Physiochemical soil conditions at the Olentangy River experimental wetlands in 2004

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Introduction

Wetlands are constructed throughout the United States to provide landscape functions such as wildlife habitat, flood attenuation, and water quality enhancement (Mitsch and Gosselink, 2000). Where regulatory requirements stipulate monitoring of wetland creation areas, hydrology and vegetation are usually used as indicators of wetland condition. Soils are often the least considered component of wetland systems, despite their importance as the substrate for many of the biological and chemical processes that make them valuable components of the landscape (Vepraskas and Faulkner, 2001; Collins and Kuehl, 2001). There have been an increasing number of studies conducted to evaluate soil conditions in created wetlands. Many of these studies have been designed to compare the soils of created wetlands to natural reference wetlands (Bishel-Machung et al., 1996; Shaffer and Ernst, 1999; Zedler and Callaway, 1999; Nair et al., 2001; Campbell et al., 2002), with most finding some progressions toward natural wetland soil conditions but with substantial differences in many key characteristics (e.g., lower soil organic matter concentrations, coarser texture, and dissimilar nutrient concentrations and pH).

A survey of soil conditions and sediment/nutrient accumulation was conducted at two experimental marshes at The Olentangy River Wetland Research Park (ORWRP) ten years after they were created. These wetlands have been studied extensively over the past ten years with data collected annually on wetland productivity, hydrology, biogeochemistry and overall ecology (see Mitsch et al., 1998, 2005, in press; Kang et al., 1998, Koreny et al., 1999; Spieles and Mitsch, 2000a, b; Ahn and Mitsch, 2002; Anderson et al., 2003; Selbo and Snow, 2004; Zhang and Mitsch, 2005; Anderson et al., 2005; Anderson and Mitsch, in revision). Several studies have identified key processes that have influenced edaphic conditions including metaphyton productivity (Wu and Mitsch, 1998), macrophyte productivity (Mitsch et al., 2005), short-term sedimentation (Harter and Mitsch, 2003), nutrient retention (Nairn and Mitsch, 2000; Spieles and Mitsch, 2000a) and the co-precipitation of $CaCO_3$ and P (Liptak, 2000)

Sediment and organic matter accretion have been identified as major contributing factors to soil development in the two wetlands (Nairn, 1996; Harter and Mitsch, 2003) and in 2004 the mean depth of the sediment layer between the two wetlands was 9.3 ± 0.4 cm (Anderson et al., 2005). In the open water (OW) zones, the sediment layer tended to be deepest (8-22 cm), was grey-black in color, and homogeneous with very fine particulate matter that was almost gelatinous in structure, suggesting the formation of a gyttja layer (Wetzel, 2001). The sediment layer in the emergent vegetation (EM) zones was found to be slightly more cohesive and heterogeneous, with samples containing variable amounts of indistinguishable macrophyte detritus, living macrophyte roots/rhizomes, fine mineral/organic sediment, and soil fauna (Anderson and Mitsch, in revision).

Methods

A series of soil surveys was conducted at the Olentangy River Wetland Research Park on The Ohio State University campus in Columbus, Ohio, USA (latitude N40.021°, longitude E83.017°). The ORWRP is a 10-ha facility located along the Olentangy River, and was constructed on abandoned agricultural land. Underlying soils in this area are alluvial floodplain soils, comprised of the Ross and Eldean series (classified as a Cumlic Hapludoll), which include silt loams, silt clay, and clay loams (Mcloda, 1980). Two 1-ha experimental marshes were excavated at the ORWRP in 1993 and flooded in March 1994 with pumped Olentangy River water. The two wetlands were built and managed identically with Olentangy River water being pumped at a similar rate (typically about 25 m yr^{-1}) throughout their ten-year history. As part of a long-term study, the only difference between wetlands was that the western marsh (Wetland 1) was planted with native, wetland vegetation while the eastern marsh (Wetland 2) was left unplanted (Mitsch et al., 2004). Based on their topography, both wetlands have developed two distinct cover zones: a shallow, emergent vegetation zone and three deeper, open-water sub-basins spaced longitudinally along each wetland. The EM zones were constructed approximately 0.3 m below natural grade and the OW basins were typically 0.6 m below grade. In the first three years, both wetlands were similar in form with large areas of open water gradually colonizing with macrophyte cover in the EM zones, predominantly *Schoenoplectus tabernaemontani* (C.C. Gmel) Palla. However, between the years of 1998 and 2001, Wetland 2 became dominated by dense stands of *Typha* spp. (mostly *Typha angustifolia* L.; Selbo and Snow 2004) while Wetland 1 maintained a more mixed community assemblage. Because of their depth, the OW zones have supported only sparse amounts of emergent macrophytes, but have supported macroalgae and other aquatic vegetation (e.g., *Ceratophyllum* spp. and *Lemna* spp., Anderson and Mitsch, 2003). Although both wetlands were excavated to be 1-ha in size, after ten years of peripheral shrub encroachment, the combined marsh area of Wetlands 1 and 2 in 2004 was approximately 0.81 and 0.88 ha. respectively, with the OW zone covering approximately 29 and 28% of each wetland, respectively.

Soil sampling in 2004 was conducted based on a 10-m grid system marked at each intersection point with a permanently installed 2-cm diameter PVC pole (Anderson, 2005). A total of 127 intersection points were used to collect samples at 0-8 cm and 8-16 cm depths. During sampling, water depths were lowered to minimize standing water at each grid point and facilitate soil extraction. At each grid point, soils were collected 0.5 m east of the field marker. Soils were collected using a 10-cm diameter steel soil-corer, carefully removed, and split into 0-8 and 8-16 cm sections using a sharp knife. The 0-8 cm sections were then halved length wise and stored in separate water-tight freezer bags. Because most 8-16 cm sections were dense clay, these sections were split into quarters, and two of the quarter-sections were placed in separate plastic freezer bags. Soil remnants were replaced into the sample hole. For each sample, the hue, value and chroma were determined using a Munsell Color Chart, and other visual characteristics were noted. Because of the dense consistency of the antecedent soil, the development and boundary of the accreted sediment-layer was usually apparent. When it was, the depth was measured to the nearest 0.5 cm. Each sample section was placed in a plastic freezer bag and kept in an ice-packed cooler until being returned to the laboratory where they were refrigerated at 4˚C until laboratory analysis.

One subsection of each soil sample was weighed and placed in a drying-oven at 105 ˚C for five days or until constant mass occurred. Soil subsections were reweighed to determine moisture content and bulk density. For 10 subsamples collected entirely in the sediment layer, further analysis of soil texture was performed using the hydrometer method (Gee and Bauder, 1986). The second subsection of each soil sample was kept in its field-moist, natural condition and completely homogenized by hand. A 30-g subsample of each sample was air-dried at room temperature for and placed in a drying-oven at 60 ˚C overnight. Each soil was then ground using a pestle and mortar, and passed through a 2-mm sieve. Duplicate subsamples (approximately 10 g each) were placed in a crucible, weighed, and ignited in a muffle furnace at 550˚C for 1 hour. The post-combustion material was reweighed and the duplicates averaged to estimate the percent organic matter of the soil.

Among the samples analyzed for organic matter, a subsample was used to characterize soils for various chemical parameters. For each year, samples (at 0-8 and 8-16 cm depths) were collected and analyzed from the same grid points. Samples were selected to analyze chemical conditions over an even spatial distribution and to be proportionate among the cover zones. A total of 168 samples [two samples collected at 84 grid points (each with 0-8 and 8-16 cm depth subsections)] were analyzed for available P by Bray-P1 extraction (Kuo, 1996), exchangeable K, Ca, and Mg by 1M ammonium acetate extraction (Warncke and Brown, 1998), and pH (Thomas, 1996). A total of 72 of these samples were further analyzed for total C and N by combustion (ISO 1995, AOAC 1989), and a total of 21 samples were analyzed for total Al, B, Ca, Cu, Fe, K, Mg, Mn, Mo, Na, P, S, and Zn by digestion with $HClO_4$/ HNO_3 followed by inductively coupled plasma emission spectrometry (Sommers and Nelson, 1972).

Results and Discussion

The data collected from the varioius soil analyses is provided in Tables 1 - 5. In general, hydric soil development in the first ten years of the wetlands' existence has been extensive (see Nairn, 1996; Anderson et al., 2005; Anderson, 2005; Anderson and Mistch (in revision). Mean percent organic matter at the surface increased from 5.3 ± 0.1% in 1993 and 6.1 ± 0.2% in 1995, to 9.5 ± 0.2% in 2004. Mean total P increased from 493 ± 18 $\mu g\ g^{-1}$ in 1993 and 600 ± 23 $\mu g\ g^{-1}$ in 1995, to 724 ± 20 $\mu g\ g^{-1}$ in 2004 (Anderson et al., 2005).

The wetlands have also shown extensive spatial complexity in relation to soil organic matter (Anderson et al., 2005) and sediment accumulation (Anderson and Mitsch, in revision). High spatial structure (autocorrelation between data points) was detected in 1993 and 2004, although the 2004 data exhibited a much higher range of variance and a narrower range of autocorrelation than the 1993 data (Anderson et al., 2005).

Sediment accumulation was also evaluated in the experimental wetlands. Higher mean sediment accumulation was detected in the deeper open water zones (62 ± 6 and 74 ± 5 kg m^{-2}) for the two wetlands than in the emergent vegetation zones (38 ± 2 and 39 ± 3 kg m^{-2}) (Anderson and Mitsch, in revision). Directional spatial structure associated with sediment accumulation was detected in both wetlands, and was attributed to high accumulation in open water zones and a gradual decline in accumulation from inflow to outflow. High accumulations of Ca (2.4 ± 0.2 kg m^{-2} for both wetlands) and inorganic C (730 ± 70 and 717 ± 49 g m^{-2}) in the OW zones of both wetlands suggest that $CaCO_3$ deposition has continued to be a critical process where algae productivity has been highest (Liptak, 2000; Anderson and Mitsch, in revision)

References

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Table 1. Physiochemical soil characteristics at 0-8 and 8-16 cm depths in 2004. Percent organic C results (in bold-type) were lab-analyzed, and those in regular-type were determined by regression analysis with percent organic matter (%OC = 0.26 * %OM +1.01). Coordinates are based on the 10x10 m grid system at the experimental wetlands, and cover types consisted of emergent (EM) and open water (OW) zones (see text).

				Sediment	Bulk density		Moisture		Organic		Organic
	Cover	Coord.		depth	($g\ cm^{-3}$)		content (%)		matter (%)		C (%)
Wetland	Type	x	y	(cm)	[0-8 cm]	[8-16 cm]	[0-8 cm]	[8-16 cm]	[0-8 cm]	[8-16 cm]	[0-8 cm]
1	EM	1	4	5.0	0.65	1.37	49.7	30.3	11.8	5.3	4.02
1	EM	1	5	7.0	0.51	1.08	60.9	29.7	10.9	5.6	3.78
1	EM	1	7	8.0	0.48	1.23	56.7	31.5	8.3	5.5	3.12
1	OW	1	8	9.5	0.39	0.65	64.2	49.0	8.7	5.4	**3.06**
1	OW	1	9	19.0	0.66	--	50.2	59.9	6.6	7.6	2.70
1	OW	1	10	21.5	0.37	--	65.6	68.4	8.5	7.9	3.17
1	EM	1	11	9.0	0.61	1.25	54.0	28.5	7.8	4.6	2.99
1	EM	1	13	8.0	0.69	1.33	48.1	29.1	7.5	4.8	2.92
1	EM	1	14	5.0	0.6	1.3	50.1	27.5	14.0	4.9	4.58
1	EM	2	3	13.0	0.49	1.05	60.8	44.7	11.2	6.4	**4.05**
1	EM	2	4	11.0	0.47	1.36	60.8	33.9	9.8	3.9	3.50
1	EM	2	5	9.0	0.46	1.03	63.2	31.1	8.9	5.0	3.26
1	EM	2	6	9.0	0.49	--	58.3	31.8	7.7	4.1	2.96
1	OW	2	7	20.5	0.49	--	61.7	66.7	8.8	7.5	**2.57**
1	OW	2	8	14.0	0.38	--	66.7	40.8	8.5	4.5	3.18
1	OW	2	11	16.0	0.25	--	72.9	70.3	7.3	5.6	2.83
1	EM	2	12	10.0	0.6	0.93	47.7	39.5	6.3	5.5	2.60
1	EM	2	14	10.0	0.59	1.19	57.1	33.7	10.3	5.0	3.62
1	EM	2	15	8.0	0.80	1.34	44.0	27.5	8.4	4.6	**2.86**
1	EM	3	3	5.0	0.73	1.50	48.6	22.2	6.2	3.6	2.59
1	EM	3	5	9.0	0.45	1.28	62.4	30.9	10.2	4.6	3.59
1	EM	3	6	8.0	0.56	1.23	52.7	25.8	7.3	4.3	2.87
1	EM	3	7	6.5	0.57	1.40	53.0	25.5	7.9	4.5	3.03
1	EM	3	8	3.5	1.03	1.34	31.5	25.5	4.8	4.0	2.22
1	EM	3	9	1.5	1.48	1.67	23.5	22.9	4.2	4.2	2.08
1	EM	3	10	4.0	1.19	1.66	29.7	22.3	4.6	3.7	2.19
1	EM	3	11	3.5	0.87	1.53	33.5	24.4	4.2	3.5	2.07
1	EM	3	12	2.0	0.89	1.27	34.7	27.5	4.6	4.0	2.17
1	EM	3	13	7.0	0.76	1.37	50.5	26.4	10.0	4.7	3.57
1	EM	3	14	8.0	0.85	1.62	43.5	25.0	7.9	4.1	3.02
1	EM	3	16	2.0	0.96	1.51	34.9	24.0	5.2	4.2	2.33
1	EM	4	2	5.0	0.81	1.27	41.3	26.8	6.7	4.3	2.72
1	EM	4	5	5.0	0.98	1.41	40.2	25.3	5.4	4.1	**3.15**
1	EM	4	6	10.0	0.54	1.14	57.8	33.4	10.8	5.0	3.75
1	EM	4	7	13.0	0.46	0.77	61.8	52.4	11.8	6.8	4.01
1	EM	4	8	8.0	0.54	1.36	58.6	30.0	10.4	4.7	3.64
1	EM	4	9	8.5	0.50	1.31	64.5	35.7	10.8	5.5	3.76
1	EM	4	11	5.0	0.62	--	52.0		10.8	6.2	3.75
1	EM	4	12	--	0.66	1.17	53.4	31.0	9.3	5.2	3.37
1	EM	4	13	8.0	0.42	1.07	60.7	37.8	9.7	6.0	**4.15**
1	EM	4	14	4.0	--	--	--	--	--	5.4	--
1	OW	4	15	9.0	0.38	1.08	63.4	36.0	8.1	--	3.02
1	OW	4	16	--	--	0.37	50.8	51.5	7.1	6.7	2.82
1	EM	4	17	--	0.78	1.44	45.5	24.1	9.8	4.0	3.49
1	EM	5	2	12.0	0.49	1.24	58.2	34.4	9.8	4.5	**3.70**
1	OW	5	3	10.0	0.48	--	62.3	54.7	8.5	6.8	3.17
1	OW	5	4	17.0	0.50	--	59.1	56.0	7.2	7.0	2.84
1	EM	5	5	11.0	0.55	1.13	57.1	36.8	9.6	5.3	**3.66**

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Table 1, continued.

				Sediment	Bulk density		Moisture		Organic		Organic
	Cover	Coord.		depth	(g cm^{-3})		content (%)		matter (%)		C (%)
Wetland	Type	x	y	(cm)	[0-8 cm]	[8-16 cm]	[0-8 cm]	[8-16 cm]	[0-8 cm]	[8-16 cm]	[0-8 cm]
1	EM	5	6	9.0	--	0.93	--	36.8	--	5.0	--
1	EM	5	7	9.0	0.62	0.98	56.8	40.1	10.7	5.2	3.73
1	EM	5	8	10.0	0.43	1.21	66.1	37.7	15.5	5.9	4.96
1	EM	5	12	--	0.81	1.43	38.7	27.6	10.2	4.9	3.61
1	EM	5	13	5.0	0.65	1.29	51.5	31.1	11.2	5.6	3.85
1	EM	5	14	--	0.74	--	45.3	54.9	6.5	7.1	**2.49**
1	OW	5	15	12.0	0.49	0.64	--	55.9	7.4	6.8	2.90
1	EM	5	17	--	1.03	1.54	37.3	25.1	7.0	5.2	2.78
1	EM	6	3	5.0	0.51	1.35	59.5	25.6	10.8	4.3	3.93
1	EM	6	4	2.0	0.68	1.09	53.9	35.6	11.7	5.5	3.99
1	EM	6	6	--	0.82	1.15	41.6	32.7	9.9	5.9	3.53
1	EM	6	14	--	0.62	1.09	53.1	34.7	9.4	5.2	3.41
1	OW	6	16	8.0	0.47	--	58.1	--	6.8	--	2.73
1	EM	6	17	5.5	0.74	1.74	43.7	24.5	7.3	5.3	**2.72**
1	EM	7	15	--	0.53	--	49.5	31.2	10.7	5.3	3.74
1	EM	7	16	--	0.80	1.39	44.6	27.8	8.0	5.1	3.05
2	EM	8	5	--	0.81	1.37	37.0	25.6	9.4	4.5	3.41
2	EM	9	3	12.0	0.48	0.50	61.6	61.8	13.5	9.3	4.45
2	OW	9	4	17.0	0.62	0.68	54.8	54.2	7.3	7.9	2.86
2	EM	9	5	13.0	--	1.59	29.8	23.6	5.0	3.7	2.28
2	EM	9	6	9.0	0.35	--	67.7	--	12.4	--	4.16
2	EM	9	7	--	0.86	1.43	37.4	27.9	10.5	5.8	3.68
2	EM	9	16	--	0.88	1.25	36.7	27.5	11.5	5.6	3.93
2	EM	9	17	7.0	0.59	1.40	58.8	27.5	--	4.8	--
2	EM	9	18	5.5	0.63	1.55	43.2	25.2	5.3	4.7	2.37
2	EM	10	3	15.0	0.48	0.36	58.3	70.4	12.3	12.1	4.13
2	OW	10	4	12.0	0.48	1.22	59.9	39.0	8.6	5.6	3.20
2	OW	10	5	22.0	0.43	0.52	61.1	50.3	8.3	6.4	3.13
2	OW	10	6	18.0	0.52	0.51	62.0	57.6	8.0	7.4	3.05
2	EM	10	7	8.0	0.57	--	56.2	26.7	8.5	4.0	**3.71**
2	EM	10	8	10.0	0.54	1.37	57.0	29.8	13.5	4.9	4.45
2	EM	10	9	--	0.99	1.41	32.9	26.3	8.8	5.0	3.24
2	EM	10	15	4.0	0.91	1.44	38.6	28.0	6.9	4.8	2.77
2	EM	10	16	6.5	0.54	1.48	57.0	27.1	8.3	5.0	3.11
2	OW	10	17	16.0	0.46	0.64	65.0	52.6	8.2	6.2	3.09
2	EM	10	19	8.0	0.55	1.29	57.0	27.7	9.3	5.2	3.37
2	EM	11	3	9.0	0.51	1.40	65.0	26.4	12.3	4.1	**4.24**
2	OW	11	4	20.0	0.32	--	65.1	67.6	10.2	9.7	3.61
2	OW	11	6	15.0	0.50	0.73	62.0	54.3	7.7	6.3	**2.81**
2	EM	11	9	3.0	0.92	--	38.5	--	6.2	--	**2.01**
2	EM	11	10	11.0	0.38	1.41	63.4	31.8	11.2	--	3.85
2	EM	11	11	8.0	0.58	1.39	58.9	28.9	9.1	5.1	3.33
2	EM	11	12	8.0	0.73	1.35	53.7	32.1	8.7	5.4	3.23
2	EM	11	13	9.0	0.49	0.86	56.1	44.9	8.5	6.4	3.17
2	EM	11	16	5.0	0.82	1.49	38.6	26.3	5.6	4.9	2.44
2	OW	11	17	12.0	0.81	1.27	50.0	32.4	6.3	5.2	**2.39**
2	OW	11	18	9.0	0.85	--	56.0	36.8	7.5	5.3	2.92
2	EM	12	4	11.0	--	0.74	--	54.3	13.3	5.3	4.40
2	EM	12	6	7.0	0.48	1.58	57.0	25.8	8.5	4.1	3.17
2	EM	12	8	--	--	--	--	62.0	12.8	8.7	4.26
2	EM	12	9	5.0	0.78	1.63	45.4	24.3	7.5	4.2	2.92
2	EM	12	10	6.0	0.60	1.47	47.6	24.6	6.6	4.1	2.70
2	EM	12	11	6.5	0.68	1.43	45.0	27.3	6.4	4.4	2.64
2	EM	12	14	5.0	0.83	1.01	41.6	29.0	5.3	4.8	2.36

Continued

Table 1, continued.

Wetland	Cover Type	Coord. x	Coord. y	Sediment depth (cm)	Bulk density ($g\ cm^{-3}$) [0-8 cm]	Bulk density ($g\ cm^{-3}$) [8-16 cm]	Moisture content (%) [0-8 cm]	Moisture content (%) [8-16 cm]	Organic matter (%) [0-8 cm]	Organic matter (%) [8-16 cm]	Organic C (%) [0-8 cm]
2	EM	12	16	6.0	0.86	1.16	44.6	31.6	8.0	5.0	3.03
2	EM	12	17	5.0	0.66	1.28	48.5	28.7	8.3	4.9	3.12
2	EM	12	18	4.0	0.64	1	44.9	37.4	7.5	5.3	**3.39**
2	EM	13	5	9.0	0.38	--	67.8	--	16.6	--	**5.13**
2	EM	13	6	10.0	0.44	1.2	63.2	34.0	12.1	4.8	4.08
2	EM	13	7	7.0	0.69	1.51	48.8	26.5	9.1	3.5	3.33
2	EM	13	8	7.0	0.46	1.13	64.3	35.1	11.3	5.3	3.89
2	OW	13	9	21.5	0.32	--	67.7	64.3	8.8	7.8	**3.18**
2	OW	13	10	11.0	0.3	1.07	68.5	35.8	6.8	5.1	2.74
2	OW	13	11	10.0	0.45	1.16	61.3	32.1	8.3	5.0	3.12
2	OW	13	12	14.0	0.37	0.65	64.3	51.9	7.7	5.7	2.98
2	OW	13	13	15.0	0.33	0.73	65.3	66.9	7.9	7.6	**1.78**
2	EM	13	14	--	--	1.56	--	25.6	--	4.8	--
2	EM	13	15	6.0	0.60	1.34	51.1	28.0	8.5	5.1	**3.60**
2	EM	13	17	8.0	0.49	0.75	60.8	44.7	11.5	7.2	**4.31**
2	EM	14	6	9.0	0.50	--	58.0	--	12.4	--	4.15
2	EM	14	7	1.5	1.09	--	33.9	37.7	4.5	4.4	2.16
2	EM	14	8	11.0	0.30	1.02	74.5	39.6	18.9	5.3	5.82
2	EM	14	9	7.5	0.55	--	58.2	--	10.4	--	3.66
2	OW	14	11	13.0	0.61	0.58	56.5	53.4	6.1	5.9	2.55
2	OW	14	12	19.0	--	--	68.3	--	8.3	--	3.12
2	OW	14	13	17.0	0.33	--	69.9	64.0	8.1	7.8	3.06
2	EM	14	15	8.0	0.45	1.46	58.6	29.8	10.6	4.9	3.71
2	EM	14	16	19.0	0.85	0.91	41.8	41.6	6.7	6.4	2.73
2	EM	15	8	--	1.31	--	22.4	26.2	5.6	5.6	2.43
2	EM	15	9	--	1.17	1.34	30.2	27.0	5.5	--	2.40
2	EM	15	11	6.0	0.64	1.50	49.1	24.9	8.2	4.2	3.09
2	EM	15	12	8.0	0.55	1.42	58.3	28.5	--	4.5	--
2	EM	15	13	8.0	0.37	1.23	63.8	32.2	19.1	4.9	**5.58**
2	EM	15	14	--	1.18	1.45	29.5	26.5	7.2	5.1	2.84

Table 2. Total C, total N, total P, and pH of experimental wetland soils at 0-8 and 8-16 cm depths in 2004. Coordinates are based on the 10x10 m grid system at the experimental wetlands, and cover types consisted of emergent (EM) and open water (OW) zones (see text).

	Cover	Coord.		Total C (%)		Total N (%)		Total P (ug g^{-1})	pH	
Wetland	Type	x	y	[0-8 cm]	[8-16 cm]	[0-8 cm]	[8-16 cm]	[0-8 cm]	[0-8 cm]	[8-16 cm]
1	EM	1	5	--	--	--	--	--	--	6.43
1	OW	1	8	4.33	--	0.38	--	--	7.49	7.35
1	OW	1	10	--	--	--	--	--	7.48	7.49
1	EM	1	14	--	--	--	--	--	6.82	7.23
1	EM	2	3	4.07	--	0.37	--	793	7.02	6.99
1	EM	2	4	4.39	1.71	0.40	0.16	--	7.47	7.34
1	EM	2	5	--	--	--	--	--	7.64	7.24
1	EM	2	6	--	--	--	--	--	7.57	7.50
1	OW	2	7	4.06	4.46	0.32	0.39	851	7.44	7.59
1	OW	2	11	4.59	4.09	0.37	0.31	764	7.63	7.55
1	EM	2	12	--	--	--	--	--	--	7.50
1	EM	2	14	3.90	--	0.38	--	--	7.84	6.63
1	EM	2	15	2.87	1.59	0.29	0.16	679	7.12	7.42
1	EM	3	3	--	--	--	--	--	7.54	7.21
1	EM	3	6	--	--	--	--	--	7.55	7.43
1	EM	3	8	--	--	--	--	--	7.84	7.86
1	EM	3	10	--	--	--	--	--	7.40	7.30
1	EM	3	11	--	--	--	--	--	7.38	7.01
1	EM	3	12	--	--	--	--	--	7.40	6.97
1	EM	3	13	--	--	--	--	--	6.95	7.48
1	EM	3	14	4.03	--	0.38	--	--	7.08	--
1	EM	4	2	--	--	--	--	--	--	7.48
1	EM	4	5	3.64	--	0.31	--	--	7.52	7.09
1	EM	4	7	--	--	--	--	813	6.39	7.21
1	EM	4	9	4.38	1.61	0.43	0.17	704	6.15	6.72
1	EM	4	11	3.48	--	0.31	--	654	6.85	7.19
1	EM	4	12	--	--	--	--	--	6.51	7.07
1	EM	4	13	4.39	1.87	0.40	0.19	--	7.48	7.72
1	OW	4	15	4.12	1.63	0.38	0.18	731	7.55	7.36
1	EM	4	17	3.41	1.47	0.30	0.14	--	6.74	7.38
1	EM	5	2	3.96	--	0.35	--	--	7.29	7.32
1	OW	5	3	4.48	--	0.36	--	--	7.62	7.75
1	EM	5	5	4.14	1.84	0.39	0.18	--	7.72	6.73
1	EM	5	6	4.19	--	0.41	--	--	6.79	6.90
1	EM	5	12	--	--	--	--	--	6.86	6.98
1	EM	5	13	--	--	--	--	--	6.84	6.09
1	EM	5	14	2.70	--	0.28	--	--	7.78	7.83
1	OW	5	15	--	--	--	--	--	7.66	7.58
1	EM	6	3	4.07	--	0.35	--	681	6.86	6.48
1	EM	6	4	4.64	--	0.44	--	--	7.25	7.27
1	EM	6	14	--	--	--	--	--	6.60	6.74
1	EM	6	17	2.76	1.65	0.28	0.17	620	7.07	6.32
1	EM	7	15	--	--	--	--	--	6.70	6.68

Continued

Table 2, continued.

	Cover	Coord.		Total C (%)		Total N (%)		Total P ($ug\ g^{-1}$)	pH	
Wetland	Type	x	y	[0-8 cm]	[8-16 cm]	[0-8 cm]	[8-16 cm]	[0-8 cm]	[0-8 cm]	[8-16 cm]
2	EM	9	3	--	--	--	--	--	6.76	6.65
2	EM	9	5	1.23	1.07	0.14	0.13	--	7.01	6.82
2	EM	9	7	--	--	--	--	--	7.12	7.31
2	EM	9	16	--	--	--	--	--	--	6.96
2	EM	9	17	3.50	--	0.35	--	--	6.97	6.37
2	OW	10	4	4.64	--	0.33	--	--	7.50	7.39
2	OW	10	5	--	--	--	--	--	7.52	--
2	EM	10	7	3.95	--	0.34	--	--	7.35	6.38
2	EM	10	8	--	--	--	--	--	6.87	6.44
2	EM	10	9	--	--	--	--	--	7.27	--
2	EM	10	15	3.04	1.64	0.26	0.17	--	6.07	6.17
2	EM	10	16	3.21	--	0.31	--	--	7.29	6.25
2	EM	10	19	3.58	--	0.30	--	--	6.59	6.59
2	EM	11	3	4.26	1.00	0.35	0.11	--	6.51	6.72
2	OW	11	6	4.20	3.51	0.31	0.27	--	7.51	7.52
2	EM	11	9	2.05	--	0.19	--	650	6.65	--
2	EM	11	11	3.56	1.45	0.35	0.15	715	7.34	6.73
2	EM	11	12	--	--	--	--	--	6.96	6.96
2	EM	11	13	3.63		0.36	--	688	6.40	7.29
2	OW	11	17	3.07	2.15	0.27	0.23	772	7.65	7.29
2	OW	11	18	--	--	--	--	--	7.43	7.41
2	EM	12	4	--	--	--	--	--	6.52	6.60
2	EM	12	8	--	--	--	--	--	7.52	7.72
2	EM	12	9	--	--	--	--	--	7.12	6.70
2	EM	12	10	--	--	--	--	--	7.28	--
2	EM	12	18	3.43	--	0.27	--	--	6.50	7.65
2	EM	13	5	5.15	--	0.48	--	705	6.95	6.94
2	EM	13	6	4.45	--	0.41	--	--	6.97	--
2	EM	13	7	4.14	0.95	0.38	0.11	--	7.52	7.45
2	OW	13	9	4.39	4.17	0.40	0.36	863	7.59	7.62
2	OW	13	11	4.37	--	0.35	--	844	7.66	--
2	OW	13	13	2.39	1.96	0.21	0.19	747	7.66	7.52
2	EM	13	14	--	--	--	--	--	--	7.70
2	EM	13	15	3.69	1.69	0.33	0.16	--	7.48	6.50
2	EM	13	17	4.33	2.32	0.42	0.21	831	6.12	6.23
2	EM	14	8	--	--	--	--	--	5.59	6.30
2	OW	14	12	--	--	--	--	--	7.55	--
2	EM	14	16	2.36	--	0.23	--	--	7.26	6.89
2	EM	15	9	2.08	1.43	0.18	0.13	528	7.06	6.28
2	EM	15	11	--	--	--	--	--	6.26	--
2	EM	15	13	5.59	--	0.39	--	575	6.71	5.80

Table 3. Available P, exchangeable cations (Ca, Mg and K) of the experimental wetland soils at 0-8 and 8-16 cm depths in 2004. Coordinates are based on the 10x10 m grid system at the experimental wetlands, and cover types consisted of emergent (EM) and open water (OW) zones (see text).

Wetland	Cover Type	Coord.		Avail. P ($ug\ g^{-1}$)		Exch. Ca ($ug\ g^{-1}$)		Exch. Mg ($ug\ g^{-1}$)		Exch. K ($ug\ g^{-1}$)	
		x	y	[0-8 cm]	[8-16 cm]	[0-8 cm]	[8-16 cm]	[0-8 cm]	[8-16 cm]	[0-8 cm]	[8-16 cm]
1	EM	1	5	--	3	--	2243	--	363	--	78
1	OW	1	8	1	5	4271	2952	469	365	206	156
1	OW	1	10	1	1	4050	4312	465	415	211	204
1	EM	1	14	14	4	3466	2108	657	373	184	129
1	EM	2	3	14	9	2811	2125	474	360	128	101
1	EM	2	4	9	6	3198	1827	375	232	165	71
1	EM	2	5	9	7	3621	2449	465	318	184	80
1	EM	2	6	2	10	3343	2756	380	328	164	105
1	OW	2	7	2	2	4470	4017	392	426	177	208
1	OW	2	11	1	1	4059	4383	465	419	208	189
1	EM	2	12	--	3	--	2072	--	320	--	126
1	EM	2	14	8	5	3395	2009	370	323	166	122
1	EM	2	15	11	6	2582	2110	478	382	138	111
1	EM	3	3	7	4	2472	1504	251	222	90	48
1	EM	3	6	7	3	2942	1922	330	270	114	60
1	EM	3	8	12	5	2273	1971	346	409	105	101
1	EM	3	10	4	3	2240	1766	321	326	121	120
1	EM	3	11	8	6	2547	1665	313	285	124	116
1	EM	3	12	3	2	2019	1820	322	336	104	98
1	EM	3	13	12	5	2455	2157	375	337	128	92
1	EM	3	14	14	--	2924	--	531	--	167	--
1	EM	4	2	--	9	--	1998	--	369	--	102
1	EM	4	5	5	7	3474	2076	417	386	150	97
1	EM	4	7	13	8	2749	2417	472	396	217	144
1	EM	4	9	5	4	2595	2078	428	342	186	90
1	EM	4	11	9	6	2518	2196	440	391	148	138
1	EM	4	12	9	4	2614	2170	437	391	172	93
1	EM	4	13	7	8	3519	2706	372	317	195	109
1	OW	4	15	2	3	4253	2275	440	336	221	165
1	EM	4	17	13	4	2291	1865	424	427	169	105
1	EM	5	2	11	13	2964	2373	481	369	176	130
1	OW	5	3	2	2	4003	3592	434	376	200	202
1	EM	5	5	5	4	3601	2190	440	328	210	103
1	EM	5	6	12	10	2898	2734	552	488	179	168
1	EM	5	12	3	2	2070	2047	415	404	119	81
1	EM	5	13	10	2	2821	1967	491	348	158	72
1	EM	5	14	8	8	3055	3072	392	378	142	148
1	OW	5	15	1	2	3672	3955	443	418	224	197
1	EM	6	3	7	5	2885	1885	488	328	155	105
1	EM	6	4	21	12	3225	2418	615	422	201	137
1	EM	6	14	7	3	2446	2148	470	429	152	113
1	EM	6	17	6	2	2869	2105	492	380	139	113
1	EM	7	15	8	4	2211	2018	414	411	176	107

Continued

Table 3, continued.

Wetland	Cover Type	Coord. x	Coord. y	Avail. P (ug g-1) [0-8 cm]	Avail. P (ug g-1) [8-16 cm]	Exch. Ca (ug g-1) [0-8 cm]	Exch. Ca (ug g-1) [8-16 cm]	Exch. Mg (ug g-1) [0-8 cm]	Exch. Mg (ug g-1) [8-16 cm]	Exch. K (ug g-1) [0-8 cm]	Exch. K (ug g-1) [8-16 cm]
2	EM	9	3	12	8	2689	2061	449	379	149	154
2	EM	9	5	9	5	2080	1802	306	331	164	137
2	EM	9	7	12	6	2883	2346	509	425	181	138
2	EM	9	16	--	3	--	2198	--	440	--	108
2	EM	9	17	6	2	2988	1997	538	344	172	125
2	OW	10	4	1	5	3590	2777	400	301	193	163
2	OW	10	5	2	--	3682	--	363	--	186	--
2	EM	10	7	8	4	3321	1797	405	254	161	65
2	EM	10	8	7	7	2641	1934	467	360	152	137
2	EM	10	9	9	--	3071	--	500	--	152	--
2	EM	10	15	7	4	2498	2055	432	335	138	123
2	EM	10	16	9	6	1911	2908	344	373	151	147
2	EM	10	19	6	4	3000	2105	376	319	150	88
2	EM	11	3	12	6	2595	1805	462	351	210	106
2	OW	11	6	3	3	3665	4087	377	411	175	199
2	EM	11	9	7	--	2277	--	274	--	90	--
2	EM	11	11	14	10	2943	2056	491	298	189	129
2	EM	11	12	12	7	3146	2207	383	278	160	123
2	EM	11	13	8	14	3330	2647	427	353	165	149
2	OW	11	17	2	5	3407	2488	357	357	192	163
2	OW	11	18	4	4	2825	2600	383	348	167	164
2	EM	12	4	6	10	3038	1889	570	368	240	119
2	EM	12	8	11	5	3532	3404	383	269	201	111
2	EM	12	9	6	6	2322	1975	243	254	69	54
2	EM	12	10	6	--	2961	--	298	--	140	--
2	EM	12	18	8	4	2431	3027	303	226	122	84
2	EM	13	5	21	8	2842	1980	508	370	172	91
2	EM	13	6	20	--	2986	--	514	--	165	--
2	EM	13	7	14	12	3105	1790	445	318	140	109
2	OW	13	9	3	2	4137	4854	419	430	228	233
2	OW	13	11	2	--	3702	--	377	--	214	--
2	OW	13	13	2	4	3117	2844	330	338	160	163
2	EM	13	14	--	5	--	1967	--	388	--	72
2	EM	13	15	8	10	3261	2156	357	301	159	133
2	EM	13	17	11	8	2890	2270	448	336	200	139
2	EM	14	8	13	11	2600	1811	538	333	187	131
2	OW	14	12	2	--	4278	--	428	--	211	--
2	EM	14	16	10	9	2281	2220	363	360	136	134
2	EM	15	9	7	6	2019	1688	359	327	130	111
2	EM	15	11	6	--	1960	--	285	--	138	--
2	EM	15	13	8	5	2447	1502	434	298	127	117

Table 4. Percent and mean (±1 SE) textural classes of sediment in the experimental wetlands in 2004. Sample coordinates based on the 10x10 m grid system at the experimental wetlands; cover types consisted of emergent (EM) and open water (OW) zones; sub-basin refers to the proximity of each zone to the wetland inflow or outflow (see text).

		Cover	Sub-	Sediment composition		
Wetland	Sample	zone	basin	% Sand	% Silt	% Clay
1	4,7	EM	Out	51.5	41.7	6.8
1	5,3	OW	In	27.7	55.2	17.1
1	2,7	OW	Mid	22.7	61.5	15.8
1	6,16	OW	Out	40.9	40.3	18.8
1	4,15	OW	Out	36.0	47.2	16.8
2	13,6	EM	In	40.3	52.4	7.3
2	11,13	EM	Mid	48.6	46.9	4.5
2	13,17	EM	Out	28.0	54.9	17.1
2	13,11	OW	Mid	38.7	47.7	13.6
2	11,17	OW	Out	34.0	50.1	15.9
Mean				36.9	49.8	13.4
SE				2.9	2.0	1.6

Table 5. Micronutrient concentrations of sediment (0-8 depth) at the experimental wetlands in 2004. Coordinates based on the 10x10 m grid system at the experimental wetlands and cover type consisted of emergent (EM) and open water (OW) zones (see text).

	Cover	Coord.		Total Al	Total B	Total Ca	Total Cu	Total Fe	Total K	Total Mg	Total Mn	Total Mo	Total Na	Total S	Total Zn
Wetland	Type	x	y	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})
1	EM	2	3	38564	42.90	4582	27.34	24533	9477	4131	161.90	8.22	446.00	1021.44	121.66
1	OW	2	7	45950	38.79	46254	30.86	27939	11221	6458	242.28	8.95	529.05	5909.58	143.61
1	OW	2	11	44038	38.64	58255	29.27	26543	10842	5864	244.78	8.10	551.94	6267.34	131.96
1	EM	2	15	45768	36.80	4285	28.74	27018	10775	4621	162.36	9.32	476.86	741.23	136.19
1	EM	4	7	44069	36.72	4767	29.87	24457	10756	4635	166.88	8.71	487.29	1365.80	141.76
1	EM	4	9	42547	35.94	4351	28.09	26004	10230	4346	148.92	9.96	467.17	1240.96	127.80
1	EM	4	11	38880	35.88	4414	24.66	25906	9588	4191	163.39	9.29	435.26	865.70	115.92
1	OW	4	15	46170	37.62	37207	29.42	27054	11187	5475	196.36	6.94	544.83	3533.63	131.35
1	EM	6	3	39073	31.27	7940	29.15	25192	9558	4362	160.11	9.78	461.99	2005.91	132.17
1	EM	6	17	40115	31.38	4602	25.17	28500	9617	4104	173.02	8.87	445.09	915.78	112.74
2	EM	11	9	40963	40.45	4152	26.41	30962	10287	3981	235.81	9.31	425.69	568.13	119.50
2	EM	11	11	41592	33.62	6486	28.94	24524	10443	4534	160.89	8.52	454.49	1189.28	137.74
2	EM	11	13	40888	27.74	6434	27.37	24998	10338	4242	228.88	8.18	451.33	1329.46	131.42
2	OW	11	17	41811	28.97	24912	27.00	26716	10675	4451	272.98	8.01	464.55	3116.29	125.70
2	EM	13	5	49572	41.31	4862	34.16	23801	12214	4898	144.57	9.12	502.90	1262.34	161.37
2	OW	13	9	46906	33.74	39942	32.39	26409	11968	5814	219.78	7.92	535.34	5642.61	154.49
2	OW	13	11	42439	40.87	50012	29.38	25381	10909	5211	244.68	9.43	523.30	5151.37	141.16
2	OW	13	13	38463	27.10	22857	25.00	27019	9848	4121	311.96	8.08	433.38	2368.82	117.02
2	EM	13	17	51012	48.11	4813	32.96	29444	12543	4909	192.63	9.88	520.54	1443.85	150.59
2	EM	15	9	36114	35.46	3401	23.00	30897	9214	3632	245.26	9.40	387.49	343.66	110.52
2	EM	15	13	36149	37.42	4235	25.26	21729	8921	3675	147.79	9.43	417.51	1100.50	101.58

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