Spatial and temporal changes of soil properties in the experimental wetlands in 2003

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Introduction

It is estimated that 54% of the wetlands present in the U.S. at the time of settlement have been lost to anthropogenic causes (Kelly, 2001). Losses in some states, including Ohio, approach 90% of original wetlands (Dahl, 1995). High percentages of wetland losses have resulted in a greater awareness of wetland function, such as flood water retention, base flow augmentation, and water quality maintenance (Mitsch and Gosselink, 2000).

Acknowledgement of the importance of wetlands to our environment has resulted in the implementation of wetland protection policies (Bishel-Machung et al., 1996). Under §401 and §404 of the Clean Water Act, United States policy requires developers to replace the wetlands they destroy in the process of building through compensatory mitigation. Wetland policy assumes parity of created and natural wetlands; however, there is evidence that created wetlands do not function as self-sustaining wetlands (National Research Council, 2001), causing concern that created wetlands are not adequate replacements for natural wetlands (Roberts, 1993; Mitsch and Wilson, 1996; Ehrenfeld and Toth, 1997; Cole and Brooks, 2000).

Failures of created wetlands to compare to natural wetlands have been partially attributed to a lack of developed soils in created wetlands (Bishel-Machung et al. 1996; Stolt et al., 2000; Cole et al., 2001; Campbell et al., 2002). Soils have been described as "the physical foundation of every wetland ecosystem" (Stolt et al., 2000). They have tremendous importance in wetland function, as most biogeochemical processes and nutrient storage occur in the soil layers (Mitsch and Gosselink, 2000; Stolt et al., 2000). Nutrient cycling drives the wetland system, especially vegetative communities which are often used as indicators to determine wetland "success" (see Mitsch and Wilson, 1996).

Mitsch and Wilson (1996) attribute the lack of success of created wetlands to an inadequate understanding of natural development and self-design of wetlands. The goal of this study was to evaluate soil development in two 10-year-old created wetlands at the Olentangy River Wetland Research Park by addressing three specific questions: 1) are soils influenced by proximity to point source inflow, 2) how do the soil properties differ between created wetlands and upland areas, and 3) are wetland soils changing over time? In order to answer our questions, we compared bulk densities, soil moisture content, and organic matter content of wetland soils and upland soils, wetland soils from different locations throughout the wetlands, and data collected in 1993, 1995, and 2003.

Methods

Site Description

Two 1-ha experimental wetlands located at The Olentangy River Wetland Research Park (ORWRP) in Columbus, Ohio were used in this study. The experimental wetlands were excavated in 1993 on historically water-logged agricultural land used by The Ohio State University. The wetlands, connected to the nearby Olentangy River via water intake pumps, PVC inflows, and outflow weirs, were constructed to allow for hydrologic control. They were created as hydrologic and geomorphic replications of each other, but Wetland 1 was planted with a variety of hydrophytic species, common to Ohio wetlands, while Wetland 2 was left unplanted. Although Mitsch et al. (1998) found that three years after initial planting, the plant communities between wetlands had converged, the communities continue to shift due to natural processes. Since early 1994, river water from the Olentangy River has been pumped into the wetlands. Floods and drawdowns that would occur in natural freshwater marshes are simulated through occasional fluxes in the amount of water pumped into the wetlands.

Field Work

Field work was conducted on 19 October 2003. A total of 21 soil cores were obtained from 3 sites: Wetland 1, Wetland 2, and the Upland (Figure 1). From each of the wetland sites, 3 replicate cores were taken from each of 3 locations, the inflow, middle, and outflow. Only 3 cores total were obtained from the upland site. All soil cores collected in the wetlands were collected from the main boardwalks, in deep open-water areas. Water depth was similar between wetlands. An open-ended soil auger designed for water-logged soils was plunged approximately 30-cm into the wetland soil (to the top of the muck layer). Two soil horizons were clearly defined in the wetland soil, a layer of sapric material (O-horizon) and a layer of mineral soil (C-horizon). To minimize error in the bulk density calculation due to soil loss, the mucky O-horizon (approximately 0 to 15-cm from the surface) was removed from the open end

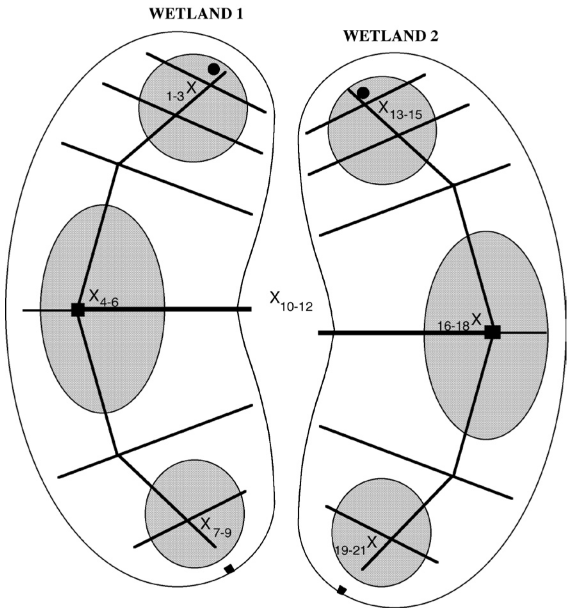

Figure 1. Coring locations (as indicated by the "X"s) and corresponding sample numbers in the ORWRP experimental wetlands. Bold lines represent boardwalks and gray ovals represent deep open-water areas within the wetlands.

of coring device and returned to the wetland after a sample was collected. The C-horizon (approximately 15 to 30-cm from the surface) was left intact in the corer while excess soil was removed from the outside and open ends of the auger, after which the remaining intact C-horizon core was collected. The upland sample consisted of one A-horizon taken to a depth of 15-cm.

Soil coloration is an indicator of soil type, and the determination of soil hue, value, and chroma is standard practice in wetland delineations. Chroma values of 2 or less on a Munsell Soil Color Chart indicate hydric soils (Tiner, 1986, Mitsch and Gosselink, 2000). The value and chroma for the O-horizon and A-horizon of each sample was determined on-site using a Munsell Soil Color Chart (Kollmorgen Instruments Corporation, Baltimore, MD). Ohio wetland soils are generally described as yellow-red in hue, thus values and chromas were determined using color chips in the 10YR hue. Mottling of the soils, an indicator of oxidized materials, was also noted.

Laboratory Work

Wet intact soil cores were immediately weighed in the lab after returning from the field. A wet sample of the C-horizon (or A-horizon for the upland site) was removed from each core, and a wet sample of the O-horizon was removed from the collected muck-layer. Samples of approximately 15 g were placed into porcelain crucibles of determined weight, and the wet soil weight for each of these samples was measured.

Inaccuracies in the percent organic matter can result from the release of carbon from carbonate materials at temperatures above 500°C (Konen et al., 2002). A standard procedure of adding 10% solution of hydrochloric acid (HCl) was used to liberate carbonates from the soil. The samples were left in the HCl solution for half-an-hour or until any bubbling and fizzing stopped. The HCl supernatant was removed from each sample using a pipette. Each sample was weighed again to obtain the wet weight after adding HCl. All samples were allowed to air dry for 48 hours or until weight was constant, and a dry weight was measured. To determine loss-on-ignition (LOI), crucibles containing air-dried samples were placed in a muffle furnace (Thermolyne 1500 Series Furnace) and combusted at 550°C for three hours (Davies, 1974). The weight after combustion was measured.

Data Analysis

Soil moisture content, bulk density, and (LOI) organic matter were calculated using standard methods (Forster 1995). This data was analyzed through two-sample t-tests and analysis of variances (ANOVA) using Minitab v.13. Fisher's Pairwise Comparisons were used to determine confidence levels between means in ANOVA tests. Data for bulk density and LOI was also statistically compared to data collected near the same points in each wetland in 1993 and 1995 by Nairn (1996). Significant differences were established at a 0.05 confidence level. Figures were created using Microsoft Excel, and tables were created using Microsoft Word.

Results

Soil Coloration

The soil coloration was evaluated for a total of 39 samples (Table 1). There was no statistical difference in soil coloration between the wetlands. Both values and chromas of O-horizon soils were lower than those of the C-horizons, and values and chromas of upland A-horizons were higher than both the O-horizons and C-horizons of the wetlands ($p < 0.05$). The most frequent value/chroma for O-horizon, C-horizon, and A-horizon samples was 2/1, 3/2, and 4/3, respectively. The value/chroma for wetland soils was lower in 2003 than 1995, although the variability in soil color was higher in samples taken in 1995 (Table 2). Mottling was noted in both O-horizons and C-horizons of wetland soils.

Bulk Density

Soils did not show any significant difference in bulk density by site or location; however, there were temporal differences in soil bulk density. Bulk density was significantly different between all three years (Figure 2, $p < 0.01$). Mean bulk density in 1995 was 0.31 g/cm^3 lower than the 1993 value and 0.55 g/cm^3 lower than the 2003 value (1.21±0.03 g/cm^3, 0.90±0.06 g/cm^3, 1.45±0.03 g/cm^3 for 1993, 1995, and 2003, respectively).

Table 1. Munsell soil colors for O-horizons, C-horizons, and A-horizons throughout the ORWRP experimental wetlands and an upland site. All hues determined as 10YR.

Horizon	Site	Wetland	Value	Chroma
O	Inflow	1	2	1
O	Inflow	1	2	1
O	Inflow	1	2	1
O	Middle	1	2	1
O	Middle	1	2	1
O	Middle	1	2	1
O	Outflow	1	2	1
O	Outflow	1	2	1
O	Outflow	1	2	1
O	Inflow	2	2	1
O	Inflow	2	2	1
O	Inflow	2	2	1
O	Middle	2	2	1
O	Middle	2	2	1
O	Middle	2	2	1
O	Outflow	2	2	1
O	Outflow	2	2	1
O	Outflow	2	2	1
C	Inflow	1	2	1
C	Inflow	1	2	2
C	Inflow	1	2	2
C	Middle	1	3	4
C	Middle	1	3	3
C	Middle	1	3	2
C	Outflow	1	3	2
C	Outflow	1	3	2
C	Outflow	1	3	2
C	Inflow	2	4	2
C	Inflow	2	2	1
C	Inflow	2	4	3
C	Middle	2	3	3
C	Middle	2	3	2
C	Middle	2	3	4
C	Outflow	2	3	2
C	Outflow	2	3	1
C	Outflow	2	3	2
A	Upland	Upland	3	3
A	Upland	Upland	4	3
A	Upland	Upland	4	3

Table 2. Frequency (percent of samples) of value/chroma coloration in O-horizons, C-horizons, and A-horizons. N_{2003} = 18, 18, 3 and N_{1995} = 6, 6.

Year	Horizon	Value	Frequency	Chroma	Frequency
2003	O	2	100%	1	100%
2003	C	3	67%	2	56%
2003	A	4	67%	3	100%
1995	O	3	83%	2	67%
1995	C	4	67%	4	50%

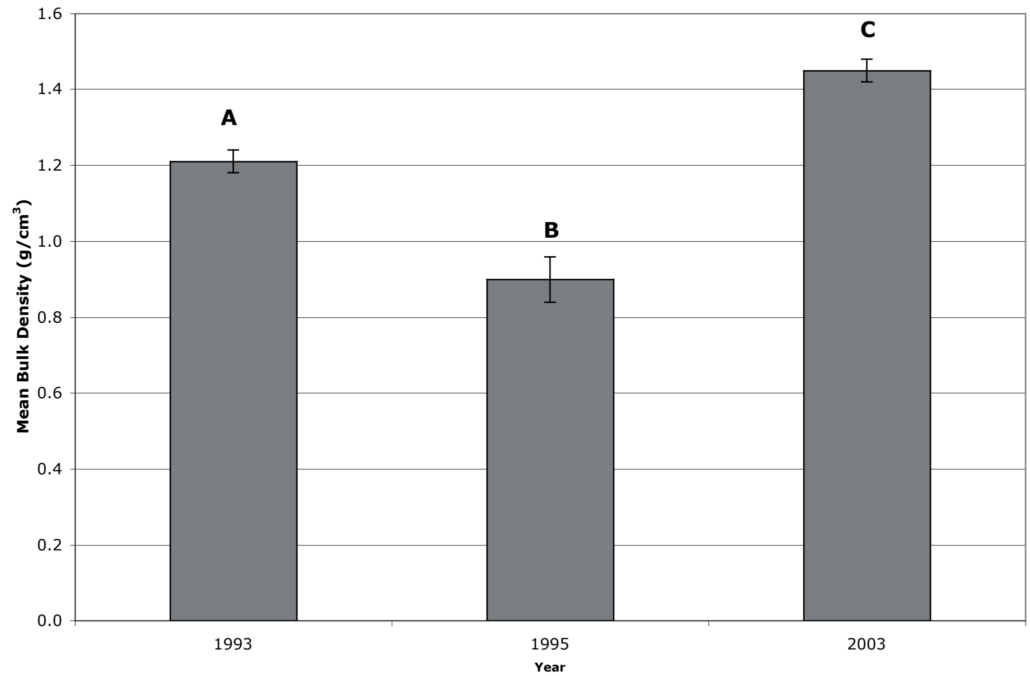

Figure 2. Mean bulk density (g/cm^3) over a temporal scale in the ORWRP experimental wetlands (N = 6, 6, 6 for 1993, 1995, and 2003, respectively). ANOVA was used to determine differences between years. Means with different letters are significantly different at $p < 0.05$. Error bars represent standard error. 1993 and 1995 data per Nairn (1996).

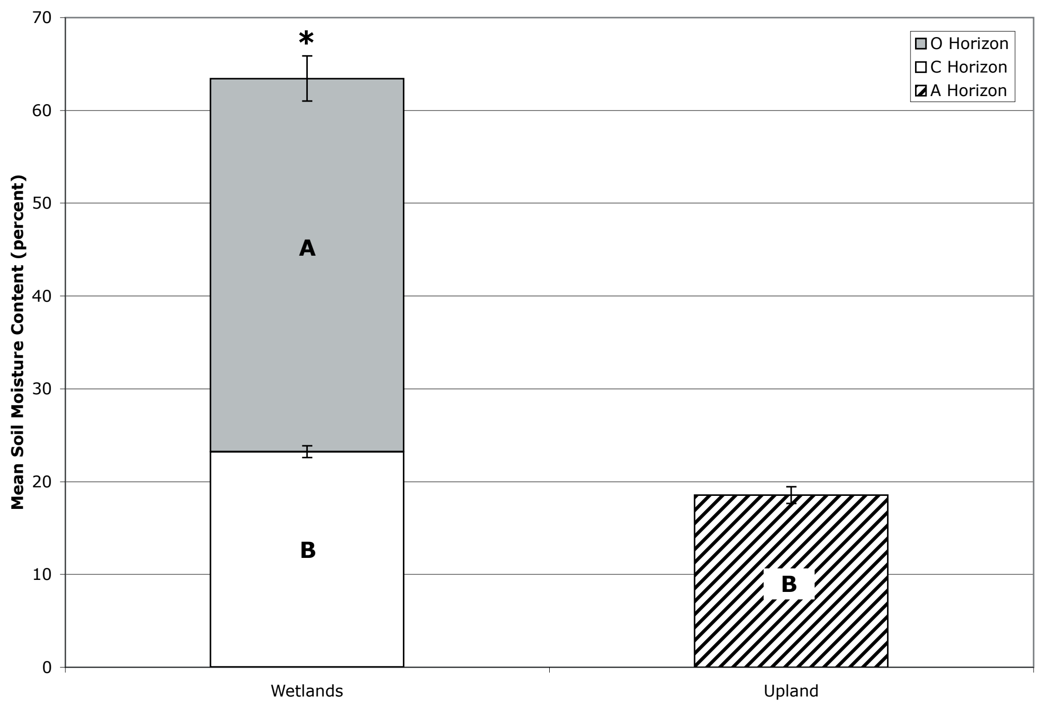

Figure 3. Mean soil moisture content (percent) in wetland and upland O-horizons, C-horizons, and A-horizons, ORWRP 2003. T-test was used to determine differences between sites and ANOVA was used to determine differences between horizons. Combined horizon site means with an asterisk are significantly different at $p < 0.05$. Means with different letters signify a significant difference between horizons at $p < 0.05$. Error bars represent standard error.

Soil Moisture

Wetland 1 and Wetland 2 did not have significantly different soil moistures. Combined mean soil moistures in the wetlands were more than three times those of the upland (63.43% and 18.55% in wetlands and upland, respectively; $p < 0.01$, Figure 3). Mean soil moisture contents were 12.08±0.83%, 7.26±0.28%, and 8.09±1.07 for the O-horizon, C-horizon, and A-horizon. O-horizons showed a 42% and 54% higher soil moisture content than both the C-horizons and the A-horizons ($p < 0.01$). There was no significant difference between C-horizon of the wetlands and the A-horizon of the upland.

Although there was no significant difference between locations, we found a trend between distance from the inflow and soil moisture content. O-horizon soil moisture content decreased with increasing distance from the inflow of the wetlands ($p = 0.068$). A-horizons did not follow this trend.

Organic Matter

Wetland 1 and Wetland 2 did not have significantly different organic matter contents, nor were organic matter contents affected by location. Site data did show strong differences; combined mean organic matter content in wetlands was more than twice that of the upland (19.34% and 8.09% in wetlands and upland, respectively; $p < 0.01$, Figure 4). O-horizons had a high organic matter content at 12.08±0.83%, while C-horizons and A-horizons showed significantly lower organic matter content ($p < 0.01$). We did not find a significant difference between C-horizons and A-horizons.

Organic matter content for combined O and C-horizons was not significantly different between 1993 and 1995, but there was a significant increase in organic matter content between 1993/1995 and 2003 ($p < 0.01$, Figure 5). Additionally, there was no difference between O-horizons and A-horizons in 1993 or 1995. In 2003, the O-horizon had a mean organic matter content 39% higher than the C-horizon ($p < 0.01$).

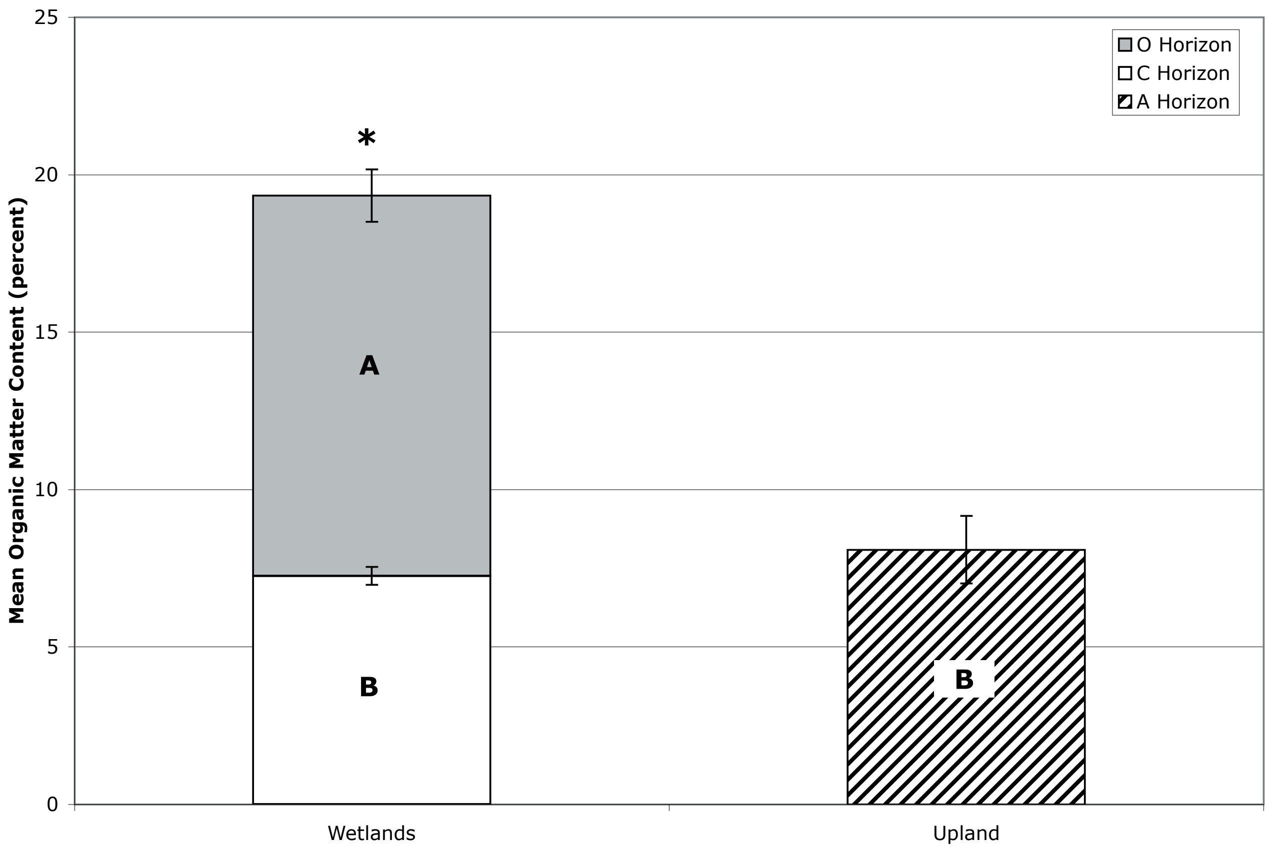

Figure 4. Mean organic matter content (percent) in wetland and upland O-horizons, C-horizons, and A-horizons, ORWRP 2003. T-test was used to determine differences between sites and ANOVA was used to determine differences between horizons. Combined horizon site means with an asterisk are significantly different at $p < 0.05$. Means with different letters signify a significant difference between horizons at $p < 0.05$. Error bars represent standard error.

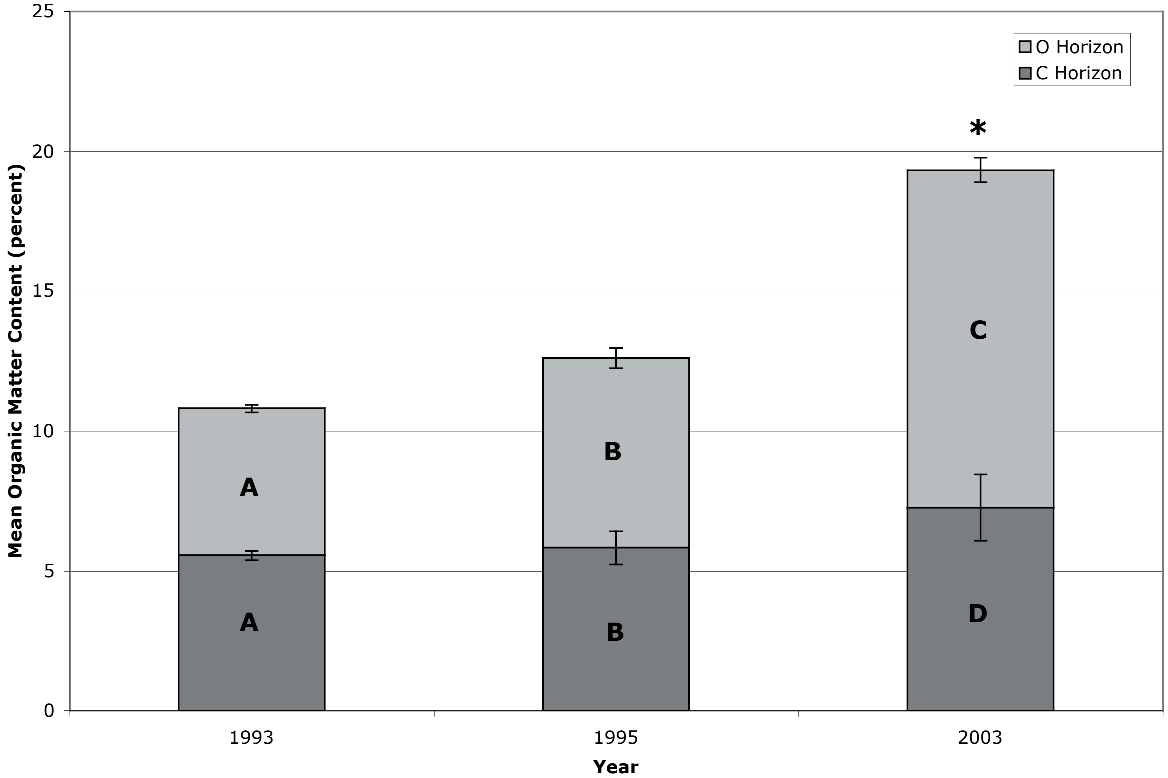

Figure 5. Mean soil organic matter content (percent) in O-horizons and C-horizons over a temporal scale in the ORWRP experimental wetlands ($N_{O\text{-horizon}}$ = 6, 6, 6 for 1993, 1995, and 2003, and $N_{A\text{-horizon}}$ = 6, 6, 6 for 1993, 1995, and 2003, respectively). ANOVA was used to determine differences between years. Combined horizon annual means with an asterisk are significantly different at $p < 0.05$. Means with different letters signify a significant difference between horizons at $p < 0.05$. Error bars represent standard error. 1993 and 1995 data per Nairn (1996).

Discussion

Soil coloration notably shifted between the O-horizon, C-horizon, and A-horizon of the wetlands and upland. The O-horizon, the top layer of sapric-hemic, had the darkest value and chroma of the three horizons sampled. Standard delineation practices require a minimum chroma of 2 for hydric soils. The O-horizons, with a mean chroma of 1, are classified as hydric wetland soil. The C-horizon, the lower layer of mucky-mineral soil, was markedly lighter in color than the O-horizon. It was determined that the mean chroma for the C-horizon was 2, indicating that these soils are hydric wetland soils. The chroma for upland A-horizon soil was above the threshold for hydric soils. The soil coloration and the absence of mottling in the upland soils indicate that they are not exposed to frequent flooding or anaerobic conditions.

In concurrence with Anderson and Kettlewell (2003), the values/chromas showed a clear difference between 1995 and the present. Both the values and chromas for the O- and C-horizons generally decreased in number (became darker/more hydric) from 1995 to 2003. It has been suggested that seasonal accumulation of organic matter has resulted in a deeper O-horizon that covers the previously exposed C-horizon (Anderson and Kettlewell, 2003). Values for both horizons have decreased since the last soil color evaluation in 2002 (Anderson and Kettlewell, 2003), although the sudden change in soil coloration is suspect due to differences in evaluators.

The bulk density is expected to be low in wetland soils with high organic matter content due to high porosity (Mitsch and Gosselink, 2000); however, we found that mean bulk densities of wetland soils were not statistically different from the means of upland soils. Our means may be higher than expected due to the fact that we collected bulk density from only the muck-mineral dominated C-horizon, which has been found to be the same as upland A-horizons for several other soil measurements (see Results).

As reported in Nair et al. (2001), it would be expected that as wetland soils develop over time and a rich sapric layer accumulates above the C-horizon, the bulk densities would decrease or remain the same, regardless of the horizon sampled. There was an initial decrease in mean bulk densities from 1993 to 1995, most likely due to the accumulation of organic matter (Mitsch and Gosselink, 2000); however, there is an increase in mean bulk density between 1995 and 2002-2003 (mean bulk densities were similar for the C-horizons in 2002 and 2003, Anderson and Kettlewell, 2003). The decreasing porosity and water-holding capacities in soils may be due to compaction of soils within the wetland, a reported occurrence in other studies involving created wetlands (Nair et al., 2001).

Mean soil moisture content was significantly higher in wetlands than uplands due to the consistent saturation of the wetland soils. The high water-holding capacities of soils rich in organic matter due to high porosity (as indicated by low bulk densities) is evident; the soil moisture content of O-horizon soils were significantly higher than the dense mineral soils of the C- and A-horizons. Although statistical tests did not show significance between the soil moisture content in O-horizons and the distance from the point-source inflow, mean soil moisture contents decreased with increasing distance from the inflow. A possible explanation for this trend is that as water flows through the wetland to the outflow, it is detracted from soil absorption by environmental factors (e.g. evaporation) and community factors (e.g. water uptake by vegetation).

Soil organic matter has been described as an effective catalyst for development of function in created wetlands (Kentula et al., 1992; Bishel, 1994 in Stauffer and Brooks, 1997). Past studies focusing on short-term soil development have consistently reported low (1-8%) organic matter content in created wetland soils (Bishel-Machung et al., 1996; Stauffer and Brooks, 1997; Cole et al., 2001; Nair et al., 2001); we found that our wetlands had relatively high organic matter content. As expected, O-horizons had the highest organic matter content, averaging around 12%, comparable to the lowest organic matter contents reported in natural wetlands (Stauffer and Brooks, 1997). C- and A-horizons had significantly lower organic matter contents, indicating that these soils were mineral soils, and for the wetland C-horizon, any accumulation of organic matter was occurring at the surface layer (O-horizon).

Wetland soils take time to develop substantial layers of organic matter, and in some cases, soils in created wetlands only begin to show indicators (e.g. soil mottling, oxidized rhizospheres) of hydric soil after five years of saturation (Cole et al., 2001; Vepraskas et al., 1999). There was a slight, but not significant, increase in soil organic matter between 1993 and 1995. Between 1995 and 2003, soil organic matter increased by more than 5%. The large increase in organic matter may be attributed to temporal factors, especially the break-down of vegetative litter over several growing seasons.

Even though soils have been subject to wetland hydrology for about a decade, the current soil characteristics are comparable only to the lowest values of natural wetlands. This study has indicated that wetland soils are slowly changing over a temporal scale, and given adequate time, soils in created wetlands are likely to develop characteristics comparable to natural wetlands.

Acknowledgements

The author would like to thank Jake Elder and Chris Hurdzan for help in the field and Chris Anderson for his invaluable input and support during this project.

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