Ecological characteristics of a natural wetland receiving secondary effluent

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Abstract The Boot wetland treatment system is a 115-acre, hydrologically altered cypress-gum wetland in Polk County, Florida. The Poinciana Wastewater Treatment Plant No. 3 has discharged secondary effluent to the bermed Boot wetland since August 1984. Before that time this natural wetland had been affected adversely by forestry, drainage, and surrounding development which contributed to dying trees and a groundcover of invasive upland plants. In accordance with the Florida Department of Environmental Protection’s Wetlands Application Rule (Chapter 62–611, F.A.C.), a routine biological and water quality monitoring program has been in effect since October 1990. Components of the biological monitoring program include surveys of canopy and subcanopy, herbaceous and shrub groundcover species, benthic macroinvertebrates, fish, and nuisance mosquitoes. Effluent addition to the Boot wetland has resulted in continuous wetland inundation with a typical water depth of 2.5 to 3.0 feet for the past 15 years. Dominance and density of trees has steadily increased, upland invader species were eliminated, and stable plant, fish, and invertebrate communities were established. The long term biological data from this treatment wetland is compared to data from other natural treatment wetlands and a control wetland.

Keywords Fish; macroinvertebrates; natural wetlands; treatment wetland; vegetation; wastewater effluent

Introduction

The Boot wetland is a 115-acre natural cypress dome that has been receiving secondarily treated municipal wastewater since 1984. Because the wetland had been completely bermed to support the retention and treatment of wastewater, the entire wetland has been continuously inundated with water depths typically ranging from 2.5 to 3 feet. Before 1985, forestry, drainage canals, and surrounding land development had adversely affected this wetland. In the early 1980s, peat was rapidly oxidizing, cypress trees were leaning and dying, and groundcover vegetation had changed to invasive upland plants (Breedlove, 1986). The Boot wetland now supports a healthy and growing stand of trees, diverse wetland groundcover species, and a stable population of fish and macroinvertebrates.

The Boot wetland is located in Poinciana, Polk County, Florida (Figure 1). It lies within the Marion Creek/London Creek watershed, which is a subbasin of the Reedy Creek and Kissimmee River basin. Severn Trent-Avatar Utility Services, LLC., operates the Poinciana Wastewater Treatment Plant No. 3 (WWTP No. 3) which discharges secondarily treated municipal wastewater via a submerged discharge pipe into the north end of the Boot wetland (Station 1). The treated wastewater discharge to the Boot wetland has been nearly continuous since August 1984. The wetland seasonally overflows from its south end to the M-7 drainage canal (Station 3).

As part of the permit to operate WWTP No.3, required monitoring of the treatment wetland was conducted in accordance with Florida Administrative Code Chapter 62–611 (Wetland Application), Table 1. The permit has allowed for the continuous discharge of up to 0.35 million gallons per day (mgd) from WWTP No.3 to the Boot wetland. CH2M HILL has generally collected monthly water quality and quarterly biological data from the Boot
wetland since October 1990. This report presents the findings of the biological monitoring in this unique wetland.

**Methods**

**Vegetative communities**

Three permanent vegetation sampling plots in the Boot wetland treatment system were established in 1990 (Figure 1). Plot 1 is located near the submerged influent distribution pipe at the northern end of the Boot wetland. Plot 2 is located in the approximate center of the wetland, and Plot 3 is located near the overflow weir at the southwest corner of the wetland.

Canopy and subcanopy strata are monitored within Plots 1, 2, and 3. Each plot measures 10 m by 30 m and is permanently marked with plastic stakes. All canopy trees (trees greater than 4 inches (10.16 cm) diameter at breast height – (dbh)) and subcanopy trees (trees between 1 and 4 inches (2.54 and 10.16 cm) dbh) within each plot are identified to species and permanently marked with numbered aluminium tags. Tree diameter measurements are conducted annually and measured at the bottom edge of the hanging tag to maintain consistency between measurements.

Canopy and subcanopy tree diameter data are used to calculate dominance and density as follows:
Dominance = Total basal area of Species A (centimetres)

Density = Number of individuals of Species A
          ________________________________
          Total area sampled (hectares)

Shrub and herbaceous strata are monitored quarterly within each vegetation plot. The line-intercept method is used in which a tape measure is stretched through the middle of the plot (30 metres), and the linear coverage of each plant species lying vertically over, under, or touching the tape is recorded. The shrub/herbaceous stratum is defined as all vascular plant species exclusive of the canopy and subcanopy. The line-intercept data are used to generate estimates of percent cover as follows:

Linear Cover Distance for Species A = Sum of all line-intercept distances for Species A (cm)

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\text{Percent Cover} = \frac{\text{Linear cover distance of Species A}}{\text{Total transect distance}} \times 100
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Mosquitoes
The density of mosquito larvae and pupae is monitored at Stations 1, 2, and 3 (Figure 1) on a monthly basis from April to November each year. Twenty surface dips with a 0.45 litre dipper are made at each station. The total number of mosquito larvae and pupae captured in these dips is recorded.

Benthic macroinvertebrates
Benthic macroinvertebrates are sampled at Stations 1, 2, and 3 (Figure 1) in the Boot wetland using Hester-Dendy artificial substrate samplers. Five samplers with a combined surface area of 0.75 m² are placed on a quarterly basis at each station. Hester-Dendy samplers are suspended from a floating frame that holds the samplers within two inches of the water surface, regardless of water level fluctuations, for a period of 28 days of incubation. Taxonomic identification to the lowest practical level is completed by a subcontracted taxonomic laboratory.

Fish
Fish populations are sampled along Transects 1, 2, and 3 (Figure 1) in the Boot wetland on a quarterly basis. A Wegener ring with a surface area of 0.94 m² is used to quantitatively sample fish in the wetland. Five ring tosses are made at approximately 30 m intervals along each transect. After each toss, the bottom of the ring is pressed into sediment and the water column inside the ring is inventoried with at least 10 sweeps of a dip net. All collected fish are identified to species, counted, and preserved in alcohol for laboratory determination of wet weight for biomass calculations.

Control wetland
A control wetland located approximately one mile south of the Boot wetland was monitored for a period of one year, from October 1990 to September 1991. This wetland represented a typical unimpacted cypress dome in the Poinciana development. No drainage activities have taken place in this wetland, however shallow ditches are located adjacent to the wetland on its north and southwest sides. This wetland did experience seasonal drawdowns during the monitoring program. Biological monitoring in the control wetland was identical to that conducted at the Boot wetland, but at a single station. Therefore, there
was a single vegetation plot, mosquito and macroinvertebrate station, and fish monitoring transect.

**Results and discussion**

Biological monitoring data are reviewed to provide a quantitative comparison of biological communities within the wetland and in some cases comparisons with other regional treatment wetlands. Three types of biological data are presented: vegetation, fish, and invertebrates.

**Vegetation**

*Canopy and Subcanopy.* A total of nine canopy and subcanopy species have been identified in the Boot wetland monitoring plots since 1990. They include pond cypress (*Taxodium ascendens*), blackgum (*Nyssa sylvatica* var. *biflora*), wax myrtle (*Myrica cerifera*), dahoon (*Ilex cassine*), Virginia-willow (*Itea virginica*), sweet bay (*Magnolia virginiana*), fetter-bush (*Lyonia lucida*), swamp bay (*Persea palustris*), and red maple (*Acer rubrum*).

The dominance of canopy and subcanopy species has steadily increased in the wetland during the past nine years of continuous inundation. Figure 2 shows that the average canopy basal area for the entire wetland increased from 51.8 to 70.9 m²/ha, while the subcanopy increased from 1.3 to 2.7 m²/ha. Pond cypress and blackgum have consistently dominated the canopy during this period, with respective basal area increases of 45.2 to 61.0 and 6.5 to 9.8 m²/ha. In the subcanopy there was a general shift in dominant species from pond cypress to wax myrtle, beginning about 1995. Dominance of subcanopy pond cypress decreased slightly from 0.7 to 0.5 m²/ha from 1990 to 1999, while wax myrtle dominance increased from 0.09 to 1.7 m²/ha. The cause was a gradual reassignment of five pond cypress into the canopy size class, lack of new recruitment of young pond cypress, and the new recruitment of 70 wax myrtles in recent years.

Dominance was also compared between tree plots along the surface water flow path in the Boot wetland. Plot 1 is located in close proximity to the effluent distribution pipe, Plot 2 is in the center of the wetland, and Plot 3 is the most distant from the outfall and near the wetland overflow. Canopy dominance increased steadily at all three plots and indicated no adverse trend associated with proximity to the outfall (Figure 2). Subcanopy dominance also showed an increase over time at all three plots and no apparent relationship with proximity to the outfall. The increased wax myrtle recruitment into the subcanopy affected all plots similarly with a greater rate of basal area increase beginning in 1996.

The mean annual growth rate of trees within this continuously inundated wetland is illustrated in Figure 3. Pond cypress was identified as a representative species due to its dominance throughout the wetland, and only those trees (canopy and subcanopy) which had been measured since 1990 were included. A total of 102 pond cypress were evaluated, and on average the mean annual diameter growth for all trees was 0.44 cm/year. This growth rate is higher than that measured by Straub (1984) where bald cypress (*Taxodium distichum*) in two separate wastewater receiving wetlands had annual growth rates ranging from approximately 0.20 to 0.40 cm/yr. The control wetland in this same study had a slower mean annual growth rate that ranged from approximately 0.01 to 0.20 cm/yr. In an unpublished study conducted by CH2M HILL, tree growth in an unimpacted natural wetland (Green Swamp Wildlife Management Area, Florida) was measured. Growth rates of cypress trees ranged from 0.29 to 0.67 cm/year, with an average of 0.54 cm/yr, and is comparable to the growth rate of Boot wetland cypress. Amongst the three Boot wetland plots, Plot 3 (wetland overflow area) had an annual average growth rate that was typically higher than the other two plots, and for the period of record averaged 0.63 cm per year, compared with 0.42 cm per year at Plot 1 (near effluent discharge) and 0.38 at Plot 2 (middle wetland)
It is apparent from these comparisons that pond cypress growth rate in the Boot wetland has not been adversely affected by the addition of treated effluent or the continuous inundation, and is similar and sometimes better than other treatment or natural wetlands.

There was no significant tree mortality recorded during the nine years of monitoring. The first vegetation monitoring event in 1990, five years after initiation of effluent discharge, identified the following standing dead trees in all plots: 11 pond cypress, 4 wax myrtle, and 4 red maple. Since 1990 only 8 subcanopy size class trees out of 222 monitored canopy and subcanopy trees died, including 1 magnolia, 3 pond cypress, 3 wax myrtle, and 1 swamp bay. Thus, there has been no significant tree mortality in the Boot wetland during the last nine years.

The nearby, unimpacted control wetland was dominated by pond cypress. In 1990, total canopy dominance in the control wetland was 19.4 m²/ha, compared to the higher 51.8 m²/ha in the Boot wetland. This corresponded with canopy density measurements of 400 trees/ha in the control wetland compared to the much higher 1,259 trees/ha for the Boot wetland. The control wetland however is a subcanopy dominated system. Subcanopy dominance was 10.3 m²/ha in the control wetland compared to 1.3 m²/ha at the Boot.
wetland. Subcanopy density in the control wetland was measured at 4,650 trees/ha, much higher than in the Boot wetland which had 353 trees/ha.

Canopy data have been recorded at five other southeastern natural treatment wetlands: Eastern Service Area, Reedy Creek, Bear Bay, Central Slough, and Deer Park (CH2M HILL, 1998). Canopy basal area varies from about 11 to 140 m²/ha from these systems, with Eastern Service Area having the highest value recorded. The Boot treatment wetland had the second highest canopy basal area. A high basal area is indicative of a long period of tree growth since the forest was logged. Tree density varies from 400 trees/ha in the Boot control wetland, to 3,785 trees/ha in the Reedy Creek Treatment Wetland. Tree density data illustrate the different successional status of each of these ecosystems. The Boot wetland canopy density lies near the median of the reported values. Overall the data demonstrate that continuous effluent discharge is compatible with forested wetland tree populations. One exception is Central Slough which has shown a decrease in average basal area (58.2 to 32.6 m²/ha) and density (848 to 460 trees/ha) from 1989, which may be related to the consistently high inflow constituent concentrations (especially ammonia nitrogen).

Shrub/Herbaceous Vegetation. The Boot wetland has supported a consistently diverse community of groundcover vegetation over the last nine years. Over 60 shrub and herbaceous species have been identified during this period. There was no exposed ground surface within any of the plots due to the continuously high water level, and the resulting surface water typically had 100 per cent cover of floating aquatic plants. As a result, the dominant groundcover species occurring in the Boot wetland were duckweeds (Lemna spp.), frog’s bit (Limnobium spongia), and water fern (Salvinia rotundifolia). Mosquito fern (Azolla caroliniana), water-meals (Wolffia spp.), and bog mats (Wolffiella spp.) were commonly associated with these floating species. Of the plant species attached to the bases of trees, cypress knees, and fallen logs, the most common were swamp fern (Blechnum serrulatum), cinnamon fern (Osmunda cinnamomea), chain fern (Woodwardia virginica), water primrose (Ludwigia peruviana), water hoarhound (Lycopus rubellus), Virginia-willow (Itea virginica), saw-grass (Cladium jamaicense), and poison ivy (Toxicodendron radicans).

The diversity of groundcover species within each plot and the wetland as a whole was measured quarterly since 1990. Species diversity was high at all transects, and remained relatively stable over the nine year monitoring period with seasonal fluctuations. The average number of groundcover species for Plots 1, 2, and 3 were 20, 11, and 13, respectively. For the Boot wetland as a whole, the number of groundcover species per monitoring event ranged from 21 to 36, with an average of 29. The data do not indicate any adverse effects of effluent on the diversity and density of groundcover species during the last nine years of wetland treatment.

The control wetland groundcover species community was different from the Boot wetland primarily due to the low frequency of inundation. A single vegetation plot in this wetland was monitored four times in 1990–91. Twenty-nine groundcover species were identified in the control wetland compared to over 60 in the Boot wetland. Thirteen plant species were common to both wetlands. The dominant herbaceous species in the control wetland was water hyssop (Bacopa carolinianum). Other common groundcover species included wax myrtle seedlings, cinnamon fern, rush (Juncus polycaphalus) water hoarhound, and pond cypress seedlings. None of the floating aquatic plant species observed in the Boot wetland were present in the control wetland.

Fish and invertebrates

Mosquitoes. Mosquito larvae and pupae monitoring was conducted monthly during the
summer months. Samples were collected in areas that typically contained about 70 per cent floating or rooted wetland plants, and about 30 per cent open water. The number of immature mosquitoes collected at each station was typically low. For the period of record (67 events), the average number of mosquitoes at Stations 1, 2, and 3 was 143, 506, and 527 larvae/m³, respectively. This is comparable to the nearby control wetland, where although only 8 sampling events were conducted during one summer, the average number of mosquitoes was 296 larvae/m³. The average immature mosquito density for all Boot wetland stations combined was 392 larvae/m³. These larvae densities are less than those reported at two natural treatment wetlands (791 and 4830 larvae/m³) at Reedy Creek, Florida (CH2M HILL, 1998). As described below, the abundance of small fish species appears to provide a significant control on mosquito populations in the Boot wetland.

**Benthic macroinvertebrates.** Macroinvertebrate density, as measured using Hester-Dendy samplers, has been consistently low throughout the wetland during the period of record. A total of 34 sampling events have been conducted. Overall, the average density of macroinvertebrates in the wetland was measured at 39.6 organisms/m², and the average number of taxa was 11.1. The most common group of organisms found in the samples were of the family Chironomidae, and to a lesser extent Naididae.

Across the three wetland monitoring stations, average density was low and showed a slightly increasing trend from Station 1 near the effluent discharge to Station 3 near the wetland overflow. For the period of record, average macroinvertebrate densities for Stations 1, 2, and 3 were 15.5, 40.2, and 63.1 organisms/m², respectively. The corresponding average number of taxa for Stations 1, 2, and 3 were 3.0, 5.8, and 5.6. The maximum number of taxa recorded at a single station was 19 at Station 3, and the maximum density recorded was 347 organisms/m², also at Station 3. At Stations 1 and 3 there were many sampling events where no organisms were identified on the five Hester-Dendy samplers. The most significant factor affecting macroinvertebrate populations is the low dissolved oxygen concentration in the wetland water column. Typically dissolved oxygen within one to two inches of the water surface is between 1 to 2 mg/L, and then drops to less than 0.5 mg/L, and often less than 0.1 mg/L, at mid depth.

The nearby control wetland was monitored with Hester-Dendy samplers only once in January 1991 due to the lack of or very shallow water conditions over its annual monitoring period. The results of this single event identified a much greater diversity and density of macroinvertebrates compared to the Boot wetland, with a total of 28 taxa and 467 organisms/m². It is likely that the higher dissolved oxygen (3.0 mg/L) in this control wetland was a significant factor in the greater relative diversity and abundance of macroinvertebrates.

The use of Hester-Dendy artificial substrate samplers in the Boot wetland (required by permit conditions), has not provided a representative picture of the macroinvertebrate community. Qualitative observations of macroinvertebrates occupying the root structures of floating macrophytes indicate a greater density and diversity than was measured with the suspended Hester-Dendy samplers. Other sampling methods (e.g. dip net sampling) would likely measure a more productive macroinvertebrate community than was indicated by the submerged artificial substrate samplers.

**Fish.** The Boot wetland supports a diverse and healthy fish population. A total of six fish species were collected which included the least killifish (*Heterandria formosa*), mosquitofish (*Gambusia affinis*), sailfin molly (*Poecilia latipinna*), everglades pygmy sunfish (*Elassoma evergladei*), golden topminnow (*Fundulus chrysotus*), and pirate perch (*Aphredoderus sayanus*).

A total of 34 fish monitoring events were conducted at each of the three wetland tran-
sects during the period of record. Total fish biomass in the wetland averaged 1.2 grams/m² for the sampling period. This is primarily due to the small size of the species that occur in this type of natural wetland environment. No game fish species were captured during the study, although a yellow bullhead (*Ameirurus natalis*) was observed once in the wetland. Density of fish in the Boot wetland ranged from 2.8 to 20.7 fish/m², and averaged 8.3 fish/m².

The mosquitofish and least killifish were the most abundant species, ranging in average density from 3.5 to 3.8 fish/m², respectively. The remaining species, including the everglades pygmy sunfish, sailfin molly, golden topminnow, and pirate perch had average densities of 0.6, 0.4, 0.2, and 0.1 fish/m², respectively.

Fish were sampled in the control wetland twice in 1991 (two other events during the single monitoring year were dry). A total of six species were collected, including the everglades pygmy sunfish, mosquitofish, golden topminnow, flagfish (*Jordanella floridae*), a juvenile sunfish species (*Lepomis* sp.), and a shiner species (*Notropis* sp.). Average fish biomass in the control wetland was 0.3 grams/m², lower than in the Boot wetland (1.2 grams/m²). The average fish density of 2.4 fish/m² was also less than the Boot wetland (8.3 fish/m²). The most abundant species was the mosquitofish, averaging 1.8 fish/m² (also less than in the Boot wetland) while all other species averaged 0.2 fish/m².

**Conclusions**

The Boot natural wetland treatment system has received treated municipal wastewater for over 15 years. A significant biological database has been collected for the Boot wetland during the past 10 years. These data demonstrate that long-term discharge of treated municipal effluent into a continuously inundated natural cypress-dominated wetland supports healthy and diverse populations of trees, vegetative groundcover, fish, and macroinvertebrates.

The only detrimental responses identified in the wetland were the lack of new recruitment by the dominant tress (pond cypress and black gum) and low ambient dissolved oxygen conditions. No adaptation to the lack of tree recruitment is necessary in the Boot wetland due to the very long lifespan of the dominant tree species (typically many hundreds of years in the absence of logging or drainage). The Boot wetland has adapted to low dissolved oxygen conditions by compressing diverse and large populations of aquatic fauna at or near the water surface.

Compared to the impacted conditions of the Boot wetland before the addition of treated wastewater and compared to a control wetland not receiving treated effluent, the structure and function of the Boot wetland have been significantly improved.

**References**

