Estimation and comparison of gross primary productivity patterns in created riparian wetlands

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Introduction

This study was conducted to update and expand the work of previous researchers who evaluated diurnal changes in dissolved oxygen (DO) and primary productivity (Fleishman et al., 2003; Leonard et al., 1999; Yu et al., 1996) at the Olentangy River Wetland Research Park (ORWRP).

The primary goal of this study was to evaluate two created riparian wetlands in order to determine intra- or inter-basin variation in dissolved oxygen, and, therefore, gross primary productivity (GPP). A secondary goal was to expand upon spatial results provided in previous ORWRP annual reports regarding diurnal variation in DO, by collecting data at a variety of points throughout each experimental wetland, i.e. inflow, middle, and outflow, rather than solely in a longitudinal pattern, thereby providing a larger sample size and covering a wider area.

Intra-basin diurnal and longitudinal variations of DO have been previously demonstrated at the ORWRP (Fleishman et al., 2003). Yu et al. (1996) speculated that inter-basin variations in productivity and respiration were likely random, owing to the small number of observations. Comparisons between the two constructed wetlands have been conducted for 10 growing seasons and are of interest because W1 was planted with emergent macrophytes and W2 was left to develop naturally (Mitsch et al., 1998). Mitsch (1999) noted that a divergence in productivity between the two created wetlands may occur over time, a hypothesis supported by Leonard et al. (1999).

Measurement of diurnal changes in dissolved oxygen concentration is a practical method for estimating the gross primary productivity of a wetland. Brinson et al. (1981) defined GPP as the sum of daytime photosynthesis and nighttime respiration of plants, which provides a dynamic view of the life of the wetland.

Methods

Site Description

Sampling stations were located at experimental wetlands 1 and 2 (W1 and W2) at the ORWRP. The wetlands are 1-hectare freshwater marshes that receive their water from the adjacent Olentangy River via pumps. After construction of the wetlands in 1994, W1 was planted with 2400 hydrophytes representing 12 species (Mitsch et al., 1998) while W2 was left unplanted. Water quality data have now been collected for 10 years. A summary of these data can be found elsewhere in this Report (Mitsch et al., 2004).

Estimation of Gross Primary Productivity

The GPP of the two created wetlands was estimated by using the DO measurement method. This method is based on the principle that the photosynthesis of all autotrophs, including phytoplankton, submerged macrophytes, periphyton and floating algal mats will contribute to the DO in the water column; while the respiration of all living organisms will reduce the DO. During the daytime, the DO change in the water column is a net result of photosynthesis and respiration (Yu et al., 1996). Calculations assume a constant respiration rate throughout the day and no net oxygen diffusion.

Dissolved oxygen (DO) concentration was measured in the morning and evening on six consecutive days - October 20 through 25, 2004. The measurements were obtained directly with a Yellow Springs Instrument (YSI) 600 xL sonde handheld system (laboratory calibrated prior to the initial measurement). Measurements were taken in the mornings between 6:30 and 9:00 and in the evenings between 17:00 and 19:00. All measurements were made directly with the YSI, and no sample preparation or laboratory analysis was performed.

Twelve sampling locations were selected along the permanent boardwalks in each of the two experimental wetlands, to provide a longitudinal and lateral pattern (Figure 1). Sampling was initiated near the inflow area (Station 1) of each wetland and terminated near the outflow area (Station 12). Stations 1-3 represent the inflow area; Stations 4-6 represent the midsection of each wetland; and Stations 10-12 represent the outflow area for comparative purposes in this paper.

The Diurnal gross primary productivity for the water column was estimated by calculating the rate of change in DO over a specified time using the following equation:

GPP (g O_2 m^{-3} h^{-1}) = (dt) [dDO/dt current day - (dDO/dt previous day + dDO/dt) next day/2)] Where:

dt = change in time of reading from time 1 to time 2

dDO = change in DO from time 1 to time 2

The estimated GPP (g O_2 m^{-3} d^{-1}) was normalized by multiplying the GPP value by the measured water column depth so that the graphed results (GPP m^{-2} d^{-1})

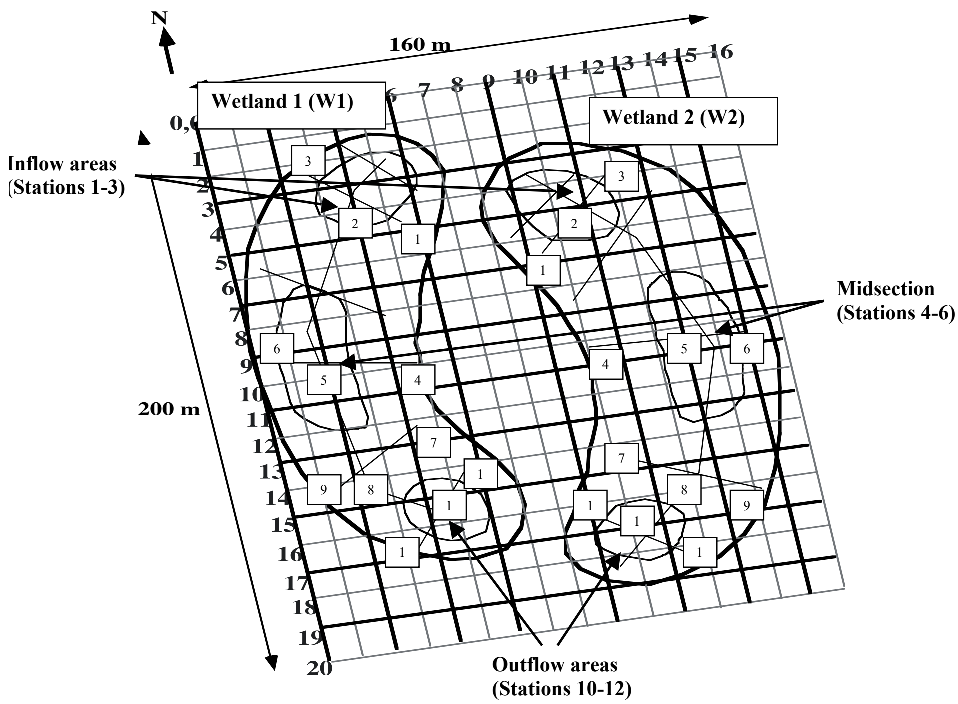

Figure 1. Sampling stations (1-12) in each of the two experimental wetlands at the Olentangy River Wetland Research Park.

could be directly compared to assess intra- and inter-basin productivity rates.

Data Analysis

Primary analyses focused on the identification and interpretation of major intra- and inter-basin relationships, as defined by diurnal changes in DO, and subsequently GPP. Intra-basin analyses consisted of an examination of AM and PM variations in mean DO concentrations for each of the 12 stations within each wetland. Changes in DO concentrations between the inflow and outflow areas of each wetland along the axial stations in each wetland over the 6-day investigation were evaluated by comparing the mean readings from Stations 1-3 and 10-12. Lateral variations within each wetland were evaluated by comparing mean DO concentrations from Stations 3, 6, 9 and 12 and Stations 1, 4, 7, and 10 in each wetland (Figure 1). Inter-basin relationships were assessed by comparing the mean daily DO and GPP concentrations recorded at all 12 stations in each wetland, and by comparing mean daily DO and GPP concentrations at the inflow and outflow areas of the two wetlands over the study period.

The mean daily GPP was plotted against daily solar radiation data to note the positive correlation of GPP with solar radiation. Solar data were obtained from the Ohio Agricultural Research & Development Center station at Delaware.

All data were analyzed and presented using Microsoft ® Excel (Microsoft ® Excel, 2002), and comparisons were made using two-tailed, paired t-tests. Data ware reported as means ± one standard error.

Surfer ® 8.02 Surface Mapping System (Golden Software, Inc., 2002) was used to produce shaded contour maps of the mean daily GPP for the each of the 12 stations in the two wetlands. The point kriging geostatistical gridding method was utilized in the production of both contour maps because of the irregularly spaced, small data sets.

Results

Dissolved Oxygen (DO) Concentration

Wetland 1

The AM dissolved oxygen readings in W1 ranged from 4.92 to 9.04 mg L^{-1} while the PM measurements ranged from 6.48 to 9.91 mg L^{-1} (Figure 2B). The mean AM and PM concentrations were 7.22 ± 0.15 and 8.34 ± 0.12 mg L^{-1}, respectively. The diurnal variation was highly significant ($p < 0.001$). The overall mean daily DO concentration for W1 was 7.78 ± 0.18 mg L^{-1}.

The mean daily DO concentration for the inflow area was 8.32 ± 0.18 mg L^{-1} while the mean daily outflow DO concentration was 7.98 ± 0.23 mg L^{-1} ($p = 0.048$). A significant difference from inflow to outflow has also been noted by others (Fleishman et al., 2003).

Laterally, the mean daily values for Stations 3, 6, 9, 12 and 1, 4, 7, 10 were 7.35 ± 0.17 mg L^{-1} and 7.89 ± 0.24 mg L^{-1}, respectively. This variation was significant ($p = 0.01$). Lateral, intra-basin comparisons have not previously been reported at the ORWRP.

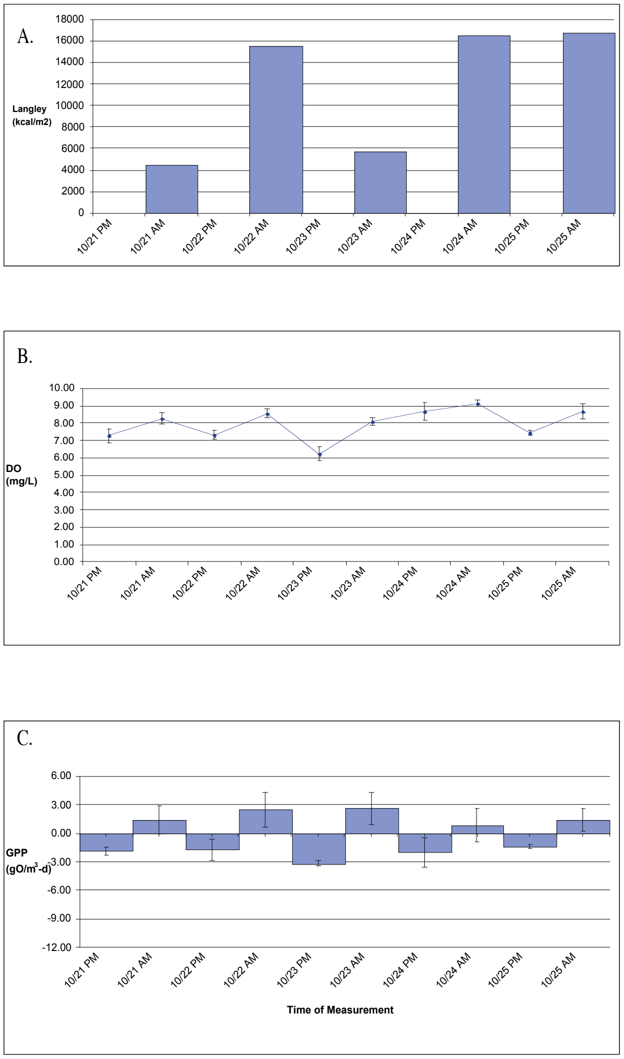

Figure 2. Diurnal patterns of (A) solar radiation, (B) dissolved oxygen (DO), and (C) rate of change of gross primary productivity (GPP) for Wetland 1.

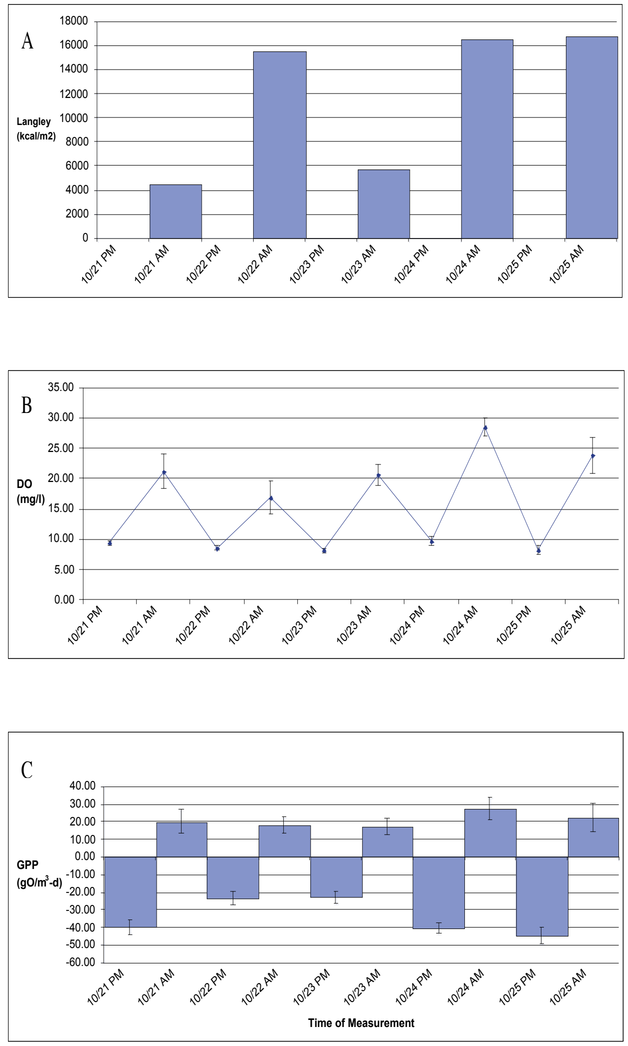

Figure 3. Diurnal pattern of solar radiation, dissolved oxygen (DO), and rate of change of gross primary productivity (GPP) for Wetland 2.

Wetland 2

The AM dissolved oxygen readings for W2 ranged from 4.03 to 11.69 mg L^{-1} while the PM reading range was 9.95 to 44.39 mg L^{-1} (Figure 3B). The mean AM and PM readings were 8.67 ± 0.20 and 22.78 ± 1.08 mg L^{-1}, respectively. The overall mean daily DO for W2 was 15.73 ± 0.84 mg L^{-1}. The diurnal variation is highly significant ($p < 0.001$).

The mean daily DO for the inflow area was 16.72 ± 1.89 mg L^{-1} while the mean outflow DO concentration was 16.36 $\pm$ 1.63 mg L^{-1}. In contrast to the W1 results presented above, these results are not significantly different ($p = 0.7$).

Laterally, mean DO values for Stations 3, 6, 9, 12 and 1, 4, 7, 10 were 17.01 ± 1.89 mg L^{-1} and 14.15 ± 1.17 mg L^{-1}, respectively. Lateral differences in W2 were not statistically significant ($p = 0.4$).

Inter-Basin

Inter-basin comparisons of mean daily DO for the two wetlands resulted in very highly significant differences ($p = 0.00$). Similarly, the inflow and outflow areas were found to be significantly different ($p = 0.01$ and 0.00, respectively).

Estimated Gross Primary Productivity (GPP)

The gross primary productivity was estimated using the change in DO and the change in time from one measurement to the next. The values graphed and presented in Figures 2 and 3 C represent the change in mean daily GPP for each wetland.

Wetland 1

The mean daily GPP for W1 was 1.68 ± 0.18 g O_2 m^{-3} d^{-1}. The average daily inflow area GPP was 1.31 ± 0.19 g O_2 m^{-3} d^{-1} and the daily mean outflow value was 2.18 $\pm$ 0.29 g O_2 m^{-3} d^{-1}.

On an areal basis, the mean daily GPP for W1 was 0.25 ± 0.04 g O_2 m^{-2} d^{-1}. Intra-basin rates of GPP were not statistically different, with the exception of inflow vs. outflow ($p = 0.02$). Mean station GPP per unit area ranged from 0 to 0.44 g O_2 m^{-2} d^{-1} (Figure 4, shaded contours). Highest mean station GPP values were located in the west-central region and southern end of the wetland, near the outflow.

Wetland 2

The mean daily GPP for W2 was 20.92 ± 1.56 g O_2 m^{-3} d^{-1}. The average daily GPP in the inflow area was 20.4 ± 3.72 g O_2 m^{-3} d^{-1} and the mean daily outflow value was 24.42 ± 2.67 g O_2 m^{-3} d^{-1}.

On an areal basis,the mean daily GPP for W2 was 2.32 ± 0.29 g O_2 m^{-2} d^{-1}. Intra-basin comparisons for W2 were unremarkable, with no statistically significant differences in the lateral or inflow and outflow areas. Mean station GPP per unit area ranged from 0 to 6.39 g O_2 m^{-2} d^{-1} (Figure 5, shaded contours). Highest mean station GPP values were found in the east-central region and near the southern end of the wetland, adjacent to the outflow.

Inter-Basin

Inter-basin comparisons did show significant differences (Figure 6), with the inflow, outflow and overall GPP for W2 being significantly higher than that of W1 ($p = 0.00$).

Solar Data

Solar radiation ranged from 940 to 3520 kcal m^{-2} during the study period (Figures 2A and 3A). This data was obtained from the Ohio Agricultural Research & Development Center station, Delaware, Ohio. There is a weak positive correlation between the solar radiation and the GPP. The weak association is due to the sporadic data for some stations due to low water depth and the variability in readings from three different observers, as well as local differences in solar radiation between Delaware and Columbus.

Discussion

Many comparisons and correlations could be made using the 6-days of diurnal data collected for this project. The primary goal of this study was to determine intra- or inter-basin variations in dissolved oxygen in two created riparian wetlands, and their resultant GPP. Statistically significant differences were recorded in the mean diurnal DO readings within each wetland basin. In all instances, PM values were higher than AM values. This is undoubtedly the result of the photosynthesis by aquatic autotrophs, which enhance the DO level in the water column over the course of the day. Specifically, the remarkably high mean daily DO values recorded in W2 (15.73 mg L^{-1}) are most likely directly attributable to the photosynthetic activity of the abundant and extensive benthic algae observed covering much of

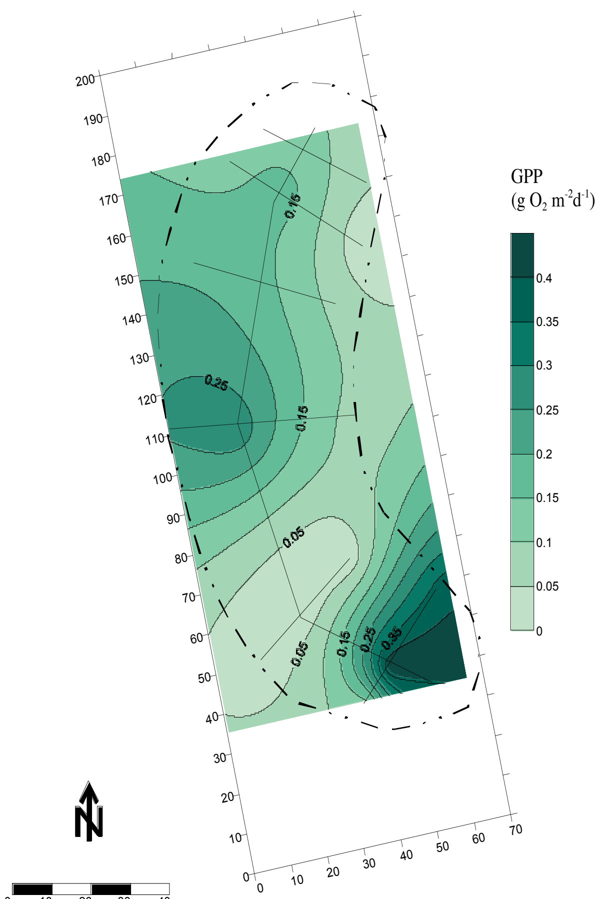

Figure 4. Surfer ® 8.02 contour plot of the mean station gross primary productivity (GPP) in Wetland 1 (W1).

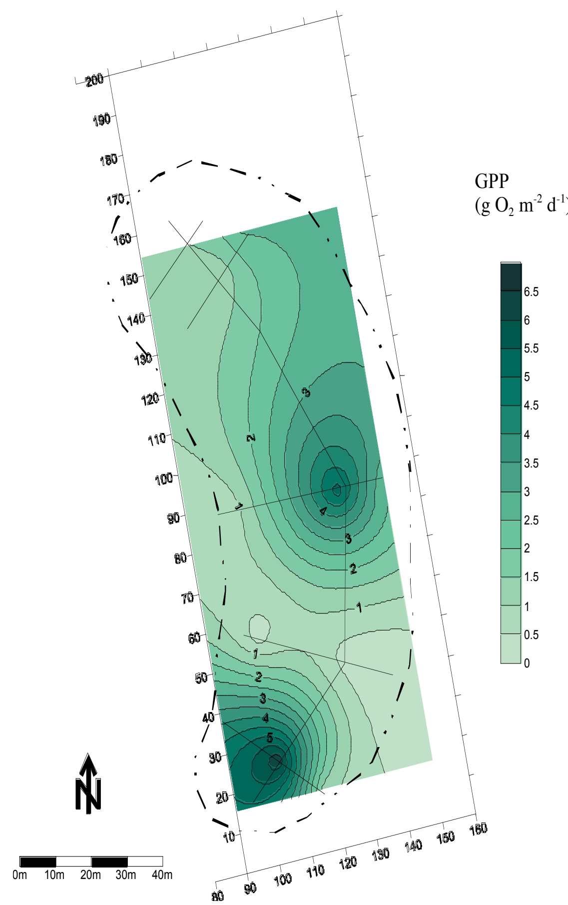

Figure 5. Surfer ® 8.02 contour plot of the mean station gross primary productivity (GPP) in Wetland 2 (W2).

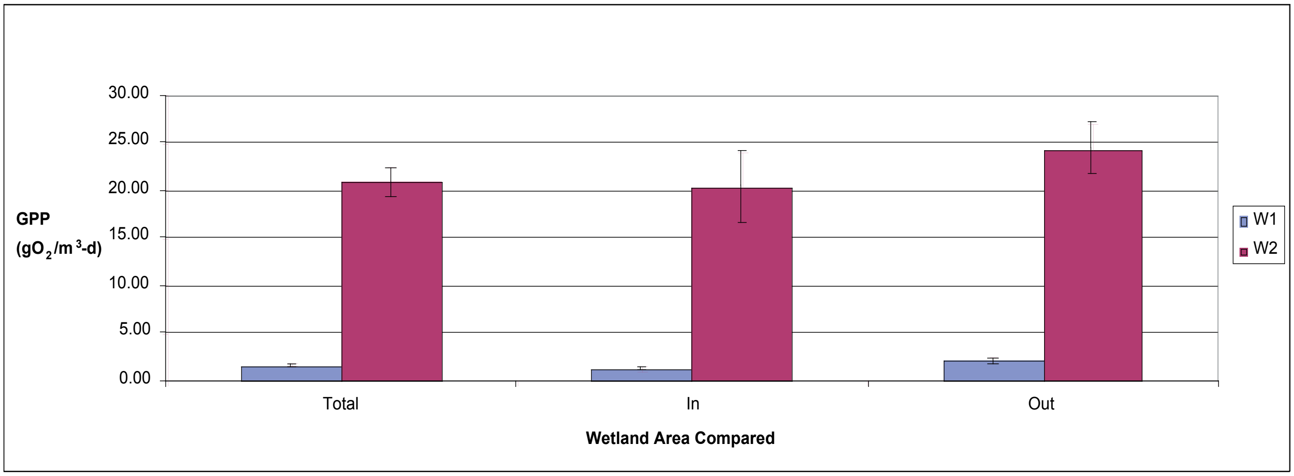

Figure 6. Comparison of average inflow and outflow area gross primary productivity for Wetlands 1 and 2 (W1 and W2).

the substrate. An in depth analysis of algal communities was beyond the scope of this project, but previous investigations identified *Cladophora, Rhizoclonium, Spirogyra, Chamydomonas*, and *Oscillatoria* as common genera in W1 and W2 (Deal and Kantz, 1997, 2001). The higher PM and lower AM values are corroborated by the correlation between solar radiation and DO.

Intra-basin mean daily DO concentration values were statistically different between the inflow and outflow areas for W1, but not for W2. In both instances, inflow concentrations were higher than outflow concentrations. Lateral variations in mean daily DO concentrations were significant in W1, with higher values located on the eastern side of the basin. Although roughly double the values in W1, lateral variations in DO concentrations in W2 were not statistically significant. Again, higher DO concentrations were recorded on the eastern side of the basin. A number of factors may explain the areal distribution of DO concentration values recorded within the two wetland basins, but two are more dominant. First, previous studies done in the same wetland have shown that water near the inflow areas have higher nutrient levels than water near the outflow areas (Yu et al., 1996). Nutrients and light conditions are the major factors affecting autrotroph activity which produce DO during photosynthesis. Secondly, the presence and distribution of autotrophs within the wetland basins (especially the observed benthic algae) will directly affect the recorded DO concentrations.

Inter-basin comparisons of mean daily DO concentrations were statistically significant. As stated above, the location and activity of the observed benthic algae is undoubtedly the reason for the observed differences in DO concentrations between the two created wetland basins.

Acknowledgments

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