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NITROGEN AND PHOSPHORUS MOVEMENT IN A FRESHWATER TIDAL WETLAND RECEIVING SEWAGE EFFLUENT

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ABSTRACT

Recent work on nutrients in tidal wetlands has led to the suggestion that they can be managed for treatment of sewage effluent. In this paper we report some results of a three year study on the effects of spraying chlorinated secondarily treated sewage effluent on a Delaware River freshwater tidal wetland near Trenton, New Jersey. Biomass and standing crops of N and P at the end of the 1975 and 1976 growing seasons did not differ between experimental areas and control sites. The only consistent response of the aboveground vegetation was that plant material in areas receiving effluent had significantly greater %N and % P concentrations. Total N, %N, Total P and %P of plant litter was significantly greater in the experimental areas. There were no significant substrate responses due to spray irrigation. Tide cycle studies showed that the irrigated wetland was a sink for N and an exporter of P.

INTRODUCTION

Eutrophication of our inland and near shore waters, largely from sewage, is a major environmental problem. While nutrient removal from sewage is possible using a variety of chemical treatment methods, the cost of such treatment is often prohibitive leading in recent years to the consideration of biological alternatives for treatment of nutrient rich effluent (Tourbier and Pierson, 1976). Among the wetland ecosystems suggested as possible nutrient filters are cypress domes (Ewel, 1976), northern peatlands (Richardson et al, 1976), salt marshes (Valiela et al, 1976), swamps (Boyt et al, 1977; Brinson, 1977; Kitchens et al, 1975) and artificial wetlands (Small, 1976; Spangler et al, 1976; Stanlick, 1976). Recent reviews on the subject of marsh management (Sloey et al, in press; Stearns, in press; Tilton et al, 1976) indicate that wetlands may efficiently trap nutrients, particularly nitrogen, but caution that they should not be routinely used for sewage effluent disposal until natural processes in those systems are better understood.

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In this paper we consider the potential use of freshwater tidal wetlands for tertiary treatment of municipal wastes. Those wetlands are highly productive (Whigham et al, in press) and cover extensive areas in the freshwater portions of most eastern U.S. estuaries. Grant and Patrick (1970) have reported that Tinicum Marsh, a Delaware River freshwater tidal wetland located immediately south of Philadelphia, acts as a water purifier and we have noted similar processes occurring in the Hamilton Marshes, the northernmost freshwater tidal wetland in the Delaware River estuary (Simpson et al, in press; Whigham and Simpson, 1976a). In 1975 we initiated experiments to assess the potential of freshwater tidal wetlands to remove nitrogen and phosphorus from chlorinated secondarily treated sewage effluent. In this paper, we summarize experiments that focused on the following ecosystem responses: 1) aboveground biomass; 2) storage of nitrogen (N) and phosphorus (P) in aboveground biomass; 3) nitrogen and P storage in confined and unconfined litter; 4) storage of N and P in the substrate; 5) N and P dynamics of surface water. More detailed reports of our work are currently in preparation and will be forthcoming.

METHODS

The experimental area and treatment regimes that were used during these experiments have been described (Whigham and Simpson, 1976a and 1976b) and will only be briefly outlined here. The study site was located in the Hamilton Marshes, a 500 ha freshwater tidal wetland connecting with the Delaware River estuary near Trenton, New Jersey. The experiments were conducted on a high marsh site that had been previously studied (Whigham and Simpson, 1975). The site was chosen because it was representative of the most widespread habitat in the wetland and it was located near the Hamilton Township Sewage Treatment Plant which discharges approximately 7.5 million gallons of secondarily treated effluent daily. Chlorinated secondarily treated effluent was screened to remove large suspended particles and pumped to the wetland where it was sprayed into 12 three-sided enclosures (20 m X 10 m). Four enclosures were irrigated continuously, four during 2 three hour periods coinciding with high tide and four during 2 nine hour periods coinciding with the drawdown period of each tide cycle. Two enclosures from each set received 5 cm of effluent daily and two received 12.5 cm daily. Two control enclosures received tap water applied continuously at 12.5 cm per day and two control enclosures received no treatment. Application of effluent to the high and low tide enclosures was accomplished with an electronically timed switching mechanism synchronized to tide level indicators. Effluent was applied continually throughout the 1975 and 1976 growing seasons except during the winter when it was impossible to spray because of freezing conditions and on occasions when the system did not operate because of vandalism or equipment malfunction.

Biomass and production estimates were determined by periodically harvesting aboveground biomass from 50 cm X 50 cm quadrats during each growing season. Six quadrats were harvested from each enclosure. The plants were separated by species, dried at 80 C, weighed and analyzed for N and P. Litter decomposition experiments were performed in 1975 and 1976 by confining dried plant material in 2 mm mesh litter bags. Litter bags were placed on the wetland surface in the two control areas and in the treatment enclosures that received 12.5 cm of effluent per day. In 1975, we examined decomposition of Arrow arum (*Peltandra virginica*) and Bur marigold (*Bidens laevis*) leaves and stems and in 1976 we used leaf material of Arrow arum, Bur marigold, Tearthumb (*Polygonum arifolium*), Arrowhead (*Sagittaria latifolia*) and Sweet flag *Acorus calamus*). In 1975, duplicate litter bags were collected at 7, 15, and 30 days and monthly thereafter for 9 months. In 1976, duplicate samples were collected at 3, 7, 14, 30, 60, 90 and 120 days. Dry weight %N and %P were determined for each sample. Five 5 cm^2 samples of unconfined litter were collected from each enclosure between April 1976 and and May 1977 and analyzed for N and P. The upper 50 cm of substrate, not including litter, was sampled from June 1975 until October 1976 at approximately monthly intervals. Duplicate samples were collected from each enclosure and divided into 0-20 cm and 20-50 cm depth intervals prior to drying and analysis for N and P. Nitrogen and P determinations on plant, soil and litter samples were performed using micro-Kjeldahl (Amer. Soc. Agr. 1965) and tube digestion techniques (Sommers and Nelson, 1972) respectively.

To assess the fate of effluent applied to the wetland, a series of tide cycle studies were conducted during the summers of 1976 and 1977. In addition, we monitored the effects of irrigation within the watershed that contained the enclosures by measuring water quality parameters at a number of locations for one year. In this paper, we only report results of the 1977 experiments and only include data for selecting areas. Water was collected at the low point of each enclosure beginning when flood tide water reached the surface of the high marsh and continued hourly until the next flood tide reached the marsh surface. Simultaneous samples of effluent and water in the stream channel immediately downstream from the study area were also collected. Samples were analyzed for reactive nitrate (NO_3-N), reactive nitrite (NO_2-N) ammonia plus amino acids (NH_3-N) and reactive phosphorus (PO_4-P) following Strickland and Parsons (1968). Total N and Total P were determined using a single sample wet digestion procedure outlined by Golterman (1969). For the purpose of developing nutrient budgets, the effluent entering each experimental enclosure was metered and each enclosure was mapped so that the volume of water entering with the flood tide could be accurately determined. It was assumed that the volume of water in an enclosure at high slack water plus the volume of effluent applied to that enclosure during the study period equalled the total output from the enclosure in a tide cycle. This assumption seemed justified because there was little lateral movement of water through the enclosures and the marsh surface drained completely during each tide cycle. Mean nutrient concentrations of effluent applied during the study period and mean concentrations of stream flood tide water during the period between when the high marsh was first flooded and high slack water were used to calculate input budgets. Output budgets were based on mean nutrient concentrations of water leaving the enclosures between high slack water and when the marsh was reflooded.

RESULTS

Aboveground Vegetation (Biomass, N and P)

Aboveground biomass at the end of the 1975 and 1976 growing seasons ranged from 1021.6 gm^2 to 533.2 gm^2 and 475.4 gm^2 to 743.5 gm^2

respectively (Table 1). There were no significant differences between the the 3 treatments during either year. In 1975, the controls were significantly different while in 1976 the enclosures receiving effluent continuously had significantly less biomass than the control that was not irrigated.

Plant %N and %P were significantly greater in the treatment enclosures but there were no differences between treatments. Percent N in the treatment enclosures ranged from 3.19% to 2.77% in 1976 and 3.37% to 3.13% in 1975. The mean %N in the tap water control was 2.54% during both years and was 2.31% (1976) and 1.99% (1975) in the other control. Percent P in the treatment areas ranged from .385% to .364% in 1976 and .378% to .332% in 1975. Percent P of vegetation in the control enclosures did not differ significantly and were .314% and .280% in 1975. Percentage P in the controls was slightly less in 1976.

Although %N and %P differences were significant, Total N and Total P in the aboveground standing crop did not follow the same pattern. In 1975, there were no significant differences in Total N and Total P. In 1976, vegetation in the enclosures that received effluent during the high tide had significantly more Total N and Total P than did the tap water control. None of the experimental enclosures were, however, significantly different than the other control. Total N ranged from 21.7 to 11.8 gm^2 and 20.9 gm^2 to 16.4 gm^2 in 1976 and 1975 respectively. Total standing crop P ranged from 2.3 gm^2 to 1.4 gm^2 in 1976 and 2.7 gm^2 to 2.0 gm^2 in 1975.

N and P in Confined and Unconfined Litter

Results of the litter decomposition experiments are shown in Table 2. Almost all of significant effects were due to species differences. There were no significant species-site interactions and only %N, %P, and Total P of the confined litter were affected by site. In 1975, the species effects were caused by higher %N, %P, Total N and Total P in Arrow arum litter even though it decayed at a significantly faster rate. Site responses were due to higher %P and Total P in the three areas receiving effluent. Although only leaf material was used in 1976 experiments, the results were very similar. For every variable measured there were species effects. There were no significant species-site interactions, but %N, %P, and weight loss were affected by site. Percent N of Bur marigold and Arrow arum and %P of Arrowhead and Arrow arum leaves was higher in the treatment enclosures. After 120 days, Arrowhead leaves exposed to effluent weighed significantly less than leaves exposed to tap water. The %N and %P of unconfined litter was greater in the experiment areas (Table 3). In contrast to confined litter, Total N and Total P of unconfined litter were significantly greater in virtually all treatment enclosures.

Substrate N and P

Substrate Total N, %N, Total P and %P were not affected by treatment. The only significant differences were due to depth where both %N and Total N were significantly greater at the 0-20 cm depth interval. There were, however, no depth site interactions. Percent N averaged 1.23% in the 0-20 cm depth interval and 0.85% in the 20-50 cm depth interval.

Table 1. The response of aboveground vegetation to sewage spray irrigation. All values in the table are means. Means that are significantly different ($\alpha = .01$) from the tap water control are indicated with * while means significantly different from the no water control are shown with +.

	TREATMENTS									
	(N)	HIGH TIDE	(N)	LOW TIDE	(N)	CONTINUOUS	(N)	TAP WATER CONTROL	(N)	NO WATER CONTROL
					1976					
Biomass (gm^2)	23	672.800	24	531.100	24	563.600	12	475.400	12	743.500
Total N (gm^2)	23	21.70*	24	16.800	24	18.000	12	11.800	12	15.800
%N	93	3.130*+	88	3.26*+	90	3.370*+	42	2.540	64	2.310
Total P (gm^2)	23	2.300*	24	2.000	24	2.000	12	1.400	12	1.900
%P	93	0.336*+	88	0.385*+	90	0.364+	42	0.314	64	0.280
					1975					
Biomass (gm^2)	24	598.400	24	703.200	24	533.200	12	794.400	12	1021.600
Total N (gm^2)	24	16.900	24	20.900	24	16.400	12	18.100	12	17.300
%N	88	2.77+	74	3.06+	70	3.19+	55	2.540	54	1.990
Total P (gm^2)	24	2.100	24	2.700	24	2.000	12	2.000	12	2.500
%P	88	0.332*+	74	0.378*+	70	0.368	55	0.251	54	0.287

Table 2. Results of the confined litter experiments. Values are means of 48 samples for 1975 data and 70 samples for 1976 data. Weight represents the mean amount of material in the litter bag during the experiment. Means significantly different from the tap water control (α=.01) are indicated with * while means significantly different (α = .01) from the no water control are shown by +

	TREATMENTS				
	HIGH TIDE	LOW TIDE	CONTINUOUS	TAP WATER CONTROL	NO WATER CONTROL
			1976		
Weight (g)	4.830+	5.020+	4.800+	5.230	5.600
Total N (g)	0.170	0.163	0.164	0.157	0.145
%N	3.950*+	3.650*+	3.750*+	3.350	3.650
Total P (g)	0.011	0.013	0.013	0.013	0.013
%P	0.233+	0.279	0.276+	0.236	0.229
			1975		
Weight (g)	4.550	4.120	4.240	4.370	4.670
Total N (g)	0.118	0.119	0.126	0.120	0.124
%N	2.970	3.300	3.320	3.020	3.130
Total P	0.010*+	0.010*+	0.010*+	0.007	0.007
%P	0.247*+	0.273*+	0.255*+	0.117	0.173

Table 3. Results of unconfined litter experiments. Values are means of 11 samples. Both Total N and Total P means are gm^2. Treatments significantly different from the tap water control are indicated by * (α = .05) and ** (α = .01). Treatments significantly different from the no water control are indicated by + (α = .05) and ++ (α = .01).

	TREATMENTS				
	HIGH TIDE	LOW TIDE	CONTINUOUS	TAP WATER CONTROL	NO WATER CONTROL
Total N	57.900	65.200**++	73.300**++	53.100	54.800
%N	01.970+	02.290**++	02.160**++	01.810	01.730
Total P	15.100*++	17.400**++	17.000**++	12.400	09.400
%P	00.491*++	00.576*++	00.497*++	00.423	00.294

N and P Flux in Water

Results of some of the tide cycle nutrient budget studies are given in Table 4. Except for NO_2-N, nutrient flux patterns were basically the same for the two experimental sites receiving effluent and the control. The input of NH_3-N, NO_3-N and Total N was greater than the outputs, while PO_4-P and Total P were the opposite with a net flux from all sites. These patterns hold even though the high flow experimental site received almost twice as much water as the other experimental site and from ten to 100 fold more water than the untreated control. While the daily net fluxes were quite variable, it does appear that the wetland may assimilate up to 40% of the Total N and, at times, well over half of the NO_3-N it receives. These results are consistent with other studies of this wetland (Simpson et al, in press) which showed that NO_3-N levels in water running off of the marsh surface were lower than adjacent stream waters while PO_4-P levels were higher.

DISCUSSION

Generalized results of our analyses are shown in Table 5. Although the aboveground biomass has significantly greater %N and %P, Total N and Total P are not different because one of the control enclosures had more aboveground standing crop at the end of the growing season. Percent N, Total N, %P and Total P of the unconfined litter was significantly greater in the enclosures that received effluent but N and P did not accumulate in the substrate. Results of the decomposition experiments with confined litter showed similar results but also demonstrated that the Total N and Total P in the unconfined litter are due to the continuous fall of leaves to the wetland surface during the growing season.

Nutrient budget studies showed that this wetland acted as a sink for N, particularly Total N. However, only the litter compartment showed a significant increase in Total N. This suggests that denitrification was occurring which eliminated N at approximately the rate it was being accumulated by the marsh. Certainly conditions on the wetland surface where oxygen levels approach zero when the high marsh is drained (Simpson et al., in press; Whigham and Simpson, 1976b) favored denitrification. While the high marsh does have the ability to assimilate some of the N from effluent, it is not particularly effective. Coupled with the fact that there is a net movement of P from the high marsh as the wetland drains, it would appear that the high marsh habitat is not capable of efficient removal of nutrients from large volumes of sewage. However, where it is desirable to remove some N from sewage it does appear that freshwater tidal wetlands with sufficient aerial extent may be important because they mix and redistribute N righ sewage over a considerable area of high marsh where conditions strongly favor denitrification.

Table 4. Flux of N and P for two experimental enclosures and one control enclosure during complete tide cycles on five dates in 1977. All values for the effluent treated enclosures are grams (g) while data for the control enclosure are milligrams (mg). Parenthesis around flux values indicate a net loss from the enclosure during the study interval.

PART 1. CONTINUOUS SPRAY ENCLOSURE: HIGH FLOW

	7 June	21 June	22 June	5 July	6 July
			NH_3-N		
Input					
Effluent	30.309	27.295	17.820	20.743	25.042
Tide water	0.007	0	2.675	3.208	4.967
Output	32.256	40.470	14.425	16.649	19.497
Net flux	(-1.940)	(-13.075)	6.070	7.402	10.512
			NO_2-N		
Input					
Effluent	0.265	0.157	0.152	0.124	0.108
Tide water	0.047	0.067	0.048	0.082	0.065
Output	0.373	0.787	0.671	0.959	0.701
Net flux	(-0.061)	(-0.563)	(-0.471)	(-0.753)	(-0.528)
			NO_3-N		
Input					
Effluent	6.172	6.654	6.509	2.914	2.292
Tide water	0.633	1.151	0.769	1.018	0.754
Output	4.955	7.310	7.141	6.489	5.937
Net flux	1.850	0.495	0.237	(-2.557)	(-2.891)
			TOTAL N		
Input					
Effluent	520.096	637.553	575.488	647.472	746.306
Tide water	12.828	17.702	15.153	18.898	18.089
Output	531.655	724.161	566.898	549.842	643.448
Net flux	1.269	(-68.906)	23.743	116.528	110.943
			PO_4-P		
Input					
Effluent	5.074	5.577	5.598	4.994	6.085
Tide water	0.053	0.109	0.088	0.110	0.189
Output	1.745	7.698	6.438	7.175	7.608
Net flux	3.382	(-2.012)	(-0.752)	(-2.071)	(-1.334)
			TOTAL P		
Input					
Effluent	80.215	100.673	112.269	96.564	107.346
Tide water	2.231	5.338	3.427	5.673	4.224
Output	83.323	144.523	130.631	134.598	130.054
Net flux	(-0.877)	(-38.512)	(-14.935)	(-32.361)	(-18.483)
			Water entering the enclosure (m^3)		
Effluent	19,3149	24.7200	24.8182	23.2853	22,7706
Tide water	6.1975	13.8300	9.2625	12.6075	9.2625

Table 4. Cont'd.

PART II. CONTINUOUS SPRAY ENCLOSURE: LOW FLOW

	7 June	21 June	22 June	5 July	6 July
			NH_3-N		
Input					
Effluent	19.992	18.674	12.610	14.099	17.537
Tide water	0.002	0	0.998	0.386	1.011
Output	16.460	26.899	12.623	9.312	12.850
Net flux	3.534	(-8.225)	0.985	5.173	5.698
			NO_2-N		
Input					
Effluent	0.174	0.107	0.107	0.085	0.075
Tide water	0.014	0.051	0.018	0.010	0.013
Output	0.095	0.191	0.142	0.269	0.269
Net flux	0.093	(-0.033)	(-0.017)	(-0.174)	(-0.181)
			NO_3-N		
Input					
Effluent	4.072	2.862	4.606	1.980	1.605
Tide water	0.193	0.885	0.287	0.122	0.153
Output	0.918	1.054	0.911	1.061	1.151
Net flux	3.347	2.493	3.982	1.041	0.607
			TOTAL N		
Input					
Effluent	343.058	434.598	406.007	440.029	552.636
Tide water	3.901	13.609	5.656	2.274	3.681
Output	317.632	490.714	401.308	307.512	407.032
Net flux	29.327	(-42.507)	10.355	134.791	119.285
			PO_4-P		
Input					
Effluent	3.347	3.802	3.961	3.394	4.262
Tide water	0.016	0.084	0.033	0.013	0.024
Output	1.069	5.791	4.713	3.821	4.969
Net flux	2.294	(-1.905)	(-0.719)	(-0.414)	(-0.683)
			TOTAL P		
Input					
Effluent	52.910	68.616	79.434	66.308	75.170
Tide water	0.678	4.104	1.279	0.682	0.859
Output	48.696	109.699	95.957	69.682	86.553
Net flux	4.892	(-36.979)	(-15.244)	(-3.374)	(-10.524)
			Water entering the enclosure (m^3)		
Effluent	12.7403	16.8508	17.5624	15.8250	15.9462
Tide water	1.8850	10.6325	3.4575	1.5175	1.8850

Table 4. Cont'd.

PART III. NO WATER CONTROL ENCLOSURE

	7 June	21 June	22 June	5 July	6 July
			NH_3-N		
Input					
Effluent	-	-	-	-	-
Tide water	0.733	0	319.902	20.355	6.702
Output	0.129	0.725	70.873	7.678	2.092
Net flux	(-0.604)	(-0.725)	249.029	12.677	4.610
			NO_2-N		
Input					
Effluent	-	-	-	-	-
Tide water	0.898	15.419	5.745	0.518	0.088
Output	0.363	5.638	2.118	0.124	0.028
Net flux	0.535	9.781	3.627	0.394	0.060
			NO_3-N		
Input					
Effluent	-	-	-	-	-
Tide water	12.004	266.800	92.038	6.457	1.017
Output	3.688	48.318	2.073	1.258	0.213
Net flux	8.688	218.482	89.965	5.119	0.804
			TOTAL N		
Input					
Effluent	-	-	-	-	-
Tide water	243.225	4102.400	1811.870	119.920	24.412
Output	141.979	3620.047	1303.749	83.216	25.782
Net flux	101.246	482.353	508.121	36.704	(-1.369)
			PO_4-P		
Input					
Effluent	-	-	-	-	-
Tide water	1.013	25.335	10.550	0.695	0.160
Output	1.099	37.593	13.574	1.038	0.293
Net flux	(-0.086)	(-12.258)	(-3.024)	(-0.343)	(-0.133)
			TOTAL P		
Input					
Effluent	-	-	-	-	-
Tide water	42.3	1237.130	409.775	36.000	5.700
Output	37.6	1415.808	522.659	39.549	10.221
Net flux	4.7	(-178.678)	(-112.884)	(-3.549)	(-4.521)
			Water entering the enclosure (m^3)		
Effluent	-	-	-	-	-
Tide water	0.1175	3.2050	1.1075	0.0800	0.0125

Table 5. Summary of treatment effects for the variables discussed. All information in the table compares the effects of effluent application to the experimental enclosures against the controls.

	Total N	%N	Total P	%P
Aboveground biomass	No change	Increases	No change	Increases
Unconfined surface litter	Increases	Increases	Increases	Increases
Confined surface litter	No change	Increases	No change	Increases
Substrate (0-20 cm)	No change	No change	No change	No change
Substrate (20-50 cm)	No change	No change	No change	No change
Nutrient flux	No change*		No change*	

*While there was no change in the patterns of nutrient flux between treatment and control sites, absolute nutrient levels were higher in the experimental enclosures.

Our results contrast with those of workers in other wetland systems. Boyt et al (1977) found that a Florida mixed hardwood swamp affected 87% removal of P from treated municipal wastewater. Nitrogen concentrations were also greatly reduced. They found no buildup of nutrients in the sediments, but suggested that increased productivity was responsible for most of the reduction in nutrients. Similarly, Kitchens et al (1975) has concluded that the vegetation, not sediments, acted as a sink for nutrients moving through the Santee Swamp in South Carolina. Klopatek (1975, in press) has also suggested that emergent macrophytes in a Wisconsin riverine marsh effectively remove nitrogen and phosphorus from the water during the growing season. Marshall (1970) has reported that salt marsh cord grass (Spartina alterniflora) productivity increased significantly in a North Carolina salt marsh with the experimental addition of municipal wastewater. His study would also suggest that salt marsh macrophytes can act as nutrient sinks. Brinson (1977) has found immobilization of N and P beyond values added by leaf fall in a North Carolina swamp and concluded that the litter, not vegetation or sediments, compartment acted as a nutrient sink. Studies of a northern Michigan peatland (Richardson et al, in press) have shown that wetland sediments may also effectively remove N and P from domestic sewage. They found a dramatic decline in nutrient concentrations occurring within a few meters of the discharge point. Their budget studies clearly show that most of the N and P was trapped in the sediments (peat). Indeed, Stanlich (1976) has shown that peat can be used as an effective nutrient trap for wastes from campground treatment facilities.

Artifically created marshes have also been shown to remove N and P from sewage. An artificial pond/marsh system described by Woodwell (1977) reduced inorganic N by at least 84% and PO_4-P by at least 94% when primary-treated sewage was introduced into the marsh, trickled into an adjoining pond and then recirculated through the marsh. Spangler et al (1976) using an artificial marsh with a gravel bottom also effected substrate removal of P from sewage with most being trapped in the sediments. In that study, however, a spring flush removed most of the P suggesting that a gravel substrate is not appropriate for long term storage of P.

Unlike the wetlands described above, the marsh we studied did not accumulate N or P in the vegetation or sediments, but did accumulate both N and P in the litter. Three factors may have been operative in our system. First, the effluent we applied was chlorinated as required by the State of New Jersey. Observations of the emergent vegetation clearly showed that prolonged contact with chlorinated effluent reduced the vigor of certain species and completely eliminated sensitive species (Whigham and Simpson, 1976b). Thus, while the vegetation in the experimental enclosure did show elevated %N and %P when compared with controls, the chlorine stress was just too great for plants to overcome. Second, litter decomposition rates in the Hamilton Marshes are extremely high (Simpson and Whigham, 1976a and 1976b; Simpson et al, in press). Nutrients stored in the vascular plants are leached rapidly following senescence and death and, for most species studied, decomposition is essentially complete before the onset of the next growing season. Because litter turnover is almost complete on an annual basis, we wouldn't expect that the litter compartment would ever become extensive enough to account for long-term storage of large amounts of N and P as Brinson (1977) has found in a North Carolina swamp and Richardson et al (in press) found in a northern bog wetland. Third, the wetland we studied was a pulsed system with the high marsh being flooded and drained twice daily. While the flood and ebb tide waters tended to move over the wetland surface as a slow sheet water movements were substantially greater than that normally encountered in most southern swamp forests, peatlands, or for that matter, artificial marshes. This, combined with the high rate at which we applied effluent and its resultant rapid drainage from the high marsh surface may have prevented efficient uptake of nutrients. Pond-like areas of the same wetland (Whigham and Simpson, 1976a) which are drained only at very low tide, where water movement is much slower and where there is an accumulation of litter from one growing season to the next, may be more efficient at nutrient removal than the high marsh. Water quality studies (Simpson et al, in press) indeed suggest that the pond-like habitat does act as a nutrient sink throughout the year. On the basis of our preliminary analysis of the data, it would appear that the high marsh habitat of freshwater tidal wetlands does not have the tremendous nutrient removal characteristics of other wetlands. However, where limited removal of N from sewage is a management goal, freshwater tidal wetlands can play an important role.

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