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IMPACTS OF SECONDARILY TREATED MUNICIPAL EFFLUENT ON A FRESHWATER FORESTED WETLAND AFTER 60 YEARS OF DISCHARGE

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Abstract: Secondarily treated municipal effluent from Breaux Bridge, Louisiana has been discharged into the Cypriere Perdue forested wetland since the early 1950s. Approximately one million gallons per day (3,785 m^{-3} day^{-1}) are discharged into the 1470 ha wetland, with average total nitrogen and phosphorus loading rates of 1.15 g N m^{-2} yr^{-1} and 0.31 g P m^{-2} yr^{-1}, respectively. Vegetation and water quality of this wetland, along with a reference wetland, were monitored. Study sites were dominated by bald cypress and water tupelo, and species composition did not change significantly during the time of monitoring. Mean litterfall was higher near the effluent discharge point compared to sites located further away or the reference site. Mean stem growth was lower at the site furthest from the discharge point compared to the other sites. Nutrient concentrations measured at the site where water exits the assimilation area and at the reference site were not significantly different. Removal efficiencies for total nitrogen and phosphorus are typical of other forested wetlands receiving treated effluent in Louisiana, ranging between 65 and 90%. These results demonstrate that this wetland assimilates nutrients to background concentrations even after 60 years of operation, stimulating productivity, and causing no measurable impacts to the wetland or to the river into which the water eventually flows.

Key Words: cypress swamp, nutrient reduction, primary productivity, wastewater, wetland assimilation

INTRODUCTION

Wetland assimilation involves the discharge of treated, disinfected municipal effluent, pumped stormwater, or other types of wastewater into a constructed or natural wetland to improve water quality and/or to restore the wetland (Day et al. 2004). In Louisiana, discharge is generally into natural wetlands. Inorganic nutrients in the discharge are typically nitrate (NO_3^-), ammonium (NH_4^+), and phosphate (PO_4^{3+}), and organic matter occurs in particulate and dissolved forms. Nitrogen and phosphorus in the treated effluent can be removed by plant uptake, peat and sediment accumulation, denitrification, and burial (Hemond and Benoit 1988, Breaux and Day 1994, Day et al. 2004). Settling of solids and organic soil formation enhance vertical accretion while nutrients increase productivity (Rybczyk et al. 2002, Brantley et al. 2008). Wetland assimilation systems currently in use in Louisiana have resulted in improved effluent water quality, enhanced soil accretion, and increased primary productivity over periods up to 50 years. (Delgado 1995, Hesse et al. 1998, Day et al. 1999, Zhang et al. 2000, Rybczyk et al. 2002, Day et al. 2004).

Cypriere Perdue Swamp is a freshwater, forested wetland located in St. Martin Parish, 3.5 km west of Breaux Bridge, Louisiana. This wetland is dominated by water tupelo (*Nyssa aquatica* L.), baldcypress (*Taxodium distichum* (L.) Rich.), red maple (*Acer rubrum* L.), black willow (*Salix nigra* Marsh.), and Chinese tallow (*Sapium sebiferum* (L.) Small). The wetland is hydrologically bounded to the east, north, and west by natural levees, and drains into Ruth Canal that forms the southern boundary and connects Bayou Teche and the Vermillion River (Figure 1). The hydrology of the area is dominated by backwater flooding, primarily from the Vermillion River, runoff from adjacent uplands, precipitation, and input of treated municipal effluent. Backwater flooding can cause water level variations of almost two meters, while during dry periods effluent discharge causes an increase of only a few cm near the point of effluent discharge.

Secondarily-treated municipal effluent has been discharged into the Cypriere Perdue wetland since the early 1950's. Over the past six decades, however, the type of treatment has changed. Initially, a trickling filter was used, then the first oxidation pond was constructed in 1970, and the second and third oxidation ponds were put in use by 1980.

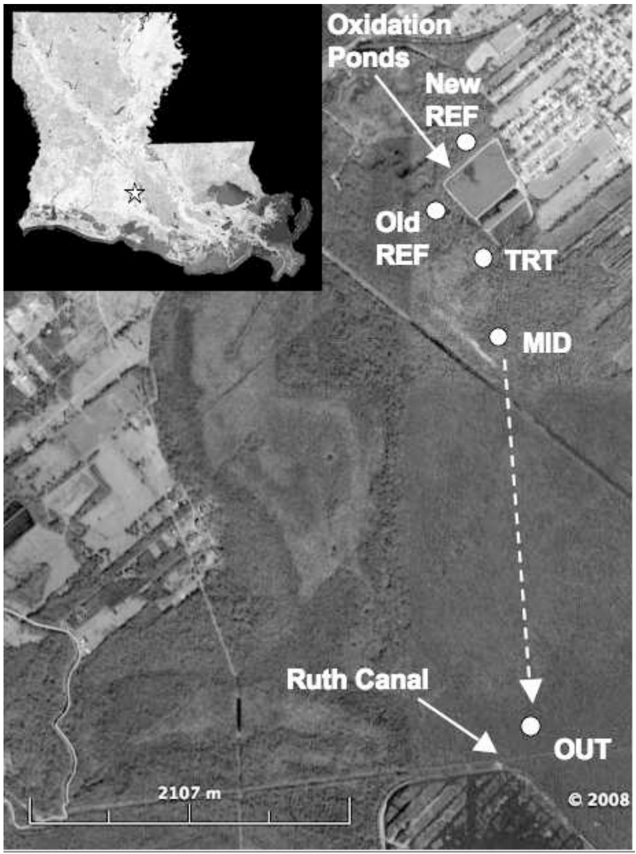

Figure 1. Location of study sites in the Cypriere Perdue Swamp.

In the late 1980's the City of Breaux Bridge received a compliance order from the USEPA to achieve stricter discharge limits (10 mg l^{-1} BOD_5 and 15 mg l^{-1} total suspended solids) from its oxidation ponds. These limits normally apply to discharge to water bodies such as streams or lakes. The discharge at Breaux Bridge, however, flows through more than 1400 ha of wetlands before reaching a receiving stream. Because of the large area of wetlands available and an apparent lack of ecological impact, the City suggested the possibility of obtaining less stringent effluent discharge limits for water flowing into wetlands prior to release into open waters. A one-year baseline study was carried out to determine the status of the system before a permit was granted. This study included measurements of vegetation structure and productivity, hydrology, and soil and water chemistry, and monitoring water, soil, and biota for toxins (Day et al. 1994).

The Louisiana Pollutant Discharge Elimination System (LPDES) Permit for the City of Breaux Bridge's wastewater treatment facility was issued on November 3, 1997 and became effective on March 27, 1998. Discharge limits were 30 mg l^{-1} BOD and 90 mg l^{-1} TSS. The City treatment system currently includes three oxidation ponds (one 12.5 and two 3.2 ha ponds) and a chlorination/dechlorination system with the capacity to treat a flow of one million gallons (MGD) per day (3,785 m^{-3} day^{-1}). Under the guidelines of the LPDES permit, water quality, primary productivity, and hydrology in the assimilation wetland (into which treated municipal effluent is being discharged) must be monitored and compared to a reference wetland, a nearby and ecologically similar wetland not impacted by the effluent. Monitoring has been carried out at the Cypriere Perdue Swamp since the early 1990's (Day et al. 1994, Hesse 1994, Delgado 1995, Hesse et al. 1998, Blahnik and Day 2000). The overall monitoring program was designed to accomplish three objectives: 1) to meet the monitoring requirements of the LPDES permit; 2) to determine the impacts of the discharge on the structure and productivity of the wetland community; and 3) to determine the ability of the wetland system to assimilate nutrients in the treated effluent.

The purpose of this paper was to compile and to analyze vegetation and water quality data gathered at the Cypriere Perdue forested wetland. Our objectives were: 1) to present an overview of the functioning of this wetland after nearly 60 years of treated effluent input; 2) to determine impacts of treated effluent on water quality, primary productivity, and species composition; and 3) to discuss management implications based on this information.

METHODS

Study Area

Cypriere Perdue swamp is approximately 1470 ha, with a moist, subtropical climate and an annual mean temperature of 20°C. Precipitation averaged 163 cm yr^{-1} from 1990 through 2007, with a low of 105 cm in 2005 and a high of 203 cm in 1993, with the average driest month being October (8 cm) and the wettest month being July (18 cm). Average annual evapotranspiration is 106 cm and is relatively constant from year to year (Day et al. 1994).

Three study sites were established in the wetland. The area at the vicinity of the southwest corner of the oxidation pond where treated effluent is discharged was designated the Treatment (TRT) area (Figure 1), and it was established in 1992. The second study site (designated the MID site) is approximately 700 m downstream from the TRT area. The third study site (designated the OUT site) is approximately 2800 m downstream from the MID site. The OUT site is located near the point where water flows out of the wetland and into Ruth Canal. Both the MID and OUT sites were established in 2000 to satisfy the requirements of the LPDES permit. A Reference area (REF) was established in 1992 adjacent to the northwest corner of the oxidation ponds, and 500 m upstream from the effluent discharge site. Treated effluent is discharged into the Cypriere Perdue Swamp through one of five outflow pipes that are spaced across the west containment levee of the oxidation pond for approximately 500 m. Although the REF area was 500 m from the effluent when it was established, we discovered that it was affected by the discharge when flow occurred from the northern-most discharge pipe. Because of this, the REF site was moved in 2007 to an un-impacted location further away from the point of discharge (Figure 1).

Dominant species at the TRT, MID, and REF sites were bald cypress, water tupelo, and red maple, while the OUT site was dominated by bald cypress, water tupelo, red maple, buttonbush (*Cephalanthus occidentalis* L.), and American elm (*Ulmus americana* L.). Soils are poorly drained, subject to frequent flooding, and consist of Fausse-Sharkey association (USDA 1977). The soils include clay and silty clay sediments deposited primarily by the nearby bayous. Organic material, debris left by generations of plants, varies in thickness and degree of decomposition on the surface of the soil.

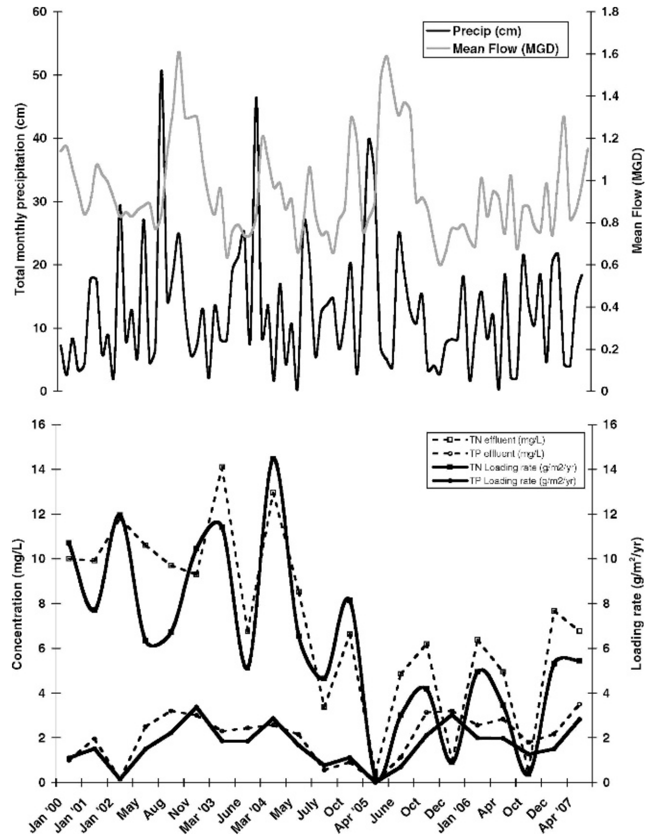

Figure 2. Effluent discharge from the City of Breaux Bridge wastewater treatment plant into Cypriere Perdue Swamp and precipitation (upper figure) and total nitrogen (TN) and total phosphorus (TP) in effluent (lower figure) from January 2000 to January 2007.

Effluent Input

Total discharge from 2000 to 2007 ranged from 0.6 to 1.6 million gallons per day (or 2,271 to 6,057 m^3 day^{-1}), depending on rainfall, and peak discharge followed heavy rainfall (Figure 2). Average monthly discharge of treated effluent into the assimilation wetland was 0.95 MGD from January 2000 to June 2007. Highest discharges occurred after heavy rains. Discharge data were obtained from City of Breaux Bridge Wastewater Treatment Plant Discharge Monitoring Reports (available online at Louisiana Department of Environmental Quality Electronic Document Management System). Monthly discharge data prior to 2000 were not available, but discharge was estimated to average about 1 MGD between 1992 and 1994 (Day et al. 1994).

The average concentration (from 2000 to 2007) of total nitrogen and phosphorus in secondary effluent discharged into Cypriere Perdue Swamp was 7.2 and 2.1 mg l^{-1}, respectively (Figure 2). Blahnik and Day (2000) demonstrated with dye studies in this wetland that flow distributions showed strong preferential pathways and the majority of effluent flowed across only about 10% of the wetland during dry periods. This is a dry weather situation, however, because when there is heavy rain or backwater flooding the whole swamp can be covered. Thus, in order to calculate loading rates, a range was used. For the lower range, mimicking a dry weather condition, the total wetland area of 1470 ha was reduced to 10% of the total area or 147 ha. For the upper range, mimicking a period of heavy rainfall, 100% of the total area, or 1470 ha, was used. For a mean of the range, 55% of the 1470 ha was used, or 808.5 ha. Using this mean area, the average application rate to the forested wetland area from 2000 to 2007 was approximately 1.15 g N m^{-2} yr^{-1} and 0.31 g P m^{-2} yr^{-1} (Figure 2).

Vegetation

Vegetation litter and stem productivity were estimated from 1993 to 1995 at the TRT and REF sites and from 2001 to 2006 at all sites. Three 25 × 25 m quadrats were established in each study site. Litter productivity was measured by collecting monthly litterfall in three 0.25 m^2 leaf litter boxes, with screened bottoms and approximately 10-cm high sides, placed randomly in each quadrat. Litter included all non-woody material including leaves, flowers, fruits, and seeds (the non-leaf materials typically account for $<$ 10% of the non-woody litterfall total) (Megonigal and Day 1988). Non-woody litter was separated from woody litter and dried to constant mass at 65°C.

Diameter at breast height (dbh) of all trees $\geq$ 10 cm, and above the butt swell of larger trees, in TRT, MID, OUT, and REF sites were measured annually above and below ($\approx$ 5 cm) an identification tag. It was assumed that the contribution of wood from stems $<$ 10 cm dbh and herbaceous vegetation was a relatively small fraction of aboveground net primary production (Megonigal et al. 1997).

Stem production was estimated from annual changes in wood biomass calculated using allometric equations based on stem dbh as the independent variable (Megonigal et al. 1997). Aboveground net primary production (NPP) was calculated as the sum of non-woody litter and stem growth. Woody litter was not included because it was assumed that all wood production was accounted for by the allometric equations that were based on measurements of whole-plant wood biomass.

Water Quality

Water quality was measured quarterly at the TRT and REF sites from 1993 to 1995 and in all sites from 2001 to 2007. Discrete water samples were taken 5 to 10 cm below the water surface with effort taken not to stir bottom sediments or include any film present on water surface. The samples were immediately stored on ice for preservation. Samples analyzed for nitrate + nitrite ($NO_3 + NO_2$-N) were filtered in the laboratory within 24 hours using 0.45 μm Whatman GF/F glass fiber filters. Unfiltered samples were subsampled into 125 mL bottles. Both filtered and unfiltered samples were frozen until analysis. Samples were analyzed for NO_3 + NO_2-N, ammonium (NH_4-N), total Kjeldahl nitrogen (TKN), ortho-phosphate (PO_4-P), total phosphorus (TP), and total suspended solids by an EPA-approved laboratory in Baton Rouge, Louisiana, using EPA methods 353.2T, 4500nh3c, 351.3, 365.2, 365.4, and 2540D, respectively (Kopp and McKee 1983). Total nitrogen (TN) was calculated by adding $NO_2 + NO_3$-N and TKN values.

Removal efficiency (RE) for a particular nutrient was calculated using equation (1) and is expressed as a percentage,

$$RE = \left(\left(Mass_{pipe} - Mass_{out} \right) / Mass_{pipe} \right) * 100 \quad (1)$$

where $Mass_{pipe}$ is the concentration of the constituent in treated effluent at the point of discharge and and $Mass_{out}$ is the concentration in surface water at the point where surface water leaves the wetland.

Statistics

To determine differences in net primary productivity (NPP) and nutrient concentrations among sites, one-way analysis of variance analysis (ANOVA, α = 0.05) was conducted using JMP 7.0 statistical software (SAS Institute Inc. 1999). Replicates were individual litter boxes for litterfall analyses, sample plots for stem growth analyses, and individual sampling dates for nutrient analyses. For significant ANOVA tests, comparisons of means were made using Tukey-Kramer Honestly Significant Difference (HSD) test (Sall et al. 2005). Two-way ANOVA tests with interaction were used to determine differences in vegetation growth between the 1993–95 and 2001–2006 sample periods. We only had composite data for the 1993–95 sampling period, so data from this time could not be analyzed for variation. Linear relationships between dependent and independent variables were examined using regression.

RESULTS

Vegetation

From 1993–95, mean litterfall was 647 and 590 g m^{-2} yr^{-1} and stem growth was 673 and 681 g m^{-2} yr^{-1} for REF and TRT wetlands, respectively (Figure 3). From 2001–06, mean litterfall ranged from 547 g m^{-2} yr^{-1} at the OUT site to 882 g m^{-2} yr^{-1} at the TRT site, while mean stem growth ranged from 162 g m^{-2} yr^{-1} at the OUT site to 487 g m^{-2} yr^{-1} at the TRT site (Figure 3). Mean litterfall for the 2001–06 period varied significantly among wetlands (P = 0.001), with the TRT site having higher litterfall than the other sites. Significant differences in mean litterfall were also found among the sites for individual years (2001–06) (Figure 4). Over the entire 2001–06 period, mean stem growths in the TRT, REF, and MID sites were higher than the OUT site (P = 0.0370), although differences were not detected when analyzed annually (all P $>$ 0.1172). When data were compared between sampling periods (1993–95 vs. 2001–06), mean litterfall, stem growth, and net primary productivity (NPP) were not different (all P $>$ 0.05).

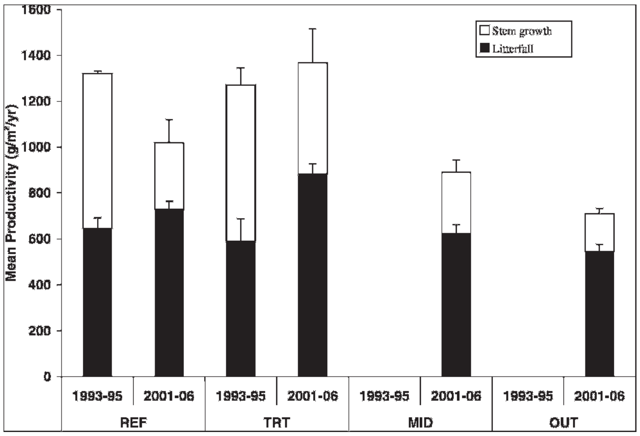

Figure 3. Mean productivity in reference and assimilation wetlands at Cypriere Perdue Swamp (± standard error).

Results of a regression analysis between mean annual total nitrogen loading rate and vegetation leaf productivity showed that approximately 57% of the variation in litterfall could be explained by nitrogen loading rate (Figure 5). Similarly, 46% of the mean variation in litterfall was explained by changes in growing season (March through October) precipitation (Figure 5).

Nutrient Removal

In general, all nutrient concentrations declined from the point of discharge to the point where water flowed from the assimilation wetland (i.e., OUT site). Concentrations of nutrients in the REF site were typically the same as or higher than concentrations measured at the OUT site. For the time period from 1993–95, removal efficiencies averaged 92% for NO_3, 91% for NH_4, and 68% for PO_4.

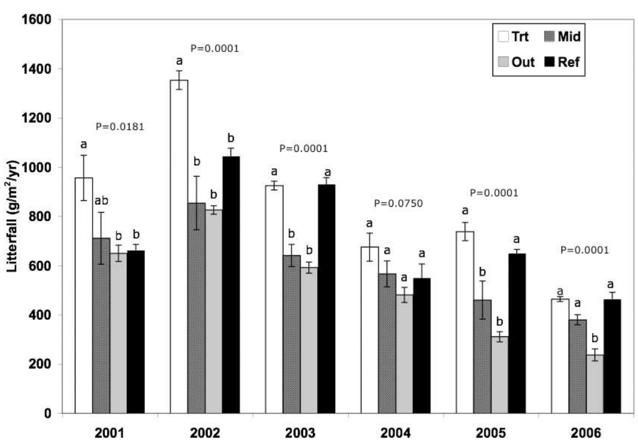

Figure 4. Mean litterfall in assimilation and reference wetlands at Cypriere Perdue Swamp (± standard error). Sites with same letter are not significantly different.

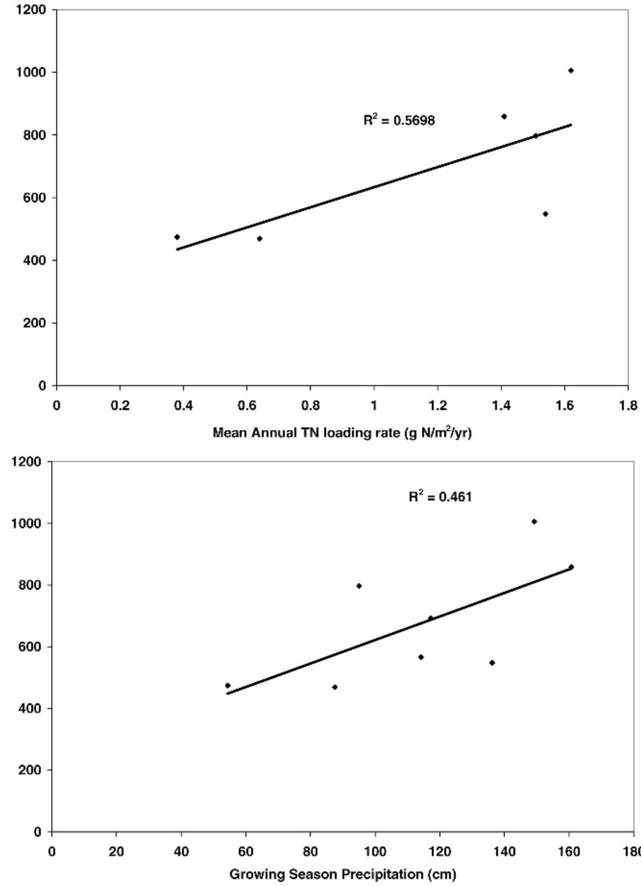

Figure 5. Effect of total nitrogen loading rate (upper figure) and growing season (March through October) precipitation (lower figure) on litter production in Cypriere Perdue Swamp from 2001 to 2006.

From 2001 to 2007, removal efficiencies averaged 67% for NO_3, 64% for NH_4, 90% for PO_4, 73% for TP, and 75% for TN.

From 1993–95, nitrate concentrations averaged 0.57 mg NO_3-N l^{-1} at the discharge pipe and decreased to a mean of 0.05 mg NO_3-N l^{-1} at the OUT site, while average concentrations at the REF site were 0.02 mg NO_3-N l^{-1} during this time (Figure 6). No significant difference was detected between nitrate concentrations in the OUT and REF sites ($P = 0.2124$). From 2001–07, nitrate concentrations averaged 0.69 mg NO_3-N l^{-1} at the discharge pipe and decreased to a mean of 0.23 mg NO_3-N l^{-1} at the OUT site, not significantly different from average concentration of 0.07 mg NO_3-N l^{-1} at the REF site during this time ($P = 0.0691$, Figure 6). No significant difference in mean effluent NO_3-N concentration between 1993–95 and 2001–07 was detected ($P = 0.6614$).

From 1993–95, ammonium concentrations averaged 1.22 mg NH_4-N l^{-1} at the discharge pipe and decreased to a mean of 0.11 mg NH_4-N l^{-1} at the

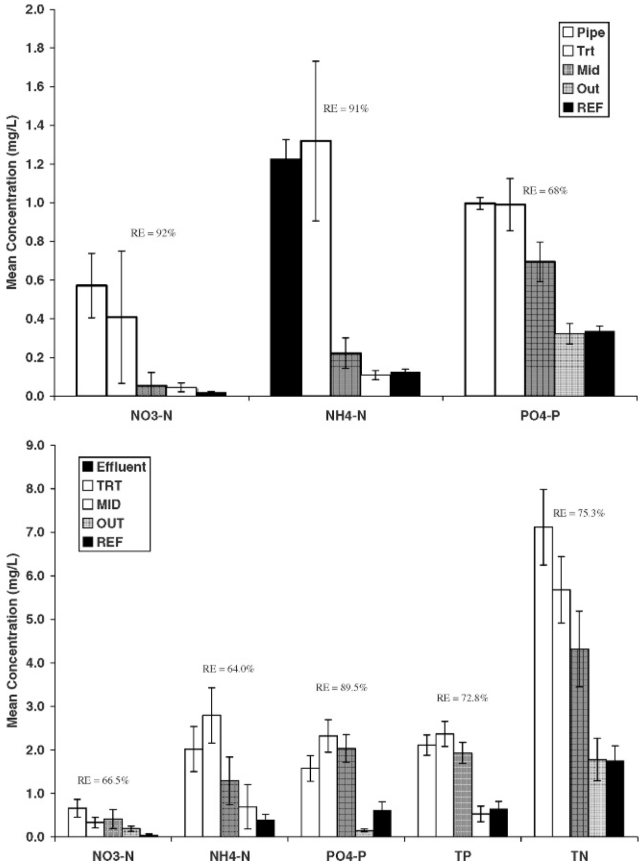

Figure 6. Mean nutrient concentrations measured in surface water of assimilation and reference wetlands from 1993 to 1995 (upper figure) and from 2001 to 2007 (lower figure). RE is removal efficiency calculated as the difference between the nutrient concentration in the effluent compared to that in the OUT site.

OUT site, while average concentrations at the REF site were 0.13 mg NH_4-N l^{-1} (Figure 6). No significant differences were detected between the OUT and REF sites (P = 0.6149). From 2001–07, ammonium concentrations averaged 2.02 mg NH_4-N l^{-1} at the discharge pipe and decreased to a mean of 0.73 mg NH_4-N l^{-1} at the OUT site, not significantly different from the average of 0.40 mg NH_4-N l^{-1} measured at the REF site during this time (P = 0.5857, Figure 6). No difference in effluent means between 1993–95 and 2001–07 was detected (P = 0.1467).

From 1993–95, ortho-phosphate concentrations averaged 1.0 mg PO_4-P l^{-1} at the discharge pipe and decreased to a mean of 0.32 mg PO_4-P l^{-1} at the OUT site, while average concentrations at the REF site were 0.34 mg PO_4-P l^{-1} (Figure 6). There were no significant differences in ortho-phosphate concentrations between the OUT and REF sites (P = 0.4134). From 2001–07, phosphorus concentrations averaged 1.58 mg PO_4-P l^{-1} at the discharge pipe and decreased to a mean of 0.17 mg PO_4-P l^{-1} at the OUT site, significantly lower than the mean of 0.62 mg PO_4- P l^{-1} measured at the REF site for the same time period (P = 0.0286, Figure 6). No difference in effluent means between 1993–95 and 2001–07 were detected (P = 0.0758).

From 2001–07, total phosphorus averaged 2.11 mg P l^{-1} at the discharge pipe and decreased to a mean of 0.57 mg P l^{-1} at the OUT site, while average concentrations at the REF site were 0.65 mg P l^{-1} during this time (Figure 6). From 2001–07, total nitrogen averaged 6.78 mg N l^{-1} at the discharge pipe and decreased to a mean of 1.67 mg N l^{-1} at the OUT site, while average concentrations at the REF site were 1.75 mg N l^{-1} (Figure 6). No significant differences were found between the OUT and REF sites for total phosphorus or total nitrogen concentrations (P = 0.6363 and P = 0.9522, respectively).

DISCUSSION

Vegetation

Treated municipal effluent delivers nutrient-rich water to wetlands, stimulating vegetative productivity such as was seen in the treatment site at Cypriere Perdue Swamp (Breaux 1992, Day et al. 2004). While nutrient inputs can lead to eutrophication in some aquatic systems, wetlands in the Mississippi Delta evolved as nutrient-rich ecosystems, but are now mostly isolated from historic pulses of nutrients and sediments by dams, dikes, and levees (Lane et al. 2007). Treated municipal effluent will enhance productivity, increasing organic matter deposition and leading to an increase in surface elevation (Day et al. 2004). Mean litter production for 2001–06 was highest at the treatment site compared to the other sites. Stem growth was similar among most sites, but was lower at the site furthest away from the effluent discharge. In other assimilation wetlands that are currently being monitored in Louisiana, net primary productivity is usually higher in assimilation wetlands than in reference wetlands (Table 1). Because the Cypriere Perdue wetland is composed of a mature cypress-tupelo forest, stem growth rates may naturally be low and less responsive to nutrient inputs. Alternatively, because the reference site was receiving effluent in some years, additional nutrients may have stimulated vegetation growth.

Much of the variation (57%) in leaf productivity could be explained by changes in mean annual total nitrogen loading rate at the Cypriere Perdue wetland. As stated, increases in litterfall in forested wetlands in coastal Louisiana are important because

Table 1. Litterfall, stem growth, and total net primary productivity (NPP) for forested assimilation wetlands (TRT) and reference wetlands (REF) in Louisiana. Data are from the most recent sampling year available (in parenthesis).

Site	Litterfall ($g\ m^{-2}\ yr^{-1}$)	Stem Growth ($g\ m^{-2}\ yr^{-1}$)	Total NPP ($g\ m^{-2}\ yr^{-1}$)	Reference
Amelia, LA TRT (1997)	717	751	1467	Day et al. 2006
Amelia, LA REF (1997)	622	440	1061	Day et al. 2006
Hammond, LA TRT (2006)	403	319	722	Comite Resources, Inc. 2007
Hammond, LA REF (2006)	115	202	317	Comite Resources, Inc. 2007
Luling, LA TRT (2006)	535	NA		Comite Resources, Inc. 2007
Luling, LA REF (2006)	219	NA		Comite Resources, Inc. 2007
Thibodaux, LA TRT (2006)	258	136	394	Comite Resources, Inc. 2007
Thibodaux, LA REF (2006)	218	435	653	Comite Resources, Inc. 2007

deposition of organic matter helps offset subsidence (Breaux and Day 1994). However, rainfall also impacts productivity, and about 50% of the variation in litterfall could be explained with changes in growing season precipitation. These data indicate that even with effluent discharge, the swamp may be water and/or nutrient deficient during periods of low rainfall.

Dominant species composition was similar in the assimilation and reference wetland sites, which is to be expected for forested wetlands with similar soils and hydrology within a relatively small area. In forested wetlands, with the exception of some catastrophic event (e.g., hurricane, logging, etc.), species compositional changes occur over many decades (Mitsch and Gosselink 1993). While Hurricanes Katrina and Rita impacted this area in 2005, as evidenced by newly dead and downed trees recorded at all sites the following year, no change was seen in species composition.

Nutrient Removal

Results of our nutrient analyses show that the Cypriere Perdue assimilation wetland was effectively removing nutrients from treated effluent in the early 1990s and it continues to do so. There was a consistent decrease in nutrient concentrations with distance away from the point of effluent discharge for all nutrients measured in this study. Also, nutrient concentrations measured in the reference site and the site furthest from effluent discharge were very similar, regardless of the time period in which concentration was measured. This similarity demonstrates that by the time surface water reaches Ruth Canal, nutrient concentrations are very comparable to wetlands that have received no treated effluent at all. Thus, the assimilation wetland at Cypriere Perdue Swamp can reduce nutrient concentrations in treated municipal effluent with little or no impact to other water bodies within the same watershed, even after nearly 60 years of receiving effluent.

For wetland assimilation systems in Louisiana, typical loading rates for total nitrogen range from 2 to 20 $g\ N\ m^{-2}\ yr^{-1}$ and from 0.4 to 3 $g\ P\ m^{-2}\ yr^{-1}$ for total phosphorus (Day et al. 2004, 2006, Brantley et al. 2008). Mean total nitrogen loading at Cypriere Perdue Swamp was below this range, averaging 1.55 $g\ N\ m^{-2}\ yr^{-1}$ between January 2001 and December 2004 and decreasing to a mean of 0.71 $g\ N\ m^{-2}\ yr^{-1}$ between January 2005 and April 2007. Nitrogen was lower in the effluent in 2005–07 most likely because rainfall was lower during this time period than in 2001–04, and lower rainfall will lead to higher residence time in the oxidation pond. A higher residence time will cause reduction in nitrogen concentrations due to sequential nitrification/denitrification. Phosphorus loading rate was fairly consistent throughout this time period, with a mean of 0.31 $g\ P\ m^{-2}\ yr^{-1}$.

Loading rate will impact nutrient removal in wetlands, with higher REs at lower nitrogen and phosphorus loading rates and lower removal efficiencies at higher loading rates (Richardson and Nichols 1985). The relationship between loading rate and nutrient removal efficiency decreases exponentially, however, with removal efficiency leveling off at low ($<$ 5–10 $g\ N\ m^{-2}\ yr^{-1}$ and $<$ 2–4 $g\ P\ m^{-2}\ yr^{-1}$) and high ($>$ 75–100 $g\ N\ m^{-2}\ yr^{-1}$ and $>$ 15–20 $g\ P\ m^{-2}\ yr^{-1}$) loading rates (Richardson and Nichols 1985). At the Cypriere Perdue Swamp total nitrogen removal efficiency increased as the loading rate increased ($r^2 = 0.42$, Figure 7), probably because loading rates were so low and assimilative capacity was not reached. Similar results were documented for NO_3-N by Blahnik and Day (2000) at this same wetland.

Assimilative capacity refers to the nutrient threshold where significant alteration of wetland function and structure occurs (USEPA 2002). Exceeding this

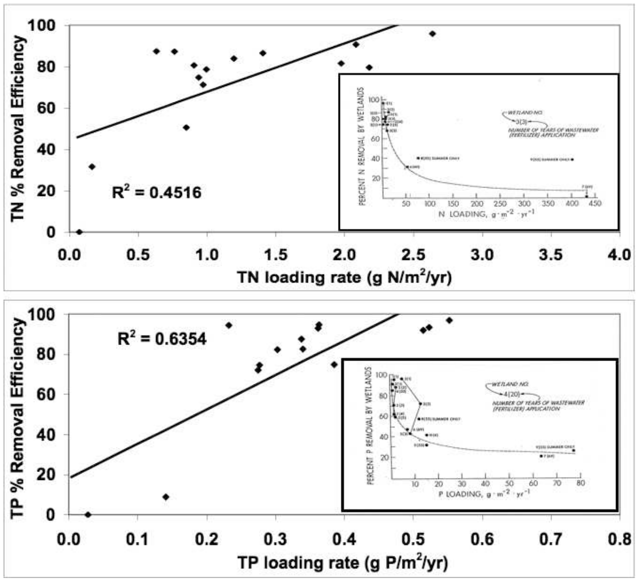

Figure 7. Total nitrogen (upper figure) and total phosphorus (lower figure) removal efficiency plotted by loading rate. Data collected from 2001 to 2007. n = 14. Inset graph shows data from Richardson and Nichols (1985).

threshold causes increases in productivity, shifts in species composition, changes in decomposition rates, and other impacts on ecosystem processes (USEPA 2002). Certainly, there is some point where assimilative capacity may be exceeded, but the relatively low loading rates into this wetland are below this capacity and are also much lower than most loading rates (Richardson and Nichols 1985). Similarly, total phosphorus removal efficiency increased with loading rate ($r^2 = 0.64$, Figure 7), emphasizing the fact that this wetland is receiving nutrients below assimilative capacity.

Nutrient assimilation in wetlands will fluctuate based on many factors, such as loading rate, season, form of the nutrient, and residence time (Faulkner and Richardson 1989). Removal efficiencies for total nitrogen and total phosphorus at loading rates typically seen in Louisiana assimilation wetlands (2 to 20 g N m^{-2} yr^{-1} and 0.4 to 3 g P m^{-2} yr^{-1}) average between 65 and 90%, while nitrate removal is between 90 and 100% (Day et al. 2004). Mean removal efficiencies measured at the Cypriere Perdue Swamp were within this range for TN and TP, but slightly lower from 2001–07 for nitrate. However, NO_3-N concentrations were so low that they were unimportant in the overall loading analysis.

Even though the reference wetland may have been receiving treated effluent periodically when the northern-most outfall pipe was in use, mean nutrient concentrations were not different between the reference site and the site furthest from the effluent discharge. Background nutrient concentrations are those found in the wetland naturally, without anthropogenic additions (USEPA 2006), and these data suggest that by the time surface water leaves the wetland, nutrient concentrations have been reduced to background concentrations. If background concentrations were used to calculate removal efficiency (i.e., data from the reference site in Figure 6), then removal efficiency would be 74% for NO_3-N, 80% for NH_4-N, and 100% each for PO_4-P, TP, and TN. This use of a background concentration may be a realistic way to calculate removal efficiency because all nitrogen and phosphorus coming into an assimilation wetland will not be completely removed.

There has been some concern that discharge of treated effluent into wetlands will cause an enrichment effect (i.e., impairment of ecological integrity by nutrient enrichment and eutrophication), but in wetlands that are cut off from their historical source of nutrients (e.g., wetlands in the Mississippi River Basin) treated municipal effluent may be a beneficial source of nitrogen, phosphorus, and suspended material (Day et al. 2004). In addition, our assimilation wetland has been receiving discharge for nearly 60 years and appears to be self-sustaining, unlike many forested coastal wetlands in the Mississippi Delta (Conner and Day 1998).

CONCLUSIONS

Cypriere Perdue Swamp is a healthy forested wetland that has been assimilating nutrients in treated municipal effluent for nearly six decades with no apparent negative impacts to ecosystem function or water quality. Many forested wetlands in Louisiana are in a degraded condition due to impoundment and subsidence and outside sources of nutrients are needed to increase productivity, organic matter deposition, and subsequent accretion. Treated municipal effluent can be a valuable source of nutrients and suspended material for degraded wetlands in coastal Louisiana, especially because increases in litterfall, as seen in the treatment wetland, can help to offset subsidence which may increase flooding duration and frequency.

The Cypriere Perdue wetland has been effectively reducing nitrogen and phosphorus in the treated effluent at least since the early 1990's and most likely since discharge first began in the early 1950's. Nutrient removal rates remain within the range typically seen in other assimilation wetlands in Louisiana. Analysis of nutrient removal efficiencies show that this wetland could assimilate higher nutrient loadings. Capacity for greater nutrient removal will be important if the population of the City of Breaux Bridge increases in the future and, consequently, increases treated municipal effluent discharge into the wetland.

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