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Pore-Water and Substrate Quality of the Peat Marshes at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, and Comparison with Penchant Basin Peat Marshes, South Louisiana, 2000-2002

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2005-5121

U.S. Department of the Interior
U.S. Geological Survey

Front cover photographs

Diverse moss and liverwort species within floating *Panicum hemitomon* and *Myrica cerifera* communities at Barataria Preserve, Jean Lafitte National Historical Park and Preserve, south Louisiana

(Photographs by Christopher M. Swarzenski)

Pore-Water and Substrate Quality of the Peat Marshes at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, and Comparison with Penchant Basin Peat Marshes, South Louisiana, 2000-2002

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Conversion Factors, Datum, and Abbreviated Water-Quality Units

Multiply	By	To obtain
	Length	
micrometer (µm)	0.00003937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
	Volume	
milliliter (mL)	0.003	gallon (gal)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Abbreviated water-quality and chemical concentration units:

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L), micrograms per liter (µg/L), or parts per thousand (ppt).

Pore-Water and Substrate Quality of the Peat Marshes at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, and Comparison with Penchant Basin Peat Marshes, South Louisiana, 2000-2002

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Abstract

Pore-water and substrate quality of the peat marshes at the Barataria Preserve of Jean Lafitte National Historical Park and Preserve were measured from January 2000 to June 2002. The six major plant communities, including those dominated by *Panicum hemitomon,* were studied. The data were compared with pore-water and substrate quality of peat marshes dominated by *Panicum hemitomon* in the Penchant Basin, an area of coastal Louisiana that has functioned as the hydrological and ecological equivalent of a freshwater diversion for over 30 years. Surface-water quality between the two areas also was compared. The comparisons were made to evaluate possible long-term responses of the peat marshes in the Barataria Preserve to the Davis Pond Freshwater Diversion, which began operations in 2003, and is introducing Mississippi River water to Barataria Preserve waterways and marshes.

The marshes sampled at the Barataria Preserve align along a gradient of increasing exchange with adjacent surface water and proximity to the southern portion of the Barataria Preserve, where pulses of higher salinity water from the Gulf of Mexico first enter waterways. The gradient influences pore-water salinity and sulfide concentrations. *Panicum hemitomon* occurred as the dominant marsh community only at the two innermost habitats, which are better protected from saltwater intrusion than areas closer to waterways. These two sites had significantly lower median chloride concentrations (about 380-670 mg/L [milligrams per liter]) than the four other habitats (about 1,300-1,800 mg/L). Pore-water concentrations of inorganic nutrients, potassium, sulfate, and sulfide increased from the innermost sites to the southernmost sites, marsh communities dominated by *Spartina patens* and *Schoenoplectus americanus.* Median filtered ammonium concentrations ranged from about 0.022 to 1.95 mg/L as nitrogen; median sulfide concentrations ranged from about 0.07 to over 11.0 mg/L. The substrate of the *Panicum hemitomon* dominated communities was more fibric and less decomposed than that at the remaining four sites. The soil at the southernmost community, with the highest nutrient and sulfide concentrations, was the most highly decomposed. Environmental conditions in the Barataria Preserve may represent the extremes under which peat can accumulate and peat marshes can sustain themselves in coastal Louisiana.

Flow of river water across wetlands and shallow ponds in the Penchant Basin resulted in the transformation and uptake of nutrients, sulfate, and atrazine. Pore-water chloride concentrations in *Panicum hemitomon* dominated marshes were significantly lower, and average inorganic nutrient and sulfide concentrations were significantly higher in the Penchant Basin than in the Barataria Preserve. Median pore-water ammonium concentrations were about 0.26 mg/L as nitrogen, and median sulfide concentrations were about 0.33 mg/L in the Penchant Basin. The peat substrate of marsh communities dominated by *Panicum hemitomon* was more decomposed in the Penchant Basin than the substrate of any of the six marsh communities in the Barataria Preserve. Elevated concentrations of inorganic nutrients and sulfide in pore water and a more decomposed peat substrate represent a substantial deterioration of the *Panicum hemitomon* habitat. Long-term exposure of a peat substrate to the regular influx of nitrate and sulfate may initiate and sustain biogeochemical reactions in the organic matter that result in the deterioration of the peat substrate. Such reactions could include the reduction of nitrate and sulfate, as well as the inhibition of nutrient uptake by the plants resulting from elevated sulfide concentrations. In this view, freshwater diversions may compromise the long-term sustainability of highly organic marshes in coastal Louisiana.

Introduction

Severe wetland loss is occurring along much of Louisiana's coastline, in part because of disruptions to the inflow of freshwater and sediments to the wetlands and because of regional submergence of the wetlands below long-term sea level (Gagliano and others, 1981; Mendelssohn and others, 1983; Turner and Cahoon, 1988; Boesch and others, 1994; Reed, 1995). The confinement of the Mississippi River between flood-control levees in much of southeastern Louisiana has reduced and in places eliminated the regular overbank flooding that historically brought freshwater and sediment to coastal wetlands. Even though accretion rates in many coastal Louisiana wetlands are among the highest anywhere in the world, they are insufficient to keep pace with increasing water levels (Hatton and others, 1983). To combat the loss of these economically and ecologically valuable wetlands, large-scale restoration projects are being proposed and implemented (Barataria-Terrebonne National Estuary Program, 1994). One restoration approach is to divert freshwater from the Mississippi River across flood-control levees and into adjacent wetlands in order to recreate the natural springtime overbank flooding that occurred before the levees were built.

Despite the potential benefits, the use of large river diversions to restore Louisiana's coastal wetlands is largely experimental, with uncertain outcomes. Most coastal Louisiana marshes increasingly rely on in-situ produced organic matter to maintain elevation with respect to sea level. Large volumes of organic matter accumulate in the shallow substrate (Turner and others, 2004; Nyman and others, 1990). Moreover, water quality of the Mississippi River has changed markedly since the turn of the 20th century (Turner and Rabalais, 1991) when the river last overflowed its banks unencumbered by flood-control levees. Since the early 1950's, the annual spring floodwaters of the Mississippi River have been characterized by a variety of agricultural chemicals, as herbicides and fertilizers are washed from farm fields in the Midwest (Meade, 1995; Clark and others, 1999; Goolsby and Battaglin, 2000). Nitrate concentrations are now (2005) as much as three times higher than in previous times when the river historically overflowed its banks during the spring flood (Turner and Rabalais, 1991). Atrazine, a herbicide commonly used on corn and sugarcane crops, was not present in the Mississippi River prior to the early 1960's. By 2002, atrazine was present in low levels throughout the year, and concentrations routinely peaked during the spring flood (Demcheck and Swarzenski, 2003).

The increased reliance of marshes on organic matter to maintain elevation, coupled with the changed water quality of the Mississippi River, creates considerable uncertainty in using freshwater diversions to restore coastal wetlands. Potential problems include substrate biogeochemical changes, especially those that affect the degradation and decomposition of the organic matter. Nitrate and atrazine in particular could adversely affect the ability of marshes to maintain elevation by interfering with the incorporation of organic matter into the marsh substrate. Other potential problems include changes to plant productivity and patterns of biomass allocation between aboveground and belowground partitions. Atrazine, designed to inhibit root production, could interfere with the accumulation of organic material into the peat substrate. Alone or in combination, these potential problems could lead to other than the desired outcome of wetland restoration.

The highest uncertainty of marsh response to the influx of river water probably lies with peat marshes. These are common in the freshwater reaches of coastal Louisiana (O'Neil, 1949; Swarzenski and others, 1991; Sasser and others, 1994). The Barataria Preserve of Jean Lafitte National Historical Park and Preserve, hereinafter referred to as the Preserve, is one such area containing large expanses of peat marsh. The Preserve is located about 10 miles southwest of New Orleans, Louisiana (fig. 1) and about 15 miles southeast of the Davis Pond Freshwater Diversion, the largest freshwater diversion project in coastal Louisiana. The U.S. Geological Survey, in cooperation with the National Park Service, surveyed pore-water and substrate quality in the peat marshes of the Preserve from January 2000 to June 2002 (fig. 2).

The study was originally designed to characterize pore-water and substrate quality prior to and after the opening of the Davis Pond diversion and to describe the rate, extent, and duration of river-water infiltration into the marsh interior (fig. 1). The Davis Pond diversion was not open during the study period due to construction delays. Since the first opening in 2003, only small volumes of Mississippi River water have been diverted (usually about 500-1,000 ft^3/s), and then only intermittently (Baumann and others, 2005). Flow has been well below the 10,650 ft^3/s capacity of the Davis Pond diversion. The data collected from the Preserve were instead compared and contrasted with data on pore-water and substrate quality collected from similar peat marshes receiving annual river water influx from the Lower Atchafalaya River. These marshes are located in the Penchant Basin, adjacent to the Lower Atchafalaya River (fig. 1). The Penchant Basin area is the hydrological and ecological equivalent of a large freshwater diversion, although the river inflow is passive, due to prevailing hydraulic gradients rather than deliberate routing through diversion structures. The marshes and waterways of the Penchant Basin are ideally located to evaluate the long-term effects of regular inflow of river water on water quality and sustainability of a peat marsh habitat in coastal Louisiana.

Purpose and Scope

This report describes pore-water and substrate quality of the peat marshes at the Barataria Preserve of Jean Lafitte National Historical Park and Preserve from January 2000 to June 2002. The data collected at the Barataria Preserve provide a baseline in anticipation of future changes in pore-water chemistry and possible changes in peat quality. The report also compares similar constituents and properties sampled in some peat marshes in the Penchant Basin and discusses potential changes in pore-water and substrate quality in Preserve marshes that could result after many years of regular inundation by Mississippi River water. Data on water quality of the Mississippi

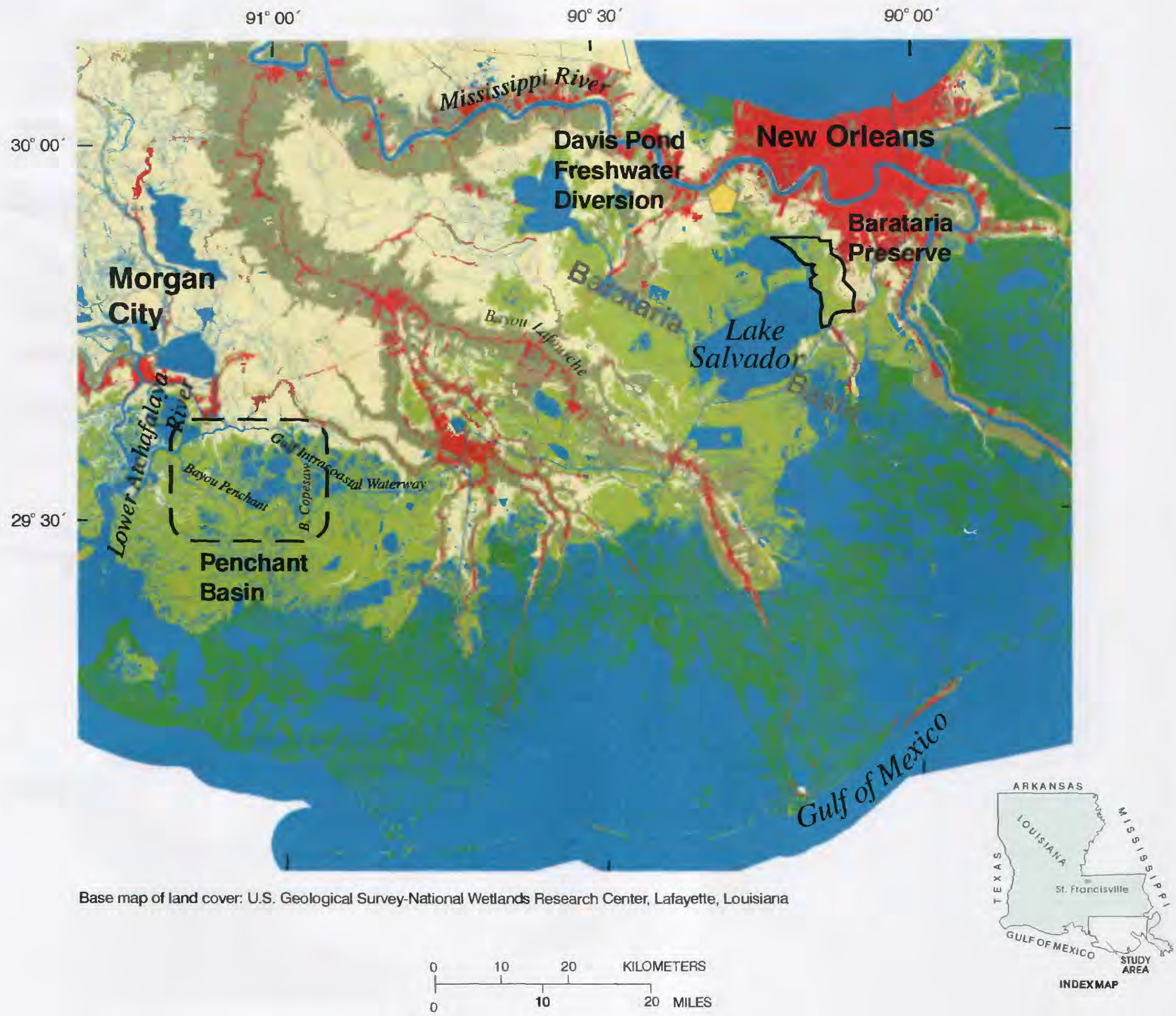

Figure 1. Barataria Preserve, Jean Lafitte National Historical Park and Preserve, and the Penchant Basin in south Louisiana.

River, Lower Atchafalaya River, and large bayous and canals in the two areas are presented as part of the comparison, to highlight the chemical differences of the surface waters that influence pore-water quality in the two study areas.

Description of the Study Area

The Barataria Preserve is located in Barataria Basin (fig. 1), a low-lying interdistributary basin flanked by the Mississippi River to the east, and by Bayou Lafourche, a former distributary of the Mississippi River, to the west. There is a continuum from freshwater to saltwater in Barataria Basin from north to south. Salinity of surface water at a given location is variable over time and depends on the mixture of saltwater from the Gulf of Mexico and freshwater runoff from precipitation and local drainage. Direct inflow of freshwater from the Mississippi River is limited mostly to the Davis Pond Freshwater Diversion, and leakage from two locks connecting the Intra-coastal Waterway to the Mississippi River in the New Orleans area. There are no structural impediments to the flow of water and materials from the Gulf of Mexico into the Preserve. Prior to the opening of the Davis Pond diversion, precipitation, local surface-water runoff, and marine intrusion largely determined the quality of surface water in the Preserve (Swarzenski, 2003a).

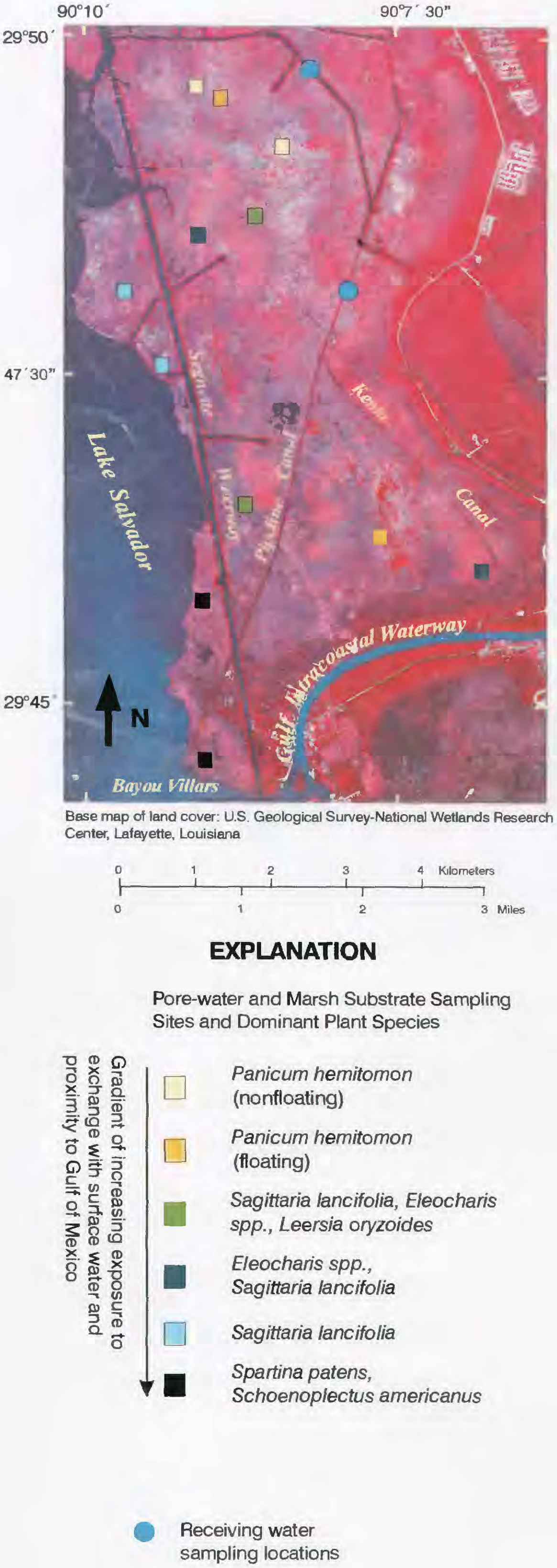

Figure 2. Sampling sites in the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, Louisiana.

In the low-salinity (0.5 to 4 ppt) portion of Barataria Basin where the Preserve is located, almost all emergent marshes are peat-based because of the lack of available mineral sediment for vertical accretion of the marsh substrate. Peat marshes are mats of emergent vegetation that to varying degrees adjust vertically to ambient water-level changes (Swarzenski and others, 1991). These mats (consisting of live belowground roots, associated dead and decaying organic material, and small amounts of mineral sediment) either completely separate from the underlying substrate (floating) or shrink and swell (nonfloating). Dry bulk density of the substrate is very low, and typically contains about 80 to 95 percent organic matter (Swarzenski and others, 1991).

In the local vernacular, these marshes are collectively known as flotant (Russell, 1942), referring to the buoyant properties of some of the mats. Vertical mat movement can be ecologically important by altering marsh flooding characteristics. Buoyancy is controlled by dominant plant community (Swarzenski and others, 1991) and soil mineral content (Holm and others, 2000; Swarzenski, 1992), and may be reduced by exposure to elevated nitrate concentrations (Fisher, 2003). Buoyancy also enhances the lateral exchange of water between canal and marsh interior and can influence pore-water salinity profiles (Swarzenski and Swenson, 1994). However, the key characteristic of flotant marshes in terms of their long-term sustainability in coastal Louisiana would appear to be the organic substrate, which reacts to ambient water-quality and chemical constituents such as nitrate and sulfate independently of mat buoyancy. In this study, peat marsh refers to floating and nonfloating marshes interchangeably except where specifically noted.

Six peat marsh habitats with distinct plant communities can be distinguished in the Preserve. The locations of the six habitats roughly parallel a gradient of (1) increasing water exchange with adjacent bayous, canals, and lakes and (2) proximity to the entry points of more saline waters into the Preserve. The gradient spans interior locations distant from surface-water exchange, to the southern boundary of the Preserve (fig. 2). Because pore-water quality is controlled by exchange with surface waters, the gradient influences pore-water salinity conditions within the marsh substrate. The two innermost habitats are dominated by *Panicum hemitomon* (paille fine) (fig. 3), differing only in whether the peat marshes float or are attached. At the southern end of the Preserve closest to the Gulf of Mexico and where salt pulses first enter the Preserve, the peat marshes consist of a mixture of *Spartina patens* (wiregrass), *Schoenoplectus americanus* (three-cornered grass), and varying amounts of *Sagittaria lancifolia* (bulltongue). In between the interior *Panicum hemitomon* marshes and the southernmost peat marshes are three additional marsh habitats with discernible plant communities. *Eleocharis spp.*, growing about 80-100 cm tall, are present in all three of these habitats in variable proportions. Photograph 1 shows plant communities at the Barataria Preserve, Louisiana.

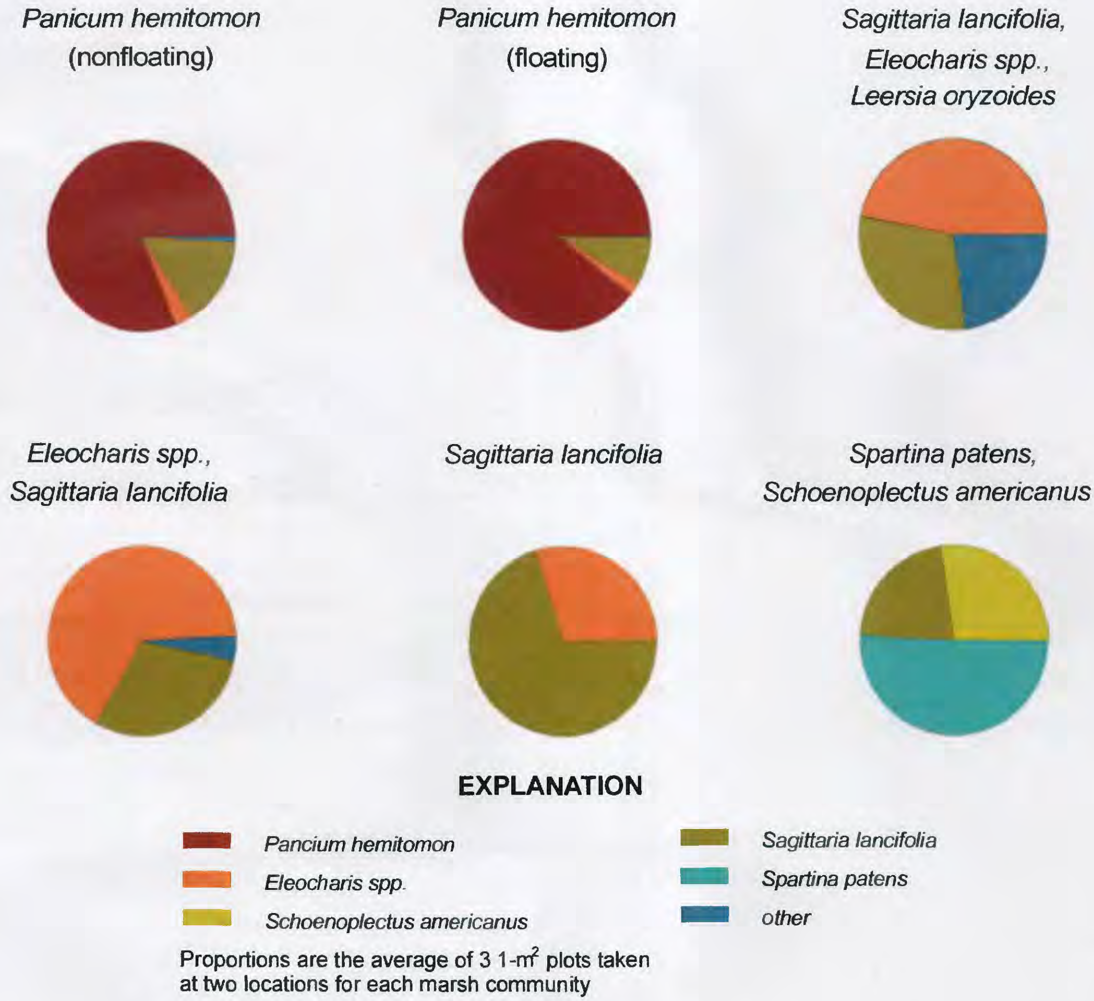

Figure 3. Proportions of dominant plants, by dry weight, at the six major marsh communities at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, Louisiana, June 1997.

Typha dominguensis (cattail) is common in the Preserve and occurs mixed in with all plant communities except for those dominated by *Panicum hemitomon.* Sampling sites were deliberately selected to exclude the presence of cattail.

The Penchant Basin is located to the east and south of the Lower Atchafalaya River and is loosely bounded by the Gulf Intracoastal Waterway to the north, Bayou Penchant to the west and south, and Bayou Copesaw to the east (fig. 1). The Lower Atchafalaya River has been regularly inundating the area for over 30 years (Swarzenski, 2003b). The peat marshes in the Penchant Basin are mainly *Panicum hemitomon* dominated marsh communities, or a degraded form of peat marsh, a thin unstable mat dominated by *Eleocharis parvula* (dwarf spikerush) (Visser and Sasser, 1996). Some *Sagittaria lancifolia* marshes occur farther downstream from the inflowing river water.

Methods

Pore water, water contained within the interstitial spaces of the marsh substrate, was sampled at two separate locations for each of the six distinct marsh habitats within the Preserve (see fig. 2). Pore water at the marshes dominated by *Panicum hemitomon* was sampled about 16 times between June 2000 and June 2002. The other marsh sites were sampled 12 to 14 times during the same period. On occasion, a specific location was not sampled because of accessibility problems. Pore water was sampled at 15- and 45-cm depths with a clean acrylic tube (4-mm inside diameter) inserted into the substrate. Pore water was withdrawn through this tube with a plastic syringe. Pore water from three randomly chosen points separated by no more than 15 m within each marsh site was composited in 250 mL bottles during each sampling trip. Composite samples were

Photograph 1. Plant communities at the Barataria Preserve, Louisiana: (A) nonfloating *Panicum hemitomon*, (B) *Eleocharis spp.*, (C) *Sagittaria lancifolia*, and (D) *Spartina patens* and *Schoenoplectus americanus*.

immediately chilled. Water was either immediately filtered in the field or in the laboratory on the same day through disposable 0.45-μm nylon filters (Whatman GD/X). Samples were shipped on ice to the Ocala Water Quality Laboratory (OWQL) in Ocala, Florida, within 24 hours of collection. The nutrients nitrite-plus-nitrate (cadmium reduction, diazotization), ammonium (salicylate hypochlorite) and orthophosphate (phosphomolybdate) were analyzed using automated colorimetry (Fishman, 1993). Calcium and magnesium were analyzed using inductively coupled plasma atomic emission spectrometry (USEPA, 1983). Chloride and sulfate were analyzed using ion chromatography (USEPA, 1983). Potassium was analyzed using flame absorption spectrometry (Fishman and Friedman, 1989).

During each sampling trip, pore water also was collected at 5-, 15-, and 45-cm depths for pH and sulfide determinations. The pH was measured with a digital pH meter (Cole Parmer Digi-Sense) standardized with a two-point calibration using buffers of pH 4 and 7. For sulfide measurements, a dilute sodium salicylate antioxidant buffer and standards were prepared in the laboratory prior to field trips and stored on ice in airtight containers (McKee and others, 1988). In the field, 5 mL of pore water was collected and mixed with an equal volume of buffer solution. Duplicate samples were collected at each depth. Samples and standards were analyzed on the same day with a sulfide-specific electrode (Orion 96-16) and the digital pH meter with millivolt conversion capabilities. Readings were converted from millivolts to milligrams per liter by using a log regression standard curve.

Oxidation-reduction (redox) potential of the substrate was measured at 2, 9, and 18 cm below the marsh surface during a subset of trips at the two habitats dominated by *Panicum hemitomon* and at the habitat dominated by a mixture of *Sagittaria lancifolia, Eleocharis spp.,* and *Leersia oryzoides*. These are the three innermost habitats along the gradient. Five multidepth probes (Hargis and Twilley, 1994) were inserted at random points into the soil at each site and left to stabilize for 30 minutes. A portable voltmeter (Digi-sense) and a calomel reference probe (Corning 476350) were used to take readings in millivolts (mV). All five values were averaged for each depth, and 230 mV added to determine the redox potential of the soil. During the study, the probes were routinely checked in a quinhydrone solution buffered to a pH of 4 to read at approximately 230 mV. When the tips did not read 230 mV, they were lightly sanded with emery paper to improve the contact. For the period of sampling, the same five redox probes were used at each site. In general, redox numbers are best interpreted as a relative measure of electron availability and anaerobic condition in wetland soils (Whitfield, 1969; Bohn, 1971); in absolute terms, the values are frequently inaccurate.

Substrate samples were collected from the surface to a depth of 25 cm in 5-cm increments at all 12 sites to determine carbon and fiber content. The latter is a measure of substrate decomposition or humification (Lynn and others, 1974). A portion of each soil sample was dried at 70 °C to constant weight and ground using a Wiley Mill. Total carbon content of this subsample was measured using an elemental carbon analyzer (PerkinElmer 2400 Series II CHN). For the fiber determination, 30 mL of wet soil from each sample increment was placed into a 60-mL syringe split longitudinally and marked in 1 mL increments. The soil was packed to approximate natural moisture conditions, removed from the syringe, and then gently rinsed through a sieve with 0.12-mm openings. The volume of material remaining in the sieve was measured as a percentage of the original by repacking the syringe. This remainder was again rinsed through the same sieve, but this time was rubbed between the thumb and fingers 10 times, to fractionate and remove well decomposed material. The syringe was repacked with the soil material remaining after the two rinsings, and the volume measured as a percentage of the original. This procedure was performed two or three times on each depth increment.

Fiber analysis is a standard technique used by soil scientists to qualitatively assess the state of decomposition of a given soil (Lynn and others, 1974). The analysis is subjective and involves breaking down the organic matter by rubbing the material between thumb and finger (mechanical fractionation). Absolute values can differ depending on the person performing the analyses, but the technique provides data useful for qualitative trends. The technique has been successfully applied to coastal Louisiana peat marshes in previous studies (Swarzenski and others, 1991; Holm and others, 2000).

Samples from marshes in the Penchant Basin were collected and analyzed in the same way as samples from the Preserve. Sampling in the Penchant Basin and the Preserve was usually carried out within a day of each other. Pore water in the Penchant Basin was sampled at four sites dominated by *Panicum hemitomon*. Fiber analyses were performed for the organic substrate at the same four sites and at two additional sites dominated by *Sagittaria lancifolia*.

Most water-quality data did not meet the normality and equal variance criteria necessary to use parametric statistical comparisons. Transforming the data using a logarithmic function did not effect a substantial change. For this reason, all statistical comparisons of water-quality constituents among plant communities at the Preserve were made using the Kruskal-Wallis ANOVA (analysis of variance) on ranks, with p< . If a difference in median were detected, Dunn's method for pair-wise multiple comparisons ($p<0.05$) was then applied to the data from individual sites. Comparisons of water-quality constituents between the Preserve and the Penchant Basin were made using the non-parametric equivalent of the paired student's t-test, the Mann-Whitney Rank Sum test.

Minimum reporting levels at OWQL for nutrients were 0.002 mg/L. In some instances, median concentrations were just slightly above this level. Inferences among sites for these constituents, even if statistically significant, should be made with this in mind. Minimum reporting levels for atrazine were 0.004 µg/L. Values for all other constituents were at least 5 times greater than the minimum reporting level. The coefficients of variation for nitrite plus nitrate, orthophosphate, and atrazine were 11, 7, and 3.7 percent, respectively, on duplicate analyses for a subset of samples.

Substrate data met the requirements of normality and equality of variance. The different plant communities at the Preserve were compared using a one-way ANOVA. Tukey's test was used for the pair-wise multiple comparison. A paired student's t-test was used to compare substrate quality between the two study areas. All water-quality data are presented as 25th percentile, median, and 75th percentile. Substrate data are presented as the average ± 1 standard deviation.

Acknowledgments

The authors thank David Muth and Bill Hulslander of the National Park Service, Jean Lafitte National Historical Park and Preserve, for their assistance and support throughout the study. The late Robert Belous, former Superintendent of Jean Lafitte National Historical Park and Preserve, initiated the collaboration that formed the basis for this effort. Kelia Fontenot and Ben Handley of Johnson Control World Services assisted with much of the field sampling and laboratory work. Mandy Foreman of the USGS helped with the soil analyses in the laboratory. Continental Land and Fur, Inc., generously granted access to marshes in the Penchant Basin.

Pore-Water and Substrate Quality of Barataria Preserve Marshes

The pore-water constituents analyzed were selected either because they were directly related to the health of the peat marshes, including plants and the substrate, or because they could be used to track the influx of river water into Preserve marshes. Inorganic nutrients (ammonium and orthophosphate), potassium, chloride, and sulfate affect marsh productivity and processes that control the accretion of the peat substrate. Peat-based wetlands generally are adapted to low-nutrient conditions by extensive root systems. If nutrient concentrations increase, the balance between accretion and decomposition may be altered and thereby compromise the stability of the marsh (Boar and others, 1989). Chloride in this study is used as a surrogate for salinity. Both chloride and its ionic complement sodium can be toxic to plants. Sulfide, the reduced form of sulfate, is toxic to wetland plants, and inhibits uptake of inorganic nutrients (Koch and Mendelssohn, 1989). The sulfate-sulfide redox pair is involved in many biogeochemical reactions in marsh soils. Calcium and magnesium, and especially the relative proportions of their concentrations, can be used to track influx of water from the Mississippi River (Hem, 1985; Swarzenski, 2003a).

Pore-Water Quality

Concentrations of the inorganic nutrients ammonium and orthophosphate, the ions potassium and sulfate, and sulfide generally increased in a consistent manner from the innermost *Panicum hemitomon* dominated marsh communities to the southernmost marsh communities dominated by *Spartina patens* and *Schoenoplectus americanus* (table 1). Median concentrations of filtered ammonium and orthophosphate in pore water varied more than one order of magnitude among the six major marsh communities at the Preserve. Nutrient concentrations were much greater at the marsh communities dominated by either *Sagittaria lancifolia* or by *Spartina patens* and *Schoenoplectus americanus*, than at the four more interior marsh communities. The nonfloating marsh dominated by *Panicum hemitomon* had the lowest concentration of ammonium at 45-cm depth, with a median of 0.022 mg/L as nitrogen. Median filtered ammonium (1.95 mg/L) and orthophosphate (about 0.16 mg/L at 45-cm depth) concentrations were highest at the southernmost marsh community dominated by *Spartina patens* and *Schoenoplectus americanus*. The floating marsh dominated by *Panicum hemitomon* contained higher inorganic nutrient concentrations at both 15- and 45-cm depths than the non-floating *Panicum hemitomon* marsh.

Calcium, magnesium, and chloride concentrations were about two to three times lower in the floating and nonfloating marshes dominated by *Panicum hemitomon* than in the other four marsh communities (table 1). Median chloride concentrations were about 380-670 mg/L in the innermost habitat, and about 1,400-1,800 mg/L in the remaining four communities. The interior marshes are relatively well isolated from intrusion of saltwater from the Gulf of Mexico, which has a higher chloride, calcium, and magnesium content. Ratios of calcium to magnesium at all six marsh communities were lower than the 3-to-1 ratio typical of Mississippi River water (Swarzenski, 2003a) and decreased in order from the innermost sites to the exposed marshes at the southern end of the Preserve (table 1). A decrease was expected because the relative proportion of magnesium relative to calcium is higher in saltwater (Hem, 1985). The consistent decrease in calcium to magnesium ratio was surprising because concentrations of calcium and magnesium did not vary consistently among marsh communities along the same gradient. Potassium concentrations increased inversely in relation to calcium to magnesium ratios among the six marsh communities, with one exception at 45-cm depth at the marsh type monotypically dominated by *Sagittaria lancifolia* (table 1). Sulfate concentrations increased steadily along the gradient of increasing exchange with adjacent surface waters except at the marsh dominated by *Sagittaria lancifolia* (table 1).

Median sulfide concentrations in pore water varied from about 0.07 mg/L at 5-cm depth in the nonfloating marsh dominated by *Panicum hemitomon* to 6.0 mg/L at 5-cm and 11.0 mg/L at 45-cm depth at the southernmost site dominated by *Spartina patens* and *Schoenoplectus americanus* (table 2). Concentrations generally increased with depth, except at the nonfloating *Panicum hemitomon* marsh. In the two marsh communities dominated by *Panicum hemitomon*, pH was around 5.7-5.9; pH did not vary much with depth and was highest, around 6.4, at the southernmost site. The redox potential of the soil decreased rapidly and consistently with depth; values at corresponding depths were similar at the three marsh communities sampled (table 2).

The segregation of plants in the Preserve into distinct communities is readily apparent, and formed the basis for the sampling design for this study. Sharply contrasting concentrations in pore water among the six major marsh communities indicate that differential tolerance to salinity and sulfide are important factors underlying this segregation (fig. 4). Chloride (and its complement sodium) and sulfate are introduced to the Preserve by water from the Gulf of Mexico; pore-water concentrations are influenced by the frequency and duration of saltwater intrusion events into the Preserve. Locations within the Preserve experience the salinity pulses with differing intensity, depending on their proximity to canals and the southern end of the Preserve. Interior areas of the Preserve are better protected from intrusion by higher salinity water than areas closer to waterways and the southern end of the Preserve.

Salinity, as represented by chloride, appeared to divide Preserve marshes into two zones that differed in whether *Panicum hemitomon* was dominant or was at best marginally present (table 1). At the four communities not dominated by *Panicum hemitomon*, sulfide appeared to play a bigger role in segregating the plants into readily identifiable communities because median chloride concentrations were similar (1,400-1,800 mg/L). Sulfide concentrations rapidly increased with increasing exchange and proximity to the southernmost part of the Preserve.

The consistent decrease in calcium to magnesium ratios in pore water was mirrored by a consistent increase in sulfide concentrations along the gradient of increasing exchange with adjacent surface water and proximity to the southern end of the Preserve (fig. 4). There was no direct relation between chloride and the ratio of calcium to magnesium (fig. 4). The sensitivity of this ratio to changes in sulfide concentrations suggests that it may be useful in distinguishing among the plant

Table 1. Concentrations of constituents in filtered pore water at 15- and 45-cm depths in marshes of six plant communities at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, Louisiana, January 2000 to June 2002.

[Medians within a depth were compared using a Kruskal-Wallis one-way analysis of variance on ranks; $p<0.001$ unless otherwise indicated; if significant differences were detected, Dunn's method was then used for pair-wise multiple comparisons ($p<0.05$); numbers in the same row with the same superscript are not statistically different. n, number of samples; mg/L, milligrams per liter; %, percentile]

Parameter	Depth, in centimeters	Statistic	n	*Panicum hemitomon* (nonfloating)	n	*Panicum hemitomon* (floating)	n	*Sagittaria lancifolia, Eleocharis* spp., *Leersia oryzoides*	n	*Eleocharis* spp./ *Sagittaria lancifolia*	n	*Sagittaria lancifolia*	n	*Spartina patens, Schoenoplectus americanus*
Ammonium, NH_3 (mg/L as N)	15	Median	34	0.022[a]	32	0.030[a]	34	0.034[a]	28	0.030[a]	30	0.54[b]	29	1.20[b]
		25%		.014		.020		.017		.015		.23		.074
		75%		.030		.041		.050		.040		1.70		1.92
	45	Median	29	.022[a]	30	.090[a]	30	.030[a]	24	.042[a]	26	1.20[b]	26	1.95[b]
		25%		.012		.020		.017		.025		.47		.50
		75%		.040		.250		.040		.145		2.52		3.60
Orthophosphate, PO_4 (mg/L as P)	15	Median	34	.003[a]	33	.005[a]	34	.005[a]	28	.006[a]	30	.061[b]	30	.11[b]
		25%		.002		.002		.004		.002		.040		.020
		75%		.005		.009		.009		.017		.19		.20
	45	Median	29	.002[a]	30	.008[a]	30	.004[a]	24	.010[a]	26	.083[b]	26	.16[b]
		25%		.002		.004		.002		.005		.030		.020
		75%		.004		.012		.008		.032		.17		.39
Calcium (mg/L as Ca)	15	Median	38	36[a]	37	22[a]	36	79[b]	30	72[b,c]	32	65[b,c]	32	55[c]
		25%		27		14		65		56		54		38
		75%		45		28		89		82		71		70
	45	Median	34	43[a]	34	27[a]	33	93[b]	27	91[b]	29	80[b]	29	72[b]
		25%		32		17		80		84		63		67
		75%		52		34		118		96		89		85
Magnesium (mg/L as Mg)	15	Median	38	32[a]	37	21[a]	36	108[b]	30	111[b]	32	96[b]	32	96[b]
		25%		22		12		88		72		78		74
		75%		37		32		120		119		115		124
	45	Median	30	36[a]	30	14[a]	30	111[b]	24	126[b]	24	112[b]	26	120[b]
		25%		24		15		94		115		92		110
		75%		41		35		140		142		130		168

Table 1. Concentrations of constituents in filtered pore water at 15- and 45-cm depths in marshes of six plant communities at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, Louisiana, January 2000 to June 2002.—Continued

[Medians within a depth were compared using a Kruskal-Wallis one-way analysis of variance on ranks; p<0.001 unless otherwise indicated; if significant differences were detected, Dunn's method was then used for pair-wise multiple comparisons (p<0.05); numbers in the same row with the same superscript are not statistically different. n, number of samples; mg/L, milligrams per liter; %, percentile]

Parameter	Depth, in centi-meters	Statistic	n	*Panicum hemitomon* (nonfloating)	n	*Panicum hemitomon* (floating)	n	*Sagittaria lancifolia, Eleocharis spp., Leersia oryzoides*	n	*Eleocharis spp./ Sagittaria lancifolia*	n	*Sagittaria lancifolia*	n	*Spartina patens, Schoenoplectus americanus*
Calcium to magnesium ratio	15	Average		1.18		1.00		0.75		0.69		0.66		0.54
	45	Average		1.23		.98		.84		.73		.71		.55
Potassium (mg/L as K)	15	Median		3.0[a]		5.7[a,b]		11[b]		14[b,c]		18[c,d]		23[d]
		25%	38	1.6	37	2.9	36	6.7	30	9.6	32	15	32	19
		75%		5.3		11		14		17		24		31
	45	Median		3.6[a]		7.2[a,b]		14[b]		18[b,c]		21[c,d]		25[d]
		25%	25	2.3	26	3.9	24	9.9	30	16	30	15	30	23
		75%		5.9		10		16		25		23		35
Chloride (mg/L as Cl)	15	Median		574[a]		377[a]		1,630[b]		1,665[b]		1,505[b]		1,380[b]
		25%	36	439	37	199	36	1,300	30	1,090	32	1,235	32	1,055
		75%		690		564		1,809		1,850		1,715		1,910
	45	Median		410[a]		667[a]		1,795[b]		1,835[b]		1,710[b]		1,850[b]
		25%	30	245	29	467	30	1,590	24	1,735	26	1,150	26	1,680
		75%		650		740		2,130		2,020		1,870		2,420
Sulfate (mg/L as SO_4)	15	Median		1.0[a]		1.4[a]		16[b]		52[c]		50[c]		87[c]
		25%	38	.5	37	1.0	36	6.7	30	20	32	28	32	57
		75%		2.2		2.5		44		139		98		125
	45	Median		.7[a]		1.7[a,b]		6.6[b]		36[c]		61[c]		110[c]
		25%	30	.5	30	1.0	30	3.3	24	17	26	27	26	50
		75%		1.2		7.3		25		65		83		151

Table 2. Sulfide concentrations and pH of pore water and redox conditions in the substrate at various depths in marshes of six plant communities at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, Louisiana, January 2000 to June 2002.

[Medians within a depth were compared using a Kruskal-Wallis one-way analysis of variance on ranks; $p < 0.001$ unless otherwise indicated; if significant differences were detected, Dunn's method was then used for pair-wise multiple comparison ($p < 0.05$); numbers in the same row with the same superscript are not statistically different. n, number of samples; mg/L, milligrams per liter; %, percentile; n.d. not determined]

Parameter	Depth, in centimeters	Statistic	n	*Panicum hemitomon* (nonfloating)	n	*Panicum hemitomon* (floating)	n	*Sagittaria lancifolia, Eleocharis spp., Leersia oryzoides*	n	*Eleocharis spp./ Sagittaria lancifolia*	n	*Sagittaria lancifolia*	n	*Spartina patens, Schoenoplectus americanus*
Sulfide (mg/L)	5	Median	33	0.07^{a}	33	0.23^{a}	28	0.16^{a}	23	0.85^{b}	26	2.14^{b,c}	25	6.00^{c}
		25%		.04		.15		.07		.30		1.49		2.91
		75%		.19		.30		.50		1.70		3.60		10.91
	15	Median	33	.13^{a}	33	.27^{a}	28	.45^{a,b}	23	1.40^{b}	26	4.10^{c}	25	8.29^{c}
		25%		.07		.20		.13		.29		3.50		5.88
		75%		.26		.45		.84		3.13		6.55		10.85
	45	Median	33	.12^{a}	33	.28^{a}	28	.52^{a,b}	23	2.93^{b,c}	26	6.59^{c}	25	11.00^{c}
		25%		.05		.15		.14		.75		5.17		8.33
		75%		.24		.35		1.06		5.75		9.46		14.62
pH	5	Median	25	5.7^{a,b}	24	5.7^{a}	24	6.0^{b,c}	13	6.2^{c,d}	16	6.1^{d}	16	6.5^{d}
		25%		5.6		5.4		5.8		6.1		6.0		6.2
		75%		6.1		6.0		6.2		6.3		6.3		6.5
	15	Median	25	5.8^{a,b}	24	5.8^{a}	24	6.0^{b}	13	6.1^{b}	16	6.1^{b}	16	6.4^{c}
		25%		5.6		5.7		5.9		6.0		6.0		6.2
		75%		5.9		6.0		6.1		6.3		6.3		6.6
	45	Median	25	5.8^{a,b}	24	6.0^{a}	24	6.0^{b}	13	6.2^{b}	16	6.2^{b}	16	6.4^{c}
		25%		5.6		5.8		6.0		6.1		6.0		6.3
		75%		6.0		6.1		6.2		6.3		6.3		6.6
Redox (millivolts)	5	Median	21	280^{a}	21	270^{a}	18	224^{a}		n.d.		n.d.		n.d.
		25%		233		251		189						
		75%		291		319		389						
	15	Median	21	202^{a}	21	209^{a}	18	202^{a}		n.d.		n.d.		n.d.
		25%		184		176		165						
		75%		224		19		290						
	45	Median	21	158^{a}	21	158^{a}	18	187^{a}		n.d.		n.d.		n.d.
		25%		122		120		141						
		75%		194		183		249						

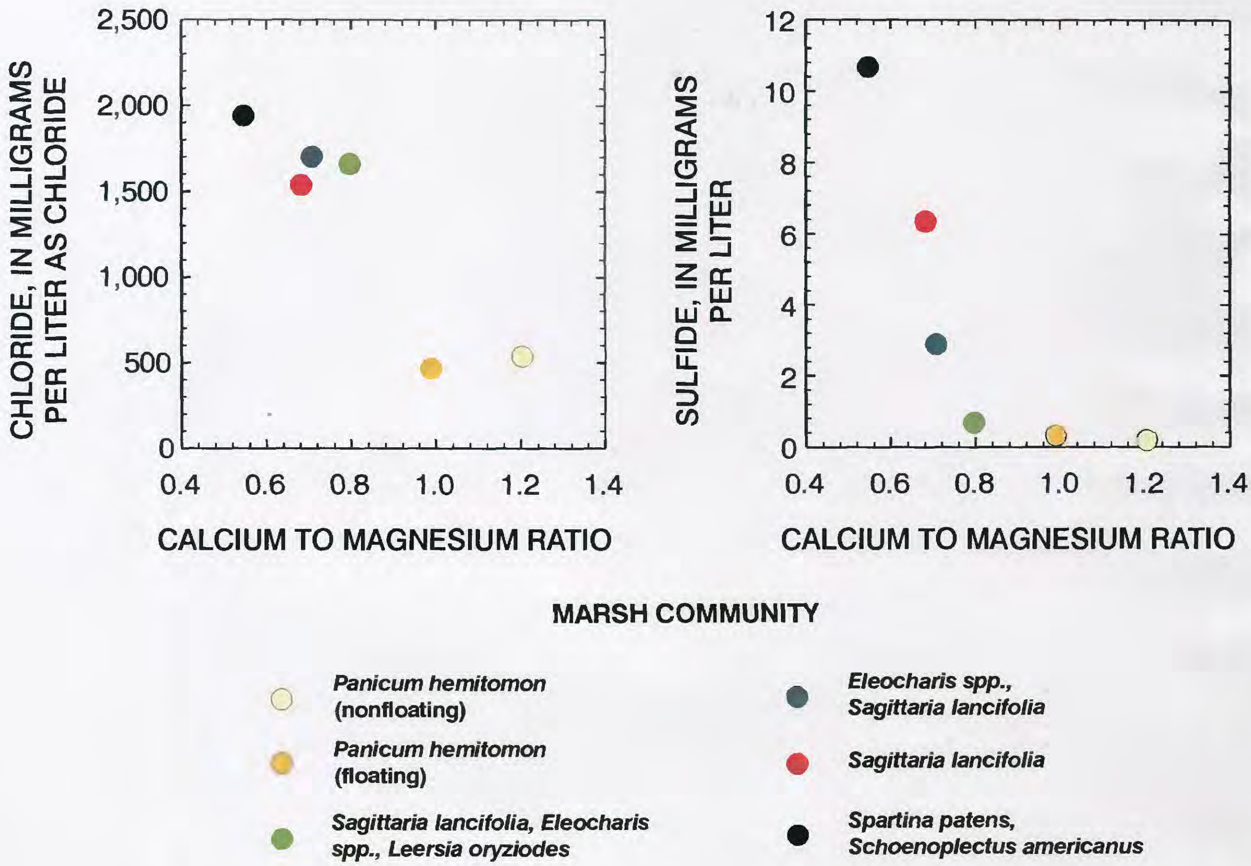

Figure 4. Relation between depth-averaged calcium to magnesium ratio and depth-averaged chloride and sulfide concentrations in pore water of the six major marsh communities at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, Louisiana.

communities at the Preserve, in addition to tracking the movement of introduced river water. Presumably the relation differentiates among plant communities in the Preserve because it measures the intensity of saltwater intrusion, and also integrates hydrological processes such as evapotranspiration and flooding at a given location.

Substrate Quality

Carbon content in the upper 25 cm of substrate at all six marsh types at the Preserve averaged between 37.7 and 45.6 percent (table 3). Carbon content of the two marsh habitats along Lake Salvador (see fig. 2) was slightly lower, likely reflecting mineral sediment input from overwash from the lake. Organic matter content of soils is about twice the carbon content (Mitsch and Gosselink, 2000). Soils can be classified as peat when they have an organic matter content of 70 percent or more (Mitsch and Gosselink, 2000). By this definition, soils at all six marsh communities at the Preserve are peats. Peat accumulates in the Preserve under the varied pore-water chemistry described in the preceding section, under a considerable range of sulfide and nutrient concentrations, and with different dominant plant species.

In general, the degree of decomposition of the peat substrate, as measured by percentage of fiber content, increased along the gradient of increasing exchange with adjacent surface water and proximity to the southern end of the Preserve. The peat was most decomposed at the southernmost marsh community dominated by *Spartina patens* and *Schoenoplectus americanus*. The average amount of soil material retained after the initial rinsing of the material through a sieve (unrubbed content) ranged from over 88 percent at the nonfloating *Panicum hemitomon* innermost habitat to 76.2 percent at the *Spartina patens* and *Schoenoplectus americanus* southern, most exposed habitat. The nonfloating *Panicum hemitomon* habitat also retained the most soil material after the mechanical fractionation. This habitat contained the least decomposed substrate. The marsh dominated by *Spartina patens* and *Schoenoplectus*

Table 3. Carbon content and fiber analysis of substrate (surface to 25-cm depth) in marshes of six plant communities at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, Louisiana.

[Averages within a category were compared using a one-way analysis of variance, $p < 0.001$ unless otherwise indicated; if significant differences were detected, Tukeys's method was then used for pair-wise multiple comparisons ($p<0.05$); numbers in the same row with the same superscript are not statistically different. n, number of samples; s.d., standard deviation of average]

Parameter	Statistic	*Panicum hemitomon* (nonfloating) (n=15)	*Panicum hemitomon* (floating) (n=15)	*Sagittaria lancifolia, Eleocharis* spp., *Leersia oryzoides* (n=10)	*Eleocharis* spp./ *Sagittaria lancifolia* (n=10)	*Sagittaria lancifolia* (n=10)	*Spartina patens, Schoenoplectus americanus* (n=10)
Percent carbon	Average ± 1 s.d.	44.8[a] 1.9	45.5[a] .9	45.6[a] .6	43.5[a] 2.5	39.1[b] 6.9	37.7[b] 2.7
Percent fiber content							
Unrubbed[1] (percent of original soil volume)	Average ± 1 s.d.	87.8[a] 2.3	88.5[a] 3.5	84.3[a] 2.6	83.5[a] 0.9	84.1[a] 1.9	76.2[b] 5.2
Rubbed[2] (percent of original soil volume)	Average ± 1 s.d.	70.8[a] 2.4	67.0[a,b] 4.5	62.7[a,b] 5.7	57.3[b] 2.3	61.7[b] 5.7	54.7[c] 8.9
Rubbed (percent of unrubbed soil volume)	Average ± 1 s.d.	80.6[a] 1.0	75.9[a,b] 6.0	74.2[a,b] 4.5	68.6[b] 2.2	73.2[a,b] 5.6	71.5[a,b] 7.7

[1]Unrubbed refers to volume of soil remaining after rinsing through a sieve with an opening of 0.12 millimeters.
[2]Rubbed refers to volume of soil remaining after fractionation of the soil and rinsing over the same sieve.

americanus retained the least (54.7 percent) amount of original soil material after the soil was mechanically fractionated (rubbed); this habitat contained the most decomposed substrate. Among soil samples from all six habitats, between 68.6 and 80.6 percent of the unrubbed soil volume remained in the sieve after mechanical fractionation. Although a fairly high proportion of the unrubbed soil material was retained after mechanical fractionation even in the marsh community dominated by *Spartina patens* and *Schoenoplectus americanus*, the low unrubbed fiber content at this marsh community indicates a peat substrate of low quality.

The increasing decomposition along the gradient likely resulted from changes in dominant plant communities and from differences in pore-water quality among the six marsh communities. *Panicum hemitomon*, with its prolific root-building capability, has been called the best plant to sustain peat marshes in coastal Louisiana (O'Neil, 1949). No other plant along the environmental gradient at the Preserve can build an equally fibric substrate. In terms of water quality, the supply of sulfate in pore water increases with increasing exposure to surface-water exchange. Sulfate reduction reactions increase; sulfide builds up in pore water; and organic matter is fractionated during sulfate reduction (Mistch and Gosselink, 2000). This can result in increased humification of the substrate. Sulfide in pore water also inhibits plant uptake of nutrients (Koch and others, 1990), leading to increased inorganic nutrient concentrations in pore water. These elevated nutrient levels may stimulate microbial activity and further enhance decomposition of the peat.

Water quality in the Preserve may represent the extremes under which peat marshes can sustain themselves in coastal Louisiana. Pore-water quality, with the exception of chloride, appears to be optimal to sustain *Panicum hemitomon*. Low nutrient concentrations and low potassium to nitrogen ratios tend to enhance belowground production, which is important for the long-term sustainability of peat marshes. Sulfide concentrations at the nonfloating *Panicum hemitomon* marsh community also are low. Only chloride concentrations appear high and may be near a threshold, beyond which *Panicum hemitomon* would be replaced by species that are better able to tolerate salinity. The increase in chloride, sulfide, and nutrient concentrations at the remaining marsh communities suggests a departure from optimal conditions for peat-based marshes, with corresponding shifts to other dominant plant communities with less prolific root-building capability. Photograph 2 shows examples of substrate samples from the Barataria Preserve. The environmental conditions and dominant plant communities at the southernmost sites appear marginal in sustaining peat marshes. Further increases in ambient saltwater at the southernmost end of the Preserve may shift vegetation communities to those that require an increased supply of mineral sediment to ensure their long-term sustainability (see Nyman and others, 1990).

A

B

Photograph 2. Peat soil of selected marsh communities at the Barataria Perserve, Louisiana: (A) left, nonfloating *Panicum hemitomon*, right, *Spartina patens* and *Schoenoplectus americanus*, and (B) floating *Panicum hemitomon*.

Comparison of Preserve and Penchant Basin Marshes

Pore-water and substrate quality of marshes at the Barataria Preserve and at Penchant Basin were compared. Pore-water quality was compared only for marshes dominated by *Panicum hemitomon*. The substrate quality of marshes dominated by *Panicum hemitomon* and of marshes dominated by *Sagittaria falcata* in both areas was compared. Data concurrently collected from surface-water stations in both areas through USGS programs independent of the present study are presented to provide context for the comparison.

Quality of Source and Receiving Water

Surface-water quality in the Preserve and the Penchant Basin was differentiated into source and receiving water, depending on location within the respective hydrological systems. The Mississippi River will become the source water for the Preserve when the Davis Pond freshwater diversion is fully operational. Until then, the large waterways in the Preserve function as both source and receiving water for the marshes. Water flows into the marshes and then back, depending on rainfall and tide levels. Over the course of a year, there is no directional flow. In contrast, in the Penchant Basin, the hydrology is clearly separated into upstream and downstream during the 3-7 months every year when the Lower Atchafalaya River is in flood (Swarzenski, 2003b). During this time, there is steady directional flow in

Penchant Basin from northwest to southeast; water quality of receiving water represents a transformation of source water through uptake by plant communities and biogeochemical processing during overland flow.

Data for the Mississippi River at St. Francisville, collected routinely by the USGS as part of the NASQAN program (U.S. Geological Survey, 2004), represent the quality of future source water for the Preserve. For source water in the Penchant Basin, data from the Lower Atchafalaya River at Morgan City and Bayou Boeuf at Railroad Bridge at Amelia (fig. 5) were used. The former station also is part of the NASQAN program. Data from the latter station were collected through the NAQWA program (Demcheck and others, 2004). Receiving water stations in the Penchant Basin stations (fig. 5), and the Barataria Preserve (see fig. 2) were sampled through a special study of the NAQWA study unit (Demcheck and others, 2004; Swarzenski, 2003a).

Filtered nitrite-plus-nitrate concentrations in water from the Lower Atchafalaya River were slightly lower than in water from the Mississippi River, but not surprisingly, patterns were similar (table 4). Most of the water in the Lower Atchafalaya River comes from the Mississippi River and has similar water-quality characteristics (Wells and Demas, 1977). Receiving water in the Penchant Basin had much lower concentrations of nitrite-plus-nitrate than did the inflowing source water, but concentrations were still about 2 to 10 times greater than in comparable waterways in the Preserve. Filtered orthophosphate concentrations were similar in source water of both areas. Receiving water concentrations were lower than source water concentrations in the Penchant Basin. Water in Preserve waterways had higher concentrations of filtered orthophosphate than did receiving water in the Penchant Basin (table 4). The freshwater inflow from the Lower Atchafalaya River reduced chloride and sulfate in Penchant Basin receiving water to concentrations much lower than those detected in Preserve waterways (table 4). The proportion of nitrogen relative to potassium also was much higher in Penchant Basin receiving water than in Preserve waterways.

Source water containing atrazine enters the Penchant Basin from both the mid-continental flush of agricultural chemicals through the Lower Atchafalaya River, and from local sources through Bayou Boeuf at Railroad Bridge at Amelia (Demcheck and Swarzenski, 2003). Concentrations of atrazine in source water and receiving water were greater in the Penchant Basin than in waterways in the Preserve (table 4). There was a reduction of about 75 percent in median atrazine concentrations from source to receiving water in Penchant Basin waterways, suggesting a substantial loss during the overland flow and possible uptake by the peat marshes. Even then, median atrazine concentrations in receiving water in the Penchant Basin were more than four times greater than concentrations in Barataria Preserve waterways.

Quality of Interior Waterways and Pore Water

Water quality also was determined in small (less than 2-m wide) waterways in marsh interiors where *Panicum hemitomon* was the dominant plant community and in pore water of these marshes. Small waterways wind through interior marshes and eventually connect with the larger canals and bayous.

Median filtered nitrite-plus-nitrate concentrations in small interior waterways were significantly lower at the Preserve than in the Penchant Basin (table 5). Concentrations in these waterways generally were proportional to, but an order of magnitude lower than, concentrations in the larger canals and waterways (receiving waters) in each area (tables 4 and 5), but median filtered orthophosphate concentrations were lower in the interior waterways at the Preserve than in similar waterways in the Penchant Basin. Nutrient values in the Preserve were fairly close to the minimum reporting level of 0.002 mg/L. Ammonium and orthophosphate concentrations were higher in pore water of Penchant Basin marshes than in marshes of the Preserve by a factor of about two at 15-cm depth and more than one order of magnitude at 45-cm depth (table 5). Median pore-water ammonium concentrations averaged about 0.26 mg/L from the two sampling depths in the Penchant Basin. At 45-cm depth, they were about 0.455 mg/L as nitrogen in Penchant Basin pore water, but only 0.036 mg/L as nitrogen in Preserve pore water.

Calcium to magnesium ratios in samples collected in pore water and interior waterways in the Penchant Basin were greater than 2.5 and characteristic of river water. The substrate in Penchant Basin marshes was saturated with river water to at least 45-cm depth. In the Preserve, surface-water and pore-water quality showed no river-water influence. Filtered potassium concentrations were significantly higher in the small waterways and pore water of the marshes in the Preserve than in those in the Penchant Basin. There was about five times as much nitrite-plus-nitrate relative to potassium in the Penchant Basin system in interior waterways. Chloride concentrations were much higher in the marshes and small waterways of the Preserve compared with those in the Penchant Basin. Median concentrations in the Penchant Basin were about 51 mg/L. In small interior waterways, filtered sulfate concentrations were similar in the two areas, but in pore water, concentrations were lower in the Preserve (table 5).

Pore-water sulfide concentrations averaged about 0.32 mg/L in the Penchant Basin (table 6). Sulfide concentrations in pore water at 5-cm depth were similar in both areas, but at 15-and 45-cm depth, they were significantly higher in Penchant Basin marshes (table 6). At 45-cm depth, median sulfide concentrations in the Penchant Basin were more than twice the concentrations in the marshes at the Preserve. At the Preserve, pH was about 0.5 units lower at all depths compared with Penchant Basin marshes. The redox potential of the substrate was similar at 2-cm depth in both areas, but was significantly lower

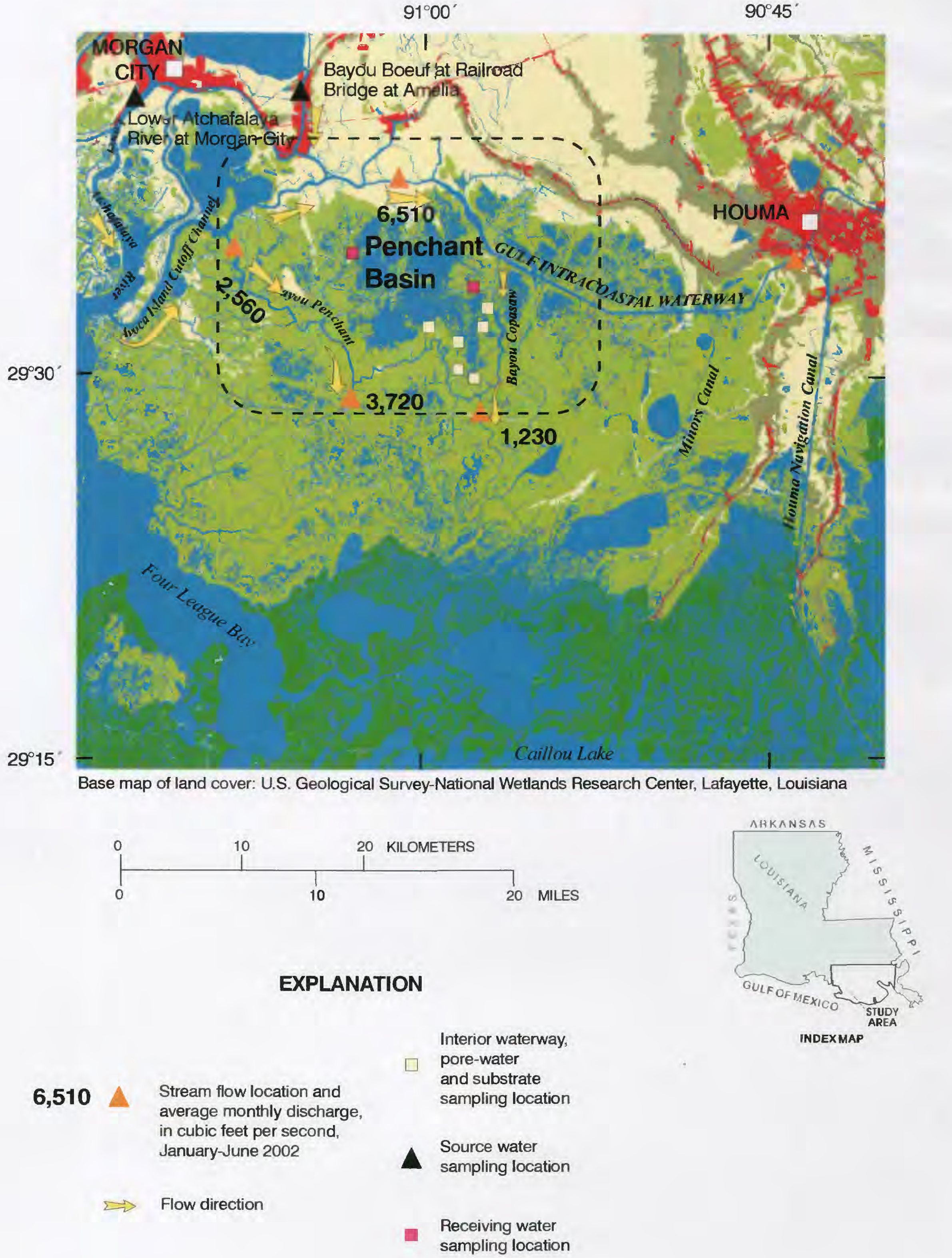

Figure 5. Water and substrate sampling sites and average monthly discharge of freshwater to the Penchant Basin, south Louisiana, January-June 2001.

Table 4. Concentrations of selected filtered constituents in source waters and in receiving waters at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, and the Penchant Basin, Louisiana.

[Statistical comparisons made only for receiving waters using a Mann-Whitney Rank Sum test: $p<0.001$ unless otherwise indicated; numbers in the same row with the same superscript are not statistically different. n, number of samples; mg/L, milligrams per liter; µg/L, micrograms per liter; %, percentile]

Parameter	Statistic	Source waters[1]						Receiving waters[2]			
		Barataria Preserve		Penchant Basin							
		n	Mississippi River at St. Francisville[3]	n	Lower Atchafalaya River at Morgan City	n	Bayou Boeuf at Railroad Bridge at Amelia	n	Barataria Preserve	n	Penchant Basin
Nitrite + Nitrate,	Median		1.46		1.45		0.11		0.005^{a}		0.056^{b}
NO_2+NO_3	25%	57	1.05	12	.81	56	.05	46	.004	49	.010
(mg/L as N)	75%		2.04		1.80		.34		.018		.230
Orthophosphate,	Median		.07		.06		.04	$p=0.009$	$.030^{a}$		$.017^{b}$
PO_4	25%	55	.05	11	.04	56	.02	46	.013	49	.010
(mg/L as P)	75%		.09		.08		.05		.053		.026
Calcium	Median		39		38		32		29^{a}		34^{a}
(mg/L as Ca)	25%	55	36	12	33	51	29	36	22	39	30
	75%		43		40		38		56		37
Magnesium	Median		12		12		10		28^{a}		12^{b}
(mg/L as Mg)	25%	55	11	12	10	52	9	36	19	39	10
	75%		15		13		13		79		13
Calcium to magnesium ratio	Average		3.09		3.19		2.89		.72		2.85
Potassium	Median		3.3		2.9		3.6		7.6^{a}		2.7^{b}
(mg/L as K)	25%	57	3.0	12	2.6	52	3.4	46	3.5	49	1.8
	75%		3.6		3.6		3.9		17.0		3.6
Chloride	Median		22		24		26		560^{a}		39^{b}
(mg/L as Cl)	25%	57	19	12	21	46	21	28	296	26	23
	75%		26		31		35		1,570		51
Sulfate	Median		46		44		33	$p=0.022$	53^{a}		30^{b}
(mg/L as SO_4)	25%	57	41	11	41	50	23	33	21	335	25
	75%		55		49		48		153		39
Atrazine	Median		.308		.494		.479		$.029^{a}$		$.128^{b}$
(µg/L)	25%	58	.122	11	.214	31	.287	12	.015	13	.054
	75%		.836		.784		.787		.093		.253

[1]Samples were collected from source waters from October 1997 to September 2001.

[2]Samples were collected from the receiving waters at two sites in each area from October 1998 to September 2000. Data were combined from the two sites for statisticl analyses.

[3]Water from the Mississippi River was not flowing into the Barataria Preserve during the sampling.

Table 5. Concentrations of selected filtered constituents in interior waterways and in marsh pore water at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, and the Penchant Basin, Louisiana, January 2000 to June 2002.

[Medians within a water type or depth (pore-water) were compared using a Mann-Whitney Ranks Sum test; $p < 0.001$ unless otherwise indicated; numbers in the same row with the same superscript are not statistically different. n, number of samples; mg/L, milligrams per liter; %, percentile; n.s., not sampled]

Parameter	Statistic	Waters in marsh interior				Pore water							
						15-cm depth				45-cm depth			
		n	Barataria Preserve	n	Penchant Basin	n	Barataria Preserve	n	Penchant Basin	n	Barataria Preserve	n	Penchant Basin
Nitrite+Nitrate,	Median		0.003[a]		0.007[b]								
NO_2+NO_3	25%	26	.002	53	.003	0	n.s.	0	n.s.	0	n.s.	0	n.s.
(mg/L as N)	75%		.005		.022								
Ammonium,	Median		.120[a]		.110[a]	p=0.005	0 .030[a]	49	0.060[b]		0 .036[a]		0.455[b]
NH_3	25%	30	.030	58	.069	65	.020		.020	58	.014	40	.086
(mg/L as N)	75%		.237		.212		.039		.146		.110		1.010
Orthophosphate,	Median		.005[a]		.009[a]		.004[a]		.014[b]		.004[a]		.034[b]
PO_4	25%	30	.002	57	.003	66	.002	40	.006	58	.002	40	.020
(mg/L as P)	75%		.015		.018		.006		.034		.008		.065
Calcium	Median		28[a]		28[a]		28[a]		27[a]		33[a]		24[b]
(mg/L as Ca)	25%	35	24	69	24	74	21	61	21	59	24	41	16
	75%		34		35		41		31		49		28
Magnesium	Median	35	33[a]		10[b]		27[a]		9.8		29[a]		9.8[b]
(mg/L as Mg)	25%		25	69	9	74	19	61	7.9	59	22	41	7.2
	75		45		13		35		11		40		11
Calcium to magnesium ratio	Average	35	.82		2.72		1.10		2.78		1.12		2.56
Potassium	Median		7.4[a]		3.2[b]		3.6[a]		1.6[a]		5.1[a]		2.2[b]
(mg/L as K)	25%	35	4.4	65	2.1	57	2.7	52	.8	59	3.2	41	1.8
	75%		11.0		4.8		7.4		2.7		8.3		2.7
Chloride	Median		548[a]		42[b]		477[a]		47[b]		512[a]		51[b]
(mg/L as Cl)	25%	35	420	65	31	72	332	57	38	58	360	41	38
	75%		770		54		655		54		728		66
Sulfate	Median		13[a]		16[a]		1.2[a]		2.6[a]		1.0[a]		2.5[b]
(mg/L as SO_4)	25%	35	4	65	12	74	.7	57	1.5	59	.7	41	1.5
	75%		36		26		2.3		6.7		2.4		5.4

Table 6. Sulfide concentrations and pH of pore-water and redox conditions in the substrate at various depths in marshes dominated by *Panicum hemitomon* at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, and Penchant Basin marshes, Louisiana, January 2000 to June 2002.

[Medians within a depth were compared using a Mann-Whitney Ranks Sum test. $p < 0.001$ unless otherwise indicated; numbers in the same row with the same superscript are not statistically different. n, number of samples; mg/L, milligrams per liter; %, percentile]

Depth, in centimeters	Statistic	Sulfide, in mg/L				pH				Depth, in centimeters	Statistic	Redox, in millivolts			
		n	Barataria Preserve	n	Penchant Basin	n	Barataria Preserve	n	Penchant Basin			n	Barataria Preserve	n	Penchant Basin
	Median		0.16[a]		0.16[a]		5.7[a]		6.3[b]		Median		276[a]		246[a]
5	25%	42	.06	42	.08	40	5.5	27	6.0	2	25%	42	245	32	199
	75%		.26		.27		6.0		6.5		75%		310		314
	Median		.20[a]		.34[b]		5.8[a]		6.3[b]		Median		204[a]		170[b]
15	25%	42	.09	42	.23	48	5.6	35	6.0	9	25%	42	179	31	138
	75%		.31		.58		6.0		6.4		75%		219		186
	Median		.18[a]		.45[b]		5.8[a]		6.3[b]		Median		158[a]		93[b]
45	25%	42	.09	42	.25	43	5.7	32	6.1	18	25%	42	122	32	62
	75%		.33		.69		6.0		6.4		75%		187		121

at the 9- and 18-cm depths in the Penchant Basin marshes (table 6). Soil conditions in Penchant Basin marshes were more reduced at these depths than those in the Preserve.

Substrate Quality

There was significantly less organic matter in the upper 25 cm of substrate in Penchant Basin marshes than in Preserve marshes (table 7). This held for both marsh habitats sampled. The higher mineral content in Penchant Basin marshes demonstrated that suspended mineral sediment from river water reaches marsh interiors.

Penchant Basin marshes were more decomposed than those in the Preserve by all three measures of fiber content used (table 7). The rubbed fiber content of Penchant Basin marshes was less than 50 percent of the original, unsieved soil volume. About 75 percent of the unrubbed soil volume of samples from Preserve marshes remained in the sieve after mechanical fractionation in both marsh community types. In the Penchant Basin area, the corresponding value was more than 20 percent lower.

Lower fiber content indicates a more decomposed substrate (Lynn and others, 1974). Substrate with high fiber content can be considered of higher quality, and less likely to break apart.

Relevance to the Barataria Preserve

The marshes of the Preserve provide a good contrast for an ecologically similar area that through June 2002 had received very little, if any, inflow of river water. A comparison of conditions in the two study areas can provide some insight into how the marshes of the Preserve may respond to the future regular influx of water from the Mississippi River through the Davis Pond Freshwater Diversion.

Surface-Water Quality

One purpose of diverting freshwater into estuaries is to keep salinity of surface waters low. Chloride and sulfate concentrations in surface water were significantly lower in the Penchant Basin than in the Preserve. Regular inflow of river water

Table 7. Carbon content and fiber analysis of substrate (surface to 25-cm depth) of marshes at the Barataria Preserve, Jean Lafitte National Historical Park and Preserve, and the Penchant Basin, Louisiana.

[Averages within a plant community were compared using a paired student's t-test, $p < 0.001$; numbers in the same row with the same letter superscript are not statistically different. n, number of samples; s.d., standard deviation]

Parameter	Statistic	*Panicum hemitomon* (n = 4)		*Sagittaria lancifolia* (n = 2)	
		Barataria Preserve n=30	Penchant Basin n=20	Barataria Preserve n=10	Penchant Basin n=10
Percent carbon	Average ±1 s.d.	45.1[a] 1.5	37.9[b] 5.5	39.1[a] 6.9	31.9[b] 1.3
Percent fiber content					
Unrubbed[1] (percent of original soil volume)	Average ±1 s.d.	88.2[a] 2.8	76.2[b] 2.5	84.1[a] 1.9	76.0[b] 6.7
Rubbed[2] (percent of original soil volume)	Average ±1 s.d.	68.9[a] 4.0	44.0[b] 3.9	61.7[a] 5.7	41.5[b] 10.4
Rubbed (percent of unrubbed soil volume)	Average ±1 s.d.	78.3[a] 4.8	57.8[b] 4.8	73.2[a] 5.6	54.2[b] 9.4

[1] Unrubbed refers to volume of soil remaining after rinsing through a sieve with an opening of 0.125 mm.

[2] Rubbed refers to volume of soil remaining after consistent fractionation of the soil and rinsing over the same sieve.

into the Penchant Basin has resulted in reduced salinity (Swarzenski, 2003b) and an expanding zone of low-salinity marshes in a southeasterly direction (Visser and others, 1999) over the past 30 years. Keeping salinity low reduces the amount of mineral sediment that marshes need to keep pace with sea-level rise (Nyman and others, 1990), allowing plant species that can build their own substrate, such as *Panicum hemitomon*, to flourish. Many marshes in the Preserve, especially the southern marsh habitat, which is most frequently exposed to exchange with surface water and marine influence, could benefit from the reduction in pore-water chloride concentrations that a nearby freshwater diversion could provide.

As a result of uptake and transformation by the marshes, the quality of the river water changed as it flowed overland across the marshes in the Penchant Basin (fig. 6). Nitrite-plus-nitrate concentrations in receiving waters in the Penchant Basin were reduced by about 80-90 percent compared with the inflowing river water (table 4). Filtered orthophosphate concentrations were reduced by about 65-75 percent (table 4). Filtered sulfate concentrations were about 30 percent lower in receiving waters than in the inflowing river water. Median atrazine concentrations were about 66-75 percent lower in receiving water.

The peat marshes reduced high nutrient concentrations of inflowing river water, but even with plant uptake, nitrite-plus-nitrate concentrations were between 2 and 10 times higher in surface waters in the Penchant Basin than in the Preserve (tables 4 and 5). The higher nutrient concentrations in the Penchant Basin occurred in the larger receiving waters as well as in small waterways in marsh interiors. Based on the response of surface water in the Penchant Basin to inflowing river water, surface-water nutrient concentrations in the Preserve may increase over time.

River water from the Davis Pond Freshwater Diversion probably will reduce chloride and sulfate concentrations in Preserve waterways. The reductions would be a positive effect because they would increase the area that could support the growth of *Panicum hemitomon*. On the negative side, nitrite-plus-nitrate concentrations could increase, resulting in a change of the nitrite-plus-nitrate to potassium ratios, and possibly reducing belowground relative to aboveground biomass production. Marsh plants growing in areas affected by freshwater diversions likely will be exposed to greater concentrations of atrazine. Atrazine concentrations of 8 µg/L caused mortality in half of exposed *Panicum hemitomon* plants in a controlled-dose greenhouse study (P.V. Zimba, U.S. Department of Agriculture, written commun., 1999). Subacute effects, such as decreased root productivity, may occur at lower concentrations.

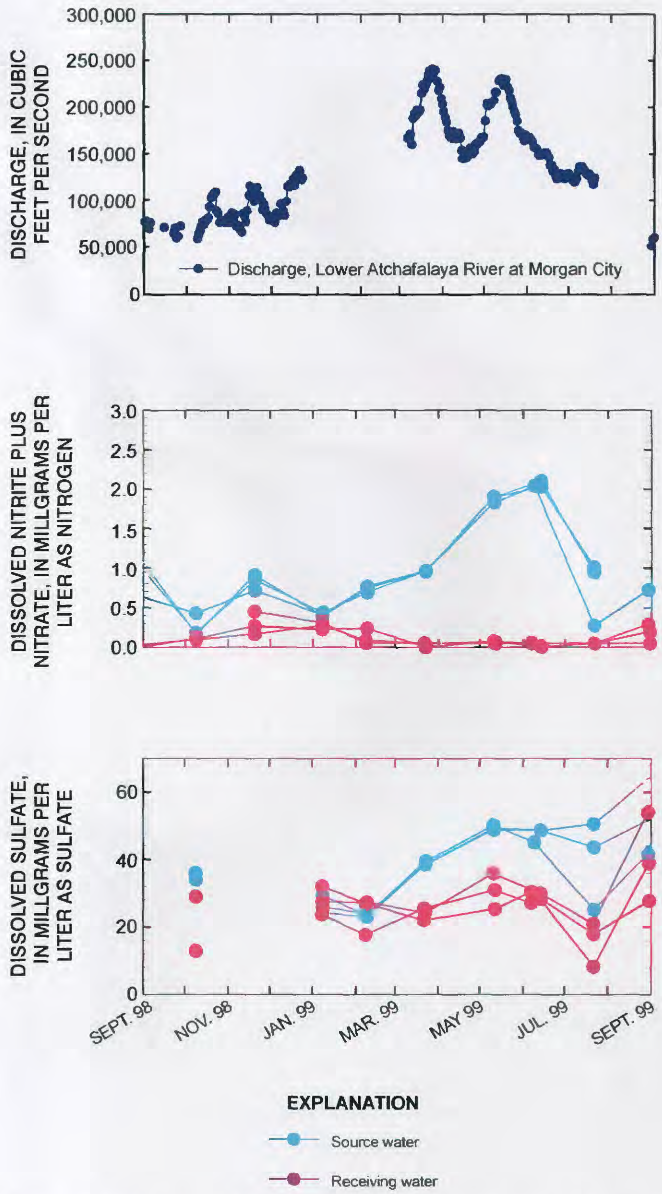

Figure 6. Discharge of the Lower Atchafalaya River at Morgan City and concentrations of filtered nitrite-plus-nitrate and sulfate in selected source and receiving waters in the Penchant Basin, south Louisiana, September 1998-September 1999.

Pore-Water and Substrate Quality

When compared with Preserve marshes, the large inflow of river water into Penchant Basin marshes every year has resulted in major differences in pore-water quality. These differences could contribute to degradation of the peat substrate, destabilize the peat marshes, and perhaps even lead to wetland loss. Among the constituents in river water that could adversely affect peat marshes, inorganic nutrients (especially nitrate), sulfate, and the herbicide atrazine may play a prominent role.

The uptake of nutrients and sulfate by the peat marshes affects the biogeochemistry of the peat substrate and pore water in ways that could cause the quality of the organic matter to decline. Both nitrite-plus-nitrate and sulfate are terminal electron acceptors. Under flooded, anoxic soil conditions, denitrification reduces the inflowing nitrite-plus-nitrate to the greenhouse gas nitrous oxide or to gaseous nitrogen. Under the same conditions, sulfate is reduced to sulfide. Organic matter, an electron donor, is oxidized during both reactions (Mitsch and Gosselink, 2000, p. 167). The peat substrate becomes more decomposed during the process. In peat-based freshwater marshes, sulfate and nitrate concentrations are typically low, and the supply of these ions is limited (Mitsch and Gosselink, 2000). Decomposition and degradation of organic matter is slow, and peat accumulates. When the supply of nitrate and sulfate to freshwater marshes increases, as occurs in freshwater diversions, the organic matter may degrade faster (Lamers and others, 1998; Beltman and others, 2000). Diversion of river water from the Rhine River into highly organic marshes in the Netherlands to replace water lost to evaporation and agricultural use increased the supply of nitrate and sulfate to the fens, and led to peat degradation (Roelofs, 1991). The microbial reduction of a steady input of sulfate carried into the *Panicum hemitomon* marshes by the inflowing river water resulted in pore-water sulfide concentrations in Penchant Basin marshes in excess of concentrations found in *Panicum hemitomon* marshes in the Preserve (table 6). This occurred even though the median sulfate concentration in surface water of the Penchant Basin was less than that in surface water of the Preserve (table 4). The elevated sulfide concentrations potentially represent a substantial degradation of the *Panicum hemitomon* soil environment. Even at low levels, sulfide can be highly toxic to freshwater plants (Koch and others, 1990; Lamers and others, 1998). Sulfide inhibits the uptake of inorganic nutrients such as ammonium and orthophosphate (Koch and others, 1990) and may decrease root production. Sulfate reduction may also interact with iron-phosphate binding in the substrate and lead to a release of phosphate. The release has been termed internal eutrophication (Beltman and others, 2000). The accumulation of sulfide in pore water decreased species diversity in floating fens in the Netherlands, and increased pools of ammonium and phosphate in pore water (Lamers and others, 1998).

Inorganic nutrient concentrations were greater in pore water of marshes dominated by *Panicum hemitomon* in the Penchant Basin than in the Preserve. The elevated concentrations in the Penchant Basin probably resulted from a combination of increased external supply, decreased uptake caused by higher sulfide concentrations, and more rapid mineralization rates of the peat. Enhanced nutrient pools in peat substrate can stimulate microbial activity and lead to further and more rapid degradation of organic matter. Mendelssohn and others (1999) reported that in some reed swamps aligned along a salinity gradient, high concentrations of inorganic nitrogen and phosphorus in pore water contributed the most to cellulose decomposition. Further, by-products of the decomposition process such as fatty acids may accumulate in pore water (Cizkova and others, 1999), and can act as phytotoxins, decreasing plant productivity and causing structural damage to the root systems (Armstrong and others, 1996). Soils that are almost entirely organic, such as peat marshes, may be particularly susceptible.

Regular inflow of river water into peat marshes may contribute to accelerated decomposition of the organic substrate through processes outlined in the preceding paragraphs. Such a response is supported by the substrate fiber analyses, which indicated that the peat soils in Penchant Basin marshes were more decomposed than in corresponding marsh habitats in the Preserve (table 7). Photograph 3 shows examples of substrate samples from Barataria Preserve and Penchant Basin. The proportion of substrate retained after mechanical fractionation relative to the unrubbed soil material in both marsh communities in the Penchant Basin was significantly less than that of not only their counterparts in the Preserve but also of all plant communities in the Preserve (see table 3). Even habitats in the Preserve that on average had higher pore-water nutrient and sulfide concentrations (see tables 1 and 2) were less decomposed than either of the two marsh habitats analyzed in the Penchant Basin. This would suggest that the regular external influx to, and reduction of nitrite-plus-nitrate in, Penchant Basin marshes during the annual flood of river water contributed substantially to the enhanced decomposition of the peat in marshes there.

The regular addition of large amounts of nitrate to a peat-based system also could affect the balance between aboveground and belowground production. As nutrient levels shift from scarcity to excess in the substrate, plants may shift more production into the aboveground component and thereby destabilize the balanced accretion of the peat substrate. In the Norfolk Broads in England, floating reed swamps converted to open water in areas where nutrient concentrations had increased over time in surface waters (Boar and others, 1989). Further, these authors demonstrated in greenhouse experiments that increasing the proportion of nitrate relative to potassium (adding nitrates) decreased rhizome-to-shoot ratios and the amount of sclerenchtymatous tissue formation. Boar and others (1989) concluded that increased nutrient levels in surface water had caused the decline in the floating reed marshes by weakening the floating mat. Ulrich and Burton (1985) also showed that aboveground production in reed swamps increased relative to belowground production as nitrate levels increased relative to potassium. Substrate integrity would be compromised if similar changes occurred in response to river-water introductions in the peat marshes of the Preserve.

High nutrient concentrations may increase biological production in the marsh plants, potentially offsetting some of the adverse effects of freshwater diversions on the peat substrate. Evaluating this aspect was beyond the scope of the study described in this report. Nevertheless, the soil fiber analyses integrated the net effect of regular exposure to river water on the organic soils. Even if belowground production had increased the amount of organic matter of the peat in Penchant

A

B

Photograph 3. Peat soil of selected marsh communities at the Barataria Perserve and Penchant Basin, Louisiana: (A) floating *Panicum hemitomon* community in the Preserve (top) and in Penchant Basin (bottom), and (B) *Panicum hemitomon* community in Penchant Basin.

Basin marshes, the peat there was more decomposed than that in the Preserve.

Atrazine could also destabilize accretion of the peat substrate by inhibiting root production. However, few studies to date have investigated responses of peat marshes to exposure to atrazine, as might occur with diversions of river water.

Panicum hemitomon marshes have declined by over 50 percent in some areas of the Penchant Basin during the past 30 and 40 years (Leibowitz, 1989; Visser and Sasser, 1996), converting to open water or degraded thin mats mono-typically dominated by *Eleocharis parvula* (dwarf spike-rush). The massive loss of wetlands has been occurring even as the Penchant Basin has received more river water than any other area in coastal Louisiana with the exception of the active deltas of the Mississippi and Lower Atchafalaya Rivers (Swarzenski, 2003b). At a minimum, influx of river water into Penchant Basin marshes did not contribute to the long-term sustainability of peat marshes there. In a worst case for coastal restoration efforts, conversion of peat marshes to open water in the Penchant Basin may be linked to the massive influx of river water. Freshwater diversions into peat marshes may result in wetland loss rather than gain, possibly because the quality of river water has changed markedly since the last time it flowed into the marshes, unencumbered by flood-control levees.

The key to understanding how freshwater diversions may affect peat marshes lies not solely in the water quality of the inflowing river water. The frequency and extent of river water influx also needs to be considered. In the Penchant Basin, there has been and continues to be an annual infusion of river water into the peat marshes that is much larger than any freshwater diversion that has been constructed to date. The annual influx of river water, fully saturating the soils in the Penchant Basin to a depth of a least 45 cm, dominates pore-water chemistry. At the current (2003) scale of Davis Pond Freshwater Diversion operations, a similar saturation of soils in Preserve marshes is unlikely to occur any time soon.

Summary and Conclusions

Pore-water and substrate quality of the peat marshes at the Barataria Preserve of Jean Lafitte National Historical Park and Preserve were measured from January 2000 to June 2002. The six major plant communities, including those dominated by *Panicum hemitomon* were studied. The data were compared with pore-water and substrate quality of peat marshes dominated by *Panicum hemitomon* in the Penchant Basin, an area of coastal Louisiana that has functioned as the hydrological and ecological equivalent of a freshwater diversion for over 30 years. Surface-water quality between the two areas also was compared. The comparison was made to evaluate possible long-term responses of the peat marshes in the Barataria Preserve to the Davis Pond Freshwater

Diversion, which began operations in 2003, and is introducing Mississippi River water to Barataria Preserve waterways and marshes.

The six major marsh communities sampled in the Barataria Preserve are aligned along a gradient of increasing exchange with adjacent surface water and proximity to the southern end, where pulses of higher salinity water from the Gulf of Mexico first enter Barataria Preserve waterways. Concentrations of the inorganic nutrients ammonium and orthophosphate, the ions potassium and sulfate, and sulfide generally increased in a consistent manner from the innermost *Panicum hemitomon* dominated marsh communities to the southernmost marsh communities dominated by *Spartina patens* and *Schoenoplectus americanus*. Median filtered ammonium concentrations ranged from a low of about 0.022 mg/L (milligrams per liter) as nitrogen in the innermost communities, to a high of over 1.95 mg/L as nitrogen in the southernmost marshes. Median sulfide concentrations ranged from 0.07 to 11.0 mg/L. Pore-water calcium and magnesium concentrations also were considerably lower at the two innermost marsh communities than at the four remaining communities, but the ratio of calcium to magnesium decreased consistently along the gradient. The two innermost habitats, floating and nonfloating marshes dominated by *Panicum hemitomon*, had lower median pore-water chloride concentrations (380-670 mg/L) than the four other habitats (1,300-1,800 mg/L).

Pore-water chloride and sulfide concentrations, influenced by the frequency and duration of pulsing of saltwater into the Barataria Preserve, play an important role in segregating the plants at the Barataria Preserve into distinct communities. Average chloride concentrations at *Panicum hemitomon* dominated marshes were low; occurrence of this community appears to be restricted to interior areas in the Barataria Preserve which are protected from frequent exchange with adjacent surface water and better buffered from intrusion by higher salinity water than the other four sites. Sulfide appeared to separate the plants into distinct communities at the four remaining sites because chloride concentrations were similar (about 1,300 to 1,800 mg/L), but sulfide concentrations rapidly increased with increasing exchange and proximity to the southernmost portion of the Barataria Preserve.

The upper 25 centimeters of soil at the six major marsh communities in the Barataria Preserve was highly organic and fell within the range for which peat would be the appropriate terminology. Pore-water quality at all habitats was sufficient to allow the accumulation of a peat substrate. The substrate of the two *Panicum hemitomon* communities was more fibric and less decomposed than that at the remaining four sites. The soil at the southernmost community, dominated by *Spartina patens* and *Schoenoplectus americanus*, was the most highly decomposed.

The peat marshes at the Barataria Preserve comprise diverse plant communities and grow under a broad range of soil conditions. Water quality in the Barataria Preserve may represent the extremes under which peat marshes can sustain themselves in coastal Louisiana. Conditions for peat accumulation appeared optimal at the innermost marsh communities with respect to dominant plant (*Panicum hemitomon*) and pore-water quality (low nutrient and sulfide concentrations), with the probable exception of high chloride concentrations. Conversely, the marshes at the southernmost position along the established gradient were dominated by plants with poor root-building qualities, had high sulfide and inorganic nutrient levels in pore water, and had a peat substrate that was fairly well decomposed. The environmental conditions and dominant plant species would appear marginal in sustaining peat marshes.

Concentrations of nitrite-plus-nitrate and orthophosphate in receiving water in the Penchant Basin were lower than the inflowing source water. Nitrite-plus-nitrate concentrations in receiving water in the Penchant Basin were 2 to 10 times higher, and orthophosphate concentrations were slightly lower, than in comparable waterways in the Preserve. The freshwater inflow reduced chloride and sulfate in Penchant Basin waterways to concentrations much lower than those in Preserve waterways. Median concentrations of nitrite-plus-nitrate and orthophosphate were lower in small interior waterways of the Preserve compared to similar interior waterways in the Penchant Basin.

Ammonium and orthophosphate concentrations were significantly higher ($p<0.001$) by a factor of about two at 15-centimeter depth and more than one order of magnitude at 45-centimeter depth in porewater of *Panicum hemitomon* dominated marshes in Penchant Basin marshes than in the Barataria Preserve. Median ammonium concentrations were about 0.26 mg/L as nitrogen at the two sampling depths in Penchant Basin marshes. Median pore-water chloride concentrations were 51 mg/L in Penchant Basin marshes, much lower than those in the *Panicum hemitomon* dominated communities in the Barataria Preserve. Median sulfide concentrations (0.33 mg/L) in pore water also were significantly higher in Penchant Basin marshes than in the Barataria Preserve.

The peat substrate of *Sagittaria lancifolia* and *Panicum hemitomon* dominated marsh communities was more decomposed in the Penchant Basin than in the Barataria Preserve. Rubbed fiber content as a percentage of the original unrubbed volume was almost 20 percent lower in Penchant Basin marshes compared with even the most decomposed marsh habitat in the Barataria Preserve, the marsh dominated by *Spartina patens* and *Schoenoplectus americanus*.

Flow of river water across wetlands and shallow ponds during the spring mid-continent flush resulted in the uptake of nitrogen, sulfate, and atrazine in peat marshes. Filtered nitrite-plus-nitrate and orthophosphate concentrations in receiving water in the Penchant Basin were reduced by about 80 to 90 percent and 65 to 75 percent respectively, compared with the inflowing river water. Filtered sulfate concentrations were about 30 percent lower in receiving waters than in the inflowing river water. Median atrazine concentrations were about 66 to 75 percent lower in receiving water.

The freshwater input in the Penchant Basin lowered chloride concentrations in surface water and pore water. River inflow could lower chloride in parts of the Preserve and increase the area where *Panicum hemitomon* communities could occur.

Regular exposure of the peat substrate to nitrate and sulfate from an external source, such as a freshwater diversion, could over time result in deterioration of the organic substrate and compromise the long-term sustainability of peat marshes. Both nitrite-plus-nitrate and sulfate are terminal electron acceptors and become reduced upon entering the flooded, anaerobic marsh soil. Organic matter, an electron donor, is oxidized during both reactions and becomes more decomposed in the process. Because of the steady input of sulfate, and its reduction to sulfide in the Penchant Basin, pore-water sulfide concentrations are higher there than in corresponding *Panicum hemitomon* dominated marshes in the Barataria Preserve. High sulfide concentrations inhibit uptake of nutrients by plants and allow pools of inorganic nutrients to accumulate in pore water. Large pools of inorganic nutrients and sulfides represent a degradation of the soil environment in which the marsh plants grow. Microbial activity is stimulated by elevated nutrient concentrations and may further accelerate decomposition of the organic substrate.

A comparison of pore-water and substrate quality in similar peat marshes either regularly inundated by river water or not at all, indicated possible adverse effects to marshes that rely almost exclusively on in-situ derived organic matter to build their substrate. The severe decline of the *Panicum hemitomon* dominated marsh community in the Penchant Basin over the past 30 years could be, in part, a response to the changed water quality associated with river water inflow. The effect the Davis Pond Freshwater Diversion, designed to simulate natural processes, will have on the peat marshes of the Barataria Preserve is uncertain, and will depend on hydrology (how much and how frequently river water penetrates the Barataria Preserve) as well as water-quality characteristics associated with the Mississippi River.

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