

2006

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Recommended Citation

Chambers, R.M., K.A. Pederson. 2006. Variation in soil phosphorus, sulfur, and iron pools among south Florida wetlands. *Hydrobiologia* 569(1): 63-70.

This material is based upon work supported by the National Science Foundation through the Florida Coastal Everglades Long-Term Ecological Research program under Cooperative Agreements #DBI-0620409 and #DEB-9910514. Any opinions, findings, conclusions, or recommendations expressed in the material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Variation in soil phosphorus, sulfur, and iron pools among south Florida wetlands

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Key words: sulfur, iron, phosphorus Everglades, mangrove, Florida Bay

“This paper has not been submitted elsewhere in identical or similar form, nor will it be during the first three months after its submission to Hydrobiologia.”

Abstract

47
48 To determine relationships between soil nutrient status and known gradients in primary
49 production, we collected and analyzed soils from 17 LTER sampling sites along two transects
50 through south Florida wetland ecosystems. Through upstream freshwater marsh, a middle reach
51 including the oligohaline marsh/mangrove ecotone, and downstream estuarine habitats, we
52 observed systematic variation in soil bulk density, organic content, and pools of phosphorus (P),
53 inorganic sulfur, and extractable iron. Consistent with observed differences in wetland
54 productivity known to be limited by P availability, total P averaged $\sim 200 \mu\text{g gdw}^{-1}$ in soils from
55 the eastern Taylor Slough/Panhandle and was on average three times higher in soils from the
56 western Shark River Slough. Along both transects, the largest pool of phosphorus was the
57 inorganic, carbonate-bound fraction, comprising 35-44% of total P. Greater than 90% of the
58 total inorganic sulfur pool in these south Florida wetland soils was extracted as pyrite.
59 Freshwater marsh sites typically were lower in pyrite sulfur ($0.2\text{-}0.8 \text{ mg gdw}^{-1}$) relative to
60 marsh/mangrove ecotone and downstream estuary sites ($0.5\text{-}2.9 \text{ mg gdw}^{-1}$). Extractable iron in
61 freshwater marsh soils was significantly higher from the Taylor Slough/Panhandle transect (3.2
62 mg gdw^{-1}) relative to the western Shark River Slough transect (1.1 mg gdw^{-1}), suggesting spatial
63 variation in sources and/or depositional environments for iron. Further, these soil characteristics
64 represent the collective, integrated signal of ecosystem structure, so any long-term changes in
65 factors like water flow or water quality may be reflected in changes in bulk soil properties. Since
66 the objective of current Everglades restoration initiatives is the enhancement and re-distribution
67 of freshwater flows through the south Florida landscape, the antecedent soil conditions reported
68 here provide a baseline against which future, post-restoration measurements can be compared.
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Introduction

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The south Florida landscape is dominated by vegetated freshwater, brackish mangrove and downstream estuarine habitats. These different wetlands exhibit variable primary production both within and between habitat types. For example, Fourqurean et al. (1992a,b) have documented the pronounced gradient in seagrass production throughout the Florida Bay estuary as a function of phosphorus availability. Nutrient availability also contributes to the greater mangrove biomass along the southwest coast of the Everglades (Chen & Twilley 1999) relative to mangrove biomass on the southeast coast (Coronado-Molina et al. 2004). Similarly, across the freshwater Everglades, Childers et al. (2003) have documented differences in vegetation and biomass related to soil phosphorus concentrations.

Given the general characteristics of phosphorus limitation in south Florida wetlands (Koch & Reddy 1992; Noe et al. 2001, 2002) coupled with a 100-year old history of changes in water flow largely driven by installation and operation of water control structures (Light & Dineen 1994; Chimney and Goforth 2001), any factors that influence the supply of phosphorus or alter the flows of water through these oligotrophic wetlands could impart dramatic changes on ecosystem structure and function (Fourqurean et al. 2003; Davis et al. 2004). To this end, the Florida Coastal Everglades Long-Term Ecological Research (LTER) program was established to examine variability in regional climate, freshwater inputs, disturbance, and perturbations affecting the coastal Everglades ecosystem. As part of the LTER program, we have initiated synoptic sampling of soils across the south Florida landscape with identical analytical methods to

91 capture in a snapshot some of the differences and similarities in soil characteristics among
92 wetland types.

93

94 Soil properties can be viewed as the integrated outcome of processes occurring over extended
95 time scales, much in the same way that climate is a description of aggregate weather conditions
96 for a region. In this study we present the aggregate soil properties along two transects, with a
97 focus on forms of phosphorus, sulfur and iron. Phosphorus is a limiting nutrient in these
98 oligotrophic wetlands and has been used to characterize ecological community types in other
99 Florida habitats (Schwandes et al. 2001). Reduced inorganic sulfur is the by-product of the
100 principle anaerobic respiratory process in marine and estuarine soils (sulfate reduction); soil
101 sulfide exerts some control on mercury speciation (Benoit et al. 1999) and can also be used to
102 track sulfate sources (Bates et al. 2002). In turn, both the phosphorus and sulfur cycles in soils
103 are influenced by the availability of reactive iron in carbonate soils (Sherman et al. 1998). Our
104 objective was to quantify the pools of sulfur, iron and phosphorus in different wetland soils and
105 establish a baseline for tracking long-term changes in the coastal Everglades ecosystem.

106

107

Methods

Study Site

109 The south Florida landscape is dominated by sub-tropical wetland environments where
110 hydrology—in terms of water volume, source, and residence time—plays a major factor in
111 ecosystem structure (e.g., Ross et al. 2003). As part of the Florida Coastal Everglades LTER,
112 two transects along separate freshwater drainage networks in the Everglades have been
113 established (Figure 1). In the western Everglades, six sampling sites are located in the Shark

114 River Slough (SRS) basin, extending from freshwater marsh (SRS sites 1 and 2), through the
115 oligohaline marsh/mangrove forest ecotone (SRS sites 3 and 4), and out through coastal estuarine
116 mangroves (SRS sites 5 and 6). Eight sampling sites are located in the eastern Taylor
117 Slough/Panhandle basin, extending from freshwater marsh (TS/Ph sites 1, 2, and 4), through a
118 region including the oligohaline marsh/mangrove forest ecotone (TS/Ph sites 3, 5, 6, 7, and 8),
119 and out to the seagrass-dominated Florida Bay estuary (TS/Ph sites 9-11).

120

121 Relative to the TS/Ph drainage, SRS is characterized during the wet season by larger inflows of
122 freshwater from canal discharge at SRS 1 and greater tidal exchange of coastal ocean water at
123 SRS 6. Additionally, soils in the SRS basin tend to be peaty, whereas soils in the TS/Ph basin
124 have less peat and more marl deposits (Childers et al. 2003). Florida Bay sediments are almost
125 exclusively comprised of marine carbonates.

126

127 *Soil Collection and Analysis*

128 Soils for determination of organic content were collected in August 2002; soils for all other
129 analyses were collected during August 2003. From each of the 17 sampling sites, three 60-ml
130 syringe cores were pushed into the soil surface to a depth a 10 cm. The syringe barrels were
131 capped with butyl rubber stoppers and stored on ice for transport to the laboratory, then cores
132 were refrigerated prior to analysis. Cores were extruded, and subsamples from each core were
133 obtained at depths from 0-2.5 cm, 2.5-5.0 cm, and 5.0-10 cm.

134

135 Soils from all 17 sampling sites were treated identically. Soil samples for bulk density, %
136 organic matter, total phosphorus and extractable iron analyses were placed in tared vials, dried at

137 80°C and weighed to determine bulk density, then ashed at 450°C for four hours to determine
138 weight loss on ignition. The ashed soils were then resuspended in 1N HCl to hydrolyze
139 phosphates, and colorimetric analyses for total phosphorus using the ascorbate method and
140 extractable iron (Fe_{HCl}) using the ferrozine method (Stookey 1970) were completed.

141
142 A four-step sequential extraction scheme based on a method used by Jensen et al. (1998) and
143 Koch et al. (2001) was completed to determine selected inorganic and organic pools of
144 phosphorus in carbonate sediment. First, extraction with 1N magnesium chloride released
145 loosely sorbed inorganic phosphate (P_{MgCl_2}). Next, extraction with a buffered dithionite solution
146 released inorganic phosphate considered sorbed to metal oxides (principally iron and manganese
147 compounds)(P_{BD}). Third, extraction with 1N HCl dissolved the carbonate minerals in the soil
148 and released inorganic phosphate sorbed to or in mineral phase with calcium carbonate (P_{HCl}).
149 Finally, subsequent ashing and 1N HCl acid extraction was used to release recalcitrant
150 phosphate, operationally defined as the residual organic phosphorus fraction (P_{Org}). Less
151 resistant organic phosphates associated with the first three extraction steps were not analyzed,
152 but have been shown to account for 10-30% of the total sediment phosphorus in Florida Bay
153 seagrass beds (Koch et al. 2001).

154
155 Soil samples for mineral sulfide extraction were first suspended in 1N zinc acetate to precipitate
156 any free sulfide in solution. Then, the soils were subjected to a two-step sulfur extraction
157 sequence following the method used by Chambers et al. (1994). Acid-volatile sulfide (AVS) was
158 extracted using a 1N HCl solution, then sequestered in an NaOH trap. Chromium-reducible
159 sulfide (CRS) was extracted using a boiling solution of concentrated HCl and reduced chromium,

160 then sequestered in an NaOH trap. The trapped AVS and CRS fractions were fixed using Cline's
161 reagent and analyzed colorimetrically (Cline 1969). The CRS fraction was assumed to be pyrite
162 (FeS_2).

163

164 Total phosphorus concentrations were calculated both by soil weight and by volume to allow for
165 comparison with other published values. All other nutrient concentrations were calculated per
166 weight of soil and compared among transect locations (i.e., freshwater marsh, oligohaline
167 marsh/mangrove forest, downstream estuary). One way ANOVAs were used to compare means
168 among transect locations, and LSD post hoc comparisons were completed using SPSS Version
169 10.0 (SPSS 1999). Percent organic values were log-transformed to normalize the data prior to
170 statistical analysis.

171

172

Results and Discussion

173 Total P concentration typically was higher along the Shark River Slough transect relative to the
174 Taylor Slough/Panhandle transect (Table 1). Expressed by soil weight, total P was fairly
175 constant from SRS 2 through SRS 6; per soil volume, however, total P increased down the
176 transect. Plant roots respond to changes in nutrient density, and the pattern of downstream soil P
177 enrichment is consistent with an observed gradient in mangrove productivity along the SRS
178 transect (Chen and Twilley 1999). Along the TS/Ph transect, however, total P concentration
179 decreased from the most northern freshwater marsh sites before rising at TS/Ph 7 and 8 to values
180 similar to those measured at SRS 4-6. The profound difference in mangrove production
181 between SRS and TS/Ph transects (Coronado-Molina et al. 2004) despite similar total P

182 concentration in the soil demonstrates that other factors in addition to soil P content influence
183 wetland productivity.

184 We expected to see a gradient of decreasing total P in sediment from west-to-east across Florida
185 Bay, concomitant with prior research demonstrating a bay-wide gradient in P availability and
186 seagrass production (Fourqurean et al. 1992a,b). We found, however, that sediment P was
187 unusually high in the eastern portion of Florida Bay (TS/Ph 9; Table 1). This site is located
188 adjacent to Duck Key where a heron rookery was recently established, so our measured high P
189 value at TS/Ph 9 may be a result of localized P enrichment from bird guano.

190
191 All soils in the current study were calcareous, but soil bulk density was significantly lower in
192 freshwater marsh environments and along the SRS transect (Table 2). The most dense soils were
193 located in Florida Bay. Concomitant with high bulk density in Florida Bay seagrass meadows
194 was low percent organic matter, averaging about 7%. In contrast, the emergent freshwater
195 marshes and mangrove forest soils had much higher organic content, and organic content was
196 significantly higher along the Shark River Slough transect. The implication from these data is
197 that marly soils are more consolidated or compacted along the Taylor Slough/Panhandle transect,
198 with higher water content in soils along the SRS transect.

199
200 As found in a prior study of sulfur in Everglades soils (Bates et al. 1998), the acid-volatile
201 component of the extracted soil sulfur pool was always less than 10% (Table 2). The
202 concentration of AVS, which includes free sulfide (HS^-) plus iron monosulfide (FeS), was
203 significantly higher in the marsh/mangrove ecotone of both transects. Most inorganic sulfide,
204 however, was extracted in the CRS fraction. As expected, the CRS concentration was highest in

205 the wetland habitats influenced by saltwater, the largest source of sulfate for bacterial sulfate
206 reduction to sulfide and subsequent pyrite formation. Between marsh, ecotone, and estuarine
207 wetland types, CRS was significantly higher along the SRS transect, relative to the TS/Ph
208 transect.

209
210 Extractable iron concentration was typically very low throughout all habitats sampled, but higher
211 along the eastern TS/Ph transect (Table 2). Still, the average concentration of Fe_{HCl} from the
212 TS/Ph mangrove sites ($\sim 1.7 \text{ mg gdw}^{-1}$) was roughly six times lower than the total soil iron
213 measured in a prior study sampling the mangrove fringe in the Taylor Slough drainage (Koch et
214 al. 2001). Because pyrite authigenesis relies on the availability of reactive iron and sulfide,
215 either species could limit its formation. Further, sulfate reduction only occurs in anaerobic soils
216 where labile organic matter is available for microbial decomposition. Relative to soils in
217 mangrove and seagrass habitats, freshwater marsh soils are exposed to lower concentrations of
218 sulfate, they experience oxidation during seasonal drawdowns of water, and microbial
219 decomposition of organic matter can be limited by phosphorus availability (Amador and Jones
220 1993). Together, these features are consistent with less net mineral sulfide formation in
221 freshwater marsh environments and more generally along the TS/Ph transect.

222
223 Though different in magnitude between transects, the patterns in pool sizes of total phosphorus
224 and total inorganic sulfur were fairly similar among transect locations (Figure 2). Brown &
225 Cohen (1995) completed a sediment survey along a transect line running from Florida Bay,
226 through the mangrove fringe and into freshwater marsh habitat near Whitewater Bay. They
227 found a pattern in mineral sulfide accumulation that was highest in the mangrove fringe, lowest

228 in the freshwater marsh, and intermediate in Florida Bay. Not only is the coastal ocean the
229 primary source of sulfate for eventual sulfide production and mineral sulfide formation; the
230 coastal ocean is also the source of much of the phosphorus enrichment observed in both Florida
231 Bay and saltwater mangrove habitats along both SRS and TS/Ph transects (Figure 2).
232 Fourqurean et al. (1992a,b) have demonstrated the longitudinal decrease in phosphorus
233 deposition in Florida Bay from west to east, effectively showing the primary source of P in the
234 bay is the Gulf of Mexico. Similarly, Chen and Twilley (1999) have documented that soil
235 phosphorus concentration in mangrove forests along the SRS transect decreases with distance
236 upstream from the Gulf of Mexico. The pattern of P enrichment in the coastal zone is smaller
237 along the Taylor Slough transect (Figure 2), but consistent with the documented decrease in total
238 phosphorus concentration in the eastern portion of Florida Bay (Boyer et al. 1997).

239
240 Our sequential extraction scheme identified the three principal inorganic soil phosphorus pools
241 and what has been measured as the major organic phosphorus pool in organic carbonate
242 sediments (Koch et al. 2001) (Table 3). The easily desorbed P_{MgCl2} pool was usually less than
243 10% of total extracted P. The size of the P_{BD} pool was approximately 25% of the total extracted
244 P, whereas Koch et al. (2001) found the P_{BD} fraction typically was below detection in organic
245 carbonate soils. We have not resolved this difference but note that the similar, large size of the
246 P_{BD} pool across wetland types (Table 2) suggests we may have extracted other forms of P not
247 associated with metal oxides in this fraction. Collectively, the average of the summed P
248 fractions ($124 \mu\text{g gdw}^{-1} \pm 21 \text{ s.e.}$) was not significantly different from the independent
249 measurement of total P in Table 1 ($129 \mu\text{g gdw}^{-1} \pm 33 \text{ s.e.}$) (paired t-test, $t = 0.437$, $p = 0.33$), but

250 we do not know whether any of the unmeasured organic fractions could have been detected
251 spectrophotometrically without prior ashing of the extract.
252

253 P_{HCl} , the fraction considered bound to calcium carbonate minerals, made up between 34 and 44%
254 of extracted P and was consistently the largest P fraction.(Table 3). The carbonate-bound P pool
255 has great potential to vary among these wetland soils because the bulk density (and thus mineral
256 density) among sites varies by a factor of 4 (Table 2). Together, bulk density and the size of the
257 P_{HCl} pool highlight the potential importance of carbonate-bound P to observed variability in
258 productivity within freshwater marsh (Childers et al. 2003), mangrove (Chen and Twilley 1999)
259 and estuarine seagrass (Fourqurean et al. 1992b) habitats in the south Florida landscape.

260 Although the sources and amounts of deposited P can be different for different habitats (e.g., P
261 sources from coastal ocean water, terrestrial runoff and groundwater, atmospheric deposition),
262 much of the variation in soil storage of phosphorus is due to variation in the carbonate-bound P
263 pool (Zhang et al. 2004), even though short-term P storage occurs in organic plant and
264 periphyton pools (McCormick et al. 1996; Dodds 2003; Noe et al. 2003).
265

266 Bioavailability of carbonate-bound P has not been demonstrated clearly but is suggested from
267 other studies. In subtropical environments where primary production is enhanced by P
268 enrichment or fertilization (DeBusk et al. 2001; Ferdie & Fourqurean 2004), soil accumulation of
269 P could be a direct consequence of organic matter deposition and decomposition (Romero et al.
270 2005), leading to P storage in carbonates. The stored P could then contribute to enhanced
271 production when soil processes such as sulfate reduction solubilize the calcium carbonate matrix
272 (Ku et al. 1999) and release inorganic phosphorus for plant uptake. Since sulfate reduction is

273 greatest in marine and estuarine wetland soils (but see Bates et al. 2002), a dynamic system of
274 inorganic P storage and P release ultimately may control whether carbonate-bound phosphorus
275 operates as a sink or a source in freshwater, brackish, and marine wetland soils. A number of
276 possible feedbacks involving carbonate saturation, wetland hydroperiod, organic matter and
277 sulfate supply would influence soil phosphorus dynamics in the south Florida wetland
278 environments.

279
280 The Florida Coastal Everglades LTER program is designed to study the structure and function of
281 subtropical aquatic ecosystems and determine how different forces contribute to long-term stasis
282 or ecosystem change. As part of that effort we measured soil characteristics across south
283 Florida habitats distinguished by hydrology and wetland type. Along transects through upstream
284 freshwater marsh, a middle reach including the oligohaline marsh/mangrove ecotone, and
285 downstream estuarine habitats we observed systematic variation in soil bulk density, organic
286 content, extractable iron, and pools of phosphorus and inorganic sulfur. Many of these soil
287 characteristics represent a collective, integrated signal of ecosystem structure, so any long-term
288 changes in factors like water flow or water quality may be reflected in changes in bulk soil
289 properties. Since the objective of current Everglades restoration initiatives is the enhancement
290 and re-distribution of freshwater flows through the south Florida landscape (Chimney and
291 Goforth 2001; Perry 2004), the antecedent soil conditions reported here are part of a five-year
292 time series to provide a baseline against which future, post-restoration measurements can be
293 compared.

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Acknowledgments

Thanks to Timothy Russell and the FCE-LTER crew for field support, and to three anonymous reviewers for their comments on earlier drafts of the manuscript. This material is based upon work supported by the National Science Foundation under Grant No. 9910514.

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428

428 Table 1. Total phosphorus concentration in soils from the Shark River Slough (SRS) and Taylor
 429 Slough/Panhandle (TS/Ph) transects in south Florida. For comparison, average concentrations
 430 (standard error, N=9) are expressed by soil weight and by soil volume.

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| Sampling Site | Total P $\mu\text{g gdw}^{-1}$ | Total P $\mu\text{g cm}^{-3}$ | Sampling Site | Total P $\mu\text{g gdw}^{-1}$ | Total P $\mu\text{g cm}^{-3}$ |
|---------------|-----------------------------------|----------------------------------|---------------|-----------------------------------|----------------------------------|
| SRS 1 | 501 (100) | 106 (10) | TS/Ph 1 | 266 (33) | 140 (14) |
| SRS 2 | 488 (29) | 88 (5.9) | TS/Ph 2 | 210 (19) | 83 (6.8) |
| SRS 3 | 876 (28) | 97 (4.0) | TS/Ph 3 | 96 (5.3) | 33 (2.5) |
| SRS 4 | 860 (60) | 167 (7.4) | TS/Ph 4 | 153 (16) | 54 (4.7) |
| SRS 5 | 813 (17) | 203 (9.3) | TS/Ph 5 | 129 (49) | 40 (1.6) |
| SRS 6 | 533 (77) | 297 (6.5) | TS/Ph 6 | 59 (3.7) | 45 (2.2) |
| | | | TS/Ph 7 | 362 (32) | 171 (5.3) |
| | | | TS/Ph 8 | 454 (24) | 160 (11) |
| | | | TS/Ph 9 | 228 (35) | 141 (21) |
| | | | TS/Ph 10 | 71 (9.6) | 60 (2.2) |
| | | | TS/Ph 11 | 296 (31) | 199 (13) |

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434 Table 2. Summary of soil characteristics by drainage basin and habitat location along each transect. Values are grand means \pm
 435 standard error. For each variable, letter superscripts show the results of post hoc comparisons among locations ($p < 0.05$).

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| Drainage Basin | Location | N | Bulk Density g cm ⁻³ | % Organic | Fe _{HCl} mg gdw ⁻¹ | AVS mg gdw ⁻¹ | CRS mg gdw ⁻¹ |
|-------------------------|------------------------|----|------------------------------------|------------------------------|-------------------------------------------|-------------------------------|-------------------------------|
| Shark River Slough | Freshwater Marsh | 18 | 0.220 \pm 0.024 ^a | 81.6 \pm 0.9 ^d | 1.14 \pm 0.17 ^a | 0.06 \pm 0.01 ^a | 0.78 \pm 0.19 ^b |
| | Marsh/Mangrove Ecotone | 18 | 0.156 \pm 0.013 ^a | 83.7 \pm 0.9 ^d | 1.22 \pm 0.21 ^a | 0.07 \pm 0.01 ^{ab} | 1.85 \pm 0.31 ^c |
| | Downstream Estuary | 18 | 0.450 \pm 0.080 ^b | 47.1 \pm 13.5 ^c | 0.83 \pm 0.10 ^a | 0.05 \pm 0.01 ^a | 2.85 \pm 0.49 ^d |
| Taylor Slough/Panhandle | Freshwater Marsh | 27 | 0.443 \pm 0.025 ^b | 14.4 \pm 1.7 ^b | 3.16 \pm 0.37 ^b | 0.04 \pm 0.01 ^a | 0.24 \pm 0.04 ^a |
| | Marsh/Mangrove Ecotone | 45 | 0.491 \pm 0.030 ^b | 35.8 \pm 7.1 ^c | 1.67 \pm 0.15 ^{ab} | 0.10 \pm 0.01 ^b | 0.95 \pm 0.15 ^b |
| | Downstream Estuary | 15 | 0.677 \pm 0.082 ^c | 6.6 \pm 0.3 ^a | 1.04 \pm 0.48 ^a | 0.06 \pm 0.03 ^a | 0.49 \pm 0.06 ^{ab} |

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 438 Table 3. Summary of soil phosphorus fractions by drainage basin and habitat location along
 439 transect, expressed by soil weight. Values are grand mean concentrations \pm standard error, with
 440 the average percent of total P in parentheses. Operational definitions: P_{MgCl_2} = loosely sorbed
 441 inorganic P; P_{BD} = inorganic P associated with metal oxides; P_{HCl} = carbonate-bound inorganic
 442 P; P_{Org} = residual organic P.

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| Drainage Basin | Location | N | P_{MgCl_2} $\mu\text{g gdw}^{-1}$ | P_{BD} $\mu\text{g gdw}^{-1}$ | P_{HCl} $\mu\text{g gdw}^{-1}$ | P_{Org} $\mu\text{g gdw}^{-1}$ |
|-------------------------|------------------------|----|----------------------------------------|------------------------------------|-------------------------------------|-------------------------------------|
| Shark River Slough | Freshwater | 18 | 49 ± 8.7 (7.6) | 179 ± 32 (27.9) | 225 ± 22 (35.1) | 189 ± 22 (29.5) |
| | Marsh | | | | | |
| | Marsh/Mangrove Ecotone | 18 | 94 ± 6.5 (9.5) | 296 ± 32 (30.1) | 332 ± 31 (33.8) | 261 ± 13 (26.6) |
| | Downstream Estuary | 18 | 41 ± 6.5 (6.8) | 104 ± 14 (17.1) | 267 ± 20 (43.9) | 196 ± 21 (32.2) |
| Taylor Slough/Panhandle | Freshwater | 27 | 32 ± 4.3 (10.0) | 83 ± 13 (26.1) | 126 ± 16 (39.2) | 79 ± 9.0 (24.7) |
| | Marsh | | | | | |
| | Marsh/Mangrove Ecotone | 45 | 20 ± 3.4 (6.8) | 82 ± 9.0 (27.9) | 107 ± 8.7 (36.6) | 84 ± 9.0 (28.6) |
| | Downstream Estuary | 15 | 21 ± 8.7 (6.9) | 87 ± 35 (29.5) | 104 ± 23 (35.2) | 84 ± 32 (28.4) |

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Figure Legends

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Figure 1. Map of south Florida, showing the location of the 17 LTER sampling sites arranged along Shark River Slough (SRS) and Taylor Slough/Panhandle (TS/Ph) transects. SRS 1, 2 and TS/Ph 1, 2, 4 are located in upstream freshwater marsh habitat, SRS 3, 4 and TS/Ph 3, 5, 6, 7, 8 are located in a mid-transect region including the marsh/mangrove ecotone, and SRS 5, 6 and TS/Ph 9, 10, 11 are located in the downstream estuary.

Figure 2. Average concentration and standard error of a) total phosphorus and b) total inorganic sulfide in soils from the upstream freshwater marsh, the mid-transect region including the marsh/mangrove ecotone and the downstream estuary along SRS and TS/Ph transects.

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