# Deepwater macrophytes and water quality in two experimental constructed wetlands at Olentangy River Wetland Research Park

Maria E. Hernandez[1] and William J. Mitsch[2]

[1]*Environmental Science Graduate Program and* [2]*School of Natural Resources*
*The Ohio State University*

## Abstract

Floating, emergent and submerged plants, together with algal biomass and water quality parameters were evaluated in the deepwater basins (inflow, middle and outflow) of two experimental wetlands in Columbus Ohio during October 2002. The biomass of floating plants in W1 was $19 \pm 3$ g m$^{-2}$, $22 \pm 11$ g m$^{-2}$ and $1.0 \pm 0.6$ g m$^{-2}$ for the inlet, middle and outflow basins respectively. In the inlet basin also $134 \pm 14$ g m$^{-2}$ of emergent plant biomass was found. In the outlet basin, $107 \pm 41$ g m$^{-2}$ of submerged plant-algal biomass was also quantified. In the inlet basin of W2, floating plants biomass was $9.4 \pm 5.1$ g m$^{-2}$ and emergent biomass was $92 \pm 9$ g m$^{-2}$. In the middle and outlet basins only submerged plant-algal biomass mat were found ($73 \pm 56$ gm$^{-2}$ and $9.2 \pm 4.7$ gm$^{-2}$). The amount of each biomass type along the different basins was not statistically different. However significant difference between vegetation in the two wetlands was found in the middle basins. Temperature , pH and redox potential were not significantly different along the basins nor between two wetlands. In W-1, a significant diminution of conductivity was observed from the inflow to the outflow ($657 \pm 31$ to $520 \pm 41$ μmhoms cm$^{-1}$). Dissolved oxygen concentrations were higher in the evening than in the morning and the average of dissolved oxygen concentration in the outlet of W1 (10.7 mg l$^{-1}$) was significant higher. Conductivity decreasing and dissolved oxygen increasing were associated with the high productivity of submerged plant-algal biomass in the outlet basin of W1.

## Introduction

Plants that are adapted to grow in saturated soil conditions are called macrophytes (Misch and Gosselink, 2000). The term includes aquatic vascular plants (angiosperms and fern), aquatic mosses and some larger algae that have tissues that are easy visible (Brix, 1997). They have an important role in wetland ecosystem. In natural systems, wetland vegetation supports a diverse wildlife including birds, amphibious and mammals. In constructed wetlands, macrophytes stabilize the surface of the bed, provide good condition for water filtration and insulate the surface against frost during cold seasons (Brix, 1997). They also supply bio-available organic carbon to microbial denitrifers and provide a large surface for microbial attachment stimulating the oxidation of organic matter carried out by associated bacteria that use the oxygen that is transported from the leaves to the bed by the arenchyma (Martin and Fernandez, 1992, Bachand and Horne, 2000, Lin, et al., 2001).

Two experimental wetlands at Olentagy River Wetland Research Park (ORWRP) have similar morphology and are fed by the same inflow from the Olentangy River. The main difference between two wetlands is that one was planted with several species of emergent plants (W1) and the other wetland (W2) was naturally colonized by plant propagules (Mitsch *et al*., 1999). In the first years of operation (1994-1995), the deep areas of experimental wetlands were dominated by mats of macroalgae that included genus such as *Hydrodyctyon*, *Cladophora* , *Rhizoclonium* and *Spirogyra*. In 1998, *Lemna minor* became more abundant and by mid summer of 1999 was dominant on the surface of both wetlands, especially in the inflow and middle basins. Duckweed also grew among the stems of *Typha* and *Shoenoplectus* in the shallower portion of the wetlands (Deal and Kantz, 2000). In 2000, both inlet basins were completely covered with a thick layer of *Lemna* and there was a noticeable difference in the coverage in the mid and outlet basin. In the middle basin, W1 had approximately 25% of *Lemna* coverage, while W2 had approximately 70% of such coverage. The outlet basin of W1 had less *Lemna* than W2 (Deal and Kantz, 2001). In 2002, duckweeds became more abundant in W1 than W2, especially in the inflow and middle basins. Duckweeds have been extensively studied for its ability to remove N and P at high rates from wastewater ( Chen et al., 2002, Hernandez et al., 1997, Caicedo et al., 2000, Vermaat and Hanif, 1998).With this in mind, a question arose: does duckweed presence in wetlands at ORWRP have any influence on water quality ?

The aim of this study was quantify aquatic plant(floating, emergent and submerged plants-algal) biomass and analyze water quality parameters in deepwater basins of the two experimental wetlands at ORWP.

## Methods

### *Site description*

This study was carried out at the two kidney-shaped 1-ha basins at the ORWRP. These wetlands were constructed on alluvial old field soils adjacent to the third order Olentangy river. Both wetlands have deeper water sections located in the north, central and southern positions of the basins. The open water area of the wetlands is subdivided

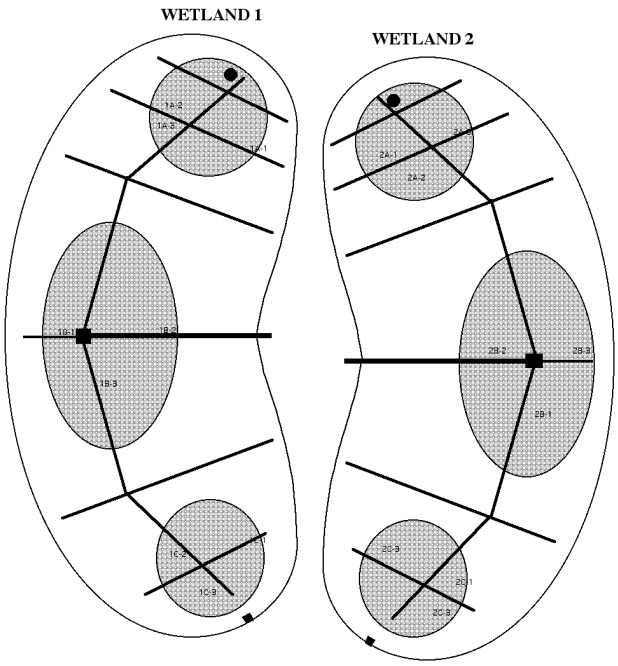


Figure 1, Deep-water areas of the experimental wetland basins.

into 3 deep (> 60 cm) basin, inflow, middle and outflow (Fig. 1), all surrounded by emergent plants. Water enters to these wetlands at their north and flows southwards and finally the water returns to Olentangy River.

## *Aquatic vegetation*

Biomass harvesting was made on October 16, 2002. All three deepwater (>60 cm) basins in both wetlands were sampled for algal and free floating, emergent and submerged plant biomass . To obtain representative samples of each vegetation type, a total of 9 samples from each wetland were taken, three samples from each basin. The sample stations were spaced throughout the three basins (inflow, center and outflow). In each point a circular frame (0.073 $m^2$) was used to delineate the area where the vegetation was harvested. Within, the sampling area all the duckweeds species were collected using a sieve and the algal and submerged plants were collected by hand. After collection, plants and algae were placed in separated paper bags and brought to the laboratory. Each sample was gently rinsed with tap water to remove mud, snails and other solid particles. In order to identify emergent, floating and submerged plants their morphology was observed and compared with the information and pictures according with Tiner (1987) and in some cases the morphology was compared with pictures from internet. To determinate the dry weight of the samples, the clean samples were collocated in pre weighed dishes, and then placed in a dry oven at 70°C over 48 hours. Dry weight was measured using an analytical balance.

## *Water Quality*

In both wetlands, in the center of each basin, (inflow, middle and outflow) water quality parameters were monitored twice per day (approximately 8:00 am and 5:00 pm). Temperature, dissolved oxygen, conductivity, pH and redox potential were measured approximately 0.20 cm below the water surface, using an YSI probe mod 610 DM, from October 18 to October 25 2002.

Table 1.- Vegetation in the three deep basins of the two experimental wetlands at the ORWRP- October 16 2002.

| Location | Plant species |
|---|---|
| Wetland 1 | |
| Inflow | |
| 1A-1 | *Lemna minor* |
| 1A-2 | *Lemna minor* |
| 1A-3 | *Lemna minor* |
| | *Typha* spp |
| | *Schoenoplectus tabernarmontani* |
| Middle | |
| 1B-1 | *Lemna minor* |
| 1B-2 | *Lemna minor* |
| 1B-3 | *Lemna minor* |
| Outflow | |
| 1C-1 | *Lemna minor* |
| | Filamentous algae |
| | *Potamogeton pectinatus* |
| 1C-2 | *Lemna minor* |
| 1C-3 | Filamentos algae |
| Wetland 2 | |
| Inflow | |
| 2A-1 | *Lemna minor* |
| 2A-2 | *Lemna minor* |
| | *Spirodella polyrrhiza* |
| 2A-3 | *Lemna minor* |
| | *Spirodella polyrrhiza* |
| | *Schoenoplectus tabernarmontani* |
| | *Typha* spp |
| Middle | |
| 2B-1 | Filamentous algae |
| 2B-2 | Filamentous algae |
| | *Ceratophylum demersum* |
| | *Potamogetum pectinatus* |
| 2B-3 | Filamentous algae |
| | *Ceratophylum demersum* |
| | *Potamogetum pectinatus* |
| Outflow | |
| 2C-1 | *Potamogetum pectinatus* |
| | Filamentous algae |
| 2C-2 | *Potamogetum pectinatus* |
| | ilamentous algae |
| 2C-3 | *Potamogetum pectinatus* |
| | Filamentous algae |

## *Statistical analyses*

Microsoft Exel version 2000 was used to analyze all data. Statistical comparisons with P- values obtained by t-test assuming unequal variance with two distribution tails was used to identify which pairs of average differ from one another (inflow, versus middle, inflow versus outflow ,

middle versus outflow in each wetland and inflow versus inflow, middle versus middle and outflow versus outflow of wetland 1 and wetland 2).

## Results

### *Aquatic vegetation*

Near the shallow water, in the inlet basin of W1, floating plant (*Lemna minor)* was found among the stems of emergent plants (*Typha spp* and *Schoenoplectus tabernarmontani*). In the middle basin a monoculture of *Lemna minor* was observed and in the outflow basin algal mats and the submerged plant *Potamogeton pectinatus* were the most abundant (Table 1). In the inlet basin of W-2, two species of duckweed (*Lemna minor* and *Spirodela polyrrhiza)* among the stems of *Typha spp* and *Schoenoplectus tabernarmontani* were found. In the middle basin, the submerged plants (*Ceratophylum demersum* and *Potamogeton pectinatus*) together with filamentous algae were harvested. In outflow vegetation was similar to W1.

In order to quantify the biomass, we grouped it into three groups: floating plants, emergent plants and submerged plant-algal biomass (Figure 2). Submerged plant and algal biomass were not separated because the filamentous algae were attached to submerged plants and the separation might have caused biomass losing. Duckweeds were the only floating plants observed in both wetlands. Duckweed biomass in W-1 was $19 \pm 3$ g $m^{-2}$ , $22 \pm 11$ g $m^{-2}$ and $1.0 \pm 0.6$ g$m^{-2}$ for the inlet, middle and outflow basins respectively. In the inlet basin also $134 \pm 14$ g $m^{-2}$ of emergent plants biomass was found. In the outlet basin, $107 \pm 41$ g $m^{-2}$ of submerged plant-algal mat was quantified. In W-2, the biomass of duckweeds was $9.4 \pm 5.1$ g $m^{-2}$ , while the emergent plant biomass was $92 \pm 91.64$ g $m^{-2}$. In the middle and outlet basin only submerged plants and algal mat was found ( $73 \pm 56$ g $m^{-2}$ and $9.2 \pm 4.7$ g $m^{-2}$) respectively. The amount of biomass along the three basins was not significantly different ( $P>0.05$). Only submerged plant-algal biomass in the middle basin was significant higher in W2 than W1.

### *Water quality*

#### Temperature

Diurnal average of temperature decreases from the inflow basin to middle basin in both wetlands, from the middle to outflow basin the temperature was very similar in each wetland (Table 2). Average of temperature in middle and outflow basin of wetland 2 were 1°C higher than W1. However these differences were not statistically significant ( $P>0.05$) In dusk, the trend of temperature in W1 was similar to the observed in the morning but in W2 temperature in middle basin and outflow basin was higher that in the inflow (Table 2). Nevertheless, such differences were not significant ( $P>0.05$)

#### pH

During the period of this study, the pH in the morning and evening was very stable along the three basins of each wetland and very similar between two wetlands (Table 2). There were not significant differences ( $P>0.05$) between the basins along the wetland nor between two wetlands. The average of 8 dawn measures of pH in the 3 basin of W1 varies from 7.64 to 7.96, while in W2, pH varies from 7.68 to 7.81. In dusk, 9 measures were taken and the range of pH average on W1 was from 7.76 to 7. 96 along the basins,

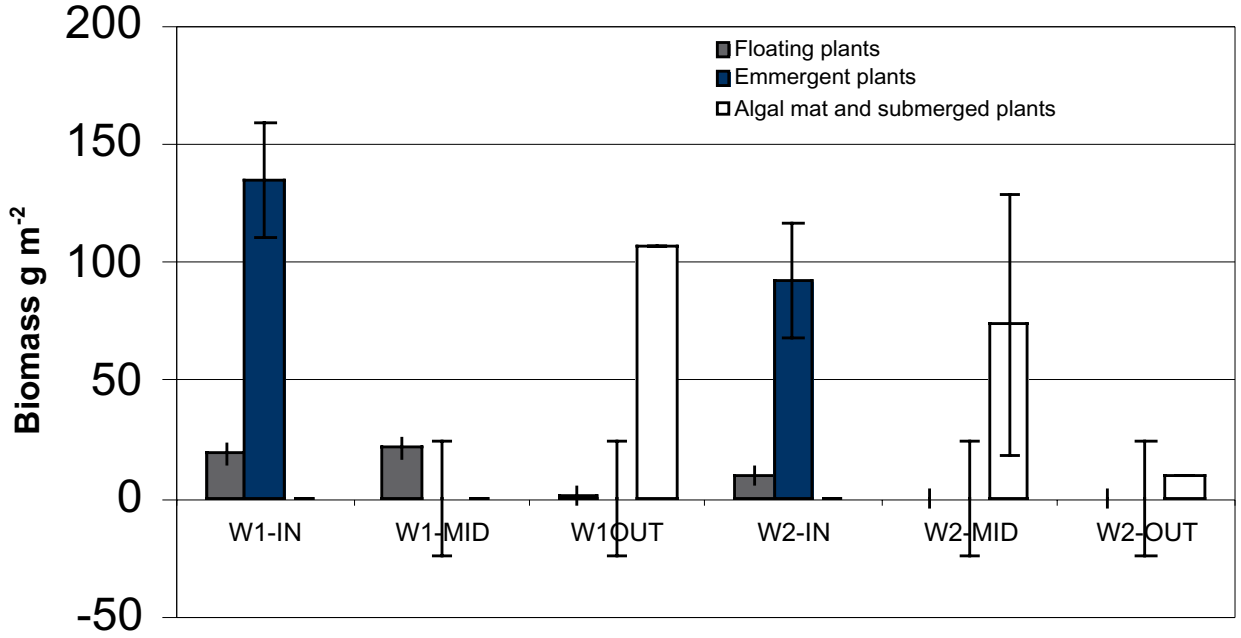


Figure 2. Biomass of floating plants, emergent plants, and algal mats/submersed plants in six deep basins,

Table 2. Water quality measurements in morning and evening in deepwater areas at Olentangy River experimental wetlands on October 2002. Numbers are average ± std error ( # of samples).

| Parameter | Wetland 1 | | | Wetland 2 | | |
|---|---|---|---|---|---|---|
| | Inflow | Middle | Outflow | Inflow | Middle | Outflow |
| *Morning* | | | | | | |
| Temp (°C) | 10.6 ± 0.8 (8) | 8.6 ± 0.7 (8) | 8.8 ± 0.9 (8) | 10.3 ± 1.0 (8) | 9.2 ± 1.1 (8) | 9.3 ± 1.3 (8) |
| pH | 7.8 ± 0.1 (8) | 7.6 ± 0.1 (8) | 7.9 ± 0.1 (8) | 7.8 ± 0.1 (8) | 7.7 ± 0.1 (8) | 7.7 ± 0.1 (8) |
| Conductivity (µmhoms $cm^{-1}$) | 711 ± 9 (8) | 727 ± 8.0 (8) | 605 ± 63 (8) | 716 ± 11 (8) | 731 ± 11 (9) | 739 ± 9.0 (8) |
| Redox (mv) | 227 ± 29 (8) | 229 ± 28 (8) | 224 ± 26 (8) | 260 ± 20 (8) | 248 ± 27 (8) | 199 ± 28 (8) |
| *Evening* | | | | | | |
| Temp (°C) | 13.8 ± 0.6 (9) | 13.5 ± 0.7 (9) | 12.2 ± 0.9 (9) | 13.6 ± 0.6 (9) | 14.7 ± 0.7 (9) | 14.2 ± 0.8 (9) |
| pH | 7.9 ± 0.1 (9) | 7.8 ± 0.1 (9) | 8.0. ± 0.1 (9) | 8.0 ± 0.1 (9) | 7.9 ± 0.1 (9) | 7.8 ± 0.1 (9) |
| Conductivity (µmhoms $cm^{-1}$) | 658 ± 31 (9) | 657 ±35 (9) | 520 ± 40 (9) | 650 ± 30 (9) | 628 ± 45 (9) | 670 ± 37 (9) |
| Redox (mv) | 255 ± 18 (9) | 251 ± 15 (9) | 246 ± 18 (9) | 256 ± 14 (9) | 258 ± 13 (9) | 261 ± 12 (9) |

while in W2 the range was from 7.84 to 7.96 in the three basins.

## Conductivity

In wetland 1, both morning and dusk reading of conductivity decreased 15% and 21% respectively from the inflow to the outflow (Table 2). However, only conductivity reduction in dusk was statistically different from inflow to outflow basin and middle to outlet (P=0.019, P=0.020). In wetland 2 was not observed decrease of conductivity from the inflow to the outflow. In the dusk, the conductivity in the outflow basin of W1 was significant lower than in the outflow of W2( P=0.017).

## Redox

Redox potential did not showed significant differences along the basin of each wetland and neither did between two wetlands (P>0.05). The range of redox potential along wetland 1 was from 225 ± 26 to 255 ± 17 ± mhomscm$^{-1}$, while along wetland the range was from 199 ± 28 to 261 ± 13.

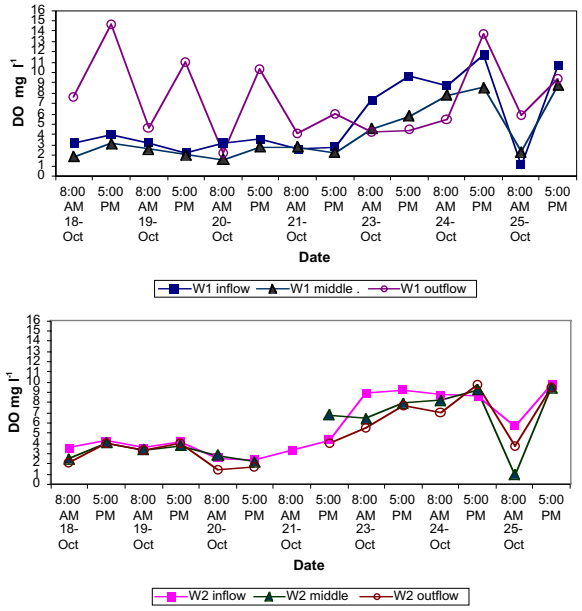


Figure 3. Dissolved oxygen in morning and evening in deepwater basins in Wetland 1 (top) and Wetland 2 (bottom)

## Dissolved Oxygen

As expected, dissolved oxygen was higher in dusk than in morning readings in both wetlands ( Figure 3). The diurnal average of dissolved oxygen was 4.3 ± 0.1, ± 3.9 ± 0.9 and 5.3 ± 0.7 mg $l^{-1}$ for inlet, middle and outlet basins, while for W-2 was 5.5 ± 0.7, 4.0 ± 1.1 and 3.9 ± 0.9 mg $l^{-1}$, respectively. Not significant differences along the basins and between wetlands were found in the diurnal dissolved oxygen ( P>0.05). However, in the outflow basin of W1, dissolved oxygen changes from dusk to dawn were higher and the average of dusk dissolved oxygen (10.8 mg $l^{-1}$) in this basin was significantly higher than in the middle basin (6.4 ± 1.5 mg $l^{-1}$).

# Discussion

Vegetation in the middle and outflow basins was different between two wetlands. In W1, *Lemna minor* was present in the inlet and covered the middle basin and in outlet basin was scarce. This pattern was probably associated with nutrient gradient along the basin as well with light intensity. Unfortunately during the period of this study, we did not have available data of these parameters. However, in the past, Lipak and Mitsch (2000) reported an average of N-$N0_3$ diminution from inlet ( 3.3 ± 1.0 mg $l^{-1}$), middle (2.4 ± 1.0 mg $l^{-1}$) to outlet basin (1.2 ± 0.5 mg $l^{-1}$). Although nutrients might be higher in the inlet basin, we did not find higher biomass of *Lemna minor*. This could be due to the presence of emergent vegetation which can provide shade to duckweeds and also they compete for nutrients. Green and Woolley (1999) described that the productivity of duckweeds was twice higher when they grew in open water compared to their growing among the *Typha*, in constructed wetlands in Australia. In the inlet basin of W2, two species of duckweeds (*Lemna minor* and *Spirodela polyrrhiza*)

were found. Under laboratory conditions, *Spirodela polyrrhiza* had better performance in wastewater with high concentration of N than *Lemna minor* (Vermaat and Hanif, 1998). However, in the case of ORWRP, nitrogen concentrations in the past has not been different in the inlet basin of two wetlands. Therefore, other factors such as light might have influenced the distribution of *Spirodela polyrrhiza* in W2. In this study duckweed coverage in W1 was bigger than in W2. These results differed from previous reports. Duckweed became abundant in 1998, at that time both wetlands have the same amount of duckweed. In 2000, 25 % of wetland 1 was covered by duckweeds, while wetland 2 had 70% of such coverage (Robert and Kantz, 2000, Deal and Kantz, 2001)

Regarding submerged vegetation, the presence of *Potamogeton pectinatus* in the outlet basin of wetland 1 and in the middle and outlet of wetland 2 is logical because this specie was introduced in 1994 in W-1. *Ceratophylum demersum* was other submerged plant found in the middle basin of W-2, however, this species has not been described in previous studies at ORWRP. Leonard et al. (2000) found that the most abundant plants in the two constructed wetlands in fall 1999 to be *Najas* sp and *Cladophora* sp. They discussed that these species also were different from the previous studies. Therefore, it seems that submerged and floating plants have spatial variations through the years.

Deepwater macrophytes of the experimental wetlands have not been monitored annually although in 1999 vegetation was quantified by Leonard et al. (2000). Figure 4 shows a comparison between their results and the present study. In W1, duckweed distribution along the basins was very similar in 1999 and 2002, although higher amount of duckweed was observed in the inlet in 1999. In both years the submerged-algal mat biomass was higher in the outlet of W1, in 1999 this kind of vegetation also was observed in the middle basin but was not found in 2002. In W2, the inlet basin had higher amount of duckweed biomass in 1999 than 2002, in the middle basin, submerged-algal biomass was higher in 2002 than 1999 and in the outlet basin, submerged-algal biomass was similar for both years. It seems that macrophytes in middle basin of W-2 were more susceptible to variations than W1. Such variations may be related with wildlife activities, since more waterfowl feces are observed on the boardwalk of W2, indicating higher use of this wetland than W1. The disturbances caused by waterfowl activities such as swimming and driving below the water surface probably caused that duckweed did not grow in the middle and outlet basins , therefore more light penetrate into the water column and this promote higher growth of submerged macrophytes. However, waterfowl graze submerged vegetation (McKnight, 1998); thus it seems that during 2002, waterfowl grazed mainly in the outlet basin causing lower amount of this kind of vegetation than in the middle basin.

In relation with water quality parameters, the values of pH found during this study are very similar to the annual average described by Leonard et al. (2000) for both wetlands in October of 1999 (7.7± 0.9 for W1 and 7.9 ± 0.8 for W2).

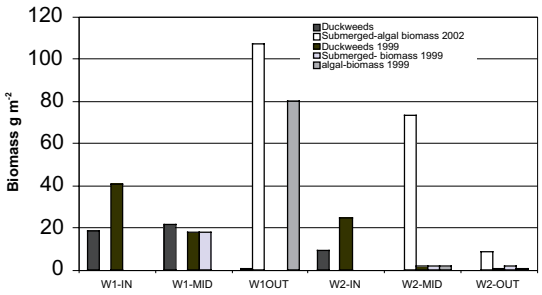


Figure 4. Comparison of deepwater pond biomass with data from previous studies.

It has been described that the annual average of pH in the outflows was significantly higher than in outflow in both wetlands (Mitsch et al., 2000). However in this short period of monitoring we did not appreciate such variation.

Redox potential found was not significantly different along the basins and between the two wetlands. The values and the pattern of potential redox found in this study is consistent with previous annual averages of this parameter, 302 mv in the inflow, 283 and 284 mv in the outflow of wetland 1 and wetland 2, respectively (Mitsch et al., 2000).

The conductivity decreased from the inflow to the outflow in wetland 1, and this parameter was significantly lower in the outflow of wetland 1 than in the outflow of wetland 2. The drop of conductivity is due to the diminution in dissolved ions which is caused by the precipitation of calcium carbonate and other minerals. Such precipitation is carried out in high pH which is produced by high water column productivity. In this case outlet basin of wetland 1, had high algal mat concentration that probably caused diminution of dissolved ions.

The dissolved oxygen concentration in water was higher in the dusk than in the morning. Such pattern is due to the photosynthesis carried out by plants during the day that increase the dissolved oxygen and the respiration during darkness that utilize oxygen. The dissolved oxygen in this study, was statistically higher in the outflow of W-1 than the other sampling points. Such results coincide with the annual pattern of dissolved oxygen observed in 1999 (Mitsch et al., 2000). The higher dissolved oxygen concentration in the outlet basin of wetland 1 probably is due to the high productivity in water column in this basin. Newuman and Pietro (2001) also observed high elevated day and nighttime DO concentrations in constructed wetlands with submerged macrophyte/algal dominant cell treating agricultural runoff in Florida. They argued that high DO concentrations were associated with the presence of algal mats that caused a continuous production of $O_2$ into the water.

## Conclusions

In the inlet basin, there were not significant differences in deepwater macrophytes between two wetlands. The middle basin of W2 had higher amounts of submerged

plant-algal biomass than did the middle basin of W1 which was covered by a monoculture of *Lemna* sp. The outlet basin of W1 had high amount of submerged plant-algal biomass. The spatial distribution of deepwater macrophytes was different from other years. Although visible duckweed coverage was higher in W1, the biomass did not show significant differences and this coverage did not have any influence in water quality parameters. The decrease of conductivity and increase of dissolved oxygen from inflow to outflow in W1 was related with the high productivity of submerged plant-algal biomass in the outlet basin of this wetland.

## References


Bachand, Philip, A.M., Horne, A.J., 2000. Denitrification in constructed free-water surface wetlands. II. Effects of vegetation and temperature. Ecol. Eng. 14, 17-32

Brix, Hans.1997. Do macrophytes play a role in constructed treatment wetlands? Wat Sci. Tech. 35, 11-17

Caicedo, J.R., Van Der Steen, N.P., Arce, O., Gizen, H.J., 2000. Effect of total ammonia nitrogen concentration and pH on growth rates of duckweeeds (*Spirodela polyrrhiza*). Wat. Res. 15, 3829-3835

Chen, J., Bergmann, B.A., Classen, J.J., Stomp, A., Howard, J.W., 2002. Nutrient recovery from swine lagoon water by *Spirodela punctata*. Bioresource Technol. 81, 81-85.

Deal, R., Kantz, J.A. Summer mat macroalgae largely replaced by duckweed, *Lemna minor*, in 1999 in two Olentangy Rivers experimental wetlands.2000. In: Mitsch, W.J. and Zhang, L. (Eds.). Olentangy River Wetland Research Park at the Ohio State University, Annual Report 1999.The Ohio State University, Columbus Ohio, pp 65-77

Deal, R. , Kantz, J.A., 2001. Algal and *Lemna* populations continue to fluctuate seasonally and basin-to-basin in the Olentangy River wetlands. In: Mitsch, W.J. and Zhang, L. (Eds.). Olentangy River Wetland Research Park at the Ohio State University, Annual Report 2000. The Ohio State University, Columbus Ohio, pp 61-63

Greenway, M ,Woolley T, 1999. Constructed wetlands in Queensland: Performance efficiency and nutrient bioaccumulation. Ecol. Eng. 12: 39-35

Hernandez, M.E., Olguin, E.J., Trujillo, S., Vivanco, J. 1997. Recycling and treatment of anaerobic effluents from pig waste using *Lemna sp*. under temperate climatic conditions. In Wise , D. L. ( Ed). Global Environmental Biotechnology. Elservier, pp 293-304

Leonard J.N., Wang L. and Mitsch W.J., 2000. Gross primary productivity and aquatic plant biomass: indicators of divergence in two constructed wetlands. In: Mitsch, W.J. and Zhang, L. (Eds.). Olentangy River Wetland Research Park at the Ohio State University, Annual Report 1999.The Ohio State University, Columbus Ohio, pp 69-82.

Lin, Y.F. Jing, R.S., Wang T.W., Lee, Y.D., 2002. Effects of macrophytes and external carbon sources on nitrate removal from groundwater in constructed wetlands. Environmental Pollution. 119, 413-420

Lipak, M.A, Svengsouk, J.L, Johnson , S..M. and Misch, W.J. 1997. Wetland macrophyte development in the experimental wetlands at the Olentagy River Wetland Research Park during the third growing seasons. In: Mitsch, W.J. (Ed.). Olentangy River Wetland Research Park at the Ohio State University, Annual Report 1996.The Ohio State University, Columbus Ohio, pp 159-172.

McKnight, S.K.1998. Diet selective of gadwalls wintering in Alabama. Journal of Wilde Life management 62(4): 1533-1453.

Martin, I., Fernandez, J., 1992. Nutrient dynamics and growth of cattail crop (*Thypha latifolia*). Developed in an effluent with high eutropihic potential- application to wastewater purification systems. Bioresource Technol. 42, 7-12.

Mitsch J.W. and Carmichael M., 1997. Water quality and nutrient removal pattern of created riparian wetlands. Third year results and 3 year summary. In: Mitsch, W.J. (Ed.). Olentangy River Wetland Research Park at the Ohio State University, Annual Report 1996.The Ohio State University, Columbus Ohio, pp 69-82

Mitsch J.W., Wang N, Bouchard V., Ford M., Mohler, K, 1999. Biogeochemical and nutrient removal pattern of created riparian wetlands: fifth-year results. In: Mitsch, W.J. and Bouchard, V.(Eds.). Olentangy River Wetland Research Park at the Ohio State University, Annual Report 1998.The Ohio State University, Columbus Ohio, pp 79-86.

Mitsch J.W., Bouchard V., Zhang, L. and Hunter, M., 2000. Biogeochemical and nutrient removal pattern of created riparian wetlands: sixth-year results. In: Mitsch, W.J. and Zhang, L.(Eds.). Olentangy River Wetland Research Park at the Ohio State University, Annual Report 1999.The Ohio State University, Columbus Ohio, pp 83-90.

Mitsch J.W. and J.G. Gosselink, 2000. Wetlands. 3ed John Wiley and Sons Inc., New York , 892 pp.

Newman, S. and Pietro, K.2001. Phosphorus storage and release in response to flooding: implications for Everglades stormwater treatment areas.Ecol. Eng.,18: 23-38.

Tiner, R.W. Jr.1988. Field Guide to Nontidal Wetland Identification. Institute for wetlands & environmental education Inc. 251pp.

Vermaat, J.E. , Khalid, Hanif., 1998. Performance of common duckweed species ( Lemnaceae) and the waterfern *Azolla filiculoides* on different types of wastewater. Wat. Res. 32, 2569-2576.