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EARLY FLOATING MARSH ESTABLISHMENT AND GROWTH DYNAMICS IN A NUTRIENT AMENDED WETLAND IN THE LOWER MISSISSIPPI DELTA

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Abstract: Nutrient dynamics and seasonal vegetation growth were examined in a newly formed floating marsh dominated by *Panicum virgatum* in the Mississippi River delta. The floating marsh formed in a shallow aquatic environment receiving secondarily treated municipal effluent. Net Areal Primary Productivity (NAPP), total belowground biomass, NO_3, and plant-tissue $\delta^{15}N$ ratios varied significantly ($P < 0.05$) along a 75-m marsh transect, while mean plant-tissue $\delta^{13}C$ values differed between the dominant species. The area nearest the effluent discharge had the highest NAPP (3876 g m^{-2} y^{-1}), total belowground biomass (4079.0 ± 298.5 g m^{-2}), and mean NO_3 (5.4 ± 2.9 mg l^{-1}). The mean $\delta^{15}N$ of *Hydrocotyle umbellata* floating marsh was less enriched at 0–75 m (9.7 ± 1.9‰) compared to 100–200 m (21.0 ± 3.8‰). The $\delta^{13}C$ of the belowground peat mat of the floating marsh was similar to *P. virgatum* but not *H. umbellata*, indicating that *P. virgatum* was forming the mat. Nutrient availability affected NAPP and $\delta^{15}N$. NAPP was greater than most reported values for floating marsh from 0–45 m then decreased along with NO_3 concentrations and $\delta^{15}N$ further from the effluent source. These results suggest that nutrient rich freshwater can promote restoration of some floating marshes.

Key Words: panicum virgatum, productivity, wetland assimilation

INTRODUCTION

In the Mississippi River delta, extensive floating marshes historically formed in fresh and low salinity areas where there was reduced mineral sedimentation, low physical energy, high subsidence, and increased peat production (Russell 1942, O'Neil 1949, Sasser et al. 2009). Over the past two centuries, the delta plain has been progressively isolated from the river by levees and distributary closures and the hydrology has been extensively altered (Day et al. 2007). These changes led to high rates of coastal wetland loss due to lack of river input, subsidence, and saltwater intrusion (Day et al. 2000, 2007, Penland and Ramsey 1990) leading to plant stress and death (Mendelssohn and Morris 2000).

A major approach to delta restoration is the reintroduction of river water to the delta plain via river diversions (USACOE and LADNR 2003, Boesch et al. 1994, Day et al. 2007). But there are other important sources of freshwater, nutrients, and sediments to the coastal zone. Point and non-point sources of freshwater can also be useful in coastal restoration (e.g., Day et al. 2004). Day et al. (2004) suggested that adding nutrient rich secondarily treated municipal effluent to hydrologically isolated, subsiding wetlands could promote vertical accretion through increased organic matter production and deposition. Breaux and Day (1994) further suggested the addition of sediments and nutrients in rapidly subsiding areas could offset accretion deficits, improve effluent water quality, and result in substantial economic savings compared to conventional water treatment.

One place where treated effluent is discharged directly to subsiding wetlands is at Thibodaux, Louisiana. Impoundment, high rates of local subsidence, and tree clearing of a power line right-of-way transformed nearly 100 ha of forested wetland to shallow open water. Discharge of treated effluent into this wetland began in 1992. By 2002, *Panicum virgatum* became established along the wetland boundary where effluent was discharged to the shallow open water area and in 2003 began to extend into the wetland. *Panicum virgatum* has not been reported as an important component of floating marshes in Louisiana (personal observations), however within four years of first establishment at

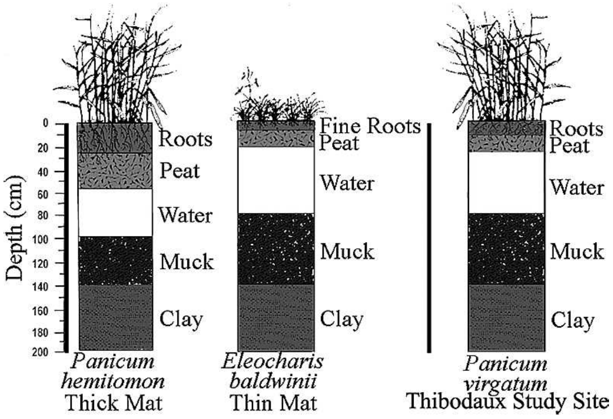

Figure 1. Thick and thin mat floating marsh profiles and a generalized profile for the Thibodaux treatment wetland (modified from Sasser 1994).

Thibodaux, a highly productive marsh developed with floating marsh characteristics. This study focused on the dynamics of this floating marsh.

Floating Marsh Ecology

Floating marshes, or flotants, are wetlands of emergent vegetation with a mat of live roots and associated dead and decomposing organic material and mineral sediments, that move vertically as ambient water levels rise and fall (Sasser 1994, Sasser et al. 2009). In contrast to attached marsh, a floating marsh can avoid the flooding stress that is commonly associated with hydrologic impoundment or high subsidence and sea level rise. Marsh plant communities create and maintain a floating substrate of live roots and decomposing plant material and once established, often are co-inhabited by other wetland plants (Figure 1). The nutrient requirements of floating marsh are partially self regulated; as much as 80% of mineral nutrient requirements are recycled from the peat (Delaune et al. 1986, Sasser et al. 1994).

Floating marshes are mostly restricted to areas with low hydrologic energy and low salt stress (Sasser et al. 1995, Holm et al. 2000). Currents and wave energy erode the mat and salt stress may change the plant community to one that is not conductive to mat flotation and cause mat decomposition. Nutria (*Myocastor coypus*) grazing also stresses floating marshes (Sasser et al. in press). Thin mat flotant types are of lower productivity and thought to be a deteriorated form of flotant (Figure 1). Thus, a continuing concern for floating marshes in coastal Louisiana is the potential for rapid deterioration. Without an understanding of these multiple stresses inherent (Sasser et al. 1996), proper conservation and restoration are not possible.

If a floating marsh is sustainable, it can continue to expand in thickness and aerial coverage, and potentially become an attached marsh. Our objective was to follow seasonal growth dynamics of the floating marsh community at Thibodaux in relation to nutrient dynamics, and to determine specific components of the marsh community that provided for mat formation. The central hypothesis was that nutrient and freshwater additions stimulate productivity and therefore sustainability of the marsh. We hypothesized that productivity and peat accumulation would be greatest where nutrient concentrations were highest near the outfall and decrease with distance. As more treatment wetlands are established and as freshwater diversions become more common, understanding the factors that lead to flotant establishment and sustainability will aid in management decisions where secondary freshwater sources are used as part of a broader restoration strategy.

METHODS

Site Description

The study was carried out at the Pointe au Chene forested wetland in south Louisiana, 10 km southwest of Thibodaux, Louisiana (Figure 2). This site is a subsiding cypress-tupelo swamp on the backslope of Bayou Lafourche, a former distributary of the Mississippi River that was diverted in 1904. Historically, Bayou Lafourche carried an average of 12% of the Mississippi River, or about 1,100 $m^3 s^{-1}$ (EPA 1998). The study site is a 231 ha semi-isolated, continuously flooded, forested wetland adjacent to the Terrebone-Lafourche drainage canal. The soils are classified as Fausse (very fine, montmorillonitic, nonacid, thermic typic fluvaquents) and effectively restrict ground-water exchange (Zhang et al. 2000). Over the past decades the study area experienced increased flooding due to subsidence and isolation from outside freshwater inputs and a transition from bottomland hardwood forest to cypress-tupelo swamp. The area immediately adjacent to the effluent input is a shallow, treeless, open water area, cleared for the construction of a power line right of way. Beginning in 1992, secondarily treated municipal effluent from Thiboduax has been discharged to the site through 40 outlets along the northern edge of the study area. Prior to effluent discharge, the only significant freshwater inputs were precipitation and backwater

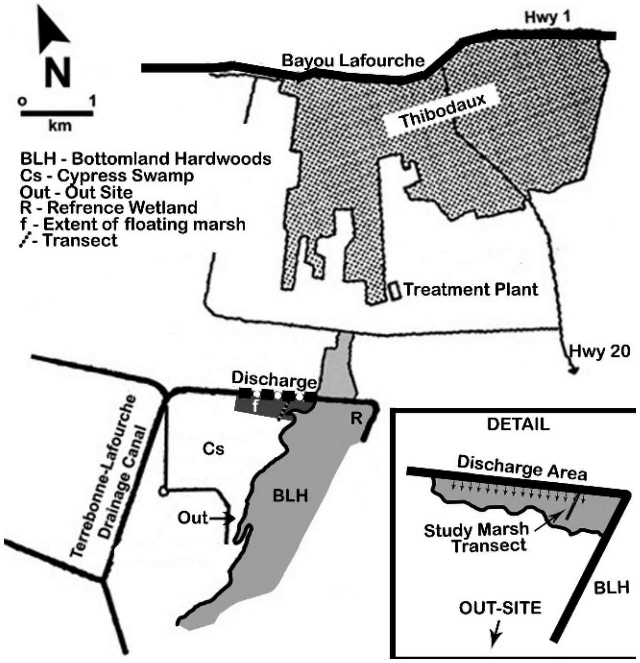

Figure 2. The Thibodaux treatment area showing the physical boundaries, locations of transects, and the out site.

flooding. The water flows south about 2 km where it exits the site between an access road and bottomland hardwood ridge into a 1430 ha wetland and then the Terrebonne-Lafourche drainage canal (Figure 2).

Floating vascular plants now cover most of the open water area year round. Near the outfall, dominant species include *Typha* spp., *Panicum virgatum*, *Panicum hemitomon*, *Hydrocotyle umbellata*, and *Alternanthera philoxeroides*. Toward the southern end of the wetland, *Panicum* spp. become less-common while *Lemna*, thin-mat flotants of *Eleocharis* and other sedges exploit canopy gaps in the otherwise baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) dominated swamp. The bottomland-hardwood ridge (mean elevation 1.2 m above MSL) is approximately 300 m wide and is vegetated with oaks (*Quercus nigra* and *Q. texana*), sweetgum (*Liquidambar styraciflua*), American elm (*Ulmus americana*), palmetto (*Sabal minor*), and boxelder (*Acer negundo*). The climate is subtropical with a mean annual air temperature of 20.6°C, ranging from 13.0°C in January to 27.5°C in July. Mean annual precipitation is 1670 mm yr^{-1}, and has ranged from 790 mm in 1962 to 2220 mm in 1940 (Zhang et al. 2000).

Field Studies

Dynamics of the developing floating vegetation marsh mat was studied from February 2005 to January 2006. A five plot transect was established along a boardwalk (15, 30, 45, 60, and 75 m from the point of effluent discharge), within which monthly sampling was carried out for dissolved oxygen, temperature, nitrate-nitrite, ammonia-ammonium, and above and belowground biomass (see also Izdepski 2008).

Dissolved oxygen and water temperature *in situ* were measured below the floating mat at each site using a field oxygen meter (Yellow Springs Instruments Model 85). Water samples were collected below the floating mat by gently lowering 1000 ml acid-washed polyethylene bottles through gaps in the floating marsh. The samples were stored on ice and taken to the laboratory for analysis. Inorganic nitrogen analyses were performed using the nitrate-nitrite #353.2 and ammonium #350.1 methods outlined by the Environmental Protection Agency (1979) and the Louisiana Department of Environmental Quality. Samples were filtered using a 0.45 μm Millipore filter and concentrations were determined by ion chromatography (Dionex I.C. Model 2010i).

To estimate seasonal growth dynamics of the dominant plants, total above ground biomass was collected monthly at five replicate plots (0.1 m^2) at 15-, 45-, and 75-m sites by cutting all vegetation at the sediment or water interface. Species composition and dry weight of living and dead material were measured. Annual productivity was estimated using Smalley's method (Smalley 1958, Shew et al. 1981).

End of season total standing crop was harvested in mid-October along with dead plant material, belowground roots, and consolidated peat. Above and belowground sections of floating mat were sampled at the 15-, 45-, and 75-m sites in five replicate 0.25 m^2 quadrants. Live plants, live roots, and dead organic material were dried and weighed separately so that the contribution of each to the mass of the floating mat could be estimated.

To determine which plants of the marsh community made up the greatest portion of the accumulating organic mat and which form of inorganic nitrogen was taken up by the plants, two of the five plots at each site and four additional plots (100, 200, 400, and 800 m) were sub-sampled seasonally for their carbon and nitrogen stable isotopes. Stable isotopes have been widely used to determine source contributions to a given carbon pool and to investigate nutrient processing in ecosystems (Fry 2006). The samples were field composites of plant material sorted to species and the underlying organic substrate. Samples were rinsed, dried at 60°C, pulverized, and analyzed for elemental and isotopic compositions with an automated analytical system

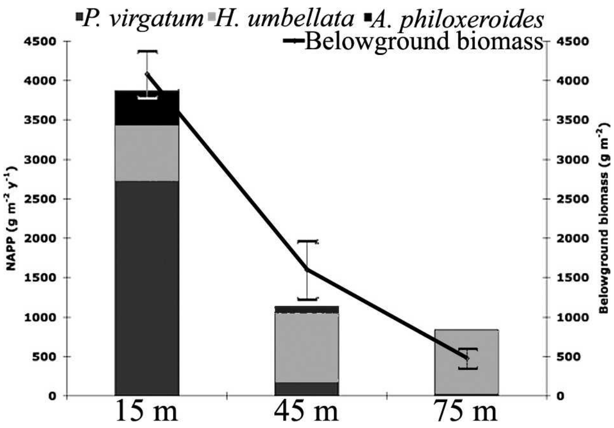

Figure 3. NAPP and Total Belowground Biomass for transect sites showing the relative contributions of dominant species.

combining an isotope ratio mass spectrometer (Finnigan Delta Plus, Thermo Electron Corporation, USA) and an elemental analyzer (Carlo Erba NA 1500, Thermo Electron Corporation) according to the methods of Fry (2006). Several samples were split in the laboratory and analyzed in duplicate. Laboratory split samples usually gave isotopic compositions that agreed within a 0.5‰ range.

Confidence intervals (95%) were developed around the mean annual nutrient concentrations. A one-way analysis of variance was run to examine differences in environmental characteristics, standing biomass, nutrient concentrations (NH_4, NO_3), and isotopic values of carbon and nitrogen ($\alpha = 0.05$).

RESULTS

Floating Marsh Biomass and Productivity

Total floating marsh biomass was highest near the outfall and decreased along the 75-m transect (Figure 3). Total belowground (living and dead) biomass was 4079.0 ± 298.5 g m^{-2} at the 15-m site, most of which was decomposing materials with the upper portion live roots and fibrist *P. virgatum*. Total belowground biomass was 1596.2 ± 373.7 g m^{-2} and 472.7 ± 125.8 g m^{-2} at the 45- and 75-m sites, respectively. End of season live aboveground biomass (EOSL) was 669.9 ± 131.8 g m^{-2}, 372.5 ± 54.8 g m^{-2}, and 287.2 ± 57.3 g m^{-2} at the 15-, 45-, and 75-m sites, respectively. *Hydrocotyle umbellata* biomass made up a greater portion of EOSL at the 45- and 75-m sites (Table 1), while there was no difference between *P. virgatum* (357.0 ± 110.3 g m^{-2}) and *H. umbellata* (313.0 ± 21.5 g m^{-2}) EOSL at 15 m.

Net annual aerial primary productivity (NAPP) was highest at 15 m (3876 g m^{-2} y^{-1}) where the productivity of *P. virgatum* was highest (2736 g m^{-2} y^{-1}), and decreased with distance. *Hydrocotyle umbellata* productivity was lowest at 15 m relative to the 45- and 75-m sites (Figure 3). NAPP decreased with distance from the effluent discharge and was primarily supported by *H. umbellata* at the 45- and 75-m sites. The peak standing crop of *P. virgatum* occurred in June (1471.9 ± 847.1) then declined to less than 400 g m^{-2} at the end of season harvest (Figure 4). *Hydrocotyle umbellata* biomass was generally robust in the cooler months from October to April, when *Panicum* growth was constrained by temperature (Figure 4). Winter standing crops at all sites were typically above 300 g m^{-2}. Low growth of *H. umbellata*, typically less than 200 g m^{-2}, was observed during the summer and where *P. virgatum* was present (Figures 3 and 4).

Over the 12-month study period, *P. virgatum* was collected during every sampling at 15 m (n = 12), between June and December at 45 m (n = 6), and from August to October at 75 m (*n* = 3) while *H. umbellata* was in all samples. At 15 m, *P. virgatum*

Table 1. Net aboveground primary productivity (NAPP), End-of-season live biomass (EOSL), and total belowground biomass at the different sampling sites.

	15 m	45 m	75 m
NAPP (gm^{-2} y^{-1})	3876	1050	832
EOSL (gm^{-2})			
Hydrocotyle umbellata	313 ± 22	292 ± 24	254 ± 18
Panicum virgatum	357 ± 110	81 ± 31	33 ± 39
Total	670 ± 132	373 ± 55	287 ± 57
Belowground Biomass (gm^{-2})			
Hydrocotyle umbellata	561 ± 31	424 ± 45	359 ± 41
Panicum virgatum	370 ± 36	143 ± 13	113 ± 85
Dead plant material	3147 ± 231	1028 ± 316	0
Total	4079 ± 299	1596 ± 374	472 ± 126

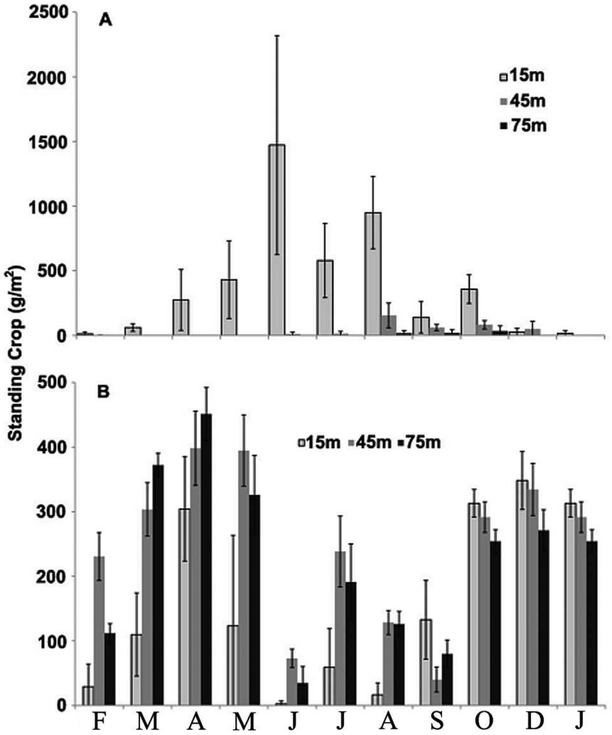

Figure 4. Seasonal growth dynamics of A) *Panicum virgatum* and B) *Hydrocotyle umbellata*.

regeneration was observed from seed and rhizome while the 45 m and 75 m sites was almost exclusively from seed. Seedlings at 75 m were supported by the roots of *H. umbellata*, where peat had not accumulated. This suggests that *P. virgatum* can germinate in all of the floating marsh area but that the growth and persistence of mature plants, and therefore expansion of the floating marsh, was constrained by environmental factors.

During the early spring, seedlings of *P. virgatum* at 15 m were limited to areas on the floating mat where *H. umbellata* was absent. As it matured, *P. virgatum* replaced *H. umbellata*. The highest biomass of *P. virgatum* occurred between June and August at 15 m and was coincident with the lowest biomass of *H. umbellata* (Figure 4). Emergence of *P. virgatum* seedlings at 45 and 75 m was delayed until midsummer when cover of *H. umbellata* was reduced, allowing for greater light penetration to the surface of the floating mat. Additionally, the marsh directly adjacent to the effluent discharge was supported by fluid ooze between June and August, and not truly floating. In June, seedlings of *P. virgatum* grew atop the floating mat at 45 m and in August were associated with *H. umbellata* roots at 75 m. However these sites did not achieve biomass comparable to 15 m before transitioning to *H. umbel*lata monocultures.

Net annual primary productivity was 3.7 times greater at 15 than 45 m, mostly due to *P. virgatum* growth between June and August (Figure 3). *Panicum virgatum* biomass was significantly lower at 45 and 75 m ($P = 0.02$), while there was no significant difference in *H. umbellata* biomass along the transect ($P = 0.12$).

Inorganic Nitrogen

Before the discharge of treated effluent, surface water inorganic nitrogen concentrations were low and not different between the treatment and reference areas, and similar to values reported for surface waters in other southern bottomland hardwood and cypress swamps (Zhang et al. 2000). The annual mean concentrations of NO_3-N + NO_2-N and NH_4-N in the Pointe au Chene swamp during the 1988–1989 pre-effluent period were 0.05 and 1.34 mg l^{-1}, respectively.

Except during December, nitrate was always the dominant inorganic form of N in the effluent, averaging 5.65 ± 2.9 mg l^{-1}, although the inlet concentration was highly variable between sampling efforts (Table 2). Inlet NO_3 concentrations were typically > 4 mg l^{-1} and were as high as 12 mg l^{-1} (Table 2). Nitrate decreased significantly from the inlet to 100 m and was always below the detection limit at the outlet site (Figure 5). Inlet ammonium concentrations were between 3.0 and 4.0 mg l^{-1} over the study period and averaged 3.73 ± 0.1 mg l^{-1}. Ammonium showed no significant change in concentration over the first 75 m, however outlet concentrations were reduced ($p < 0.001$) relative to inlet concentrations, averaging 0.77 ± 0.9 mg l^{-1}.

Stable Isotopes

The $\delta^{15}N$ values of *H. umbellata* were 9.7‰ over the initial 75 m and increased to a mean of 21.0‰ at 400 m. The $\delta^{15}N$ values of *P. virgatum* also showed $\delta^{15}N$ enrichment with distance. Isotopic values of carbon indicated that *P. virgatum* was the dominant source material of the floating marsh mat. Figure 6 shows different $\delta^{13}C$ values in *H. umbellata* and *P. virgatum* and that the peat $\delta^{13}C$ was similar to *P. virgatum* $\delta^{13}C$.

DISCUSSION

The floating vegetation mat initially developed in 2000 as emergent aquatic wetland dominated by *H. umbellata* about eight years after the initiation of the treated effluent discharge in 1992. Between 2000 and

Table 2. Mean inorganic nitrogen concentrations (mg l^{-1}) during the study. Distance is in meters from the inlet. The out site was 1700 m from the inlet and was the point where water flows out of the study area (see Figure 2).

Date:	3/31/05	4/20/05	5/24/05	6/17/05	7/29/05	8/26/05	10/3/05	10/21/05	X ± SD
Nitrate									
Inlet	7.46	3.47	4.34	6.23	5.73	12.03	5.00	4.49	5.7 ± 2.9
15 m	2.13	2.86	-	3.65	5.13	6.59	1.41	0.37	3.0 ± 2.1
30 m	-	0.67	-	2.50	2.28	5.13	-	-	2.3 ± 1.8
45 m	0.93	0.83	0.83	0.75	2.68	-	-	0.32	0.9 ± 0.8
60 m	-	0.42	-	0.56	1.12	2.50	0.31	1.05	0.9 ± 0.8
75 m	0.22	0.33	-	0.22	0.96	1.19	-	1.23	0.7 ± 0.4
Outlet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 ± 0
Ammonia									
Inlet	3.60	3.73	3.70	3.63	3.68	3.81	3.67	3.92	3.7 ± 0.1
15 m	3.15	3.30	3.62	3.01	3.59	-	3.43	4.11	3.5 ± 0.4
30 m	-	2.63	3.39	3.55	3.74	-	3.96	3.72	3.5 ± 0.4
45 m	3.69	3.57	3.02	3.72	3.58	-	3.87	4.18	3.7 ± 0.3
60 m	-	3.46	3.80	3.65	3.66	3.71	3.20	4.00	3.7 ± 0.3
75 m	3.69	3.66	1.84	3.76	3.31	3.68	4.00	4.01	3.6 ± 0.7
Outlet	-	0.24	0.38	0.24	0.22	2.76	1.78	0.26	0.8 ± 1.0

2001, *P. virgatum* became established along the edge of the spoil bank next to the discharge and over four years developed into a productive marsh with floating marsh characteristics that extended about 75 m into the shallow open water area.

A number of factors contributed to the development of the floating marsh in the study area including very low flow, continuously fresh conditions, and the effluent input that established a strong nutrient gradient. Low oxygen levels under the mat lead to slow rates of organic matter decomposition. Nutrient stimulated productivity coupled with suppressed decomposition allow for peat accumulation, critical to the development of a floating marsh. Suitable conditions for development of *P. virgatum* floating marsh are thus related to the effluent discharge coupled to biogeochemical conditions in the receiving area.

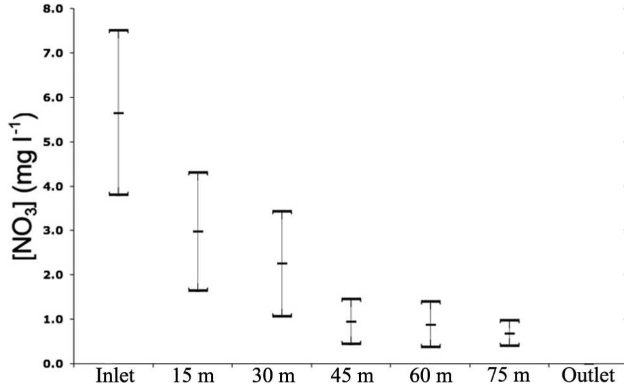

Figure 5. Mean annual nitrate concentration (95% CI) along the transect and at the outlet site (which was below detection limits).

The *P. virgatum* marsh developed in an area that was relatively clear, shallow water above a clay pan (Breaux and Day 1994). This suggests floating marsh initiation from shoreline attachment (Russell 1942). Another mechanism of floating marsh formation is that decaying organic debris accumulating on the bottom of shallow water bodies decays and becomes buoyant and is subsequently colonized by grasses and sedges (Cypert 1972). Currently the most commonly accepted theory for creation of Louisiana floating marshes is that over time a buoyant peat mass with its living vegetation breaks free from its subsiding substrate and floats freely (O'Neil 1949, Sasser et al. 1996).

Vegetation Growth Dynamics

The effluent discharge affected the dynamics of floating marsh development. High inorganic nutrient input established a strong environmental gradient that replaced pre-discharge homogenous, stagnant, more oligotrophic waters. The response was robust growth and expansion of emergent aquatic vegetation and the initiation of floating marsh formation. The 15 years of effluent discharge increased the availability of DIN, phosphate, and labile organics (Zhang et al. 2000) and likely influenced the patterns of plant succession observed in this study. *Panicum virgatum*, does not readily

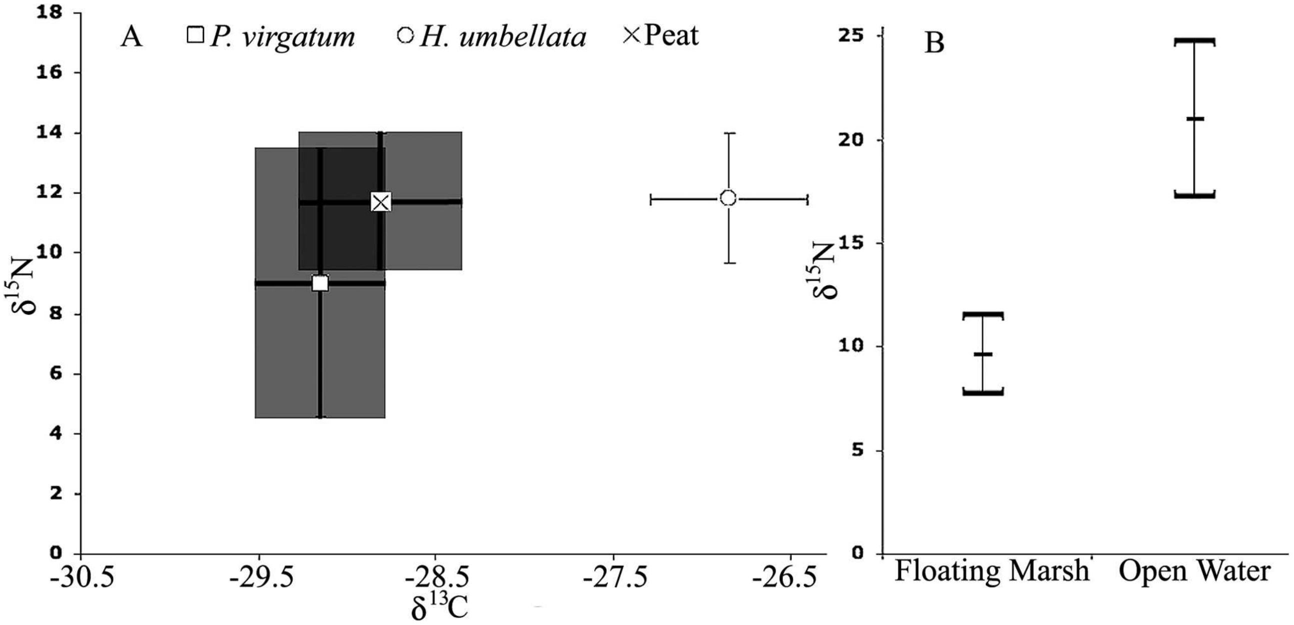

Figure 6. A) Mean Carbon and Nitrogen isotopic values of the floating marsh community. B) Mean δ^{15}N values of *Hydrocotyle umbellata* on the floating marsh transect (0–75 m) and in open water (100–400 m). All values reported with 95% confidence intervals.

grow and expand into open water, but it greatly increased the productivity of the shallow open water zone with the development of a floating marsh. The thickness of this marsh increases toward the effluent discharge where it is truly floating except during peak growing season when it is supported by thick organic muck. The ability of *P. virgatum* to exist as a floating form requires biomass production in excess of plant decomposition. In fertilization studies, *P. virgatum* has a high nitrogen requirement to achieve high biomass yields (George et al. 1995). The NAPP of *P. virgatum* (2736 g m^{-2} y^{-1}) was higher than typical values for *P. hemitomon* (970 g m^{-2} y^{-1}) floating marsh and generally exceeded growth of *P. virgatum* in bioenergy studies utilizing fertilizers (Vogel et al. 2002, McLauglin and Kszos 2005). However, studies using the best-bred varieties showed equivalent annual productivity to the values reported in this study (McLauglin and Kszos 2005). Along the 75-m transect the wetland transitions from *P. virgatum* dominated marsh with floatant characteristics (i.e., free floating, rooted in a substrate with soil-like properties) to an floating aquatic community dominated by *H. umbellata*, but *P. virgatum* was encountered at all sites. Beyond 75 m *Panicum* was uncommon.

Panicum virgatum exhibited a seasonality affected by autogenic (intraspecies competition, grazing) and allogenic (nutrient and freshwater inputs) factors. When growing in the absence of other species, *Panicum* seedlings emerged early in February. However, the cool-weather adapted *H. umbllata* produced greater biomass during the winter and spring months (Figure 4, Agami and Reddy 1991, Reddy and DeBusk 1984), especially at the 45- and 75-m sites, and effectively shaded the mat until growth slowed in June. Hydrocotyle growth contributed to late development of *P. virgatum* and thus exhibited an autogenic control on seasonal biomass yield, an important component of floating marsh development.

Marsh development may be suppressed where *Hydrocotyle* growth prevents the widespread germination of *Panicum* seedlings by shading and also as a growth response to nutria, *Myocaster coypus*, an introduced species known to trample and consume *P. virgatum*. In enclosures at the site, *P. virgatum* persisted year-round near the effluent discharge. Outside the enclosures, the marsh converted to nearly 100% cover of *Hydrocotyle* at the onset of winter. Nutria have been implicated in many areas of coastal Louisiana with decreased aboveground plant productivity and increased open area (Schaffer et al. 1992, Holm and Sasser 2001, Sasser et al. in press). *Panicum virgatum* biomass was significantly reduced in the presence of nutria in the freshwater areas of the Pearl River basin, Louisiana (Taylor and Grace 1995). Grazing and climate are likely responsible for decreased biomass of *P. virgatum* at the end of season relative to its midsummer peak. Both *P. virgatum* and *P. hemitomon* tend to achieve maximum growth during the warmest months (Sasser 1994).

Nutrient Chemistry

Prior to effluent discharge, inorganic nitrogen nutrient concentrations were similar to other impounded, low nutrient wetlands in the Mississippi delta including the adjacent reference area (Zhang et al. 2000). Ammonia remained relatively stable while there was a dramatic decrease of nitrate along the 75-m transect (Figure 5). Denitrification, which is an important pathway leading to nitrate removal, has been documented at Thibodaux and in similar assimilation wetlands where nitrate is the dominant form of inorganic nitrogen in the effluent (Boustany et al. 1997, Day et al. 2004). Furthermore, the denitrification potential of constructed wetlands has been shown to increase over time (Hernandez and Mitsch 2006). Oxygen can limit the rate of decomposition in wetland systems leading to a buildup of organic matter (Rybczyk et al. 2002) and low bulk density soil, thus contributing to floating marsh stability (Sasser 1994).

Over the entire wetland transect as flow exited the study site, significant reductions occurred in both NO_3 and NH_4, and nitrate was often below the detection limit at the outflow. Ammonia concentrations decreased to the range reported for natural forested wetland systems in Louisiana and elsewhere (Hopkinson and Day 1979, Kemp and Day 1984, Kemp et al. 1985). Similar nutrient reductions by multiple loss pathways have been observed in assimilation wetlands throughout the delta plain and other areas (Richardson and Davis, 1987, Day et al. 2004). Permanent loss pathways such as denitrification and burial are important to the sequestration of nutrients (Kaldec and Alvord 1989. DeLaune and Patrick 1990, Baustany et al. 1997). Izdepski (2008) reported that phosphate did not change over the 75-m floating marsh transect, but there was a significant reduction in phosphorus from input to the outflow (Zhang et al. 2000).

Stable Isotopes

Carbon stable isotope ratios have been used in a number of studies to determine source contributions to a given carbon pool (Fry 2006). Carbon isotope values consistently differed between *H. umbellata* and *P. virgatum* and showed that *P. virgatum* formed almost all of the peat in the floating mat.

The elevated $\delta^{15}N$ values observed were typical of nutrient enriched conditions in aquatic habitats and offer insight to transformation pathways in the mat. Numerous studies have documented $\delta^{15}N$ enrichment across nitrogen concentrations gradients (Altabet 2001, Cole et al. 2004), coincident with point and non-point nitrogen sources. Figure 6b shows $\delta^{15}N$ differences across the floating marsh transect for *H. umbellata*. Because the $\delta^{15}N$ value represents the total nitrogen in the plant tissue, no distinction can be directly made between DIN species. However, the trend of increasing tissue $\delta^{15}N$ with distance is consistent with rapid, selective NO_3 uptake, and denitrification favoring $\delta^{15}N$ enrichment in the remaining fraction. Another way this enrichment could arise requires $\delta^{15}N$ enriched ammonia originating in the treatment facility to bypass the floating marsh. There was no net concentration change in NH_4 to 75 m. This could be due to the low oxygen of the floating marsh mat environment preventing oxidation of ammonium. Under these conditions the floating marsh plants are likely incorporating nitrate more than ^{15}N-enriched ammonia. Beyond the mat, $\delta^{15}N$-enriched ammonium becomes the most readily available DIN form for plant uptake. In either case the data suggests nitrate transformations occur early and rapidly in the floating marsh zone. This is consistent with measurements of high denitrification rates at this site (Boustany et al. 1997) and in other assimilation wetlands (DeLaune et al. 1986, Day et al. 2004, Hernandez and Mitsch 2006), and high overall rates of nutrient assimilation systemwide.

We conclude that the addition of freshwater and nutrients can be beneficial to the establishment of this type of floating vegetation mat, and in turn as marsh productivity increases the capacity of the wetland to take up nutrients is enhanced. Ultimately, floating marsh may convert to rooted marsh as organic ooze fills the shallow water. Control of nutria will likely be necessary for maintenance of this type of floating marsh.

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