	0.0100
Total Mg (mg kg^{-1})	3255.19	4.28	0.72	52.7	<0.0001
Total N (g kg^{-1})	19.90	4.52	0.69	47.8	<0.0001
Total P (mg kg^{-1})	406.84	3.07	0.69	47.1	<0.0001

LOI = loss on ignition
SOD = soil oxygen demand
SRP = soluble reactive phosphorus

SAV, as found by other researchers (Jaynes and Carpenter 1986). All of the remaining sediment parameters were negatively related to SAV coverage (Table 7, Figure 3). These data are well-supported by other studies that have shown reductions in sediment nutrients, particularly SRP and Fe (Jaynes and Carpenter 1986, Wigand et al. 1997, Wigand et al. 2000). However, higher sediment TP has been associated with SAV (Jaynes and Carpenter 1986), which was not found in this study. This may be because the dominant SAV in the river is *Vallisneria americana*, which has a deep, well-developed root structure, and this may increase sediment redox potentials higher than in other common species (Chen and Barko 1988, Wigand et al. 1997).

An interesting feature of the sediment–SAV relationships may be especially relevant to restoration and management of the river. It appears from Figure 3 that there may be a threshold response to SAV coverage ~40%. In these data, high levels of nutrients, carbon, SOD, or LOI were never seen when coverage was >40%. One mechanism may be that greater amounts of SAV coverage oxygenate the sediment well enough to drive up redox potential, thereby increasing nutrient mineralization and respiration. Alternatively, it may be that sites with large amounts of reduced organic matter present may be unable to support SAV. Regardless of the mechanism underlying these patterns, it appears that managing the river in a way to achieve and maintain >40% SAV coverage is likely to result in very good sediment quality. In turn, this would support a healthier and more productive ecosystem.

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APPENDIX

Table 1. Name, date collected, and global positioning system (GPS) coordinates for each site sampled in this study

Date Collected	Site Name	Northing (UTM)	Easting (UTM)
4/28/2003	19	3342133.000070	439230.999320
4/28/2003	41	3339095.999870	438094.999310
4/28/2003	61	3336354.999940	435220.000120
5/7/2003	CRE-1	3263936.000066	451096.000098
5/7/2003	CRE-2	3263936.000066	451096.000098
5/7/2003	197	3261996.000060	434550.999928
5/7/2003	196	3267487.000130	432557.000054
5/7/2003	189	3268002.999870	432105.000054
5/7/2003	BUB-1	3273753.000011	433837.000018
5/7/2003	BUB-2	3273753.000011	433837.000018
5/7/2003	BRL-1	3274253.000012	438236.000086
5/7/2003	BRL-2	3274253.000012	438236.000086
5/21/2003	181	3273893.000010	437896.000123
5/21/2003	176	3274988.000070	441988.000127
5/21/2003	RIC-1	3286857.000023	438001.999958
5/21/2003	RIC-2	3286857.000023	438001.999958
5/21/2003	167	3285468.000080	440145.999997
5/21/2003	SCA-1	3300904.000100	441761.000025
5/21/2003	SCA-2	3300904.000100	441761.000025
5/21/2003	129	3307016.000100	440510.999933
5/21/2003	123	3308318.999910	443052.000128
5/21/2003	119	3313329.999980	443630.999936
5/21/2003	99	3321307.482740	438031.513211
5/29/2003	BOL-1	3345714.999950	439381.999959
5/29/2003	BOL-2	3345714.999950	439381.999959
5/29/2003	23	3341562.000000	438264.000123
5/29/2003	BUC-1	3338169.000071	43932.000086
5/29/2003	BUC-2	3338169.000071	43932.000086
5/29/2003	DRL-1	3331254.999937	428169.000013
5/29/2003	DRL-2	3331254.999937	428169.000013
5/29/2003	MOC-1	3333271.999875	433149.999953
5/29/2003	MOC-2	3333271.999875	433149.999953
5/29/2003	82	3332057.000060	433465.999991