THE EFFECT OF SEWAGE EFFLUENT ON THE STRUCTURE AND FUNCTION OF A FRESHWATER TIDAL MARSH ECOSYSTEM

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DISCLAIMER

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ABSTRACT

The effects of spraying chlorinated secondarily treated sewage on a Delaware River freshwater tidal wetland for three years was studied. Macrophyte net primary production was significantly lower in the experimental sites receiving sewage than in the no treatment controls in 1975 but not in 1976 or 1977. Diversity of annuals was reduced in the experimental sites largely due to the elimination of annuals. Although percent N and P were generally high in the vegetation of experimental sites, there was little difference in Total N and Total P between treatments and controls. Macrophyte decomposition rates were little affected by sewage application. Substrate N and P were not significantly different between sites, but surface litter of the experimental sites accumulated N and P. Epibenthic algae may contribute to this accumulation. Water quality studies showed the high marsh to be metabolically active. Tide cycle flux studies indicated that up to 40% of the N added to the wetland was assimilated during the late spring - early summer period. Conversely, there was a net loss of P from the wetland.

These results are compared with those of similar studies in other wetlands. It is concluded that the strongly pulsed tidal regimes of the wetland, the low organic content substrate, and the eutrophic nature of Delaware River waters contribute to the inability of the wetland to efficiently assimilate nutrients from sewage.

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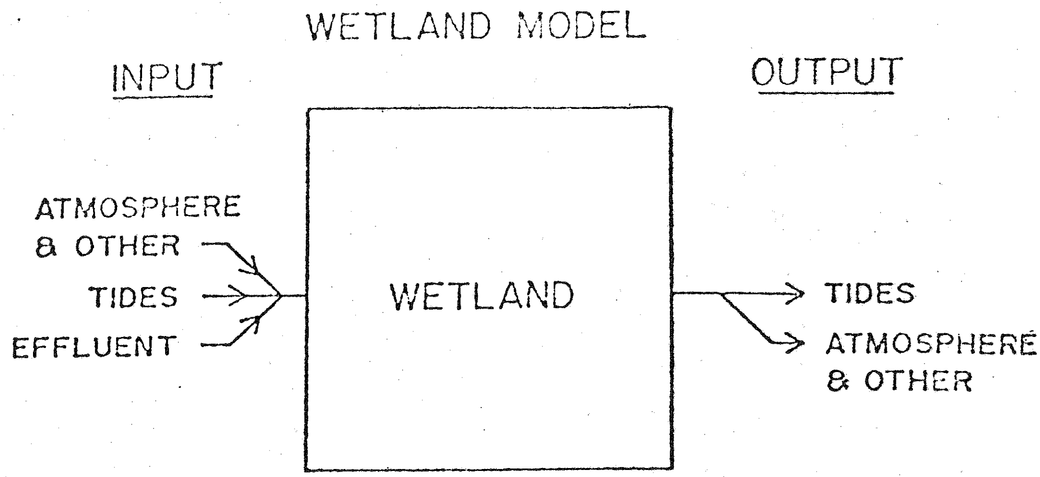
1. INTRODUCTION

This study was proposed after results of our initial work in the Hamilton Marshes (Whigham and Simpson 1974, 1975, 1976a; Simpson et al., 1978) showed that the wetlands were highly productive and that there were very pronounced seasonal patterns of selected water quality parameters. For example, water quality data showed that concentrations of nitrogen and phosphorus were high in flood tides water and were very low in water that ebbed from the wetland. Grant and Patrick (1970) had reported similar findings from their studies of the Tinicum Marshes near Philadelphia. Based on our earlier work, it seemed that the wetland was an efficient trap for nutrients, especially during the growing season, which were stored in wetland vegetation, sediments and/or in litter.

This report details results of a three year study designed to consider the potential for using the Hamilton Marshes, a freshwater tidal wetland, for the removal of nitrogen and phosphorus from secondarily treated municipal wastewater. Additional details of our earlier studies of the wetland can be found in Whigham and Simpson(1976a, 1977). Aspects of this study have been published in Whigham and Simpson (1976b, 1978), Simpson, et al. (1978) and Whigham et al. (1978). Other studies related to the Hamilton Marshes include Whigham and Simpson (1979), Simpson et al. (1979), Leck and Graveline (1979), Bonasera et al. (1979) and Whigham et al. (1979).

2. WETLAND MODEL

The research was designed around the models shown in Fig. 1. In its simplest terms the wetland represents an integrated ecosystem with



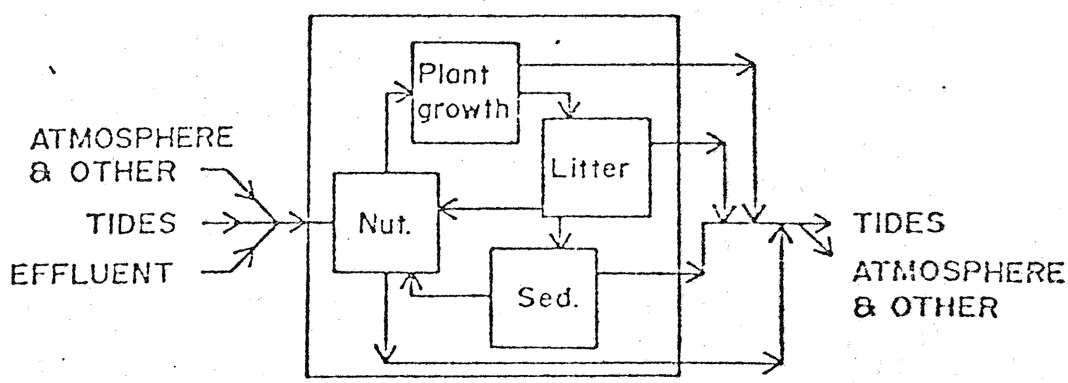


Fig. 1 Diagrammatic representation of wetland ecosystems. The upper diagram represents a mass balance approach to the study of nutrient dynamics. The lower diagram includes mass balance studies but it depicts the major compartments through which nutrients move and in which they are stored.

potentially definable inputs and outputs. If the wetland ecosystem has the potential to provide advanced treatment of municipal wastewater, we would expect that additional inputs (i.e., sewage effluent) would be assimilated and stored within the wetland or converted to another form and released immediately. A detailed analysis of the inputs and outputs shown in Part A of Fig. 1 would provide answers to the following questions:

1. Are nitrogen and phosphorus stored within the wetland?

2. Does the wetland change the quality of wastewater?

We attempted to answer those questions by performing several types of experiments. During single tide cycles, we monitored the form and quantity of nitrogen (N) and phosphorus (P) that was applied to treatment areas as effluent and the amount that entered with tidal water. We then measured N and P that was removed during the ebb tide. The data were used to calculate tide cycle input-output budgets for the treatment areas as well as determine whether or not there were changes in water quality parameters. For one year we also monitored water quality parameters in the watershed where the effluent study was located.

What is the fate of nitrogen and phosphorus that are stored in the wetland? Part B of Fig. 1 shows the approach that we used to assess that question. All inputs of N and P were categorized as nutrients that could follow several pathways. Some of the N and P would pass quickly through the wetland and be removed as tidal or atmospheric losses. Nutrients could also be stored in the litter, sediment and plant biomass compartments. Accordingly, standing stocks of N and P in the plant, litter and sediment compartments were measured throughout the study.

Based on our earlier work (Whigham and Simpson 1975, 1976a), we believed that much of the nitrogen and phosphorus that would be stored in the wetland during the growing season would be released into tidal waters during decomposition of litter following senescence of the vascular plants. We, therefore, performed studies on the effect that the application of wastewater had on decomposition, rate and the temporal patterns of N and P in the litter compartment.

In our earlier work (Whigham and Simpson 1976b) we noted that algae seemed to be important components of the wetland system and that they might play an important role in nutrient cycling. As part of the present study, we performed studies of seasonal patterns of chlorophyll standing stocks in the treated areas, a qualitative analysis of the algae species, except diatoms, present in the treatment areas and a series of field and laboratory experiments designed to determine how dominant algae species responded to nutrient addition.

3. STUDY SITE

The study site was located in the Hamilton Marshes, (Fig. 2) a 500 ha freshwater tidal wetland connecting with the Delaware River estuary near Trenton, N.J. (Whigham and Simpson 1976a, Simpson et al. 1978). The sewage spray irrigation studies were conducted on a high marsh site chosen because it was representative of the most widespread habitat in the wetland. The site was located near the Hamilton Township Sewage Treatment Plant which, during the study period, discharged approximately 7.5 million gallons of secondarily treated effluent daily into Crosswicks Creek which is the major stream in the wetland.

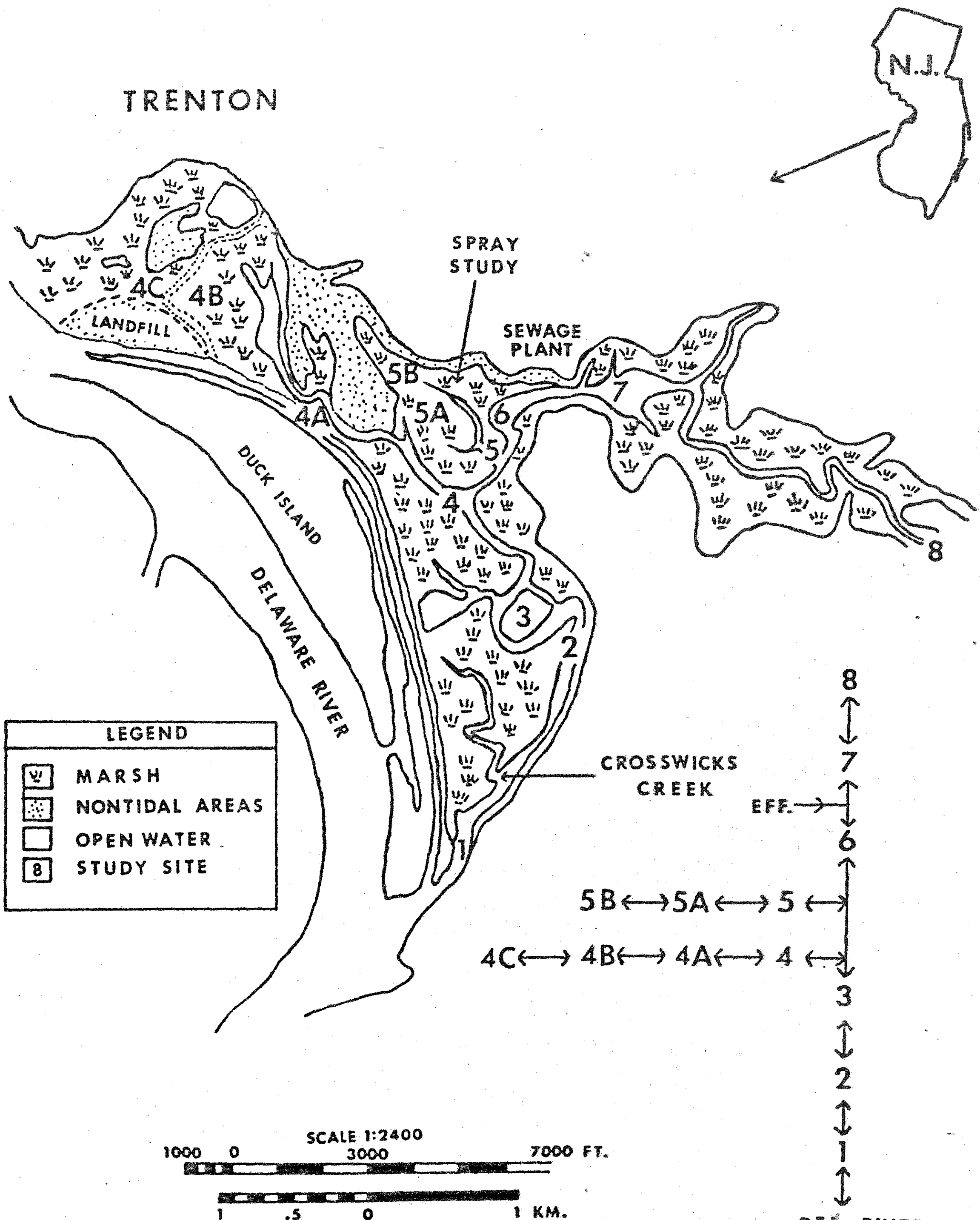


Figure 2. Map of the Hamilton Marshes showing locations of study area. Numbers represent sites for earlier water quality studies (see Simpson, et al., 1978), and arrows represent flow direction.

4. DESIGN OF THE EXPERIMENTAL ENCLOSURES AND EFFLUENT DELIVERY SYSTEM

Clorinated secondarily treated effluent was obtained from the nearby Hamilton Township Sewage Treatment Plant. The effluent was screened to remove large suspended particles and pumped to the wetland where it was sprayed into 12 three-sided enclosures. The enclosures were 20m x 10m and the sides were constructed of wood frames which were covered with reinforced polyethylene. The sides of the enclosures were pushed into the wetland so that we could minimize lateral exchange of water between the experimental areas. The open sides of each enclosure faced an adjacent stream channel so that tidal waters would be able to flow freely into and out of the enclosures. The enclosures were constructed in the spring of 1975 and spraying began in early June of the same year.

Four enclosures were irrigated with effluent continuously, four during 2 three hour periods coinciding with the high tide and 4 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 the other two received 12.5 cm daily. Two enclosures from each set received tap water continuously at 12.5 cm per day and two enclosures received no treatment. The treatment regimes are summarized in Table 1.

The amount of effluent applied to the enclosures was controlled by varying the orfice of Rain-Bird sprinklers. Application of effluent to the high and low tide enclosures was accomplished with an electronically timed switching mechanism that was synchronized to a tide level indicator that was located in an adjacent stream channel.

TABLE 1. Treatment regimes used during the study. All treatments were made in duplicate.

Treatment	Quantity (cm/day)	Site
Effluent application when tidal water covered the high marsh (2-three hour applications per day)	5	1
	12	2
Effluent application when tidal water did not cover the high marsh (2-nine hour applications per day)	5	3
	12	4
Effluent application continuous	5	6
	12	5
Tap water control - application continuous	12	7
No treatment control	0	8

Effluent was applied continuously throughout the 1975 and 1976 growing seasons except during the winter when the wetland was frozen and on occasions when the system did not operate because of vandalism or equipment malfunction. In 1976 we added flow meters to the system so that we could more precisely measure the amounts of effluent that were added to each enclosure. In 1977, wastewater was applied only to the enclosures that received effluent continuously.

5. ABOVEGROUND VEGETATION

The most salient feature of freshwater tidal wetland ecosystems is the changing physiognomic aspect of the emergent macrophytes (Whigham et al. 1978). The response of aboveground portions of that ecosystem component to application of sewage effluent was monitored for the three years of the study. For each Site we determined aboveground biomass on several occasions during each growing season, estimated yearly annual net aboveground primary production for each site, determined the concentrations and total amounts of nitrogen and phosphorus in the aboveground vegetation at each sampling date during the first two years of the study, estimated the aboveground and total amounts of phosphorus and nitrogen that was associated with the net production estimate, and calculated Shannon-Weiner diversity for each Site for each of the three years.

Methods

Biomass was determined and primary production estimated for the 1975, 1976, and 1977 growing seasons by periodically harvesting the aboveground biomass. During each sampling event, six 50cm x 50cm quadrants were harvested from each Site for a total of 12 replicates per treatment. Vegetation was cut at the wetland surface and returned to the laboratory where the plants were separated by species and dried at 80°C, weighed, ground in a Wiley Mill, and analyzed for nitrogen using micro-kjeldahl techniques (Amer. Soc. Agr., 1965) and phosphorus using a tube digestion technique (Sommers and Nelson, 1972).

All data were analyzed by both one-way and two-way analysis of variance to determine if there were any differences between Sites. Statistical comparisons between Sites were performed for each year on the following data: 1) Total biomass for each sampling data, 2) Nitrogen concentrations in plant tissue for each sampling date, 3) Phosphorus concentrations in plant tissues for each sampling date, 4) Total nitrogen (TOTAL N) in standing vegetation for each sampling date, 5) Total phosphorus (TOTAL P) in standing vegetation in each treatment for each sampling date, 6) Estimated total net annual primary production for each Site calculated following Whigham, et al. (1978) using the following formula:

$$P_n = \sum_{i=1}^{n} \text{(maximum aboveground biomass of species i for year) where}$$

P_n is net primary production.

7) Estimated net accumulation of nitrogen (NTOT) associated with the P_n estimate where $NTOT = \sum_{i=1}^{n}$ (N in maximum aboveground biomass of species i for year), 8) Estimated net accumulation of phosphorus (PTOT) associated with the P_n estimate for each site where $PTOT = \sum_{i=1}^{n}$ (P in maximum aboveground biomass of species i for year), 9) Shannon-Weiner index of diversity for each Site for each year. The index value was calculated according to the formula in Peet (1975) where $\hat{H} = \sum_{i=1}^{n} P_i \log P_i$. We used biomass data as a measure of the relative contributions (P_i) of each species.

Results

Aboveground Biomass, %N, TOTAL N, %P, TOTAL P

1975 - YEARDAY 157

Data for biomass, %N, TOTAL N, %P and TOTAL P on yearday 157 are shown in Table 2. Aboveground biomass ranged from 679.8 ± 65.9 g/m^2 at control Site 8 to 499.4 ± 71.7 g/m^2 at Site 6 where effluent was sprayed continually. There were no significant differences between any of the means (α = .41). Neither were there any significant differences in nitrogen (α = .33) which ranged from 18.9 ± 3.9 to 14.2 ± 2.4 g/m^2 or %N in the aboveground tissues (α = .19) which ranged from 3.07 ± 0.21 %N at Site 5 to 2.49 ± 0.16 %N at Site 3. Similarly, there were no differences in phosphorus (α = .65) or %P (α = .98). Ranges for the latter were 1.17 ± 0.3 g/m^2 to 2.5 ± 0.6 g/m^2 and 0.31 ± 0.003 %P to 0.35 ± 0.02 %P respectively.

1975 - YEARDAY 181

There were no significant differences when Site comparisons were made for %N, %P and TOTAL P in the aboveground vegetation (Table 3). Aboveground biomass at Site 7 (796.5 ± 108.0 g/m^2) and Site 8 (720.9 ± 76.7 g/m^2) was significantly (at least α = .05) greater than at Sites 4 (407.1 ± 126.1 g/m^2), 5 (493.1 ± 105.6 g/m^2) and 6 (410.5 ± 71.3 g/m^2). Significantly less aboveground biomass was at Sites 4 and 6 than at Site 1 (675.8 ± 100.6 g/m^2), Site 2 (688.3 ± 106.0 g/m^2) and Site 3 (668.8 ± 123.6 g/m^2). Significant differences in TOTAL N (Table 3) were due to less TOTAL N at Site 5 (10.6 ± 1.8 g/m^2) and Site 4 (10.7 ± 3.5 g/m^2).

1975 - YEARDAY 191

There were no significant differences in the total aboveground biomass (α = .39), TOTAL N (α = .59) and TOTAL P (α = .52) in the aboveground vegetation (Table 4). Significant differences (α = .01) in %N were due to lower N concentrations at Site 7 (2.31 ± 0.30%) which is the tap water control site, than at Site 6 (2.89 ± 0.13%), Site 4 (2.85 ± 0.14%) and Site 2 (2.84 ± 0.30%). The control that received no water (Site 8) did not, however, differ significantly from any other Site (Table 4).

Tissue phosphorus concentrations at Site 7 (0.22 ± 0.01%) were significantly less than at all other Sites (α = .01 at all Sites except Site 1 which was α = .05). Vegetation at Site 8 (0.26 ± 0.03%) had significantly lower (α = .01) %P than vegetation AT Site 6 (0.33 ± 0.01%) and Site 4 (0.36 ± 0.02%). Comparing Sites that received sewage, %P in vegetation at Site 4 was significantly higher than all other areas except Site 6. Site 6 vegetation had higher tissue P concentrations than vegetation at all areas except Site 1.

<u>1975 - YEARDAY 218</u>

Significant differences were found for all variables except TOTAL N in aboveground vegetation. Biomass at Site 7 (629.1 ± 75.0 g/m^2) and Site 8 (952.3 ± 94.7 g/m^2) was significantly greater (α = .01) than biomass at all other sites (Table 5). Comparisons of treated areas showed that average biomass at Site 5 (309.3 ± 48.0 g/m^2) was significantly less than at Site 3 (α = .10). The TOTAL P stock at Site 8 (2.3 ± 0.2 g/m^2) was significantly greater than at all other Sites (at least α = .05) even though %P at Site 8 (0.24 ± 0.02%) was significantly less than all areas (at least α = .05) except Sites 2 (0.28 ± 0.01%) and 7 (0.25 ± 0.02%). TOTAL P at tap water control Site 7 was significantly more than TOTAL P at Site 1 (0.29 ± 0.02%) and 2 (α = .10) but was similar to Site 1-6

(Table 5). There were no significant differences in TOTAL P when comparisons were made between sewage treated Sites. Vegetation at Sites 7 and 8 had significantly lower nitrogen concentrations (α = .01) than all other Sites and Site 7 (1.8 ± .01%) was significantly greater (α = .10) than Site 8 (1.6 ± 0.1%). Site 5 vegetation had significantly higher concentrations of N (3.1 ± 0.2%) than all treated areas except Site 6 (2.9 ± 0.2%). Site 6 %N was similar to Sites 4 (2.8 ± 0.1%) and 2 (2.7 ± 0.1%) but greater than (at least α = .05) Site 1 (2.5 ± 0.1%).

Phosphorus concentrations were least at the two control sites but those values were only significantly (at least α = .05) less than %P at Sites 3-6. Percentage P of Site 7 (0.25 ± 0.02%) vegetation was not significantly less than Site 1 (0.29 ± 0.02%) or 2 (0.28 ± 0.01%) while Site 8 (0.24 ± 0.02%) %P was significantly less than Site 1 (α = .10) but not different from Site 2. Within the treated Sites, Site 5 (0.40 ± 0.02%) had the highest %P concentration (Table 5) which was significantly greater (α = .01) than Sites 2, 1 and 3.

1975 - YEARDAY 252

There were no significant differences in TOTAL N (α = .13) and TOTAL P (α = .13) of aboveground vegetation (Table 6). Site 8 aboveground biomass (1021.7 ± 137.6 g/m^2) was significantly greater than biomass at Sites 5 (α = .10), 2 (α = .05), 1 (α = .01), 4 (α =.01) and 6 (α = .01). Site 7 aboveground biomass (794.6 ± 113.2 g/m^2) was only greater than the biomass at Sites 1 (α = .05), 4 (α = .05) and 6 (α =.01). Sites 4 and 6 (313.4 ± 30.5 g/m^2) biomass was significantly less than all other sites (α = .01). Site 5 (733.2 ± 70.2 g/m^2) had the largest amount of aboveground biomass of the treated Sites (Table 6) and that mean was significantly more than all Sites except the biomass at Site 3 (944.0 ± 169.3 g/m^2). Site 3 aboveground biomass was also significantly larger than all Sites except the controls and Site 5.

Nitrogen concentrations of vegetation at Site 8 (1.7 ± 0.1%) was significantly less than the means of all other Sites (α = .01). Site 7 (2.4 ± 0.1%) %N was significantly less (at least α = .05) than all other sites except Site 1 (2.6 ± 0.1%). Site 6 (3.4 ± 0.2%) plants had the highest %N which was significantly greater than all Sites (at least α = .05) except Site 4 (3.3 ± 0.1%). Vegetation at Sites 3 and 5 (3.0%) had significantly higher %N than vegetation at Site 1 (α = .05) while the mean %N of vegetation at Site 4 was significantly greater than at Sites 2 (α = .05) and 1 (α = .01).

Phosphorus concentrations (Table 6) at Sites 7 (0.24 ± 0.02%) and 8 (0.26 ± 0.03%) was significantly less than %P at all other Sites (at least α = .10). Site 4 (0.43 ± 0.02%) vegetation had significantly greater %P concentration than all other Sites (at least α = .10) while Site 1 (0.32 ± 0.02%) %P was significantly less (at least α = .10) than %P at the other treatment Sites.

<u>1976 - YEARDAY 161</u>

There were no significant differences between Sites for aboveground biomass, TOTAL N or TOTAL P (Table 7). The %N of vegetation of Sites 7 (2.6 ± 0.1%) and 8 (2.8 ± 0.1%) was significantly less than all other Sites (α = .01). The %N of vegetation at the treated Site was similar except that Sites 6 (4.1 ± 0.2%) and 5 (4.2 ± 0.3%) were significantly greater than at Site 1 (3.5 ± 0.2%) at the .10 significance level.

Mean %P at Site 2 (0.34 ± 0.02%) was significantly (α = .05) greater than Site 8 (0.27 ± 0.02%) and significantly less than %P at Sites 2-6

(α = .01). Site 8 %P was significantly less than all other Sites (at least at the .05 level of significance). Sites 6 (0.41 ± 0.02%), 3 (0.41 ± 0.03%) and 2 (0.42 ± 0.02%) %P was significantly greater (α = .05) than Site 1 (0.34 ± 0.02%). Site 4 %P (0.44 ± 0.02%) was significantly greater than Site 5 (0.38 ± 0.03%) at the .05 significance level and Site 1 at the .01 significance level.

1976 - YEARDAY 191

Similar to yearday 161, the only significant differences were in %P (α = .008) and %N (α = .01) of the aboveground vegetation. The mean %N at Site 7 (1.5 ± 0.3%) was significantly less than at all other sites (at least α = .05) except Sites 8 (Table 8). Site 8 %N (2.6 ± 0.2%) was less than all sites (at least α = .05) except Sites 7 and 1 (2.8 ± 0.2%). The %N of Site 4 vegetation was 3.4 ± 0.1% which was significantly greater than %N at Sites 1 (α = .01) and 2 (3.0 ± 0.1%) (α = .10). Mean %N at the other sites was similar except that %N at Sites 3 (3.1 ± 0.1%), 5 (3.2 ± 0.1%) and 6 (3.2 ± 0.1%) was greater than the %N at Site 1. Mean %P at Sites 7 (0.28 ± 0.02%) and 8 (0.27 ± 0.02%) was significantly less than %P at all other sites (at least α = .10). Sites 3 (0.41 ± 0.03%), 4 (0.40 ± 0.02%) and 5 (0.43 ± 0.03%) %P was significantly greater than %P at Sites 1 (α = .10) and 6 (α = .10).

1976 - YEARDAY 222

Aboveground biomass and %N were the only variables for which the means were significantly different (Table 9). Site 8 aboveground biomass (449.3 ± 55.2 g/m^2) was significantly more than biomass at Sites 6 (293.4 ± 42.9 g/m^2) and 5 (275.3 ± 36.6 g/m^2) at the .10 significance level and less (α = .10) than the aboveground biomass at Site 2 (643.8 ± 87.8 g/m^2). Site 7 aboveground biomass (410.5 ± 43.1 g/m^2) was also less than the biomass at Site 2 (α = .10). Sites 6 and 5 biomass was the least and the means were less than those for Sites 4 (489.2 ± 95.4 g/m^2), 3 (457.5 ± 60.9 g/m^2) at the .10 significance level and Sites 2 and 1 at the .01 significance level. Biomass at Site 2 (643.8 ± 87.8 g/m^2) was significantly greater than all Sites except Site 1. Site 1 biomass, however, was only significantly greater than Sites 5 and 6 (α = .10).

Nitrogen concentrations of plants at Site 8 (2.1 ± 0.2%) was significantly less than all other Sites (at least at the .05 significance level). Site 7 %N (2.4 ± 0.1%) was similar to Sites 1 (2.5 ± 0.1%), 2 (2.4 ± 0.1%) and 4 (2.7 ± 0.2%) but significantly less (α = .10) than Sites 3 (2.8 ± 0.1%), 5 (α = .01) and 6 (α = .01). Sites 5 (3.1 ± 0.1%) and 6 (3.1 ± 0.1%) vegetation had the highest %N concentrations (Table 9) and they were greater than all Sites except Site 3.

1976 - YEARDAY 253

Percentage nitrogen in aboveground vegetation was the only variable for which there were significant differences between Sites (Table 10). Both control Sites had the lowest mean %N and those values were significantly less than the means at the other 6 sites (all significant at α = .01 except Site 2 where the significance level between it and Site 8 was α = .10). Nitrogen concentrations ranged from 3.5 ± 0.2% at Site 1 to 2 2.1 ± 0.1% at Site 1.

1977

In 1977 only Sites 5 and 6 were irrigated with sewage effluent. In addition vegetation was not analyzed for N or P. Biomass data, therefore, represent recovery following irrigation for Sites 1-4. Table 11 lists biomass data for the 3 dates sampled in 1977. There ~~was~~ were no significant differences between mean aboveground vegetation at any of the sampling dates.

TABLE 2 1975 YEARDAY 157. Data for aboveground biomass (g/m^2), nitrogen (g/m^2) and phosphorus (g/m^2) on yearday 157. Mean %N and %P of the plant tissues are also presented. For each category, the values are means ±1 standard error for the number of replicates shown (N). None of the means are significantly different.

SITE	N	ABOVEGROUND				
		Biomass	Total N	Total P	% N	%P
1	12	534.7±83.0	14.8±2.4	1.8±0.3	2.8±0.1	0.34±0.02
2	12	653.8±129.9	18.6±3.6	2.2±0.5	2.9±0.1	0.32±0.02
3	12	740.7±129.9	18.9±3.9	2.5±0.6	2.5±0.2	0.31±0.03
4	12	535.1±100.0	15.7±3.2	1.8±0.3	2.9±0.2	0.34±0.01
5	12	542.6±65.2	17.3±2.9	2.0±0.3	3.1±0.2	0.35±0.02
6	12	499.4±71.7	14.2±2.4	1.7±0.3	2.8±0.1	0.33±0.02
7	12	629.6±57.9	16.5±1.7	1.9±0.2	2.6±0.1	0.32±0.02
8	12	679.8±65.9	16.2±1.4	2.2±0.3	2.5±0.2	0.32±0.03

TABLE 3. 1975 YEARDAY 181. Data for aboveground biomass (g/m^2), nitrogen (g/m^2) and phosphorus (g/m^2) on yearday 181. Mean %N and %P of the plant tissues are also presented. For each category, the values are means ±1 standard error for the number of replicates shown (N). Means that are significantly different are described in the text.

SITE	N	ABOVEGROUND				
		Biomass	Total N	Total P	%N	%P
1	12	675.8± 100.6	16.1± 2.3	1.9± 0.4	2.4± 0.2	0.26± 0.01
2	12	688.3 ±106.0	17.0± 3.0	2.0± 0.3	2.5± 0.1	0.30± 0.03
3	12	668.8 ±123.6	17.8± 3.4	2.0± 0.4	2.7± 0.2	0.30± 0.02
4	12	407.1± 126.1	10.7± 3.5	1.3± 0.4	2.4± 0.3	0.32± 0.02
5	12	493.1± 105.6	10.6± 1.8	1.6± 0.4	2.3± 0.2	0.29± 0.01
6	12	410.5 ±71.3	11.4± 1.9	1.2± 0.2	2.8± 0.1	0.30± 0.01
7	12	796.5± 109.0	17.1± 2.7	2.1± 0.4	2.2± 0.2	0.26± 0.02
8	12	720.9 ±76.7	17.4± 3.2	2.0± 0.2	2.3± 0.2	0.28± 0.01

TABLE 4. 1975 YEARDAY 191. Data for aboveground biomass (g/m^2), nitrogen (g/m^2) and phosphorus (g/m^2) on yearday 191. Mean %N and %P of the plant tissues are also presented. For each category, the values are means ±1 standard error for the number of replicates shown (N). Means that are significantly different are described in the text.

SITE	N	ABOVEGROUND				
		Biomass	Total N	Total P	%N	%P
1	12	938.2 ±147.9	18.8± 1.9	2.6± 0.4	2.2± 0.2	0.29± 0.02
2	12	863.5± 124.1	25.1± 5.3	2.8± 0.5	2.8± 0.3	0.31± 0.02
3	12	641.6 ±102.1	16.6± 2.8	2.0± 0.4	2.6± 0.1	0.30± 0.02
4	12	645.2± 112.4	18.6± 3.7	2.2± 0.4	2.9± 0.1	0.36± 0.02
5	12	479.6 ±65.8	11.4± 1.7	1.4± 0.2	2.4± 0.3	0.30± 0.01
6	12	367.8 ±36.5	10.5± 1.1	1.2± 0.1	2.9± 0.1	0.33± 0.01
7	12	721.9 ±77.8	16.1± 2.6	1.6± 0.1	2.3± 0.3	0.22± 0.01
8	12	644.9± 129.5	17.8 ±5.1	1.7± 0.4	2.5± 0.2	0.26± 0.03

TABLE 5. 1975 YEARDAY 218. Data for aboveground biomass (g/m^2), nitrogen (g/m^2) and phosphorus (g/m^2) on yearday 218. Mean %N and %P of the plant tissues are also presented. For each category, the values are means ±1 standard error for the number of replicates shown (N). Means that are significantly different are described in the text.

SITE	N	ABOVEGROUND				
		Biomass	Total N	Total P	%N	%P
1	12	436.9 ±72.2	10.7± 1.7	1.2± 0.1	2.5± 0.1	0.29± 0.02
2	12	397.7 ±47.1	10.5± 1.1	1.1± 0.2	2.7± 0.1	0.28± 0.01
3	12	482.6 ±79.8	11.9± 2.1	1.4± 0.3	2.5± 0.1	0.30± 0.01
4	12	413.7 ±62.1	11.8± 1.8	1.5± 0.2	2.8± 0.1	0.39± 0.02
5	12	309.3 ±49.0	9.3 ±1.1	1.2± 0.2	3.1± 0.1	0.40± 0.01
6	12	354.6 ±48.0	10.1± 1.1	1.3± 0.1	2.9± 0.2	0.37± 0.02
7	12	629.1 ±75.0	11.3 ±1.8	1.5± 0.2	1.8± 0.1	0.25± 0.02
8	12	952.3 ±94.7	14.3± 1.2	2.3± 0.2	1.6± 0.1	0.24± 0.02

TABLE 6. 1975 YEARDAY 252. Data for aboveground biomass (g/m^2), nitrogen (g/m^2) and phosphorus (g/m^2) on yearday 252. Mean %N and %P of the plant tissues are also presented. For each category, the values are means ± 1 standard error for the number of replicates shown (N). Means that are significantly different are described in the text.

SITE	N	ABOVEGROUND				
		Biomass	Total N	Total P	%N	%P
1	12	491.0 ±82.3	12.9± 2.3	1.7± 0.5	2.6± 0.1	0.32± 0.02
2	12	706.3 ±81.8	20.8± 3.2	2.4± 0.3	2.8± 0.1	0.34± 0.02
3	12	944.0 ±169.3	28.7± 5.2	3.3± 0.6	3.0± 0.2	0.37± 0.03
4	12	465.7 ±54.6	15.0± 1.6	2.0± 0.2	3.3± 0.1	0.43± 0.02
5	12	733.2 ±70.2	21.9± 1.4	2.8± 0.2	3.0± 0.1	0.37± 0.01
6	12	313.4 ±30.5	10.4 ±0.9	1.2± 0.1	3.4± 0.2	0.33± 0.02
7	12	794.6 ±113.2	18.1 ±2.2	1.9± 0.3	2.4± 0.1	0.24± 0.02
8	12	1021.7 ±137.6	17.3 ±2.3	2.4± 0.3	1.7± 0.1	0.26± 0.03

TABLE 7. 1976 YEARDAY 161. Data for aboveground biomass (g/m^2), nitrogen (g/m^2) and phosphorus (g/m^2) on yearday 161. Mean %N and %P of the plant tissues are also presented, For each category, the values are means ±1 standard error for the number of replicates shown (N). Means that are significantly different are described in the text.

	N	ABOVEGROUND				
		Biomass	Total N	Total P	%N	%P
1	12	532.3±66.8	18.5±1.6	1.8±0.2	3.8±0.2	0.34±0.02
2	12	363.6±63.6	13.5±1.5	1.5±0.3	4.0±0.2	0.42±0.02
3	12	370.1±75.5	14.0±2.8	1.5±0.3	3.8±0.1	0.41±0.03
4	12	484.8±104.1	18.2±4.0	2.1±0.4	3.8±0.1	0.34±0.02
5	12	387.5±85.3	14.6±3.1	1.4±0.3	4.2±0.3	0.38±0.03
6	12	313.1±97.4	12.2±3.7	1.2±0.3	4.1±0.2	0.41±0.02
7	12	578.3±97.9	13.4±3.1	2.0±0.4	2.6±0.1	0.34±0.02
8	12	560.5±72.7	16.2±2.7	1.6±0.2	2.8±0.1	0.27±0.02

TABLE 8. 1976 YEARDAY 191. Data for aboveground biomass (g/m^2), nitrogen (g/m^2) and phosphorus (g/m^2) on yearday 191. Mean %N and %P of the plant tissues are also presented. For each category, the values are means ±1 standard error for the number of replicates shown (N). Means that are significantly different are described in the text.

		ABOVEGROUND				
SITE	N	Biomass	Total N	Total P	%N	%P
1	12	424.1 ±78.1	11.9 ±2.1	1.5 ±0.3	2.8 ±0.2	0.35 ±0.02
2	12	357.1 ±49.9	10.7 ±1.6	1.4 ±0.2	3.0 ±0.1	0.38± 0.02
3	12	541.8 ±122.2	17.3 ±4.6	2.4 ±0.8	3.1 ±0.1	0.41 ±0.03
4	12	336.9 ±58.0	11.3 ±2.0	1.4 ±0.3	3.4 ±0.1	0.40 ±0.02
5	12	379.4 ±92.2	11.5 ±2.3	1.7 ±0.4	3.2 ±0.1	0.43 ±0.03
6	12	331.8 ±44.6	10.6 ±1.5	1.1 ±0.1	3.2 ±0.1	0.34 ±0.02
7	12	615.5 ±68.0	12.4 ±1.8	1.5 ±0.3	2.4 ±0.1	0.28± 0.02
8	12	483.5 ±86.9	12.8 ±2.6	1.3 ±0.2	2.6 ±0.2	0.27 ±0.02

TABLE 9. 1976 YEARDAY 222. Data for aboveground biomass (g/m^2), nitrogen (g/m^2) and phosphorus (g/m^2) on yearday 222. Mean %N and %P of the plant tissues are also presented. For each category, the values are means ±1 standard error for the number of replicates shown (N). Means that are significantly different are described in the text.

		ABOVEGROUND				
SITE	N	Biomass	Total N	Total P	%N	%P
1	12	519.3 ±79.0	12.7 ±2.0	1.3 ±0.2	2.5 ±0.1	0.27 ±0.02
2	12	643.8 ±37.8	15.7 ±2.3	2.0 ±0.3	2.4 ±0.1	0.32 ±0.02
3	12	467.5 ±60.9	12.0 ±1.4	1.5 ±0.2	2.8 ±0.1	0.35 ±0.03
4	12	489.2 ±95.4	12.9 ±2.5	1.6 ±0.2	2.7 ±0.2	0.36 ±0.03
5	12	275.3 ±36.6	8.4 ±1.1	0.8 ±0.1	3.1 ±0.1	0.29 ±0.02
6	12	293.4 ±42.9	8.7 ±1.2	1.0 ±0.1	3.1 ±0.1	0.37 ±0.02
7	12	410.5 ±43.1	10.2 ±1.4	1.1 ±0.1	2.4± 0.1	0.26 ±0.02
8	12	449.3 ±55.2	8.9 ±1.1	1.2 ±0.2	2.1 ±0.2	0.26 ±0.03

TABLE 10. 1976 YEARDAY 253. Data for aboveground biomass (g/m^2), nitrogen (g/m^2) and phosphorus (g/m^2) on yearday 253. Mean %N and %P of the plant tissues are also presented. For each category, the values are means ±1 standard error for the number of replicates shown (N). Means that are significantly different are described in the text.

		ABOVEGROUND				
SITE	N	Biomass	Total N	Total P	%N	%P
1	12	708.0 ±55.6	25.0 ±2.9	2.6 ±0.2	3.5 ±0.2	0.37± 0.03
2	12	640.5 ±60.3	18.1 ±2.5	2.2 ±0.3	2.8 ±0.2	0.34± 0.02
3	12	445.5 ±51.4	13.6 ±1.4	1.6 ±0.2	3.2 ±0.1	0.35± 0.02
4	12	616.5 ±52.8	19.9 ±1.7	2.4 ±0.2	3.3 ±0.2	0.39± 0.01
5	12	642.8 ±129.3	18.7 ±4.2	2.1 ±0.4	3.0 ±0.2	0.33± 0.01
6	12	530.9 ±48.9	17.8 ±1.6	2.0 ±0.2	3.4 ±0.1	0.38± 0.02
7	12	472.0 ±44.6	11.7 ±1.5	1.4 ±0.1	2.4 ±0.2	0.30± 0.02
8	12	753.3 ±83.0	15.9 ±2.1	1.9 ±0.2	2.1 ±0.1	0.25± 0.01

TABLE 11 - 1977. Data for aboveground biomass (g/m^2) are shown for the three yeardays sampled in 1977. All values are means ±1 standard error for the number of replicates shown (N). Means that are significantly different are described in the text.

SITE	N	ABOVEGROUND YEARDAY 1964	YEARDAY 1962	YEARDAY 244
1	12	376.4 ±31.0	890.1 ±124.0	463.3 ±86.8
2	12	381.8 ±94.2	655.3 ±92.7	484.7 ±25.5
3	12	382.0 ±75.3	805.4± 119.9	704.8 ±142.0
4	12	398.2 ±66.0	842.3 ±179.6	619.6 ±80.2
5	12	327.6 ±66.4	701.2 ±109.9	901.6 ±125.2
6	12	439.4 ±101.6	693.5 ±133.2	755.6 ±113.7
7	12	651.2 ±116.7	670.0 ±73.2	833.4± 103.3
8	12	522.1 ±55.7	687.9 ±134.6	856.0± 68.1

Net Primary Production and Associated N and P Standing Stocks

Using techniques described by Whigham et al. (1978), we estimated net primary production (P_n) and the amount of N (NTOT) and P (PTOT) associated with those levels of net production (see page 9 for description of calculations).

Estimated P_n values for each Site for the 3 years of the study are shown in Table 12. In 1975, there were significant differences in P_n (α = .02), NTOT (α = .07) and PTOT (α = .09). The maximum estimated P_n was at Site 8 (2387.4 ± 177.3 g/m^2) where the mean was significantly greater (α = .01) than all areas except Site 7 (1995.6 ± 143.4 g/m) where the significance level was α = .10 and Site 3 (2170.8 ± 192.7 g/m^2) which was not significantly less. Site 7 estimated P_n was significantly greater (α = .01) than Sites 6 (1089.0 ± 96.2 g/m^2), 5 (1620.4 ± 129.2 g/m^2) and 4 (1328.0 ± 126.2 g/m^2). Comparing treated areas, Site 3 P_n was significantly greater than all other sites (α = .10). P_n at the other Sites were not significantly different except for Site 6 where P_n was significantly less than Site 5 (α = .05), Site 3 (α = .01), Site 2 (α = .01) and Site 1 (α = .01).

The amount of N (NTOT) associated with the P_n at the two control Sites was similar to the treated areas with the following exceptions (Table 12): Site 8 (35.9 ± 3/5 g/m^2) was significantly greater (α = .05) than Site 6 (33.1 ± 4.2 g/m^2). Site 7 (45.3 ± 4.0 g/m^2) was greater than Site 6 (α = .10) but less (α = .10) than Site 3 (58.2 ± 7.3 g/m^2). NTOT at Site 6 was significantly less (α = .10) than Site 5 (45.1 ± 9.3 g/m^2), Site 3 (α = .01) and Site 2 (49.8 ± 6.1 g/m^2). Site 5 and 4 N were also less than Site 3 (α = .10).

TABLE 12. Yearly estimated net primary production (Pn) maximum N uptake (NTOT) and maximum P uptake (PTOT) for the 8 study sites. All values (g/m^2) are means ±1 standard error. Means that are significantly different are described in the text.

SITE	Pn	NTOT	PTOT
	1975		
1	1745.2±210.4	40.3±3.3	5.4±0.7
2	1763.9±170.3	49.8±6.1	5.8±0.7
3	2170.8±192.7	58.2±7.3	7.4±0.8
4	1328.0±126.2	40.0±3.7	4.7±0.4
5	1620.4±129.2	45.1±4.3	5.8±0.5
6	1089.0±96.2	31.6±2.7	3.7±0.3
7	1995.6±143.4	45.3±4.0	5.1±0.4
8	2387.4±177.3	49.8±6.7	6.3±0.5
	1976		
1	1371.9±91.3	42.7±2.8	4.5±0.3
2	1139.7±98.1	32.8±3.7	4.1±0.4
3	1242.0±122.2	38.5±4.5	4.9±0.8
4	1303.9±102.1	43.3±3.6	5.1±0.4
5	1090.7±121.9	33.5±3.8	3.9±0.4
6	973.5±107.8	33.1±4.2	3.4±0.3
7	1270.4±109.0	32.9±3.4	3.9±0.4
8	1525.2±101.8	35.9±3.5	4.1±0.3
	1977		
1	1307.3±113.3		
2	1082.0±95.2		
3	1540.9±141.3		
4	1310.1±180.6		
5	1268.4±194.3		
6	1516.0±214.6		
7	1560.0±176.4		
8	1635.7±135.6		

Phosphorus assimilated (PTOT) in the P_n was similar at the two control sites. Site 8 P (6.3 ± 0.5 g/m^2) was greater than Site 6 (3.7 ± 0.3 g/m^2) and Site 4 (4.7 ± 0.4 g/m^2) while Site 7 P was greater than Site 6 ($\alpha = .10$) and less than ($\alpha = .01$) Site 3 (7.4 ± 0.8 g/m^2). Site 6 P was significantly less than all areas (at least $\alpha = .05$) except Site 4.

Net primary production, nitrogen and phosphorus for 1976 are shown on Table 12. There were no significant differences between any of the Sites. In 1977, there were no differences in P_n when comparisons were made between sites (Table 12).

Shannon - Weiner Diversity

To determine what types of changes, if any, were occurring in the diversity of the wetland vegetation, biomass data were used to calculate Shannon-Weiner ($\overline{H}$) diversity values for each site (Table 13). There were no significant differences between Sites after the first year of irrigation. The mean $\overline{H}$ value for the treated Sites was 1.99 compared to a mean of 2.18 for the two controls. After 1976, there were differences between Sites. All Sites that received water, even the tap water control (Site 7), had lower $\overline{H}$ values while the value for Site 8 (2.34) remained the same. The mean $\overline{H}$ value for the treated Sites was 1.76 compared to 2.09 for the two control Sites.

Diversity values in 1977 followed a pattern similar to that in 1976. The average $\overline{H}$ values for the control Sites ~~was~~ were 1.62 and 2.07 for the two controls.

TABLE 13. Shannon-Weiner diversity values for the treatment and control Sites for the 3 years of the study. See text for explanation of data and to calculate $\bar{H}$.

SITE	1975	1976	1977
1	2.01	1.79	1.59
2	2.01	1.71	1.79
3	1.85	1.83	1.65
4	1.97	1.79	1.59
5	2.13	1.64	1.41
6	1.99	1.78	1.71
7	2.04	1.84	1.86
8	2.31	2.34	2.28

6. EPIBENTHIC ALGAE

Earlier studies showed the presence of epibenthic algae throughout the year, although algal peak standing crop was estimated to be < 2% that of the macrophyte in the wetland (Simpson and Whigham, 1975; Whigham and Simpson,(1976a) Observations during 1975 suggested that the addition of effluent enhanced the growth of epibenthic algae, especially in enclosures receiving continuous effluent application. To evaluate this response, we determined for each treatment the composition of the epibenthic algae exclusive of the diatoms, sediment chlorophyll levels (see Section 8), and the effects of shading by macrophytes on colonization and growth of epibenthic algae. In addition, representative species were cultured in the laboratory to investigate the interaction of light, temperature and effluent on growth.

Methods

Soil samples were collected biweekly during June, July and August, 1976 and monthly from September, 1976 to May, 1977. One sample was collected from each of the 16 enclosures. A sample was composed of 5 subsamples collected from the same quadrant of the enclosure. Approximately 5 g of soil from each of the 8 sets of duplicate samples were inoculated aseptically into 16 125 ml flasks containing 100 ml of autoclaved Bold's Basal Medium with three-fold nitrogen (3N BBM) (Bischoff and Bold, 1964). The flasks were incubated for two weeks under standard conditions of 20 $\pm^{1}$°C, 5000 $\pm^{500}$ lux provided by a bank of 40-w cool-white fluorescent lamps set on a 12 hour light, 12 hour dark cycle. The algae grown by this enrichment culture method were identified and characterized using routine phycological methods (Lee and Bold, 1975).

In the summer of 1977 duplicate 1 m^2 plots were cleared of macrophytes by clipping of the marsh surface. The plants surrounding these plots were clipped to a height of approximately 0.5 m. All plots were reclipped weekly. Clean glass microscopic slides were placed on the wetland surface in clipped plots and unclipped plots. Single slides from each plot were recovered one, two and three weeks after the initial clipping on 14 June. In the laboratory the slides were dipped gently into sterile distilled water to remove loose mud particles. A gentle stream of sterile distilled water was used to dislodge any obvious nonalgal material from the glass slides. The algae were then scraped from the slides with clean slides and rinsed twice with 5 ml of sterile distilled water. One ml of 3% formaldehyde was added (to this 10 ml suspension) to preserve the algae. The soil algae were identified microscopically and counted using a Spencer Bright Line Hemacytometer. Densities were expressed as number of algae per mm^2 standard counting chamber.

Soil samples were collected from the clipped plots and control areas in the enclosures at the time of clipping and 2 and 4 weeks thereafter. Each soil sample was mixed thoroughly and 6.5 cm^3 of soil was added to 20 ml of sterile distilled water. The suspension was mixed thoroughly and placed under an incandescent lamp for 2-5 min while the soil settled. Cell counts were made using a standard counting chamber and expressed as number of soil algae per cm^3.

For the laboratory experiments, algae from the soil samples were isolated and axenified using the methods of Brown and Bishoff (1962), Wiedeman et al. (1964) and Hoshaw and Rosowski (1973). Stock cultures were maintained in 3N BBM under standard conditions. Growth experiments used axenic cultures of three representative green algae, Actinastrum sp. (culture designation: HM 0681), a 408 celled colonial alga; Monoraphidium sp. (HM 0611), a unicellular alga; and Scenedesmus dimorphus (?) (HM 0141), a 4-celled colonial alga. The stocks were transferred every two weeks to provide actively growing cultures for the experiments.

Growth was studied in five media: distilled water, tap water, Hamilton Marsh water (collected on October 14, 1976), 100% sewage from the Hamilton Township sewage treatment plant, and a 1:1 mixture of sewage and marsh water. The marsh water and sewage effluent were filtered through Whitman No. 1 filter paper. One ml of a 2-week-old culture was inoculated into 100 ml of media in 125 ml flask producing an initial concentration of 2.5×10^4 cells/ml per flask. Inoculated flasks were incubated under standard conditions and cell counts were made at days 0, 3, 5, 10 and 15. In a second experiment, an initial concentration of 8.3×10^3 cells was used.

The effect of temperature and light intensity on algal growth was investigated with a cross-gradients apparatus originally described by Halldal and French (1956, 1958) and later used by Edwards and Van Baalen (1970), and Yarish (1976). The improved model of cross-gradients apparatus (Fig. 3) used in this investigation consisted of 3 aluminum alloy plates (53.34 cm x 53.34 cm x 2.54 cm) set on and surrounded by polystyrene for insulation. The plates were connected in series with all the connecting pipes insulated with polystyrene or neoprene rubber. The temperature gradient was produced by a cooling circulator (Model KT 33, Haake, Inc.) and a heating circulator (Model FE, Haake, Inc.). Antifreeze was used as the circulating fluid. A light intensity gradient

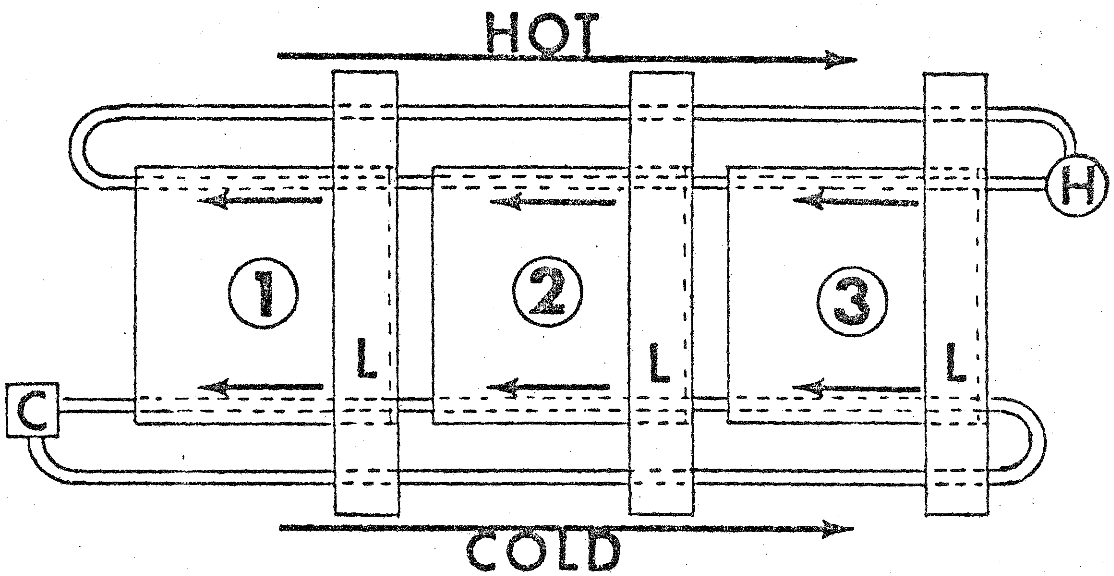


Fig. 3. Schematic representation of the cross-gradient apparatus. C, cooling unit; H, heating unit; L, cool-white fluorescent light bank; 1 - 3, aluminum plates.

perpendicular to the temperature gradient was provided by a bank of cool-white fluorescent lamps suspended above one end of each aluminum plate. For all experiments conducted, 25 dishes (100 x 80 mm) containing 100 ml of 3N BBM were arranged on each aluminum plate in 5 rows of 5 dishes each. The 25 combinations of temperature and light intensity employed are shown in Fig. 4.

The inocula for the cross-gradients plate experiments was prepared by mixing and sonication of actively growing, 2-week old stock cultures. One ml of the homogeneous stock suspension was inoculated into 100 ml of 3N BBM in each of the 25 dishes of each cross-gradients plate. The first 2 weeks represented a preconditioning period for the algae at each of the 25 combinations of temperature and light intensity. After this 2-week preconditioning period, a dish-to-dish transfer was made, using 1 ml of preconditioned culture as stock culture inoculated into 100 ml of fresh 3N BBM in each corresponding dish (the second set of dishes) on each cross-gradients plate. The cultures were incubated for 4 additional weeks.

The stock cultures were studied and cell counts (190 cells/ml) were made before inoculation. Results were observed at the end of the 2-week precondition period (designated as 2-weeks), at 2 weeks after the dish-to-dish transfer (designated as 2+2 weeks) and at 4 weeks (designated as 2+4 weeks). Visual observations rated the growth as excellent (E), good (G), fair (F), trace (T) and none (N). Cell counts were performed with a Spencer Bright Line Hemacytometer. The growth rate in terms of doublings per day (k) for each of the three 2-week periods was calculated according to the following equation (Guillard, 1973):

$$k = \frac{\log_z (N_1/N_0)}{t_1 - t_0} = \frac{3.332 \log (N_1 - N_0)}{t_1 - t_0}$$

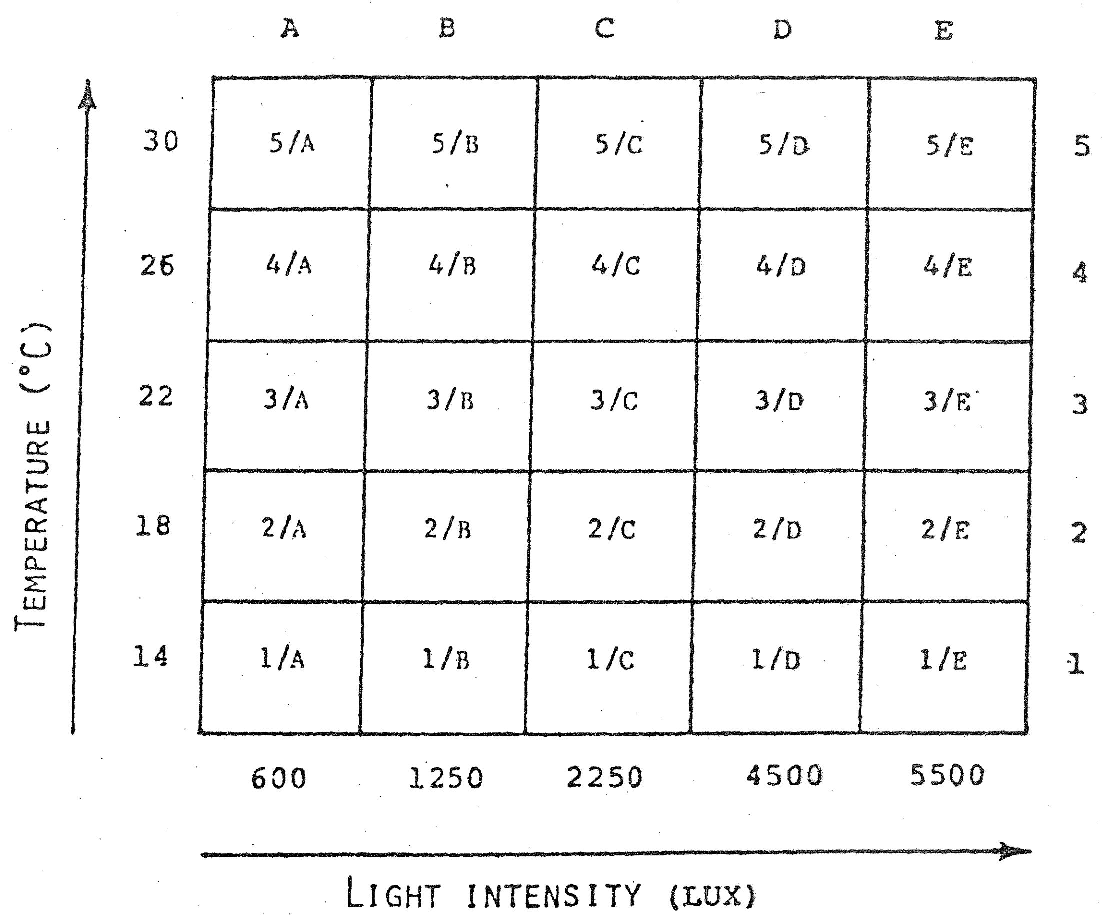


Fig.4. A diagrammatic representation of the cross-gradients of temperature and light intensity. Each of the 25 combinations is designated by a number (temperature increases from 1 to 5) and a letter (light intensity increases from A to E).

where N_1 and N_0 are cell concentrations at time t_1 and t_0, respectively. For the colonial algae Actinastrum sp. and Scenedesmus sp., calculations were prepared with single-cell equivalents, i.e., using unicells as basic units, not colonies.

Results

The observations of the soil samples collected from June 1976 through May 1977 revealed a total of 84 species exclusive of the diatoms (Table 14). These included 10 Cyanophyceae, 3 Euglenophyceae, 65 Chlorophyceae, 5 Xanthophyceae and 1 Chrysophyceae. The total number of algal species exclusive of the diatoms observed in each Sites from June 1976 through May 1977 is summarized in Table 15. Chlorococcum sp., collected in every sample, was the most common alga. The next most common algae, in order of frequency, were Chlorella sp., Characium sp., Stigeoclonium sp., Monoraphidium convolutum, Scenedesmus quadricauda, Tribonema sp., Scenedesmus obliquus, Selenastrum westii and Anabaena sp.

There were two peaks in algal diversity, one in September after macrophyte dieback began and the second in April just prior to the macrophyte growing season. The lowest algal diversity occurred in June and July when the macrophytes formed a dense canopy. Low algal diversity also occurred in mid-winter when the marsh surface was covered with ice and snow.

Results of the algal colonization experiments are summarized in Table 16. The density of the algae colonizing glass slides in unclipped control areas was low, ranging from 5 x 10^3 organisms/mm^2 at Site 8 (no treatment control) at one week to 1.66 x 10^5 organisms/mm^2 at Site 5,

TABLE 14. List of algae (excluding diatoms) observed in the soils of Hamilton Marsh from June, 1976 to May, 1977.

Cyanophyceae (10)*
- *Anabaena* sp.
- *Chroococcus* sp.
- *Glaucocystis nostochinearum*
- *Gloeocapsa* sp.
- *Lyngbya martensiana*
- *Merismopedia* sp.
- *Microcystis* sp.
- *Oscillatoria agardhii*
- *O.* sp.
- *Phormidium* sp.

Euglenophyceae (3)
- *Euglena* sp.
- *Phacus nordstedtii*
- *P.* sp.

Chlorophyceae (65)
- *Actinastrum* sp.
- *Ankistrodesmus falcatus*
- *A.* sp.
- *Arthrodesmus* sp.
- *Characium* sp.
- *Chlamydomonas* sp.
- *Chlorella* sp.
- *Chlorococcum* sp.
- *Chlorosarcinopsis* sp.
- *Chodatella* sp.
- *Closterium* sp.
- *Cosmarium* sp.
- *Crucigenia* sp.
- *Dysmorphococcus* sp.
- *Eudorina* sp.
- *Gloeocystis ampla*
- *Golenkinia radiata*
- *Gonium pectorale*
- *Kirchneriella obesa*
- *K.* sp.
- *Klebsormidium* sp.
- *Micrasterias foliacea*
- *M.* sp.
- *Microthamnion* sp.
- *Monoraphidium aciculare*
- *M. convolutum*
- *M.* sp.
- *Mougeotia* sp.
- *Netrium* sp.
- *Oedogonium* sp.
- *Palmodictyon* sp.
- *Pandorina* sp.
- *Pediastrum biradiatum*
- *P. boryanum*
- *P. duplex clathratum*
- *P. integrum*
- *P. obtusum*
- *P. tetras*
- *Planktosphaeria* sp.
- *Pleurastrum* sp.
- *Scenedesmus abundans*
- *S. acuminatus*
- *S. dimorphus*
- *S. obliquus*
- *S. quadricauda*
- *S. longus*
- *S.* sp.
- *Schizomeris* sp.
- *Schroederia* sp.
- *Selenastrum westii*
- *S.* sp.
- *Sphaerocystis schroeteri*
- *Spirogyra porticalis*
- *S.* sp.
- *Staurastrum* sp.
- *Stigeoclonium attenuatum*
- *S. pachydermum*
- *S.* sp.
- *Tetracystis* sp.
- *Tetraedron caudatum*
- *T. regulare*
- *T.* sp.
- *Ulothrix* sp.
- *Uronema* sp.
- *Zygnema* sp.

Xanthophyceae (5)
- *Botrydiopsis* sp.
- *Botrydium granulatum*
- *Tribonema bombycinum*
- *T.* sp.
- *Vaucheria* sp.

Chrysophyceae (1)
- *Ochromonas* sp.

* Number of species observed in the family.

Table 15. Total number of algal species, exclusive of diatoms, observed at each Site from June 1976 through May 1977.

Date/Site	1	2	3	4	5	6	7	8
June 1976	7	10	8	9	8	10	10	10
July	9	13	11	11	11	10	14	15
August	20	13	16	18	17	15	17	21
September	25	19	20	16	23	24	19	26
October	23	13	17	16	17	21	9	23
November	17	18	20	19	19	17	22	26
December	17	12	19	13	18	16	15	19
January 1977	17	9	14	13	17	14	21	15
February	17	13	11	17	14	11	16	16
March	18	16	12	13	17	16	14	16
April	23	17	25	25	21	20	23	20
May	25	21	18	20	18	15	17	25

also at one week. Algal density for slides placed in the clipped plots varied from low of 1.5×10^4 organisms/mm^2 at Site 8 at one week to 2.465×10^6 organisms/mm^2 at Site 5 at 3 weeks. The density of Cyanophyceae, Chlorophyceae and Bacillariophyceae increased during the three week period in the clipped plots, but not in the unclipped plots.

The results of the direct observation and cell counts of the algae in the soil samples collected from the clipped and unclipped plots are summarized in Table 17. Algal density of soil samples collected in the unclipped control areas was low, ranging from 3.4×10^4 to 3.8×10^5 organisms/cm^3 of soil. The lowest densities occurred in Sites 7 and 8. Four weeks after removal of the macrophytes algal density had increased from 46% (Site 8) to 780% (Site 5).

The results of the cross gradients plate growth studies are given in Tables 18 and 19; for all three algae, growth increased markedly in 100% sewage and in the 1:1 mixture of sewage and marsh water. Excellent growth also occurred in marsh water (Table 18). Actinastrum showed little growth in distilled water (4.1×10^5 cells/ml at 15 days) and best growth in the sewage/marsh water mixture (3.45×10^6 cells/ml at 15 days). Monoraphidium also grew best in the 1:1 mixture of marsh water and sewage, but unlike the other two species it grew well in distilled water (1.535×10^6 cells/ml at 15 days). Scenedesmus grew best in 100% sewage (4.425×10^6 cells/ml at 15 days), but its growth was only slightly less in the sewage/marsh water mixture.

Similar growth patterns were observed when the experiment was repeated with mixed populations of the three algae (Table 19). Community growth was greatest in the sewage/marsh mixture (3.49×10^6 unicells/ml at 15 days), somewhat lower for 100% sewage (2.599×10^6 unicells/ml)

Table 16. Density (10^3 organisms/mm^2) of algae on glass slides placed in clipped and unclipped plots, 14 June 1977 after 1, 2 and 3 weeks.

Site		1	2	3	4	5	6	7	8
Cyanophyceae									
wk 1:	S[a]	1.77	1.61	0.48	20.58	8.85	25.09	1.45	1.77
	C[b]	148.60	8.20	44.87	87.48	0	42.13	2.41	1.93
wk 2:	S	0.64	1.37	17.93	0.56	0.76	2.01	0.72	0.89
	C	41.01	13.99	167.41	33.77	116.75	6.43	22.19	2.41
wk 3:	S	1.93	3.94	2.33	2.49	0.97	1.05	1.13	2.65
	C	245.57	67.22	114.83	169.34	627.84	45.35	10.77	4.02
Chlorophyceae									
wk 1:	S	2.41	2.57	14.96	9.82	49.86	7.24	2.41	3.06
	C	51.79	2.41	1085.85	24.77	601.78	53.55	9.33	6.43
wk 2:	S	4.02	4.82	6.43	3.30	15.20	2.98	1.53	2.41
	C	37.31	58.86	841.57	52.27	1729.12	84.43	63.22	17.37
wk 3:	S	3.22	1.93	1.44	2.01	35.30	2.89	2.33	2.81
	C	505.22	84.59	215.49	461.71	1723.98	54.03	26.29	15.60
Bacillariophyceae									
wk 1:	S	6.59	5.79	6.60	82.50	107.42	4.98	18.98	0.64
	C	65.13	9.00	345.41	121.74	23.16	47.28	4.82	6.43
wk 2:	S	3.78	14.47	32.81	7.72	20.99	5.79	7.32	4.91
	C	25.57	28.47	218.07	32.00	174.65	4.34	41.0	11.10
wk 3:	S	9.08	22.43	5.23	8.53	27.5	3.62	6.59	6.03
	C	261.98	65.61	128.65	140.88	113.22	9.33	15.20	13.83
Total[c]									
wk 1:	S	11.09	9.97	22.04	112.90	166.13	37.31	22.84	5.47
	C	265.52	19.61	1476.13	233.99	624.94	143.44	16.56	14.79
wk 2:	S	8.52	20.66	57.17	11.58	36.95	10.78	9.57	8.21
	C	103.89	101.32	1227.05	118.52	2021.48	95.20	126.42	30.88
wk 3:	S	14.23	28.30	9.00	13.03	63.77	7.56	10.05	11.49
	C	1012.77	217.42	458.97	771.93	2465.04	108.71	52.36	33.45

a. Unclipped

b. Clipped

c. Includes other photosynthetic algae

TABLE 17. Algal density (10^3 organisms/cm^3) in soil collected from clipped and unclipped plots from 14 June to 12 July, 1977

Site		1	2	3	4	5	6	7	8
Cyanophyceae									
wk 0:		13.25	5.12	67.52	14.95	3.43	15.37	1.72	8.56
wk 2:	S[a]	0	17.08	14.49	8.52	11.97	7.69	2.55	4.28
	C[b]	51.26	34.18	106.83	308.55	34.18	168.37	33.32	39.32
wk 4:	S	17.11	11.97	4.28	11.97	4.29	3.45	0	0
	C	39.32	254.71	34.18	254.71	401.69	223.94	32.46	31.63
Chlorophyceae									
wk 0:		93.17	214.54	76.53	206.82	129.92	50.85	31.19	87.16
wk 2:	S	66.74	75.2	217.94	23.94	76.92	68.37	11.08	7.72
	C	251.29	100.89	300.03	256.40	528.25	164.98	85.54	47.88
wk 4:	S	67.57	82.06	45.32	82.09	59.85	39.32	32.49	12.80
		410.28	543.69	299.26	543.60	364.15	140.18	98.31	83.78
Bacillariophyceae									
wk 0:		20.53	17.94	76.91	158.11	41.88	33.35	8.55	22.22
wk 2:	S	44.43	73.51	106.83	104.28	100.86	58.12	35.88	22.22
	C	69.26	114.52	399.03	641.05	288.03	322.25	130.77	93.48
wk 4:	S	109.38	181.20	105.11	181.20	176.89	57.26	48.71	46.68
	C	368.37	252.98	302.58	252.98	548.68	259.82	129.08	72.65
Total[c]									
wk 0:		126.95	238.03	220.96	379.88	175.23	100.00	42.74	-117.94
wk 2:	S	111.17	172.62	341.81	136.74	192.30	134.18	49.51	34.22
	C	375.23	252.14	800.89	1206.00	851.32	660.74	249.63	180.68
wk 4:	S	194.06	275.23	154.71	275.26	240.02	100.03	81.20	59.48
	C	819 69	1051.38	636.02	1051.29	1336.74	627.34	263.26	188.92

a. Unclipped

b. Clipped

c. Includes other photosynthetic algae

TABLE 18. Density 10^3 unicells/ml) of _Actinastrum_, _Monoraphidium_ and _Scenedesmus_ grown in 5 Media for 15 days.

Medium	HM0681 (_Actinastrum_)					HM0611 (_Monoraphidium_)					HM0141 (_Scenedesmus_)				
Days:	0	3	5	10	15	0	3	5	10	15	0	3	5	10	15
Distilled Water	25	27	82	215	410	25	75	150	625	1535	25	160	205	800	687
Tap Water	25	127	380	1230	1540	25	60	155	640	1225	25	195	450	1530	1667
Marsh Water	25	67	190	900	1207	25	70	106	1007	1805	25	142	445	1170	2070
Sewage 100%	25	105	205	1930	3060	25	12	170	930	2060	25	92	428	2715	4425
Sewage/Marsh Water (1:1)	25	177	365	2020	3450	25	40	260	1880	3577	25	107	440	2220	3600

TABLE 19. Density (10^3 unicells/ml) of Actinastrum, Monoraphidium and Scenedesmus grown in mixed cultures for 15 days.

Medium	Organism	Days 0	3	5	10	15
Distilled Water	Actinastrum	8.3	22	60	420	500
	Monoraphidium	8.3	12	42	72	120
	Scenedesmus	8.3	35	62	330	440
	Total	25	69	164	822	1060
Tap Water	Actinastrum	8.3	55	130	172	100
	Monoraphidium	8.3	32	47	47	180
	Scenedesmus	8.3	60	137	327	700
	Total	25	147	314	546	980
Marsh Water	Actinastrum	8.3	30	37	282	200
	Monoraphidium	8.3	12	25	257	610
	Scenedesmus	8.3	22	75	515	1435
	Total	25	64	137	1054	2245
Sewage 100%	Actinastrum	8.3	60	190	770	623
	Monoraphidium	8.3	12	27	90	106
	Scenedesmus	8.3	32	130	705	1870
	Total	25	104	347	1565	2599
Sewagé/Marsh Water (1:1)	Actinastrum	8.3	22	110	480	770
	Monoraphidium	8.3	20	90	162	160
	Scenedesmus	8.3	25	105	1072	2560
	Total	25	67	305	1714	3490

and marsh water (2.245 x 10^6 unicells/ml) and lowest in distilled water (1.06 x 10^6 unicells/ml) and tap water (9.9 x 10^4 unicells/ml). Scenedesmus was the dominant species accounting for 65% of the cells in marsh water, 72% in the sewage and 73% in the sewage/marsh mixture at 15 days of incubation. Monoraphidium, in contrast, accounted for only 4% of the total community population in 100% sewage and 5% in the sewage/marsh water mixture at 15 days incubation.

The growth rates (k) or doublings/day of the three ~~aglae~~ algae individually and in mixed culture were calculated for intervals 0-3 days, 3-5 days, 5-10 days and 10-15 days (Figs. 5-8). The effects of treatment was variable, but all growth rates decreased to 0.25 doublings/day or less at 15 days of incubation, suggesting exhaustion of the nutrient supply in the media. Nutrient carry-over effects of the inocula, either as residual nutrients in the medium of the inoculum or stored nutrients in the cells transferred to the new media, likely account for the high growth rates observed in distilled water and tap water.

The growth response of Actinastrum to crossed-gradients of light intensity and temperature is summarized in Fig. 9. Actinastrum grew best at 30C/5500 1_x (5/E). Excellent but slightly less growth occurred at 5/D, 4/D and 4/E. Good or fair growth occurred at 2 + 4 weeks at 5/B-C, 4/B-C and 3/D-E. Growth was poor at the other 14 combinations.

The growth rate following the 2-week preconditioning period exceeded 0.7 doublings per day at 4-5/C-E and 3/D-E and 0.5 doublings per day at 4-5/B and 3/C. At 2 + 2 weeks, the growth rate was .448 doublings per day or higher at 4-5/B-E, 2-3/D-E. A very low growth rate of 0.181 doublings per day was found for 3/C. No growth was observed at all the other combinations of cross-gradients. After 2 + 4 weeks,

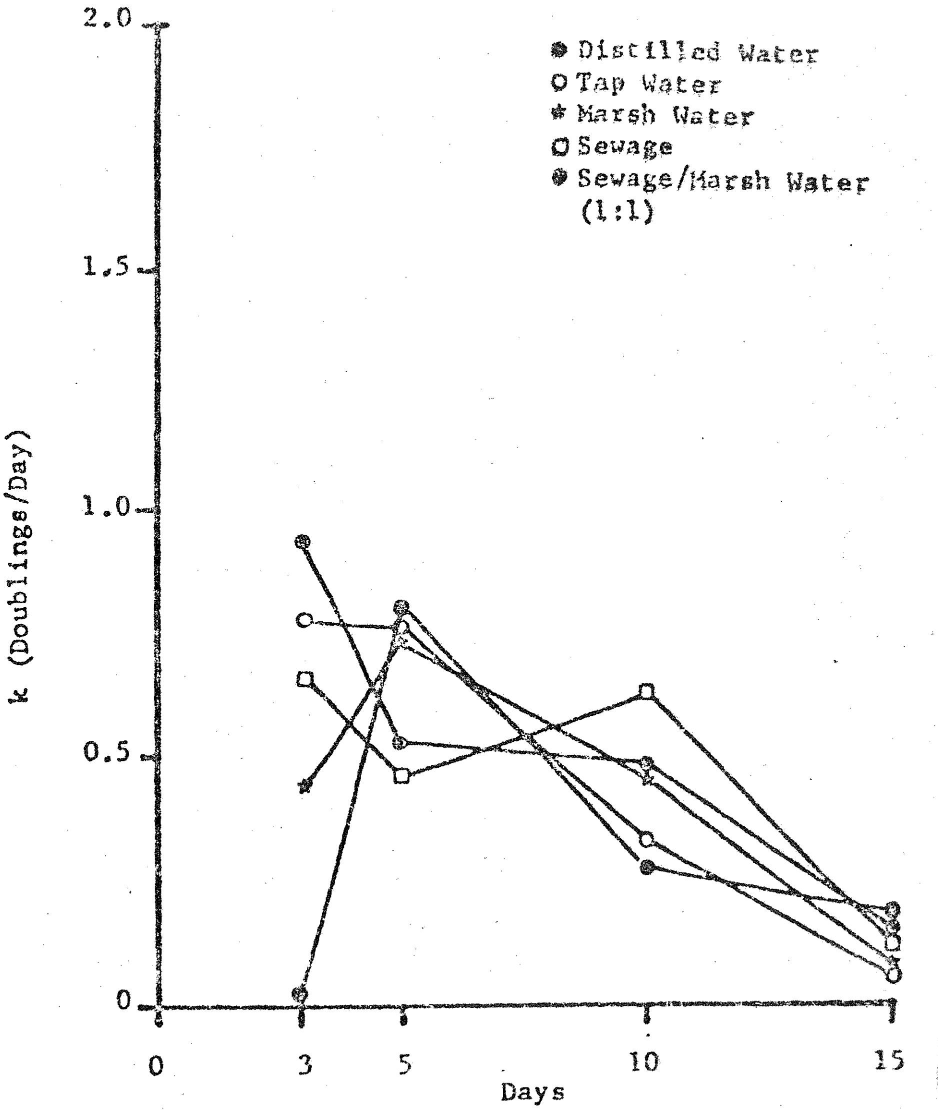


Figure 5. The growth rate k (doublings/day) of Actinastrum sp. in 5 different media.

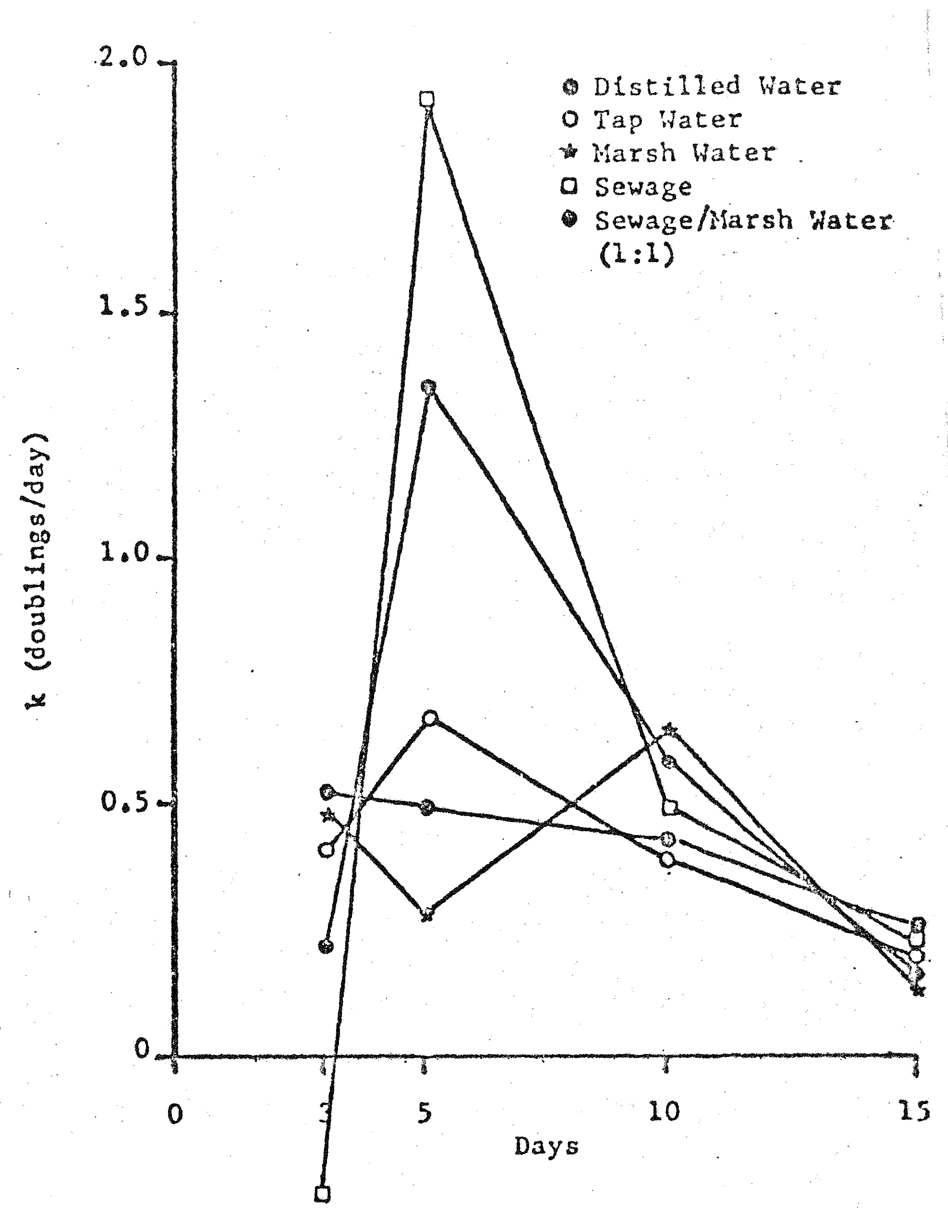


Figure 6. The growth rate k (doublings/day) of Monoraphidium sp. in 5 different media.

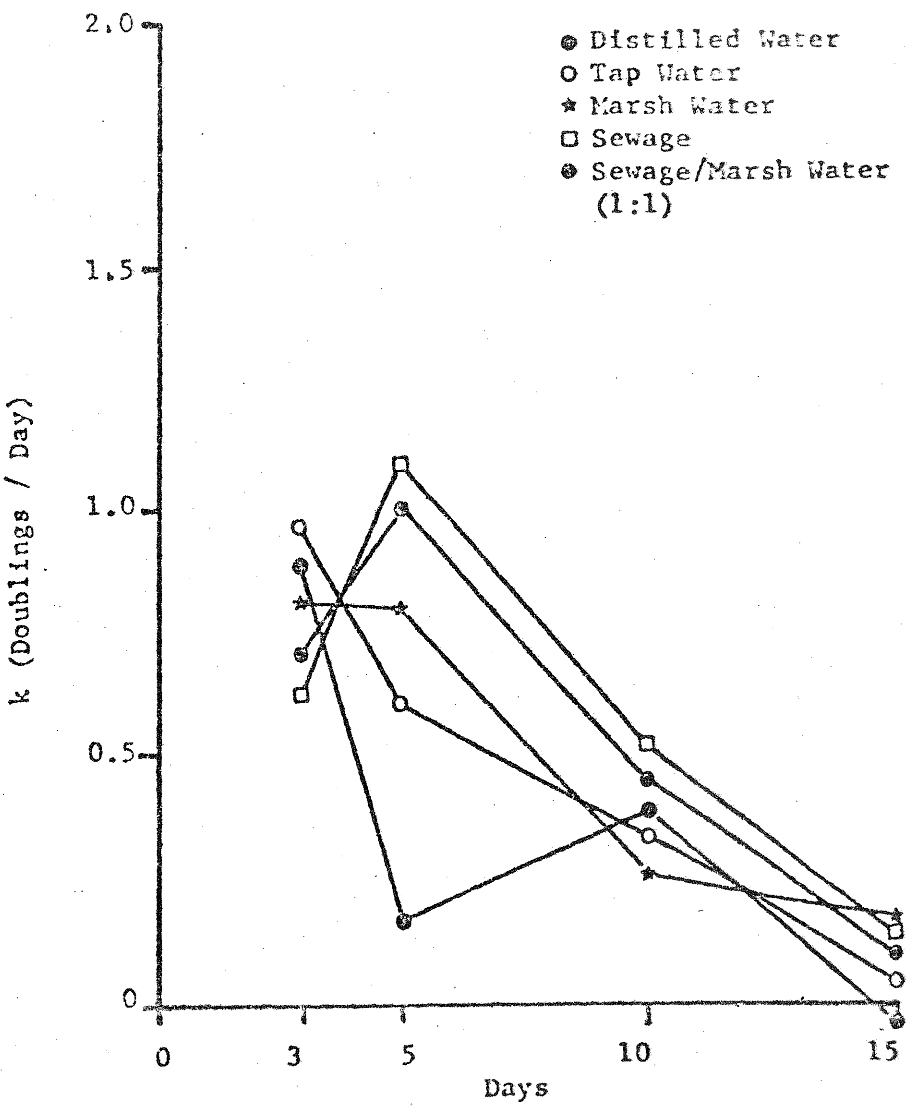


Figure 7. The growth rate k (doublings/day) of Scenedesmus sp. in 5 different media.

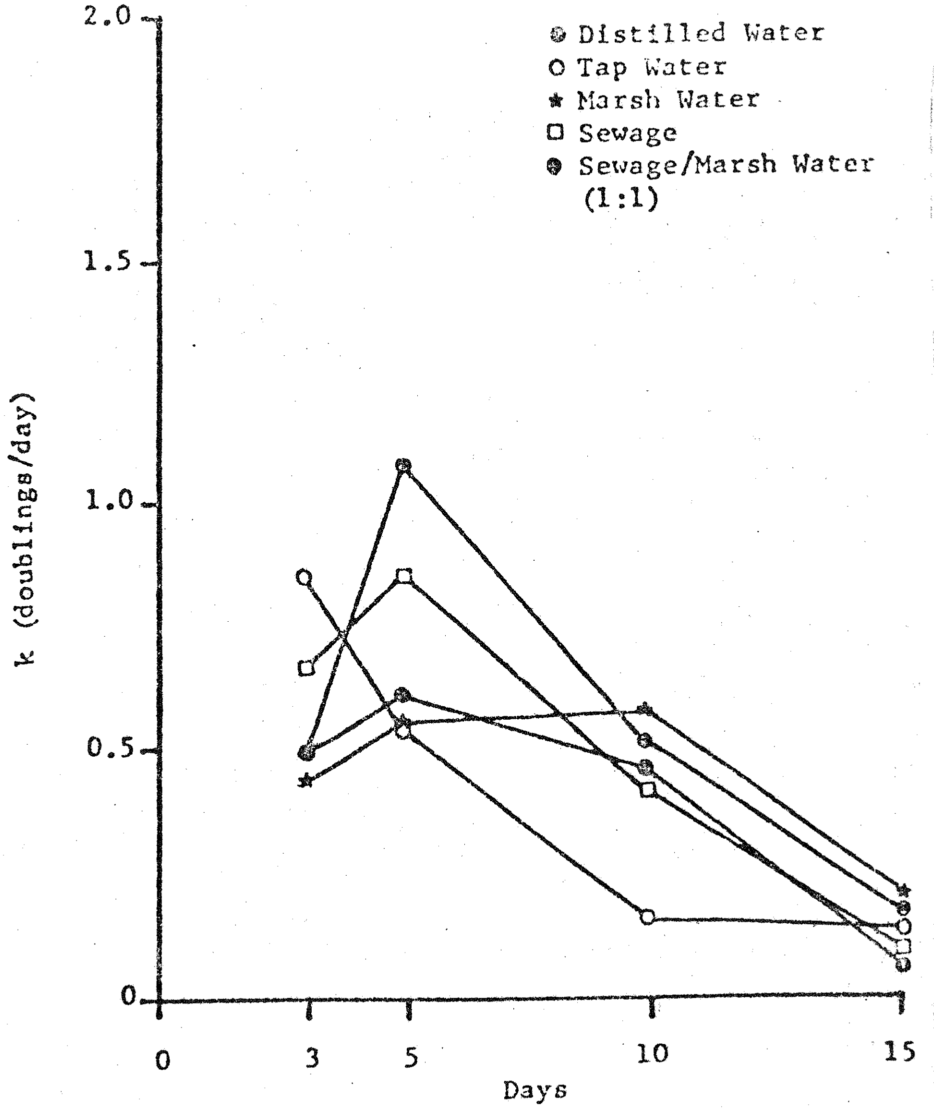


Figure 8. The community growth rate k (doublings/day) of mixed populations of Actinastrum sp., Monoraphidium sp., and Scenedesmus sp. in 5 different media.

the growth rate of Actinastrum at the optimal crossed-gradients combinations dropped markedly indicating the alga was at the stationary phase. However, it increased to 0.443 doublings per day at 3/C. Growth of Actinastrum ceased at 14C at all light intensities at 18°C with less than 4500 lx, at 22°C with less that 2250 lx, and at 26°C with less than 1250 lx (i.e., 1/A-E, 2/A-C, 3/A-B, 4/A).

The growth responses of Monoraphidium to crossed-gradients of temperature and light intensity are summarized in Fig. 10. Optimal growth (over $9x10^6$ cells/ml) of Monoraphidium occurred at 3-5/C-E at 2 + 4 weeks, good growth ($7-8x10^6$ cells/ml) occurred at 4-5/B and 2/C-E and fair growth occurred in all other combinbations of cross-gradients after 2 + 4 weeks. The growth rate of Monoraphidium varied from 0.423 (1/A) to 0.741 (2/E) doublings per day at 2 weeks, 0.466 (2/E), to 0.627 (2/A) doublings per day at 2 + 2 weeks, and 0.063 (3/B) to 0.203 (1/A) at 2 + 4 weeks.

The growth responses of Scenedesmus to cross-gradients of temperature and light intensity are summarized in Fig. 11. At 2 + 4 weeks optimum growth of Scenedesmus occurred at 22-30C/5500 1_x (3-5/E) with cell densities over 3 x 10^6 cells/ml, good growth (2 x 10^6 cells/ml) occurred at 2/E and 2-5/C-D, fair growth (5.5 x 10^5 to 1.8 x 10^6)cells/ml) occurred at 1/B-E and 2-5/B, and trace growth (1.5 x 10^5 cells/ml) occurred at 1-5/A. The growth rate following the 2-week preconditioning period was highest (0.723 doublings/day) at 5/E. High growth rates (0.5 doublings/day) were also observed at 1-5/E and 2-5/B-D. The lowest growth rate (0.284 doublings/day) was observed with the lowest temperature and light intensity (1A). As with the other two isolates, the growth rates of Scenedesmus were much lower at (2+2) and (2+4) weeks of incubation.

Temperature (°C)	A	B	C	D	E	
30	0[a] 50[b] 1330[c]	380 500 4080	2990 2430 7420	4440 5230 9920	4700 6050 10400	5
26	0 0 1300	640 450 4240	2660 1900 6620	3980 4120 9010	4300 5150 9260	4
22	0 0 180	0 0 1310	1040 30 2220	2320 1050 3920	2620 2750 6930	3
18	0	0 0 60	120 0 570	60 390 1300	100 70 1040	2
14	0	0	0	0	0	1
Light intensity (lux)	600	1250	2250	4500	5500	

Figure 9. Density (10^3 cells/ml) of Actinastrum sp. under cross-gradients of temperature and light intensity. a, 2 weeks; b, 2+2 weeks; c, 2+4 weeks.

Temperature (°C)	A	B	C	D	E	
30	1210[a] 390[b] 2600[c]	1510 2270 8010	2370 3860 9870	4180 4660 11400	3770 5960 11470	5
26	790 900 4540	1980 2900 7520	3430 4360 9470	4690 5730 12310	4460 4070 11680	4
22	960 1070 4320	1540 2720 5030	2470 4660 9120	3890 4710 10910	4710 5320 10850	3
18	260 570 3220	1750 1700 5990	2240 3160 7380	3960 2720 8420	5590 2570 8780	2
14	280 430 3090	740 860 4260	1370 1130 5330	1160 1180 5180	810 850 4050	1
Light intensity (lux)	600	1250	2250	4500	5500	

LIGHT INTENSITY (LUX)

Figure 10. Density (10^3 cells/mg) of Monoraphidium sp. under cross-gradients of temperature and light intensity. a, 2 weeks; b, 2+2 weeks; c, 2+4 weeks.

Temperature (°C)	A	B	C	D	E	
30	120[a] 20[b] 280[c]	680 310 1430	1110 800 2520	1390 1110 2930	2120 1420 3320	5
26	120 50 320	570 310 1720	1090 730 2750	1370 1050 2870	1390 1300 3400	4
22	120 0 210	470 250 1490	880 680 2350	1200 1050 2950	1200 1130 3120	3
18	50 0 270	450 220 1200	580 370 2100	800 600 2080	660 560 2870	2
14	30 0 160	110 20 570	150 20 1060	110 110 910	280 160 800	1
Light intensity (lux)	600	1250	2250	4500	5500	

Figure 11. Density (10^3 cells/ml) of Scenedesmus sp. under cross-gradients of temperature and light intensity. a, 2 weeks; b, 2+2 weeks; c, 2+4 weeks.

7. DECOMPOSITION STUDIES

The rate at which nitrogen and phosphorus are stored within or released from the wetland is, in part, controlled by the rates of litter production and litter decomposition. Our earlier water quality studies (Whigham and Simpson 1976a, Simpson et al. 1978) suggested that nutrients were being assimilated during the vascular plant growing season. The patterns seemed to reverse in the fall after the vascular plants were killed by frosts and then began to decompose. We had performed litter decomposition studies at the same time that we were doing our initial water quality studies. The purpose of our initial decomposition studies (Whigham et al. in prep; Whigham and Simpson, 1975, 1976a) was to determine if there were differences in decomposition rates between species and between sites. Results of those experiments, in part, determined the types of decomposition experiments that were performed as part of the present study. Litter decomposition studies were performed in 1975 and 1976. The specific questions addressed were how does the application of secondarily treated effluent affect:

a. Rates of litter decomposition?

b. Patterns of nitrogen and phosphorus movement into and out of the litter compartment?

c. Metabolic rates of the litter decomposer microorganisms?

Methods

Litter bag studies (1975)

Fresh leaf and petiole material of Peltandra virginica and leaf and stem material of Bidens laevis was collected and dried at 80°C.

Ten grams of dried material were placed into 2 mm mesh litter bags which were placed on the wetland surface in October in the two control enclosures and in the treatment enclosures that received 12.5 cm of effluent per day. Duplicate litter bags were then retrieved at 7, 15 and 30 days and monthly thereafter for 9 months. In the laboratory the litter bags were washed free of debris before the plant material was removed and dried at 80°C. Dried samples were weighed and ground in a Wiley Mill prior to analysis for Kjeldahl N and Total P using microkjeldahl (Amer. Soc. Agr. 1965) and tube digestion techniques (Sommers and Nelson, 1972) respectively.

Litter bag studies (1976)

Preliminary analysis of the 1975 data showed that leaf material decomposed much faster than more resistent stem material. In 1976 the litter bag experiments were repeated using only leaf material. The study was also expanded to include the 3 additional species: Tearthumb (*Polygonum arifolium*), arrowhead (*Sagittaria latifolis* and sweet flag (*Acorus calamus*). Duplicate litter bags were collected after 3, 7, 14, 30, 60, 90 and 120 days and analyzed as previously described. In addition, leaf litter samples were collected from Sites 2, 6 and 8 and returned to the laboratory where metabolism rates of the detritus community were measured using a Warburg respirometer. Measurements were made following a 1 hour period of acclimation at ambient marsh water temperatures that had been measured in the field with a YSI telethermometer and thermister probe. Water temperature in the Warburg respirometer water bath was then raised to 24°C and metabolism measurements were made again after an additional period of acclimation.

Results

The results of the 1975 decomposition study are given in Figures 12 and 13. For both Peltandra and Bidens actual initial weight losses occurred at a faster rate than predicted but that the pattern had reversed after approximately 120 days. Bidens decomposed at a slower rate than Peltandra and also had lower concentrations of nitrogen, phosphorus and contained less total nitrogen than did Peltandra litter.

Summary statistics for both species are shown in Table 20. Log weight transformations provided a better fit of the weight loss data and are presented rather than actual weight data. Transformed weight data were fitted to the exponential model of the form $N_t/N_o = e^{-kt}$ (Olson 1963) where N_t and N_o are, respectively, the amount of material present at time t and initially. The instantaneous rate of decay is K or the decomposition coefficient.

One way analysis of variance showed that Peltandra and Bidens litter differed in instantaneous rates of decomposition (α = .001), %N (α = .0001), Total N (α = .0001), %P (α = .001) but not Total P. Only %P (α = .001) and Total P (α = .01) showed significantly different site responses. A two-way analysis of variance produced the same results as the one-way analysis by species which indicates that differences between Peltandra and Bidens were more important than were differences due to site.

Results of the 1976 studies were very similar to those obtained in 1975 except decomposition of leaf material occurred at a faster rate (Figs. 14-18). Predicted weights were greater than observed rates during initial decomposition of the leaf tissue. Predicted and observed value were rather similar by day 90 while observed weights were greater than predicted weights thereafter.

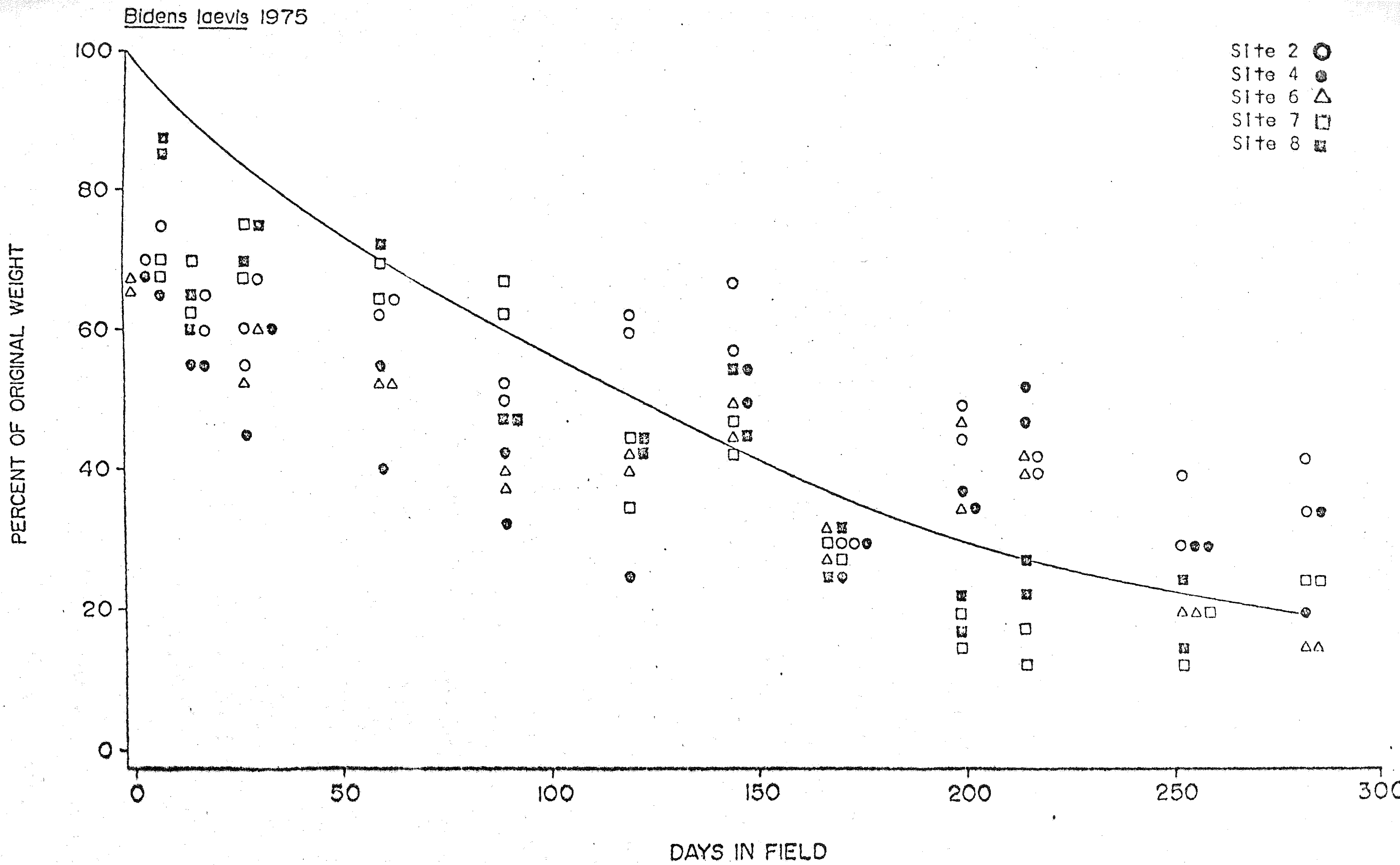


Fig. 12. Decomposition of *Bidens laevis* beginning in October 1975. A log transformation of weight loss was used to generate the best fit curve.

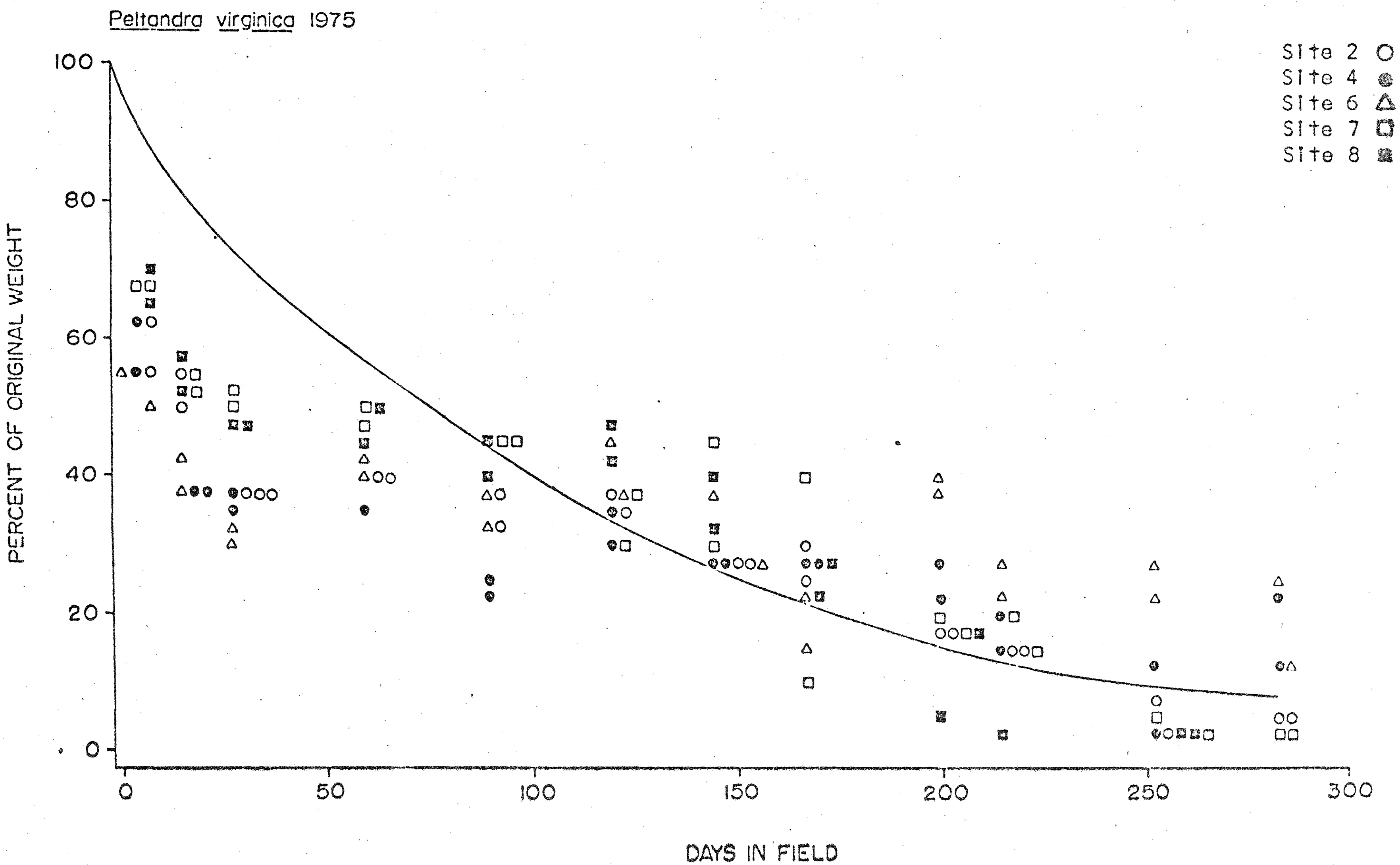


Fig. 13. Decomposition of Peltandra virginica beginning in October 1975. A log transformation of weight loss was used to generate the best fit curve.

TABLE 20. Summary statistics for 1975 litter decomposition experiments. Means that are not significantly different, at least at the 0.01 significance level, are indicated by an asterisk (*). All other means are significantly different at the .0001 significance level.

	Bidens		Peltandra	
	Mean	Standard Error	Mean	Standard Error
Log weight (g)	0.65	0.19	0.45	0.03
% N	2.72	0.07	4.17	0.09
Total N (g)	0.10	0.005	0.14	0.006
% P	0.19	0.009	0.26	0.03
Total P (mg)	8.74*	0.50	9.07*	0.76

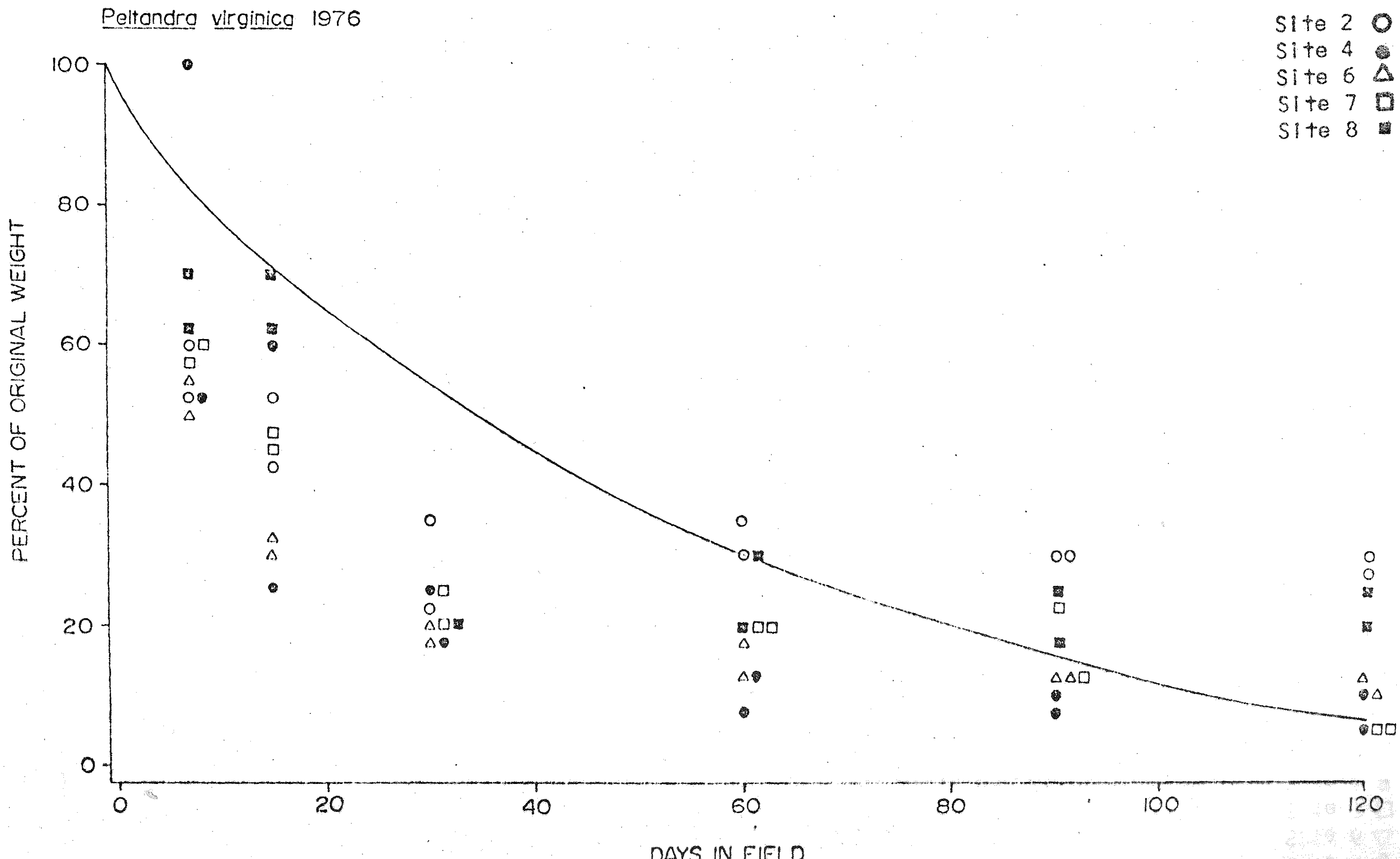


Fig. 14. Decomposition of <u>Peltandra virginica</u> leaf material beginning in September 1976. A log transformation of weight loss was used to generate the best fit curve.

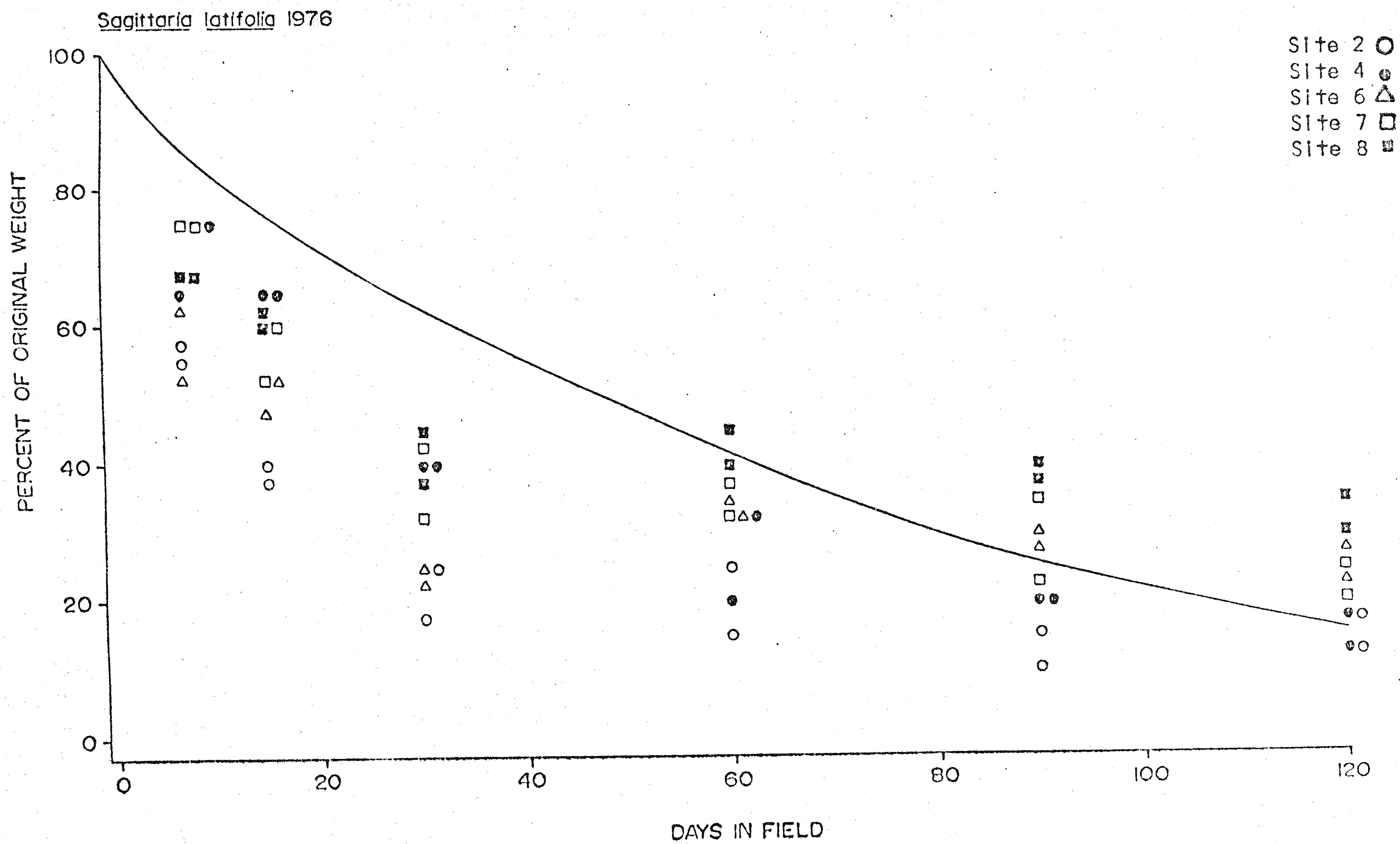


Fig. 15. Decomposition of Sagittaria latifolia leaf material beginning in September 1976. A log transformation of weight loss was used to generate the best fit curve.

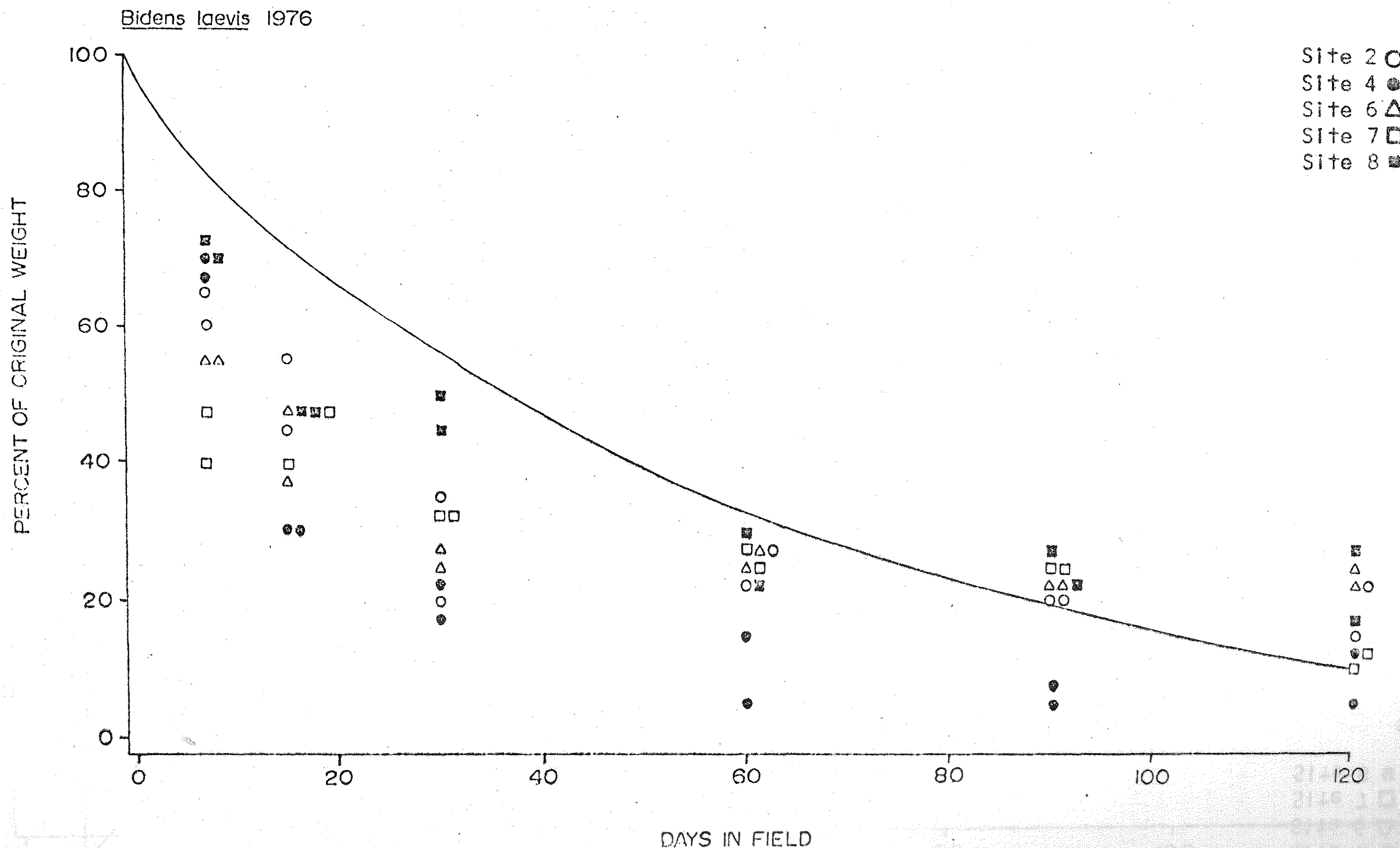


Fig. 16. Decomposition of <u>Bidens laevis</u> leaf material beginning in September 1976. A log transformation of weight loss was used to generate the best fit curve.

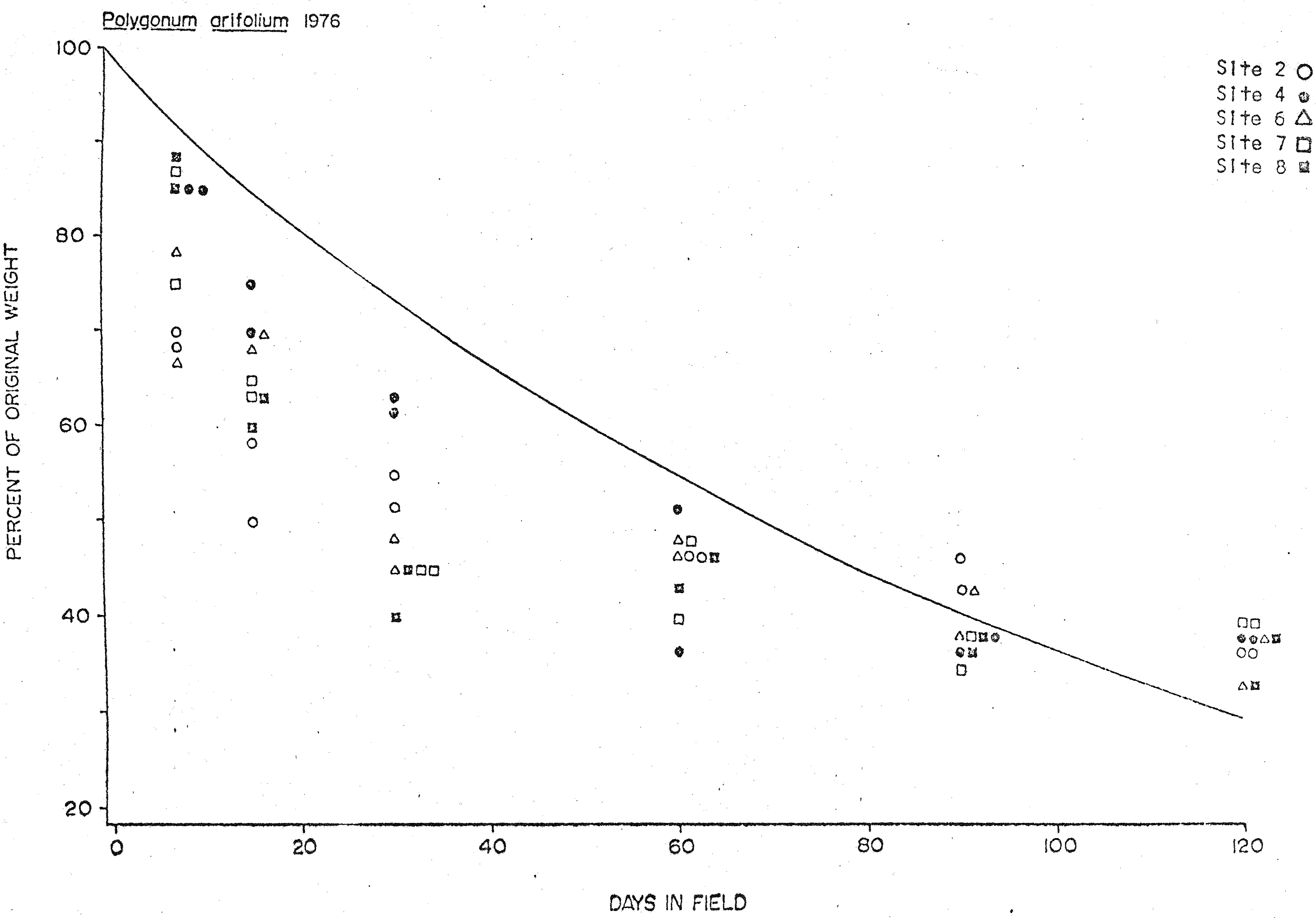


Fig. 17. Decomposition of *Polygonum arifolium* leaf material beginning in September 1976. A log transformation of weight loss was used to generate the best fit curve.

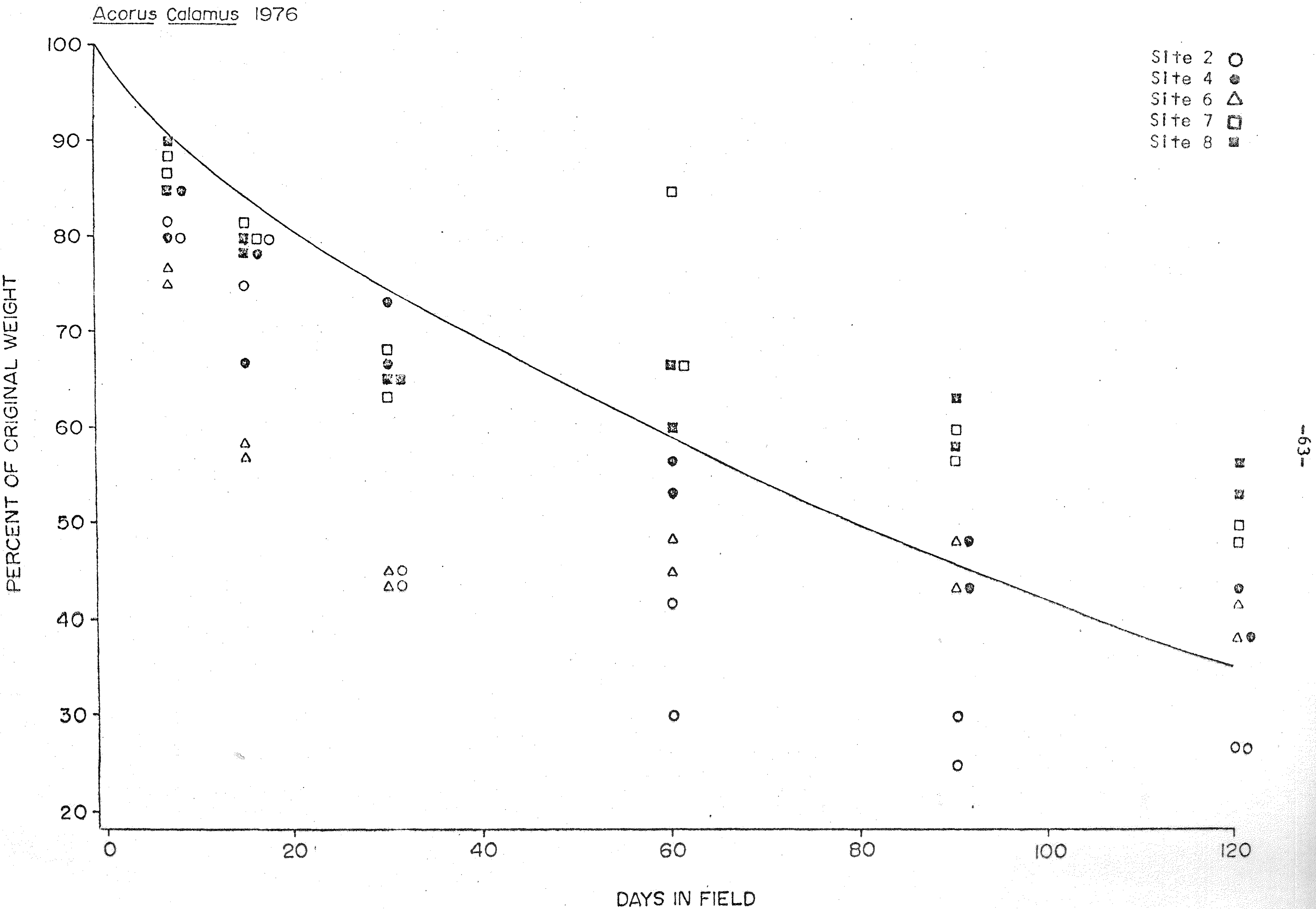


Fig. 18. Decomposition of Acorus calamus leaf material beginning September 1976. A log transformation of weight loss

There were again significant species differences for all variables measured (Table 21) while litter percentage phosphorus was the only variable that varied significantly (α = .0005) between sites. A two-way analysis of variance produced results similar to the species one-way ANOVA which again showed that species differences were more important than site differences. There was no significant species site interaction for any of the variables.

Table 22 shows results of comparing means for litter of each species in the treatment areas with means from the two control enclosures. Percent N of Bidens and Peltandra and %P of Sagittaria and Peltandra leaves was higher in treatment enclosures. Sagittaria leaves exposed to effluent weighed significantly less than leaves exposed to tap water.

Decay coefficients for leaf material only were greater than those for leaf and stem or leaf and petiole material (Table 23).

Respiration of the detritus community

Results of the metabolism studies are shown in Table 24. With one exception, maximum metabolism rates were measured on the third and seventh days for litter in the enclosures exposed to sewage effluent. Within control Site 8, metabolism peaked on day 14 for all species except Polygonum which reached maximum rates on day 7. Bidens was the only species that had litter metabolism rates that were significantly higher in the two treatment areas. Saggitaria and Polygonum litter had higher metabolism rates in the control enclosures while Peltandra litter metabolism was maximum in the enclosure (Site 6) that received effluent continuously. Metabolism rates increased very little when temperatures in the respirometer were raised to 24°C (Table 25).

TABLE 21. Descriptive statistics for species used in the 1976 litter decomposition studies. All means are significantly different at the .01 level of significance.

	Bidens		Peltandra		Polygonum		Acorus		Sagittaria	
	$\bar{x}$	$SE_{\bar{x}}$	$\bar{x}$	$SE_{\bar{x}}$	$\bar{x}$	$SE_{\bar{x}}$	$\bar{x}$	$SE_{\bar{x}}$	$\bar{x}$	$SE_{\bar{x}}$
log wt (g)	0.47	0.04	0.52	0.04	0.74	0.02	0.79	0.19	0.61	0.03
% N	3.91	0.11	4.28	0.14	4.39	0.12	2.16	0.09	3.61	0.07
Total N (g)	0.15	0.01	0.15	0.009	0.24	0.006	0.13	0.004	0.17	0.01
% P	0.21	0.009	0.27	0.01	0.29	0.01	0.22	0.008	0.26	0.01
Total P (mg)	8.07	0.79	11.35	1.26	16.46	0.75	14.03	0.65	12.61	1.18

TABLE 22. Results-simultaneous comparisons between 1976 litter in the treated areas and material in the control bins (7-8). NS indicates a non significant difference. For all other cases signifcance levels are indicated. Acorus and Polygonum showed no significant differences.

	bins 2,4,6-8	2,4,6-7	2-4-6	7-8
		Bidens		
% N	.05	.05	NS	NS
Total N	NS	NS	NS	NS
% P	NS	NS	NS	NS
Total P	NS	NS	NS	NS
log wt	NS	NS	.01	NS
		Sagittaria		
% N	NS	NS	NS	NS
Total N	NS	NS	NS	NS
% P	NS	.01	NS	NS
Total P	NS	NS	NS	NS
log wt	NS	.01	NS	NS
		Peltandra		
% N	NS	.01	NS	NS
Total N	NS	NS	NS	NS
% P	.05	.05	NS	NS
Total P	NS	NS	NS	NS
Log wt	NS	NS	NS	.01

TABLE 23. Mean decay coefficients (k) for plants during 1975 and 1976 studies. Site locations for each species are, in descending order, 2, 4, 6, 7, and 8.

1975

Peltandra	Bidens
1.139	0.429
1.038	0.527
0.686	0.612
0.909	0.693
1.055	0.698

1976

Bidens	Peltandra	Polygonum arifolium	Acorus	Sagittaria
1.399	1.720	0.983	1.351	2.178
2.774	2.794	0.999	0.849	1.685
2.395	1.579	1.032	0.959	1.452
2.439	1.920	1.017	0.609	1.385
1.659	1.622	1.088	0.593	1.133

TABLE 24. Litter Metabolism rates (mg CO_2/gm/hr) at ambient wetland surface temperatures following one hour acclimation in Warburg respirometer (± one S.E.)

Site	Species	3	7	14	30	60
2	B. laevis	4.0±0.8	81.7± 3.2	30.3±1.6	10.4±0.8	2.6±0.9
	S. latifolia	7.5±1.5	26.7±13.6	15.0±2.4	4.9±1.6	3.9±0.7
	P. virginica	47.2±1.5	40.7± 0.8	37.9±0.8	12.8±1.7	4.1±2.5
	P. arifolium	75.6±2.4	45.6± 0.7	24.2±1.6	19.3±1.6	5.8±2.5
6	B. laevis	12.2±1.5	47.2± 3.1	28.8±4.2	9.2±0.8	2.5±1.3
	S. latifolia	3.1±1.3	31.5± 2.3	31.5±2.3	11.7±1.7	6.5±1.7
	P. virginica	207.9±6.2	214.6± 0.2	224.3±1.9	22.9±2.8	1.7±0.0
	P. artifolium	179.3±7.9	199.4±13.3	22.5±1.1	5.8±1.8	2.5±1.0
8	B. laevis	18.2±3.1	35.0± 2.7	46.1±2.4	16.6±1.2	8.0±3.3
	S. latifolia	3.9±0.8	33.4± 1.5	44.3±2.7	17.2±0.5	2.4±0.8
	P. virginica	4.0±1.5	127.1± 3.4	143.2±8.8	19.8±1.4	9.8±3.3
	P. arifolium	86.1±7.2	225.2± 3.2	147.0±1.3	17.8±4.3	3.2±1.6
Ambient Temperature (°C)		19	17	14	7	6

TABLE 25. Litter metabolism rates (mg CO_2/gm sample/hr) at 24°C following ambient temperature metabolism determinations.

Site	Species	3	7	14	30	60
2	B. laevis	4.9	84.7	27.6	12.1	2.0
	S. latifolia	7.1	27.9	18.4	3.4	3.5
	P. virginica	47.0	49.5	43.3	11.7	5.6
	P. arifolium	78.5	49.2	24.8	21.1	4.9
6	B. laevis	13.1	57.5	32.7	10.4	2.6
	S. latifolia	7.5	31.4	35.2	14.2	6.9
	P. virginica	203.4	216.2	231.5	26.3	2.9
	P. arifolium	180.0	192.4	23.1	5.4	2.8
8	B. laevis	18.3	34.2	47.7	16.9	8.7
	S. latifolia	5.4	36.4	44.2	19.2	3.4
	P. virginica	5.4	134.3	141.8	18.4	11.5
	P. arifolium	86.8	226.0	151.1	17.9	3.1

8. SURFACE LITTER STUDIES

The wetland surface is an area of intense biological activity with the interaction of the microflora, litter, and soils in large measure determining whether nitrogen and phosphorus will be retained by the wetland or released. Litter bag studies give a good estimate of the changes in nutrient composition of litter as it decomposes, but they do not give information on the incorporation of nitrogen and phosphorus into the upper layer of wetland soil. Studies of unconfined surface litter ~~and~~ were performed during 1976 and 1977 to determine if the application of secondarily treated effluent influenced the incorporation of nitrogen and phosphorus into the wetland substrate.

Methods

Five 5 cm^2 samples of unconfined litter consisting of all the wetland lying on the wetland surface plus the upper 2 cm of soil were collected from each enclosure on 11 dates from April 1976 to May 1977. The samples were dried at 60°C, weighed, and ground in a Wiley mill. Each sample was analyzed for chlorophyll and phaeophytin using the techniques outlined by Golterman (1969), nitrate and ammonia nitrogen using microdiffusion techniques (Stanford, et al., 1973), total nitrogen using micro-Kjeldahl techniques (Amer. Soc. Agr., 1965), and phosphorus using tube digestion techniques (Sommers and Nelson, 1972).

Results

Results of the unconfined litter studies are summarized in Tables 26-36. Chlorophyll levels ranged from 0.03 to 6.43 mg m^{-2} and phaeophytin

Table 26. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 2 April 1976.

Site	Chlorophyll $mg\ m^{-2}$	Phaeophytin $mg\ m^{-2}$	%N	Total N $gm\ m^{-2}$	NO_3 $mg\ m^{-2}$	NH_3 $mg\ m^{-2}$	%P	Total P $gm\ m^{-2}$
1	2.48 ± 0.37	4.59 ± 0.73	1.39 ± 0.20	48.91 ± 7.28	100.6±48.7	617.9±125.3	0.46 ± 0.17	16.20 ± 6.08
2	1.50 ± 0.32	5.82 ± 1.03	1.81 ± 0.24	63.68 ± 7.46	104.9±29.7	587.5 59.9	0.53 ± 0.01	19.28 ± 5.37
3	4.73 ± 3.26	7.39 ± 0.26	1.86 ± 0.24	73.12 ± 10.43	76.6±26.3	583.9±52.3	0.51 ± 0.05	20.01 ± 2.38
4	3.24 ± 1.00	8.51 ± 1.90	2.29 ± 0.02	96.25 ± 0.87	76.3±31.1	634.1±78.7	0.67 ± 0.17	28.18 ± 7.53
5	3.62 ± 1.29	5.16 ± 0.16	1.79 ± 0.10	71.26 ± 8.92	131.3±81.1	689.4±74.1	0.61 ± 0.00	24.19 ± 1.74
6	3.12 ± 0.07	5.53 ± 0.86	1.85 ± 0.25	63.48 ± 4.90	77.5±2.9	546.6±17.0	0.49 ± 0.12	17.01 ± 3.12
7	1.48 ± 0.66	3.82 ± 0.23	1.76 ± 0.33	57.84 ± 29.47	62.0±44.6	474.2±234.9	0.60 ± 0.16	18.21 ± 1.23
8	1.83 ± 1.13	4.32 ± 1.46	1.69 ± 0.03	60.91 ± 6.62	85.3±9.3	568.6±15.5	0.43 ± 0.15	15.51 ± 4.35

Table 27. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 30 April 1976.

Site	Chlorophyll mg m^{-2}	Phaeophytin mg m^{-2}	%N	Total N gm m^{-2}	NO_3 mg m^{-2}	NH_3 mg m^{-2}	%P	Total P gm m^{-2}
1	1.31 ± 0.22	5.68 ± 1.00	1.63 ± 0.28	58.75 ± 3.70	50.8±36.9	413.1±59.6	0.38 ± 0.11	13.71 ± 2.68
2	2.05 ± 1.66	7.51 ± 4.05	2.21 ± 0.21	78.43 ± 2.63	90.6±54.8	480.6±62.2	0.54 ± 0.02	19.49 ± 1.59
3	2.70 ± 0.46	5.29 ± 4.16	2.15 ± 0.06	64.17 ± 10.39	61.7±44.6	432.0±96.9	0.56 ± 0.01	16.63 ± 1.62
4	3.47 ± 0.22	9.27 ± 0.69	2.10 ± 0.37	67.52 ± 8.42	78.2±61.5	485.3±78.7	0.59 ± 0.02	19.16 ± 1.85
5	2.11 ± 0.56	7.22 ± 1.20	1.70 ± 0.01	66.50 ± 8.25	80.5±47.1	493.2±96.9	0.49 ± 0.05	19.48 ± 4.71
6	2.62 ± 0.38	5.58 ± 0.71	2.03 ± 0.01	93.70 ± 6.50	91.3±9.8	603.6±4.5	0.46 ± 0.12	21.24 ± 4.34
7	1.15 ± 0.39	4.54 ± 0.33	1.77 ± 0.03	60.85 ± 1.07	36.8±45.4	337.4±54.2	0.45 ± 0.01	15.54 ± 0.17
8	0.33 ± 0.42	3.64 ± 2.18	1.78 ± 0.27	66.13 ± 5.70	38.4±1.75	306.2±36.8	0.28 ± 0.03	10.61 ± 1.88

Table 28. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 24 May 1976.

Site	Chlorophyll $mg\ m^{-2}$	Phaeophytin $mg\ m^{-2}$	%N	Total N $gm\ m^{-2}$	NO_3 $mg\ m^{-2}$	NH_3 $mg\ m^{-2}$	%P	Total P $gm\ m^{-2}$
1	3.38 ± 2.86	4.02 ± 1.12	1.40 ± 0.20	48.93 ± 0.14	25.7±1.9	540.2±53.0	0.38 ± 0.05	13.39 ± 0.01
2	3.33 ± 0.42	7.19 ± 0.85	1.69 ± 0.36	60.12 ± 5.29	11.2±0.3	493.2±96.7	0.57 ± 0.04	20.46 ± 1.06
3	3.38 ± 1.42	8.19 ± 1.24	1.83 ± 0.07	67.52 ± 2.28	57.6±52.2	651.1±164.0	0.61 ± 0.04	22.58 ± 1.78
4	3.31 ± 1.42	9.80 ± 1.91	2.15 ± 0.33	78.09 ± 18.45	46.9±39.3	650.96±224.4	0.61 ± 0.12	22.35 ± 6.24
5	2.85 ± 0.43	8.73 ± 1.38	1.93 ± 0.25	74.44 ± 2.38	16.0±1.1	571.5±14.1	0.48 ± 0.13	19.34 ± 8.44
6	3.07 ± 0.14	6.43 ± 2.80	2.00 ± 0.27	78.59 ± 1.86	34.9±16.6	649.7±77.4	0.50 ± 0.17	19.39 ± 3.76
7	1.24 ± 1.17	4.00 ± 0.41	1.59 ± 0.16	60.82 ± 17.28	11.2±9.4	311.4±227.6	0.43 ± 0.12	16.12 ± 1.65
8	2.16 ± 1.63	3.44 ± 0.06	1.46 ± 0.15	59.11 ± 16.95	14.2±20.1	466.4±151.7	0.28 ± 0.07	11.72 ± 4.93

Table 29. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 10 June 1976.

Site	Chlorophyll mg m^{-2}	Phaeophytin mg m^{-2}	%N	Total N gm m^{-2}	NO_3 mg m^{-2}	NH_3 mg m^{-2}	%P	Total P gm m^{-2}
1	1.08 ± 0.04	6.77 ± 1.64	1.75 ± 0.26	61.72 ± 4.85	72.1±44.2	449.3±41.9	0.54 ± 0.01	19.59 ± 4.85
2	1.55 ± 0.12	8.40 ± 2.16	1.46 ± 0.01	57.03 ± 4.60	100.6±60.5	469.9±124.9	0.56 ± 0.11	21.88 ± 2.57
3	1.97 ± 0.17	12.19 ± 0.08	2.12 ± 0.07	58.66 ± 1.23	95.6±36.0	429.8±29.3	0.76 ± 0.03	21.08 ± 0.68
4	2.76 ± 0.92	10.52 ± 0.13	2.14 ± 0.14	73.45 ± 10.24	168.2±90.1	689.8±265.5	0.70 ± 0.27	24.30 ± 11.01
5	1.59 ± 0.22	18.76 ± 2.14	3.05 ± 0.77	87.68 ± 33.66	100.9±6.3	438.5±7.0	0.78 ± 0.17	22.41 ± 8.02
6	2.25 ± 0.32	6.78 ± 1.96	2.24 ± 0.43	75.36 ± 11.76	62.7±20.0	438.6±32.6	0.45 ± 0.11	15.44 ± 3.36
7	0.53 ± 0.01	5.25 ± 1.31	1.76 ± 0.35	49.03 ± 11.53	40.6±3.5	297.5±4.2	0.50 ± 0.13	13.53 ± 0.07
8	0.31 ± 0.04	4.34 ± 1.12	1.85 ± 0.24	51.64 ± 5.90	43.5±1.3	258.2±4.0	0.29 ± 0.01	8.24 ± 0.36

Table 30. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 12 July 1976.

Site	Chlorophyll $mg\ m^{-2}$	Phaeophytin $mg\ m^{-2}$	%N	Total N $gm\ m^{-2}$	NO_3 $mg\ m^{-2}$	NH_3 $mg\ m^{-2}$	%P	Total P $gm\ m^{-2}$
1	1.53 ± 0.44	6.39 ± 2.06	1.85 ± 0.17	68.20 ± 17.19	29.7±22.0	468.8±20.1	0.41 ± 0.16	14.54 ± 3.52
2	1.84 ± 0.16	6.45 ± 2.86	1.95 ± 0.97	66.08 ± 15.46	17.2±7.0	476.1±69.7	0.42 ± 0.17	14.63 ± 0.06
3	3.07 ± 1.33	5.68 ± 1.48	2.22 ± 0.12	61.35 ± 10.79	47.1±36.8	415.8±71.2	0.42 ± 0.17	12.03 ± 6.29
4	3.42 ± 0.98	7.68 ± 1.03	2.22 ± 0.12	56.09 ± 8.09	71.0±100.5	384.5±210.3	0.59 ± 0.10	15.32 ± 5.73
5	2.71 ± 0.53	8.08 ± 1.23	1.99 ± 0.36	55.09 ± 1.63	49.6±3.4	478.1±26.5	0.57 ± 0.04	16.20 ± 3.64
6	2.69 ± 0.53	7.24 ± 1.60	2.10 ± 0.31	57.25 ± 1.08	59.2±1.7	479.5±123.8	0.51 ± 0.04	14.29 ± 3.57
7	1.74 ± 0.74	4.15 ± 0.73	1.87 ± 0.03	43.93 ± 0.86	41.4±13.3	277.6±26.3	0.45 ± 0.08	10.60 ± 2.08
8	0.85 ± 0.27	3.63 ± 0.58	1.89 ± 0.35	55.33 ± 3.86	54.1±2.7	386.1±92.1	0.25 ± 0.02	7.45 ± 1.60

Table 31. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 17 August 1976.

Site	Chlorophyll mg m^{-2}	Phaeophytin mg m^{-2}	%N	Total N gm m^{-2}	NO_3 mg m^{-2}	NH_3 mg m^{-2}	%P	Total P gm m^{-2}
1	0.78 ± 0.71	4.36 ± 1.65	1.77 ± 0.52	38.74 ± 15.91	53.7±43.0	305.5±124.1	0.40 ± 0.06	8.63 ± 0.28
2	0.59 ± 0.34	5.78 ± 1.76	2.16 ± 0.35	55.94 ± 4.03	43.7±20.7	333.7±78.3	0.48 ± 0.04	12.63 ± 2.45
3	1.15 ± 0.14	5.53 ± 0.10	2.34 ± 0.37	50.40 ± 3.87	46.1±18.2	305.6±88.7	0.53 ± 0.07	11.81 ± 4.35
4	0.27 ± 0.19	6.26 ± 0.84	2.31 ± 0.18	47.94 ± 3.23	71.5±56.3	300.6±88.9	0.42 ± 0.23	8.85 ± 5.07
5	0.54 ± 0.22	6.39 ± 0.24	2.14 ± 0.34	65.06 ± 0.13	76.4±26.8	436.3±26.0	0.41 ± 0.10	12.59 ± 1.27
6	0.57 ± 0.12	5.63 ± 0.72	2.01 ± 0.15	64.39 ± 0.59	52.1±17.0	460.9±13.2	0.51 ± 0.01	16.41 ± 1.50
7	0.27 ± 0.24	3.82 ± 1.45	1.85 ± 0.12	45.67 ± 12.52	37.5±0.5	277.2±55.7	0.36 ± 0.08	8.77 ± 0.91
8	0.17 ± 0.24	3.05 ± 0.68	1.54 ± 0.23	50.11 ± 0.17	50.5±6.9	395.0±6.1	0.28 ± 0.02	9.37 ± 1.45

Table 32. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 18 September 1976.

Site	Chlorophyll $mg\ m^{-2}$	Phaeophytin $mg\ m^{-2}$	%N	Total N $gm\ m^{-2}$	NO_3 $mg\ m^{-2}$	NH_3 $mg\ m^{-2}$	%P	Total P $gm\ m^{-2}$
1	0.20 ± 0.18	4.96 ± 2.07	2.38 ± 0.50	38.44 ± 1.48	31.6±0.9	176.6±52.8	0.48 ± 0.09	7.88 ± 0.24
2	0.03 ± 0.04	5.23 ± 1.74	2.25 ± 0.28	54.46 ± 6.06	25.5±12.3	269.7±15.8	0.50 ± 0.15	12.28 ± 3.48
3	0.65 ± 0.11	3.02 ± 0.32	1.68 ± 0.02	56.47 ± 4.05	22.9±22.8	364.6±64.8	0.41 ± 0.09	14.06 ± 3.95
4	0.83 ± 0.43	3.42 ± 0.82	2.64 ± 0.21	40.23 ± 0.38	17.8±9.3	133.1±24.5	0.63 ± 0.01	9.66 ± 0.44
5	0.26 ± 0.14	4.26 ± 1.09	1.95 ± 0.66	59.68 ± 3.47	37.1±18.2	375.2±139.1	0.49 ± 0.17	15.22 ± 1.02
6	0.64 ± 0.32	4.77 ± 0.09	2.39 ± 0.56	72.15 ± 9.84	49.0±1.9	362.9±39.7	0.53 ± 0.07	16.08 ± 0.55
7	0.49 ± 0.53	2.10 ± 0.56	2.07 ± 0.04	47.23 ± 0.41	31.2±21.8	207.2±39.8	0.29 ± 0.01	6.79 ± 0.2[illegible]
8	0.46 ± 0.26	1.65 ± 0.49	1.85 ± 0.01	54.54 ± 12.26	10.4±14.7	257.6±48.8	0.24 ± 0.01	7.29 ± 1.93

able 33. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 21 October 1976.

ite	Chlorophyll mg m^{-2}	Phaeophytin mg m^{-2}	%N	Total N gm m^{-2}	NO_3 mg m^{-2}	NH_3 mg m^{-2}	%P	Total P gm m^{-2}
1	5.15 ± 2.59	4.90 ± 5.25	2.47 ± 0.16	36.14 ± 2.02	56.0±25.9	261.6±21.7	0.32 ± 0.04	4.76 ± 0.65
2	1.62 ± 0.42	3.48 ± 1.77	2.07 ± 1.11	53.37 ± 9.44	37.1±0.8	472.3±318.8	0.37 ± 0.10	13.05 ± 11.53
3	1.29 ± 0.79	5.08 ± 2.34	2.24 ± 0.83	54.27 ± 1.28	78.6±8.8	447.8±77.4	0.54 ± 0.06	13.84 ± 3.33
4	1.15 ± 0.54	6.69 ± 1.36	2.71 ± 0.12	48.62 ± 9.15	118.0±79.8	410.6±145.1	0.45 ± 0.21	8.59 ± 5.70
5	1.09 ± 0.01	7.12 ± 0.69	2.17 ± 0.18	59.46 ± 10.63	78.0±2.0	447.8±30.8	0.35 ± 0.11	9.56 ± 2.28
6	2.42 ± 2.07	5.21 ± 2.90	2.52 ± 0.03	66.29 ± 2.77	154.5±46.2	517.8±72.9	0.47 ± 0.04	12.43 ± 0.51
7	0.62 ± 0.55	3.36 ± 0.14	1.77 ± 0.13	51.68 ± 2.61	66.5±16.2	407.5±24.9	0.37 ± 0.03	10.79 ± 0.45
8	0.35 ± 0.01	4.31 ± 1.56	1.77 ± 0.04	45.32 ± 10.58	62.4±34.5	414.9±48.6	0.27 ± 0.06	6.85 ± 0.20

Table 34. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 29 November 1976.

Site	Chlorophyll mg m^{-2}	Phaeophytin mg m^{-2}	%N	Total N gm m^{-2}	NO_3 mg m^{-2}	NH_3 mg m^{-2}	%P	Total P gm m^{-2}
1	3.42 ± 1.35	4.08 ± 1.92	2.76 ± 0.31	63.15 ± 17.83	72.2±4.2	438.5±92.2	0.54 ± 0.02	12.26 ± 1.61
2	3.65 ± 2.59	4.62 ± 0.63	2.55 ± 0.20	64.07 ± 4.75	52.5±14.4	452.6±63.5	0.54 ± 0.08	13.47 ± 0.09
3	1.34 ± 1.13	9.19 ± 0.80	2.80 ± 0.04	59.46 ± 15.02	75.1±18.3	491.4±17.1	0.67 ± 0.11	14.03 ± 0.87
4	1.29 ± 0.61	10.52 ± 4.92	3.08 ± 0.96	68.99 ± 11.64	78.8±79.56	519.3±268.9	0.67 ± 0.03	16.59 ± 8.43
5	0.67 ± 0.45	6.08 ± 0.14	2.20 ± 0.20	81.71 ± 5.60	76.6±7.3	713.7±13.6	0.52 ± 0.10	19.54 ± 4.33
6	1.25 ± 0.09	5.45 ± 0.20	3.00 ± 0.42	87.58 ± 2.07	68.8±12.1	638.3±101.3	0.63 ± 0.11	18.35 ± 1.06
7	1.60 ± 1.92	2.77 ± 1.33	1.90 ± 0.01	55.23 ± 6.17	33.9±3.2	466.3±60.9	0.48 ± 0.04	14.05 ± 0.44
8	0.66 ± 0.07	3.37 ± 0.56	1.45 ± 0.50	48.67 ± 17.15	59.7±25.2	602.0±59.8	0.37 ± 0.05	12.46 ± 1.85

Table 35. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 5 March 1977.

Site	Chlorophyll mg m^{-2}	Phaeophytin mg m^{-2}	%N	Total N gm m^{-2}	NO_3 mg m^{-2}	NH_3 mg m^{-2}	%P	Total P gm m^{-2}
1	2.74 ± 0.14	7.14 ± 2.12	2.26 ± 0.03	58.61 ± 2.62	48.1±9.1	353.8±25.0	0.47 ± 0.07	12.32 ± 1.52
2	1.06 ± 0.07	6.79 ± 2.29	2.07 ± 0.04	67.06 ± 2.32	45.1±13.8	353.7±16.2	0.55 ± 0.13	17.76 ± 4.25
3	2.19 ± 0.70	7.67 ± 0.01	2.12 ± 0.38	76.87 ± 21.55	65.1±42.7	409.8±144.2	0.59 ± 0.19	21.62 ± 9.14
4	2.46 ± 0.46	7.79 ± 2.53	2.47 ± 0.55	80.49 ± 14.18	114.0±67.4	502.7±77.1	0.58 ± 0.19	19.01 ± 5.47
5	2.68 ± 1.37	7.23 ± 2.06	2.07 ± 0.07	81.89 ± 6.07	47.6±27.6	476.6±24.9	0.42 ± 0.02	16.80 ± 2.90
6	6.43 ± 5.72	7.59 ± 0.42	2.72 ± 0.12	87.36 ± 12.23	56.3±51.9	488.7±214.1	0.41 ± 0.04	13.12 ± 0.89
7	3.33 ± 0.71	3.08 ± 2.44	1.71 ± 0.04	49.16 ± 8.63	21.6±0.2	262.3±100.6	0.24 ± 0.02	6.94 ± 0.73
8	3.38 ± 0.09	2.99 ± 3.61	1.92 ± 0.12	51.01 ± 3.79	29.1±7.89	247.6±31.1	0.25 ± 0.03	6.62 ± 0.04

Table 36. Chlorophyll, phaeophytin, N and P in the unconfined surface litter on 3 May 1977.

Site	Chlorophyll mg m^{-2}	Phaeophytin mg m^{-2}	%N	Total N gm m^{-2}	NO_3 mg m^{-2}	NH_3 mg m^{-2}	%P	Total P gm m^{-2}
1	1.31 ± 0.61	5.67 ± 1.16	1.80 ± 0.01	62.53 ± 2.88	54.1±16.5	420.4±11.8	0.75 ± 0.06	26.00 ± 1.20
2	1.10 ± 0.22	5.93 ± 2.93	2.03 ± 0.37	66.07 ± 12.56	73.7±55.0	418.0±138.2	0.51 ± 0.01	17.14 ± 5.81
3	1.32 ± 0.24	5.06 ± 1.67	2.38 ± 0.14	79.12 ± 2.30	45.9±24.6	266.7±65.1	0.63 ± 0.11	20.98 ± 1.87
4	1.86 ± 0.61	6.84 ± 1.36	2.63 ± 0.06	80.61 ± 10.57	64.1±30.0	315.9±12.4	0.44 ± 0.04	13.55 ± 0.88
5	0.59 ± 0.49	3.99 ± 0.21	1.36 ± 0.28	75.74 ± 8.13	49.2±7.5	349.1±30.3	0.42 ± 0.26	22.04 ± 7.53
6	1.35 ± 0.08	7.71 ± 3.57	2.29 ± 0.46	92.39 ± 11.54	53.9±0.2	330.2±94.7	0.35 ± 0.19	13.91 ± 6.80
7	1.71 ± 2.42	4.37 ± 0.20	1.92 ± 0.24	66.73 ± 11.43	30.0±21.3	210.3±94.2	0.44 ± 0.09	15.25 ± 1.33
8	0.52 ± 0.44	4.93 ± 2.79	1.56 ± 0.09	49.45 ± 6.97	18.6±26.4	293.1±18.1	0.24 ± 0.00	7.74 ± 0.46

levels ranged from 1.65 to 18.76 mg m^{-2} with levels of both generally lower in August and September than at other times. One way analysis of variance showed chlorophyll levels to be significantly different on two dates, 30 April ($\alpha = 0.03$) and 10 June ($\alpha = 0.001$). Phaeophytin levels were significantly different on four dates, 2 April ($\alpha = 0.02$), 24 May ($\alpha = 0.01$), 10 June ($\alpha = 0.001$), and 29 November ($\alpha = 0.03$).

Nitrate N levels ranged from 10.4 to 154.4 mg m^{-2}, NH_3-N ranged from 133.1 to 713 mg m^{-2}, and Total N ranged from 36.14 to 96.25 gm m^{-2}. Total N, NH_3-N and NO_3-N levels were depressed from July through October. One way analysis of variance showed significant site differences for Total N on four dates, 30 April ($\alpha = 0.01$), 19 September ($\alpha = 0.01$), 3 March ($\alpha = 0.04$), and 5 May ($\alpha = 0.03$). No differences in NO_3-N and NH_3-N were found.

Total P levels ranged from 4.76 to 28.18 gm^{-2} and were lowest from July through October. Significant site differences were found on four dates, 30 April ($\alpha = 0.05$), 19 September ($\alpha = 0.01$), 3 March ($\alpha = 0.05$), 5 May ($\alpha = 0.04$).

Mean values of N and P of the unconfined litter on the eleven dates sampled are presented in Table 37. When data for the high and low dosages are combined, both %P and Total P were significantly higher ($\alpha \leqslant 0.05$) in the treatment sites than either control. Percent N was significantly higher ($\alpha \leqslant 0.01$) at all treatment sites when compared with the no treatment control and significantly higher ($\alpha = 0.01$) at Sites 3 and 4 and 5 and 6 than the tap water control. Total N was significantly higher ($\alpha = 0.01$) at Sites 3 & 4 and 5 & 6 than at either control, but Sites 1 & 2 did not differ from control values. Nitrate N and NH_3-N were significantly different ($\alpha \leqslant 0.05$) from the tap water control at all sites,

Table 37. Mean N and P of the unconfined litter sampled from April 1976 to May 1977. Treatments significantly different from the tapwater control are indicated by * ($\alpha = 0.05$) and ** ($\alpha = 0.01$). Treatments significantly different from the no water control are indicated by + ($\alpha = 0.05$) and ++ ($\alpha = 0.01$).

Site	%N	Total N gm m^{-2}	NO_3 mg m^{-2}	NH_3 mg m^{-2}	%P	Total P gm m^{-2}
1 & 2	1.97+	57.9	53.4*	419.5**	0.49***	15.1*++
3 & 4	2.29**++	65.2**++	71.1**+	446.6**	0.57*++	17.4**++
5 & 6	2.16**++	73.3**++	67.9**++	499.4**++	0.49*++	17.0**++
7	1.81	53.1	37.5	320.7	0.42	12.4
8	1.73	54.8	39.7	381.4	0.29	9.4

but NO_3-N was only significantly higher ($\alpha < 0.05$) ~~then~~ than the no treatment control at Sites 3 & 4 and 5 & 6 while NH_3-N was significantly different ($\alpha = 0.01$) from the no treatment at Site 5 & 6.

9. SUBSTRATE

In the previous section, consideration was given to incorporation of nitrogen and phosphorus in surface litter and the upper 2 cm of substrate. We also monitored nitrogen and phosphorus changes within the first 50 cm of substrate at each of the treatment and control sites.

Methods

Two cores (4 per treatment) were collected from randomly chosen locations within each site at approximately monthly intervals during an annual cycle that was initiated in October, 1975. Samples were collected with a WILDCO light duty gravity core sampler. After removing surface litter, the sampler had been pushed to a depth of 20 cm. A measurement of compaction was then made by inserting a meter stick into the sampler and measuring the distance between the top of the unit andthe sample that was in the corer. By comparing the recorded value with the overall length of the sampler, we were able to determine how much compaction had occurred. The sampler was then inserted to a depth of 50 cm and a second compaction measurement made. Substrate samples were returned to the laboratory and, using the compaction data, were cut into 0 - 20 cm and 20 - 50 cm depth intervals. Samples were air dried and then ground to pass through a 2 mm sieve. Samples were analyzed for total nitrogen (TOTAL N) using micro-kjeldahl techniques (Amer. Soc. Agr. 1975), nitrate (NO_3-N) and ammonia (NH_3-N) by microdiffusion (Standford et. al

1973), and total phosphorus (TOTAL P) by a tube digestion technique (Sommers and Nelson 1972). Data were subjected to analysis of variance tests to determine whether there were site, depth, and time effects as well as depth x site and site x time interaction effects.

Results

Substrate data are shown in Tables 38-51. There were no site effects for TOTAL N, TOTAL P, percent nitrogen (%N), percent phosphorus (%P), and NO_3-N. There was a significant (α = .003) site effect for NH_3-N with less NH_3-N in the substrate at control Sites 7 and 8 compared to sites that received sewage effluent. There were no significant differences between sites receiving effluent although the two areas that received effluent during low tides had the highest NH_3-N values (1.46 ± 0.06 gm^2 for Site 3 and 1.36 ± 0.05 gm^2 for Site 4).

The only significant depth response was for TOTAL N and %N where the upper 20 cm of substrate had significantly higher (α = .001) %N (1.24 ± 0.01%) than substrate samples from the 20 - 50 cm depth interval (0.85 ± 0.01%). Total nitrogen was also significantly greater (α = .02) in the upper 20 cm (311.8 ± 3.8 g/m^{-2}) than in the 20 - 50 cm depth interval (295.0 ± 4.5 g/m^{-2}).

There were significant time effects for TOTAL N (α = .0001), NO_3-N (α = .001), NH_3-H (α = .0001), and %N (α = .0002). Closer analysis of each factor, however, did not reveal any clear temporal patterns. The significant time effect for TOTAL N was caused by a very high value on Yearday 65 (Table 41) and a low value on Yearday 176 (Table 45). In general, %N values were higher during the intervals March-May and July-September. Significant time effects for NO_3-N were due to high

Table 38. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 298 in 1975.

All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N $gm\ m^{-2}$	NO_3 $gm\ m^{-2}$	NH_3 $gm\ m^{-2}$	%P	Total P $gm\ m^{-2}$
1	0 - 20	4	1.20 ± 0.08	323.6 ± 11.0	0.06 ± 0.02	0.65 ± 0.03	0.21 ± 0.00	58.7 ± 4.1
	20 - 50	4	0.92 ± 0.04	262.5 ± 15.9	0.06 ± 0.01	0.72 ± 0.03	0.13 ± 0.01	38.0 ± 3.1
2	0 - 20	4	1.57 ± 0.07	387.0 ± 32.5	0.11 ± 0.01	0.82 ± 0.02	0.27 ± 0.02	65.8 ± 6.4
	20 - 50	4	0.92 ± 0.03	384.2 ± 18.3	0.14 ± 0.04	1.20 ± 0.05	0.15 ± 0.02	64.5 ± 7.5
3	0 - 20	4	1.18 ± 0.03	341.1 ± 21.5	0.20 ± 0.02	0.95 ± 0.12	0.16 ± 0.09	49.3 ± 28.4
	20 - 50	4	0.87 ± 0.12	280.0 ± 27.7	0.11 ± 0.02	0.86 ± 0.24	0.14 ± 0.02	45.7 ± 8.7
4	0 - 20	4	1.18 ± 0.01	389.5 ± 12.5	0.22 ± 0.07	0.96 ± 0.09	0.33 ± 0.01	110.1 ± 0.1
	20 - 50	4	0.82 ± 0.07	331.7 ± 28.5	0.13 ± 0.03	0.66 ± 0.07	0.11 ± 0.01	45.9 ± 3.2
5	0 - 20	4	1.19 ± 0.01	359.3 ± 25.0	0.09 ± 0.01	0.98 ± 0.14	0.25 ± 0.05	79.9 ± 25.0
	20 - 50	4	0.76 ± 0.03	312.4 ± 9.0	0.16 ± 0.04	1.31 ± 0.63	0.14 ± 0.02	56.7 ± 5.7
6	0 - 20	4	1.23 ± 0.02	235.8 ± 3.1	0.07 ± 0.01	0.74 ± 0.07	0.24 ± 0.02	45.9 ± 3.1
	20 - 50	4	0.88 ± 0.02	309.4 ± 17.2	0.13 ± 0.03	0.74 ± 0.04	0.15 ± 0.02	50.8 ± 5.6
7	0 - 20	4	1.12 ± 0.07	313.9 ± 54.1	0.06 ± 0.03	0.50 ± 0.11	0.22 ± 0.06	62.9 ± 21.9
	20 - 50	4	0.63 ± 0.09	281.5 ± 27.1	0.12 ± 0.03	0.72 ± 0.04	0.11 ± 0.02	50.9 ± 6.3
8	0 - 20	4	1.64 ± 0.10	393.7 ± 22.6	0.07 ± 0.01	0.37 ± 0.04	0.21 ± 0.04	50.1 ± 9.3
	20 - 50	4	0.76 ± 0.11	332.9 ± 6.1	0.16 ± 0.01	0.83 ± 0.08	0.12 ± 0.02	51.2 ± 3.0

Table 39. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 326 in 1975. All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	1.09 ± 0.00	366.3 ± 21.0	0.11 ± 0.04	0.93 ± 0.09	0.30 ± 0.03	98.0 ± 2.3
	20 - 50	4	0.83 ± 0.07	298.2 ± 7.1	0.22 ± 0.07	1.43 ± 0.44	0.22 ± 0.03	77.6 ± 4.4
2	0 - 20	4	1.23 ± 0.10	306.2 ± 32.9	0.21 ± 0.06	0.99 ± 0.18	0.19 ± 0.02	52.6 ± 13.8
	20 - 50	4	0.76 ± 0.06	223.9 ± 1.54	0.17 ± 0.04	0.88 ± 0.15	0.16 ± 0.01	47.3 ± 6.5
3	0 - 20	4	1.14 ± 0.01	362.1 ± 9.2	0.17 ± 0.06	1.54 ± 0.29	0.37 ± 0.05	119.6 ± 18.7
	20 - 50	4	0.90 ± 0.02	290.3 ± 7.3	0.09 ± 0.03	0.95 ± 0.07	0.17 ± 0.00	53.2 ± 1.04
4	0 - 20	4	1.14 ± 0.05	352.3 ± 13.9	0.20 ± 0.02	1.33 ± 0.06	0.27 ± 0.03	81.9 ± 3.6
	20 - 50	4	0.77 ± 0.05	313.3 ± 51.7	0.19 ± 0.05	1.04 ± 0.21	0.14 ± 0.01	57.5 ± 10.1
5	0 - 20	4	1.30 ± 0.02	265.0 ± 8.1	0.08 ± 0.00	0.97 ± 0.07	0.18 ± 0.03	327.0 ± 7.7
	20 - 50	4	0.81 ± 0.00	303.7 ± 9.5	0.12 ± 0.03	1.00 ± 0.11	0.14 ± 0.02	52.1 ± 7.2
6	0 - 20	4	1.34 ± 0.01	269.4 ± 18.4	0.16 ± 0.05	0.87 ± 0.02	0.25 ± 0.04	52.5 ± 11.8
	20 - 50	4	0.73 ± 0.02	181.8 ± 13.4	0.10 ± 0.01	0.69 ± 0.09	0.16 ± 0.01	41.1 ± 6.7
7	0 - 20	4	1.34 ± 0.08	253.2 ± 34.0	0.03 ± 0.01	0.57 ± 0.07	0.15 ± 0.00	27.1 ± 2.6
	20 - 50	4	0.86 ± 0.03	259.0 ± 16.4	0.08 ± 0.03	0.82 ± 0.12	0.11 ± 0.00	32.3 ± 3.9
8	0 - 20	4	1.34 ± 0.03	300.4 ± 14.5	0.10 ± 0.02	0.71 ± 0.09	0.22 ± 0.01	48.0 ± 0.6
	20 - 50	4	0.60 ± 0.13	318.7 ± 28.2	0.14 ± 0.04	1.06 ± 0.08	0.13 ± 0.01	72.0 ± 7.2

Table 40. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 25 in 1976. All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	0.83 ± 0.00	261.6 ± 0.00	0.52 ± 0.01	1.77 ± 0.04	0.33 ± 0.00	104.0 ± 0.00
	20 - 50	4	0.67 ± 0.00	161.8 ± 0.00	0.25 ± 0.08	0.28 ± 0.03	0.13 ± 0.00	30.9 ± 0.00
2	0 - 20	4	1.05 ± 0.00	397.8 ± 0.00	0.60 ± 0.01	2.12 ± 0.11	0.37 ± 0.00	140.2 ± 0.00
	20 - 50	4	0.88 ± 0.00	290.4 ± 0.00	0.31 ± 0.01	1.06 ± 0.37	0.32 ± 0.00	104.0 ± 0.00
3	0 - 20	4	1.03 ± 0.00	387.6 ± 0.00	0.22 ± 0.01	1.19 ± 0.18	0.24 ± 0.00	90.7 ± 0.00
	20 - 50	4	0.76 ± 0.00	275.2 ± 0.00	0.10 ± 0.00	0.85 ± 0.01	0.17 ± 0.00	61.6 ± 0.00
4	0 - 20	4	1.14 ± 0.00	217.1 ± 0.00	0.16 ± 0.01	0.72 ± 0.08	0.25 ± 0.00	47.6 ± 0.00
	20 - 50	4	0.90 ± 0.00	133.8 ± 0.00	0.00 ± 0.00	0.37 ± 0.04	0.10 ± 0.00	15.3 ± 0.00
5	0 - 20	4	1.26 ± 0.00	374.7 ± 0.00	0.21 ± 0.04	1.29 ± 0.04	0.28 ± 0.00	82.7 ± 0.00
	20 - 50	4	0.94 ± 0.00	179.5 ± 0.00	0.08 ± 0.00	0.45 ± 0.00	0.15 ± 0.00	29.2 ± 0.00
6	0 - 20	4	1.36 ± 0.00	331.8 ± 0.00	0.37 ± 0.16	1.65 ± 0.09	0.33 ± 0.00	81.5 ± 0.00
	20 - 50	4	0.80 ± 0.00	388.2 ± 0.00	0.26 ± 0.06	1.10 ± 0.10	0.12 ± 0.00	58.9 ± 0.00
7	0 - 20	4	1.31 ± 0.00	273.5 ± 0.00	0.20 ± 0.04	1.15 ± 0.07	0.14 ± 0.00	29.4 ± 0.00
	20 - 50	4	0.83 ± 0.00	408.3 ± 0.00	0.00 ± 0.00	0.96 ± 0.07	0.10 ± 0.00	51.2 ± 0.00
8	0 - 20	4	1.39 ± 0.00	284.6 ± 0.00	0.24 ± 0.05	1.22 ± 0.02	0.19 ± 0.00	39.1 ± 0.00
	20 - 50	4	0.94 ± 0.00	350.4 ± 0.00	0.01 ± 0.01	0.73 ± 0.10	0.12 ± 0.00	45.9 ± 0.00

Table 41. *Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 65 in 1976.*

All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	1.40 ± 0.16	463.4 ± 38.7	0.26 ± 0.07	0.89 ± 0.07	0.15 ± 0.00	50.2 ± 1.7
	20 - 50	4	0.94 ± 0.01	433.9 ± 31.2	0.42 ± 0.17	0.75 ± 0.06	0.09 ± 0.01	38.4 ± 1.7
2	0 - 20	4	1.00 ± 0.10	253.7 ± 13.8	0.09 ± 0.03	1.21 ± 0.07	0.19 ± 0.02	49.4 ± 6.8
	20 - 50	4	0.85 ± 0.08	230.9 ± 16.0	0.04 ± 0.02	1.21 ± 0.06	0.17 ± 0.02	46.8 ± 6.0
3	0 - 20	4	1.32 ± 0.54	357.2 ± 0.7	0.09 ± 0.05	1.43 ± 0.04	0.27 ± 0.02	73.2 ± 8.9
	20 - 50	4	0.93 ± 0.00	419.2 ± 27.8	0.00 ± 0.00	2.40 ± 0.22	0.16 ± 0.00	70.8 ± 3.3
4	0 - 20	4	1.35 ± 0.07	409.4 ± 27.7	0.06 ± 0.03	1.24 ± 0.34	0.24 ± 0.02	72.9 ± 8.2
	20 - 50	4	0.81 ± 0.03	465.8 ± 3.4	0.19 ± 0.02	1.56 ± 0.06	0.10 ± 0.01	53.7 ± 5.6
5	0 - 20	4	1.36 ± 0.03	381.3 ± 5.4	0.12 ± 0.02	1.28 ± 0.05	0.15 ± 0.01	41.4 ± 16.5
	20 - 50	4	1.03 ± 0.17	485.1 ± 52.3	0.02 ± 0.02	1.18 ± 0.26	0.09 ± 0.01	43.2 ± 0.00
6	0 - 20	4	1.43 ± 0.01	415.8 ± 2.1	0.09 ± 0.05	0.90 ± 0.04	0.15 ± 0.01	42.0 ± 3.8
	20 - 50	4	0.66 ± 0.04	317.9 ± 7.62	0.04 ± 0.02	1.44 ± 0.20	0.08 ± 0.01	38.0 ± 2.5
7	0 - 20	4	1.39 ± 0.04	372.1 ± 10.7	0.00 ± 0.00	0.71 ± 0.06	0.12 ± 0.01	30.9 ± 2.3
	20 - 50	4	0.74 ± 0.01	401.1 ± 12.2	0.26 ± 0.12	1.13 ± 0.19	0.07 ± 0.00	35.4 ± 1.2
8	0 - 20	4	1.33 ± 0.03	390.9 ± 2.8	0.14 ± 0.08	0.65 ± 0.06	0.12 ± 0.02	35.7 ± 5.7
	20 - 50	4	0.74 ± 0.09	215.9 ± 9.2	0.19 ± 0.08	0.53 ± 0.06	0.09 ± 0.00	27.1 ± 2.3

Table 42. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 125 in 1976. All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	1.35 ± 0.06	295.4 ± 18.8	0.15 ± 0.06	0.91 ± 0.12	0.30 ± 0.00	64.9 ± 1.04
	20 - 50	4	0.90 ± 0.03	339.7 ± 66.7	0.11 ± 0.05	0.94 ± 0.08	0.14 ± 0.00	54.4 ± 10.6
2	0 - 20	4	1.28 ± 0.16	311.0 ± 29.6	0.22 ± 0.05	1.40 ± 0.03	0.31 ± 0.13	77.4 ± 5.9
	20 - 50	4	0.78 ± 0.19	252.8 ± 62.6	0.20 ± 0.03	1.30 ± 0.03	0.14 ± 0.00	50.1 ± 0.2
3	0 - 20	4	1.21 ± 0.01	308.9 ± 11.3	0.41 ± 0.05	1.64 ± 0.23	0.28 ± 0.04	73.7 ± 13.9
	20 - 50	4	0.94 ± 0.05	423.9 ± 12.1	0.34 ± 0.05	1.82 ± 0.11	0.14 ± 0.01	63.6 ± 2.3
4	0 - 20	4	1.64 ± 0.20	410.6 ± 48.5	0.47 ± 0.08	1.43 ± 0.21	0.17 ± 0.01	43.0 ± 12.7
	20 - 50	4	1.07 ± 0.01	412.2 ± 25.3	0.41 ± 0.10	1.3 ± 0.13	0.14 ± 0.04	53.1 ± 1.1
5	0 - 20	4	1.31 ± 0.04	260.3 ± 38.4	0.26 ± 0.03	1.51 ± 0.05	0.30 ± 0.03	62.1 ± 13.4
	20 - 50	4	1.08 ± 0.05	309.9 ± 2.4	0.02 ± 0.02	1.22 ± 0.19	0.18 ± 0.03	51.2 ± 6.7
6	0 - 20	4	1.59 ± 0.13	280.6 ± 15.2	0.36 ± 0.01	1.44 ± 0.15	0.39 ± 0.06	69.6 ± 12.0
	20 - 50	4	1.18 ± 0.09	363.7 ± 25.8	0.20 ± 0.02	1.37 ± 0.09	0.15 ± 0.01	45.4 ± 3.2
7	0 - 20	4	1.31 ± 0.04	323.4 ± 22.4	0.09 ± 0.02	0.40 ± 0.03	0.22 ± 0.02	53.1 ± 2.4
	20 - 50	4	0.77 ± 0.09	351.0 ± 12.7	0.20 ± 0.04	0.94 ± 0.08	0.10 ± 0.01	47.4 ± 94.4
8	0 - 20	4	1.48 ± 0.03	362.2 ± 10.4	0.16 ± 0.01	0.57 ± 0.07	0.21 ± 0.01	50.9 ± 2.6
	20 - 50	4	0.81 ± 0.05	310.2 ± 19.2	0.16 ± 0.02	0.78 ± 0.07	0.18 ± 0.03	73.2 ± 19.1

Table 43. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 144 in 1976. All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	1.33 ± 0.09	417.4 ± 20.8	0.64 ± 0.03	2.02 ± 0.23	0.34 ± 0.03	111.9 ± 22.2
	20 - 50	4	0.88 ± 0.06	350.1 ± 3.6	0.48 ± 0.04	1.48 ± 0.08	0.17 ± 0.09	67.9 ± 7.05
2	0 - 20	4	1.22 ± 0.03	332.5 ± 25.4	0.36 ± 0.06	1.62 ± 0.20	0.28 ± 0.01	76.7 ± 5.0
	20 - 50	4	0.73 ± 0.06	251.7 ± 20.9	0.22 ± 0.10	1.30 ± 0.06	0.22 ± 0.03	77.0 ± 11.4
3	0 - 20	4	1.18 ± 0.06	253.3 ± 38.6	0.36 ± 0.05	1.48 ± 0.24	0.27 ± 0.01	57.4 ± 7.7
	20 - 50	4	0.86 ± 0.01	233.9 ± 15.0	0.22 ± 0.01	1.18 ± 0.05	0.19 ± 0.02	54.3 ± 9.4
4	0 - 20	4	1.20 ± 0.02	234.6 ± 26.2	0.30 ± 0.10	1.42 ± 0.31	0.28 ± 0.02	56.7 ± 11.3
	20 - 50	4	0.82 ± 0.04	251.9 ± 68.6	0.28 ± 0.06	1.01 ± 0.26	0.14 ± 0.01	45.5 ± 12.2
5	0 - 20	4	1.25 ± 0.03	241.3 ± 30.5	0.24 ± 0.05	0.99 ± 0.05	0.28 ± 0.03	51.9 ± 0.14
	20 - 50	4	0.90 ± 0.09	371.6 ± 40.2	0.59 ± 0.19	1.58 ± 0.20	0.18 ± 0.02	75.3 ± 7.5
6	0 - 20	4	1.38 ± 0.02	254.6 ± 46.7	0.34 ± 0.10	1.12 ± 0.28	0.32 ± 0.02	57.1 ± 7.5
	20 - 50	4	1.02 ± 0.20	196.9 ± 6.70	0.22 ± 0.07	0.89 ± 0.03	0.14 ± 0.00	28.3 ± 3.6
7	0 - 20	4	1.37 ± 0.07	333.2 ± 14.8	0.31 ± 0.02	0.80 ± 0.02	0.25 ± 0.04	60.2 ± 9.7
	20 - 50	4	0.79 ± 0.01	377.3 ± 30.0	0.37 ± 0.03	1.52 ± 0.06	0.12 ± 0.01	54.8 ± 2.6
8	0 - 20	4	1.34 ± 0.03	236.2 ± 4.4	0.19 ± 0.04	0.66 ± 0.03	0.30 ± 0.07	53.6 ± 11.9
	20 - 50	4	0.64 ± 0.11	226.8 ± 7.7	0.45 ± 0.16	1.05 ± 0.19	0.14 ± 0.01	51.8 ± 6.1

Table 44. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 162 in 1976.

All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N $gm\ m^{-2}$	NO_3 $gm\ m^{-2}$	NH_3 $gm\ m^{-2}$	%P	Total P $gm\ m^{-2}$
1	0 - 20	4	1.25 ± 0.00	436.7 ± 0.00	0.20 ± 0.02	2.00 ± 0.07	0.20 ± 0.00	69.9 ± 0.00
	20 - 50	4	0.84 ± 0.00	160.8 ± 0.00	0.19 ± 0.00	0.68 ± 0.06	0.12 ± 0.00	23.0 ± 0.00
2	0 - 20	4	1.05 ± 0.00	162.6 ± 0.00	0.21 ± 0.00	1.20 ± 0.04	0.29 ± 0.00	44.9 ± 0.04
	20 - 50	4	0.62 ± 0.00	137.7 ± 0.00	0.09 ± 0.01	0.70 ± 0.02	0.12 ± 0.00	26.6 ± 0.01
3	0 - 20	4	1.05 ± 0.06	292.9 ± 19.2	0.33 ± 0.12	1.37 ± 0.44	0.47 ± 0.01	129.5 ± 4.11
	20 - 50	4	0.75 ± 0.03	331.7 ± 23.6	0.56 ± 0.19	2.08 ± 0.52	0.14 ± 0.01	62.3 ± 10.8
4	0 - 20	4	1.04 ± 0.03	212.6 ± 45.8	0.22 ± 0.15	1.19 ± 0.39	0.44 ± 0.02	95.1 ± 26.0
	20 - 50	4	1.07 ± 0.10	311.3 ± 42.3	0.21 ± 0.08	1.09 ± 0.12	0.16 ± 0.00	48.6 ± 11.4
5	0 - 20	4	1.36 ± 0.08	443.9 ± 44.3	0.39 ± 0.11	1.76 ± 0.26	0.44 ± 0.01	142.8 ± 4.31
	20 - 50	4	0.77 ± 0.02	299.4 ± 26.9	0.23 ± 0.04	1.02 ± 0.09	0.15 ± 0.00	56.3 ± 4.5
6	0 - 20	4	1.32 ± 0.01	289.9 ± 47.6	0.10 ± 0.02	1.10 ± 0.26	0.29 ± 0.01	63.9 ± 1.9
	20 - 50	4	0.70 ± 0.01	265.5 ± 12.3	0.48 ± 0.29	2.40 ± 0.36	0.14 ± 0.00	55.4 ± 4.6
7	0 - 20	4	1.13 ± 0.03	321.7 ± 39.4	0.18 ± 0.01	0.70 ± 0.04	0.29 ± 0.03	79.4 ± 2.0
	20 - 50	4	0.67 ± 0.01	287.7 ± 39.4	0.19 ± 0.01	1.07 ± 0.11	0.13 ± 0.00	53.4 ± 4.8
8	0 - 20	4	1.08 ± 0.13	308.9 ± 0.2	0.06 ± 0.03	0.93 ± 0.19	0.21 ± 0.03	57.8 ± 2.2
	20 - 50	4	0.64 ± 0.92	306.8 ± 3.3	0.06 ± 0.04	1.07 ± 0.25	0.13 ± 0.03	64.6 ± 1.7

Table 45. *Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 176 in 1976.* All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	0.96 ± 0.04	254.8 ± 9.47	0.13 ± 0.06	1.40 ± 0.19	0.35 ± 0.06	93.1 ± 16.5
	20 - 50	4	0.79 ± 0.01	222.8 ± 19.8	0.17 ± 0.07	1.36 ± 0.17	0.20 ± 0.01	55.1 ± 1.0
2	0 - 20	4	1.14 ± 0.06	154.2 ± 13.9	0.03 ± 0.02	0.50 ± 0.15	0.44 ± 0.06	57.7 ± 5.9
	20 - 50	4	1.03 ± 0-01	172.9 ± 4.2	0.08 ± 0.05	0.74 ± 0.16	0.22 ± 0.05	37.5 ± 7.2
3	0 - 20	4	0.97 ± 0.06	267.6 ± 20.7	0.07 ± 0.02	1.20 ± 0.10	0.34 ± 0.03	93.4 ± 7.7
	20 - 50	4	0.94 ± 0.05	199.9 ± 12.8	0.04 ± 0.01	0.89 ± 0.13	0.22 ± 0.05	5.06 ± 15.4
4	0 - 20	4	1.00 ± 0.03	281.2 ± 5.6	0.01 ± 0.01	1.16 ± 0.08	0.30 ± 0.01	85.6 ± 4.9
	20 - 50	4	0.67 ± 0.14	102.1 ± 5.7	0.04 ± 0.02	1.03 ± 0.16	0.14 ± 0.01	22.0 ± 1.6
5	0 - 20	4	1.12 ± 0.17	312.0 ± 4.8	0.03 ± 0.03	1.09 ± 0.08	0.25 ± 0.00	69.8 ± 0.4
	20 - 50	4	0.75 ± 0.01	233.3 ± 10.6	0.08 ± 0.03	1.34 ± 0.08	0.12 ± 0.01	37.9 ± 2.2
6	0 - 20	4	1.31 ± 0.30	217.3 ± 16.8	0.02 ± 0.02	0.70 ± 0.11	0.34 ± 0.03	59.2 ± 12.0
	20 - 50	4	1.22 ± 0.10	291.8 ± 22.2	0.08 ± 0.08	0.62 ± 0.15	0.19 ± 0.02	46.3 ± 7.4
7	0 - 20	4	0.99 ± 0.13	168.7 ± 24.3	0.05 ± 0.03	0.65 ± 0.08	0.28 ± 0.05	48.1 ± 65.0
	20 - 50	4	0.78 ± 0.08	227.4 ± 29.3	0.13 ± 0.07	1.61 ± 0.37	0.12 ± 0.01	36.1 ± 5.2
8	0 - 20	4	1.03 ± 0.19	225.9 ± 22.8	0.00 ± 0.00	0.82 ± 0.11	0.35 ± 0.07	84.5 ± 24.3
	20 - 50	4	0.73 ± 0.16	157.6 ± 15.2	0.05 ± 0.02	0.88 ± 0.14	0.12 ± 0.01	27.0 ± 1.6

Table 46. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 197 in 1976. All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	1.18 ± 0.09	372.8 ± 20.6	0.18 ± 0.00	1.82 ± 0.06	0.29 ± 0.00	93.8 ± 0.8
	20 - 50	4	0.94 ± 0.05	270.1 ± 12.3	0.08 ± 0.03	1.18 ± 0.06	0.14 ± 0.01	42.1 ± 2.1
2	0 - 20	4	1.22 ± 0.11	361.3 ± 1.3	0.31 ± 0.07	2.01 ± 0.20	0.26 ± 0.00	78.4 ± 5.9
	20 - 50	4	0.85 ± 0.08	179.7 ± 17.5	0.08 ± 0.03	1.00 ± 0.10	0.14 ± 0.01	30.0 ± 1.0
3	0 - 20	4	1.16 ± 0.06	308.5 ± 14.5	0.21 ± 0.04	2.00 ± 0.08	0.28 ± 0.00	74.9 ± 0.8
	20 - 50	4	0.82 ± 0.02	263.4 ± 19.6	0.18 ± 0.04	1.81 ± 0.11	0.14 ± 0.01	44.4 ± 2.0
4	0 - 20	4	1.27 ± 0.03	352.1 ± 1.9	0.27 ± 0.06	2.13 ± 0.10	0.30 ± 0.01	83.8 ± 4.6
	20 - 50	4	0.92 ± 0.03	390.7 ± 47.3	0.14 ± 0.06	1.79 ± 0.16	0.12 ± 0.00	53.0 ± 6.5
5	0 - 20	4	1.35 ± 0.11	338.8 ± 7.7	0.24 ± 0.10	1.88 ± 0.04	0.21 ± 0.02	53.5 ± 2.2
	20 - 50	4	0.99 ± 0.02	284.4 ± 5.0	0.09 ± 0.05	1.39 ± 0.08	0.13 ± 0.01	37.2 ± 3.0
6	0 - 20	4	1.19 ± 0.05	246.1 ± 15.2	0.09 ± 0.03	1.10 ± 0.50	0.23 ± 0.01	48.5 ± 14.5
	20 - 50	4	0.75 ± 0.08	196.8 ± 2.7	0.13 ± 0.02	1.27 ± 0.15	0.16 ± 0.02	45.5 ± 9.7
7	0 - 20	4	1.17 ± 0.08	235.1 ± 32.1	0.07 ± 0.01	0.82 ± 0.12	0.23 ± 0.01	46.8 ± 5.9
	20 - 50	4	0.77 ± 0.05	296.9 ± 7.5	0.07 ± 0.04	1.40 ± 0.13	0.12 ± 0.01	44.9 ± 1.9
8	0 - 20	4	1.31 ± 0.12	334.2 ± 5.9	0.19 ± 0.05	1.04 ± 0.18	0.20 ± 0.01	53.3 ± 6.9
	20 - 50	4	0.85 ± 0.16	251.7 ± 41.6	0.10 ± 0.06	1.53 ± 0.51	0.10 ± 0.01	35.8 ± 10.1

Table 47. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 206 in 1976. All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	1.26 ± 0.07	350.9 ± 31.0	0.14 ± 0.07	1.30 ± 0.09	0.22 ± 0.00	61.9 ± 0.9
	20 - 50	4	0.90 ± 0.01	284.4 ± 16.1	0.06 ± 0.03	0.87 ± 0.07	0.14 ± 0.01	42.5 ± 0.1
2	0 - 20	4	1.15 ± 0.06	314.5 ± 30.5	0.23 ± 0.14	1.48 ± 0.16	0.25 ± 0.02	72.6 ± 15.1
	20 - 50	4	1.00 ± 0.06	412.2 ± 55.7	0.00 ± 0.00	1.69 ± 0.36	0.15 ± 0.01	62.1 ± 7.1
3	0 - 20	4	1.21 ± 0.08	273.1 ± 21.7	0.02 ± 0.02	1.59 ± 0.22	0.36 ± 0.03	80.2 ± 4.8
	20 - 50	4	1.03 ± 0.11	412.1 ± 35.4	0.09 ± 0.09	1.68 ± 0.32	0.15 ± 0.01	62.5 ± 7.7
4	0 - 20	4	1.21 ± 0.04	335.5 ± 1.6	0.09 ± 0.04	1.79 ± 0.06	0.32 ± 0.03	88.3 ± 11.3
	20 - 50	4	0.79 ± 0.05	402.9 ± 46.9	0.08 ± 0.08	1.82 ± 0.04	0.13 ± 0.00	68.5 ± 5.1
5	0 - 20	4	1.38 ± 0.05	296.1 ± 13.4	0.15 ± 0.09	1.38 ± 0.09	0.30 ± 0.02	64.2 ± 0.07
	20 - 50	4	0.84 ± 0.02	315.3 ± 57.4	0.00 ± 0.00	1.82 ± 0.53	0.14 ± 0.00	51.6 ± 9.5
6	0 - 20	4	1.28 ± 0.06	215.5 ± 4.7	0.02 ± 0.02	1.14 ± 0.21	0.26 ± 0.03	42.7 ± 4.2
	20 - 50	4	0.97 ± 0.09	369.4 ± 6.8	0.00 ± 0.00	1.88 ± 0.30	0.14 ± 0.02	53.7 ± 7.0
7	0 - 20	4	1.41 ± 0.05	245.3 ± 12.4	0.00 ± 0.00	1.11 ± 0.06	0.17 ± 0.00	30.3 ± 2.4
	20 - 50	4	1.22 ± 0.05	393.1 ± 74.4	0.66 ± 0.25	1.40 ± 0.29	0.11 ± 0.01	36.1 ± 6.1
8	0 - 20	4	1.14 ± 0.00	243.3 ± 48.6	0.09 ± 0.03	0.64 ± 0.13	0.22 ± 0.44	47.7 ± 9.6
	20 - 50	4	0.95 ± 0.04	346.3 ± 7.8	0.16 ± 0.02	0.99 ± 0.20	0.13 ± 0.00	48.7 ± 3.0

Table 48. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 228 in 1976. All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	1.12 ± 0.00	363.6 ± 11.4	0.31 ± 0.03	1.33 ± 0.06	0.28 ± 0.00	92.4 ± 2.8
	20 - 50	4	0.94 ± 0.12	241.6 ± 47.2	0.15 ± 0.02	0.84 ± 0.03	0.12 ± 0.00	30.9 ± 1.9
2	0 - 20	4	1.10 ± 0.11	315.4 ± 41.7	0.24 ± 0.01	1.07 ± 0.09	0.20 ± 0.01	57.7 ± 5.7
	20 - 50	4	0.80 ± 0.00	244.8 ± 20.5	0.19 ± 0.00	1.17 ± 0.21	0.16 ± 0.02	49.6 ± 9.0
3	0 - 20	4	1.30 ± 0.04	365.7 ± 4.0	0.15 ± 0.06	1.69 ± 0.56	0.26 ± 0.00	73.8 ± 1.8
	20 - 50	4	0.85 ± 0.00	266.4 ± 23.6	0.24 ± 0.10	1.35 ± 0.04	0.12 ± 0.01	38.2 ± 15.3
4	0 - 20	4	1.56 ± 0.03	362.2 ± 3.1	0.04 ± 0.01	1.40 ± 0.21	0.25 ± 0.01	58.8 ± 0.3
	20 - 50	4	0.78 ± 0.01	304.8 ± 68.3	0.22 ± 0.12	1.74 ± 0.29	0.24 ± 0.08	73.4 ± 8.6
5	0 - 20	4	1.45 ± 0.07	332.7 ± 0.3	0.14 ± 0.01	1.35 ± 0.18	0.24 ± 0.01	55.5 ± 3.8
	20 - 50	4	0.73 ± 0.01	225.4 ± 34.5	0.14 ± 0.04	1.22 ± 0.26	0.15 ± 0.01	43.9 ± 1.1
6	0 - 20	4	1.47 ± 0.01	386.1 ± 17.5	0.21 ± 0.05	1.75 ± 0.07	0.22 ± 0.04	51.4 ± 6.4
	20 - 50	4	0.78 ± 0.00	177.0 ± 0.5	0.14 ± 0.04	1.07 ± 0.17	0.14 ± 0.00	31.5 ± 1.0
7	0 - 20	4	1.33 ± 0.06	269.6 ± 4.1	0.02 ± 0.01	0.55 ± 0.05	0.20 ± 0.01	41.1 ± 3.9
	20 - 50	4	0.94 ± 0.04	241.9 ± 9.7	0.07 ± 0.05	0.89 ± 0.15	0.12 ± 0.01	31.0 ± 3.0
8	0 - 20	4	1.50 ± 0.03	381.1 ± 13.2	0.20 ± 0.05	0.66 ± 0.06	0.21 ± 0.00	52.5 ± 3.8
	20 - 50	4	0.73 ± 0.14	254.8 ± 38.1	0.17 ± 0.06	0.98 ± 0.05	0.12 ± 0.01	43.3 ± 2.8

Table 49. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 259 in 1976. All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	1.28 ± 0.07	427.1 ± 72.4	0.25 ± 0.01	1.46 ± 0.08	0.21 ± 0.00	68.9 ± 9.7
	20 - 50	4	0.83 ± 0.09	236.8 ± 12.6	0.18 ± 0.02	0.77 ± 0.06	0.13 ± 0.00	37.5 ± 1.7
2	0 - 20	4	1.48 ± 0.01	342.4 ± 2.3	0.22 ± 0.02	1.00 ± 0.04	0.23 ± 0.00	53.8 ± 0.1
	20 - 50	4	0.98 ± 0.05	285.8 ± 16.0	0.19 ± 0.02	1.11 ± 0.10	0.14 ± 0.01	42.2 ± 5.8
3	0 - 20	4	1.27 ± 0.01	354.6 ± 3.9	0.35 ± 0.04	1.71 ± 0.11	0.25 ± 0.01	70.5 ± 1.9
	20 - 50	4	0.90 ± 0.05	436.2 ± 52.3	0.32 ± 0.05	1.59 ± 0.02	0.12 ± 0.00	57.4 ± 3.1
4	0 - 20	4	1.15 ± 0.06	289.3 ± 7.1	0.26 ± 0.03	1.69 ± 0.16	0.25 ± 0.02	63.2 ± 6.4
	20 - 50	4	0.81 ± 0.05	261.3 ± 19.6	0.06 ± 0.03	0.07 ± 0.04	0.15 ± 0.01	48.2 ± 2.1
5	0 - 20	4	1.16 ± 0.05	270.9 ± 6.5	0.23 ± 0.04	1.46 ± 0.19	0.23 ± 0.01	54.2 ± 5.4
	20 - 50	4	0.75 ± 0.14	312.2 ± 45.6	0.28 ± 0.04	1.20 ± 0.11	0.10 ± 0.01	41.3 ± 3.8
6	0 - 20	4	1.21 ± 0.08	258.9 ± 13.3	0.25 ± 0.02	1.48 ± 0.25	0.20 ± 0.00	43.8 ± 0.2
	20 - 50	4	0.88 ± 0.03	289.4 ± 3.1	0.26 ± 0.07	1.50 ± 0.07	0.13 ± 0.00	41.5 ± 0.07
7	0 - 20	4	1.42 ± 0.07	307.8 ± 47.8	0.12 ± 0.05	0.56 ± 0.13	0.20 ± 0.01	41.1 ± 1.6
	20 - 50	4	0.94 ± 0.10	311.7 ± 42.2	0.18 ± 0.02	0.75 ± 0.19	0.10 ± 0.01	33.1 ± 4.8
8	0 - 20	4	1.43 ± 0.11	354.6 ± 14.3	0.18 ± 0.02	0.40 ± 0.03	0.19 ± 0.01	47.6 ± 32.4
	20 - 50	4	0.78 ± 0.18	294.7 ± 68.6	0.15 ± 0.05	0.76 ± 0.08	0.10 ± 0.00	38.9 ± 40.9

Table 50. Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday 268 in 1976. All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	1.14 ± 0.02	394.5 ± 37.8	0.17 ± 0.04	0.96 ± 0.18	0.23 ± 0.03	76.9 ± 3.5
	20 - 50	4	0.86 ± 0.03	333.6 ± 11.7	0.11 ± 0.04	0.90 ± 0.10	0.17 ± 0 03	63.6 ± 9.0
2	0 - 20	4	1.08 ± 0.00	364.8 ± 24.4	0.13 ± 0.03	0.78 ± 0.05	0.20 ± 0.04	67.1 ± 8.3
	20 - 50	4	0.76 ± 0.01	316.2 ± 14.5	0.11 ± 0.03	0.91 ± 0.04	0.21 ± 0.02	88.6 ± 12.0
3	0 - 20	4	1.06 ± 0.03	297.9 ± 17.0	0.12 ± 0.03	0.78 ± 0.03	0.35 ± 0.07	99.7 ± 3.4
	20 - 50	4	0.97 ± 0.05	368.0 ± 32.7	0.15 ± 0.02	0.79 ± 0.03	0.33 ± 0.11	129.9 ± 46.4
4	0 - 20	4	1.12 ± 0.02	294.8 ± 40.6	0.07 ± 0.01	0.97 ± 0.19	0.31 ± 0.10	69.4 ± 14.7
	20 - 50	4	0.90 ± 0.08	398.2 ± 0.9	0.13 ± 0.02	0.93 ± 0.03	0.11 ± 0.03	48.5 ± 9.8
5	0 - 20	4	1.36 ± 0.05	364.3 ± 28.9	0.12 ± 0.01	0.89 ± 0.07	0.43 ± 0.12	110.2 ± 27.1
	20 - 50	4	0.86 ± 0.01	300.2 ± 23.3	0.11 ± 0.01	0.87 ± 0.06	0.14 ± 0.01	50.0 ± 1.6
6	0 - 20	4	1.49 ± 0.01	274.8 ± 15.2	0.11 ± 0.01	1.06 ± 0.10	0.23 ± 0.03	41.4 ± 3.6
	20 - 50	4	0.86 ± 0.01	278.1 ± 27.0	0.11 ± 0.03	0.89 ± 0.07	0.17 ± 0.03	50.5 ± 0.5
7	0 - 20	4	1.41 ± 0.13	397.7 ± 13.8	0.15 ± 0.03	0.70 ± 0.04	0.30 ± 0.02	85.4 ± 0.04
	20 - 50	4	0.64 ± 0.02	389.0 ± 2,2	0,20 ± 0.03	2.08 ± 0.93	0.26 ± 0.08	131.6 ± 40.5
8	0 - 20	4	1.43 ± 0.05	121.4 ± 34.7	0.08 ± 0.03	0.54 ± 0.03	0.20 ± 0.03	42.2 ± 2.6
	20 - 50	4	0.78 ± 0.04	260.7 ± 19.8	0.14 ± 0.04	0.25 ± 0.13	0.13 ± 0.02	47.3 ± 13.5

Table 51. *Nitrogen and phosphorus content of marsh substrate for two depth intervals on yearday* 289 in 1976.

All values are means ± 1 standard error of the mean.

SITE	DEPTH INTERVAL (cm)	SAMPLE SIZE	%N	Total N gm m^{-2}	NO_3 gm m^{-2}	NH_3 gm m^{-2}	%P	Total P gm m^{-2}
1	0 - 20	4	0.79 ± 0.03	190.8 ± 51.6	0.15 ± 0.01	1.16 ± 0.26	0.22 ± 0.88	55.2 ± 17.4
	20 - 50	4	0.82 ± 0.03	269.4 ± 14.7	0.06 ± 0.02	1.54 ± 0.27	0.16 ± 0.00	54.5 ± 4.6
2	0 - 20	4	1.05 ± 0.02	303.4 ± 33.6	0.22 ± 0.01	1.90 ± 0.24	0.24 ± 0.01	69.1 ± 5.2
	20 - 50	4	0.61 ± 0.04	146.7 ± 30.1	0.15 ± 0.06	1.17 ± 0.22	0.17 ± 0.02	41.8 ± 10.5
3	0 - 20	4	1.06 ± 0.13	272.2 ± 19.7	0.35 ± 0.04	1.72 ± 0.18	0.28 ± 0.02	72.8 ± 0.8
	20 - 50	4	0.79 ± 0.03	362.2 ± 102.9	0.34 ± 0.14	1.86 ± 0.30	0.15 ± 0.02	60.1 ± 9.7
4	0 - 20	4	1.08 ± 0.00	355.0 ± 37.9	0.41 ± 0.01	2.17 ± 0.05	0.26 ± 0.04	81.3 ± 3.3
	20 - 50	4	0.85 ± 0.02	302.2 ± 21.4	0.22 ± 0.06	2.41 ± 0.39	0.16 ± 0.00	56.0 ± 1.3
5	0 - 20	4	0.76 ± 0.07	170.6 ± 19.1	0.25 ± 0.04	1.53 ± 0.38	0.19 ± 0.01	46.9 ± 12.1
	20 - 50	4	0.90 ± 0.15	270.6 ± 46.0	0.31 ± 0.12	2.26 ± 0.37	0.19 ± 0.01	57.1 ± 3.8
6	0 - 20	4	1.10 ± 0.10	207.1 ± 5.7	0.17 ± 0.02	1.40 ± 0.39	0.17 ± 0.00	33.3 ± 3.8
	20 - 50	4	1.13 ± 0.08	248.2 ± 51.9	0.20 ± 0.06	1.67 ± 0.10	0.17 ± 0.00	35.9 ± 5.7
7	0 - 20	4	1.27 ± 0.09	216.1 ± 2.6	0.08 ± 0.01	0.51 ± 0.12	0.24 ± 0.03	42.2 ± 7.1
	20 - 50	4	0.93 ± 0.12	229.4 ± 5.2	0.19 ± 0.07	0.92 ± 0.20	0.14 ± 0.00	35.6 ± 4.1
8	0 - 20	4	1.17 ± 0.03	295.8 ± 32.7	0.16 ± 0.04	1.07 ± 0.17	0.23 ± 0.01	60.5 ± 9.7
	20 - 50	4	0.99 ± 0.01	370.7 ± 29.3	0.26 ± 0.05	1.41 ± 0.39	0.18 ± 0.03	68.3 ± 4.5

values on Yeardays 125 (0.24 ± 0.02 g/m^{-2}) and 162 (0.24 ± 0.03 g/m^{-2}) and a low value on Yearday 176 (0.06 ± 0.01 g/m^{-}). Significant differences in NH_3-N were due to high values on Yeardays 162 (1.57 ± 0.10 g/m^{-2}) 289 (1.54 ± 0.09 g/m $^{-2}$), and 197 (1.51 ± 0.07 g/m^{-2}) and low values on Yearday 298 (0.82 ± 0.05 g/m^{-2}), 326 (0.99 ± 0.05 g/m^{-2}) and 268 (0.92 ± 0.07 g/m^{-2}) Although there were significant site x time interactions for TOTAL N ($\alpha = .0015$) and NO_3-N ($\alpha = .04$), there were no clear patterns. The significant interaction effects for NO_3-N were primarily due to high values between Yeardays 25 and 144 (Tables 40 and 43), but there were no clear patterns when treatment sites were compared to controls. Most of the significant differences in TOTAL N were due to several high values on Yeardays 65 and 125 but no clear site differences occurred at those times and high values occurred in at least one replicate of each of the treatment sites and controls.

Significant depth x site interactions occurred for NH_3-N ($\alpha = .05$). In general, nitrate levels were almost always highest in the upper 20 cm of substrate at all sites except the two controls where nitrate levels were greatest in the 20 - 50 cm depth interval between Yeardays 125 and 259 (Tables 43 and 49).

10. WATER QUALITY STUDIES

Our initial studies of the Hamilton Marshes (Whigham and Simpson, 1975, 1976a; Simpson, et al., 1978) and earlier work on the Tinicum Marsh by Grant and Patrick (1970) showed ebb tide waters of freshwater tidal wetlands to be lower in nutrients than flood tide waters. This effect appeared to be seasonal in the tributary channels of the high marsh with the differential between flood and ebb tide levels of N and

P being greatest during the late spring and summer corresponding with the growth of macrophytes in the wetland. In the study, we addressed three basic questions related to water quality:

1. How was the quality of water entering Crosswicks Creek from the study site affected by sewage application?

2. How was the quality of water on the high marsh surface affected by sewage application?

3. How were late spring-summer tide cycle nutrient balances on the high marsh affected by sewage application?

Methods

Water was sampled at high and low slack water at eight sites in the watershed where the effluent study was conducted (see Fig. 19 for location of sites) at approximately monthly intervals from June 1975 through October 1976. On the same dates, water was collected from the surface of one of each set of experimental enclosures and controls. Effluent was being applied on all dates sampled except 19 February and 24 March 1976.

Input-output tide cycle studies were conducted in June and July 1977. Water was collected at the low point of each enclosure beginning when flood tide ~~ater~~ 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. 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

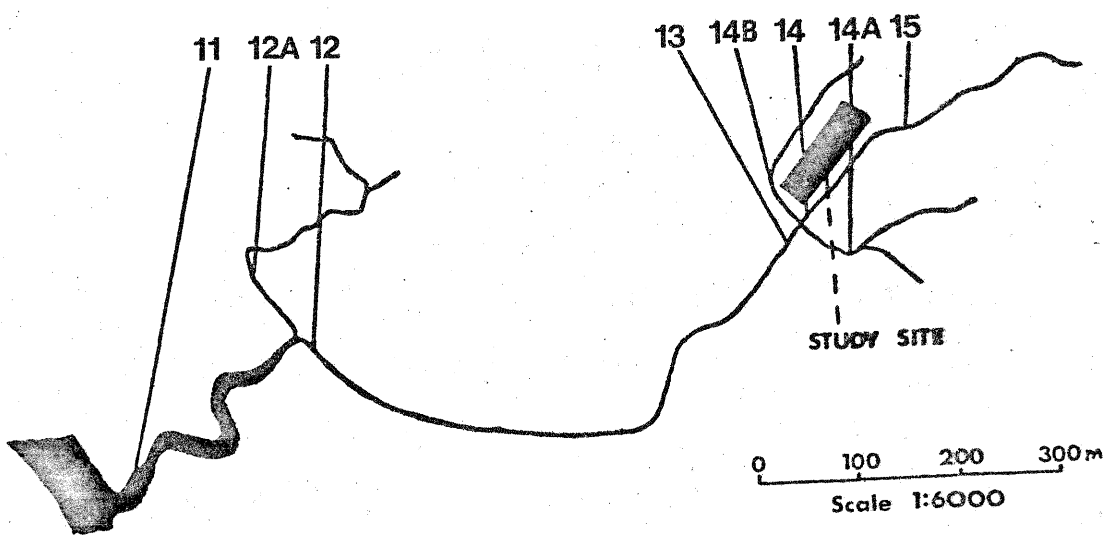


Fig. 19. Location of watershed water quality sample sites.

water plus the volume of effluent applied to that enclosure during the study period equalled the total output from an enclosure in a tide cycle. This assumption seemed justified because there was little lateral movement of water through enclosures and the wetland surface drained completely during each tide cyle. 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.

Samples were analyzed for reactive nitrate (NO_3-N), reactive nitrite (NO_2-N), ammonia plus amino acids (NH_3-N) and reactive phosphate (PO_4-P) following Strickland and Parsons (1968). Total P was determined using a persulfate digestion technique described by Menzel and Corwin (1965). Total N and Total P for mass balance studies were determined using a single sample wet digestion procedure outlined by Golterman (1969). Dissolved oxygen was determined titrametrically (APHA, 1971) or electrometrically (YSI Model 57 Dissolved Oxygen Meter), carbon dioxide and alkalinity were measured titrametically (APHA, 1971) and pH was determined electrometrically.

Results

Watershed Studies

The results of the watershed studies are presented in Tables 52 to 65. Dissolved oxygen levels followed seasonal patterns and were consistently higher at high slack water (hsw) than at low slack water (lsw), with downstream Sites 11, 12, and 12A typically having 1-3 mg L^{-1} more oxygen

Table 52. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on June 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	6.65	4.0	6.20	46	52.60	1.43	24.12	3.43	6.80
	LSW	5.30	22.5	6.10	58	45.65	3.27	20.39	12.72	24.53
12	HSW	6.80	5.0	6.50	45	63.93	1.49	39.70	3.26	9.25
	LSW	7.20	18.5	6.35	66	52.10	4.98	46.28	14.38	23.41
12A	HSW	6.05	4.5	6.65	43	55.27	1.87	8.44	4.65	11.93
	LSW	4.50	33.0	6.50	71	3.44	.44	.66	13.55	23.41
13	HSW	4.85	7.0	6.95	41	57.26	2.48	13.38	8.35	17.17
	LSW	3.15	30.0	6.50	83	46.88	5.99	153.42	16.70	31.22
14	HSW	5.40	7.0	6.90	42	68.57	2.63	32.80	8.41	17.73
	LSW	2.80	33.5	6.60	79	49.85	5.77	147.23	19.20	36.24
14A	HSW	5.05	8.0	6.90	38	89.15	2.94	26.73	10.78	21.07
	LSW	2.95	35.5	6.70	124	53.88	5.55	435.31	12.11	19.62
14B	HSW	5.30	8.0	6.90	38	78.67	2.74	46.63	9.90	21.30
	LSW	2.70	35.0	6.75	83	41.12	7.50	275.34	20.68	34.57
15	HSW	5.25	8.0	6.90	36	94.60	2.92	49.68	10.67	20.18
	LSW	2.65	30.0	6.70	64	60.25	1.49	0	12.22	21.41

Table 53. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 10 July 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	6.25	4.0	6.35	52	80.96	2.31	2.20	2.70	8.56
	LSW	6.65	18.0	6.80	66	43.56	4.53	13.67	10.15	19.44
12	HSW	6.35	5.5	6.60	50	89.98	2.20	0	2.65	8.23
	LSW	5.60	17.5	6.80	65	41.55	10.43	34.43	8.45	18.82
12A	HSW	4.60	7.5	6.30	47	47.68	3.08	0	4.56	13.57
	LSW	4.05	28.0	6.70	74	10.80	1.31	15.25	9.63	17.68
13	HSW	5.05	9.0	6.45	47	92.80	2.96	0	4.32	12.01
	LSW	3.05	27.5	6.65	74	47.41	5.08	210.04	19.97	37.22
14	HSW	4.90	9.0	6.00	47	98.07	3.62	7.89	7.21	16.57
	LSW	2.90	22.5	6.70	63	45.14	4.16	87.50	14.44	27.06
14A	HSW	4.70	9.0	6.60	45	58.46	3.41	0	6.23	15.34
	LSW	2.75	27.5	6.65	113	48.22	7.12	252.38	5.62	17.78
14B	HSW	4.65	8.0	6.60	46	94.28	3.60	4.77	6.46	15.12
	LSW	2.70	30.0	6.70	87	85.37	11.40	287.64	23.93	85.82
15	HSW	4.72	8.5	6.40	51	91.51	3.24	.86	5.95	13.79
	LSW	2.60	24.0	6.80	60	41.01	2.11	17.29	11.80	17.37

Table 54. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 11 August 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	6.45	8.0	6.50	51	136.25	2.63	1.51	5.14	13.62
	LSW	4.95	13.0	-	58	69.52	2.98	0	12.41	27.97
12	HSW	6.65	8.0	6.90	52	115.24	2.42	2.22	6.00	13.62
	LSW	5.80	17.0	-	69	59.45	6.25	0	12.25	25.81
12A	HSW	6.05	6.0	6.80	52	116.66	3.67	0	7.97	17.62
	LSW	4.15	22.0	-	72	5.93	.47	0	15.29	29.14
13	HSW	5.55	8.0	-	49	118.02	3.00	0	11.40	22.42
	LSW	3.95	25.0	-	84	86.18	4.27	75.25	13.56	27.31
14	HSW	5.15	10.0	-	49	121.44	2.91	0	10.28	20.83
	LSW	3.20	23.0	-	69	53.55	1.73	0	13.40	24.98
14A	HSW	4.75	11.0	6.30	46	151.38	3.19	5.41	12.43	27.23
	LSW	2.40	29.0	-	140	92.59	10.31	365.37	11.01	22.48
14B	HSW	5.15	9.0	-	48	113.15	2.75	1.80	10.54	22.42
	LSW	2.30	28.0	-	88	49.87	5.59	98.55	22.03	44.29
15	HSW	4.90	14.0	6.3	46	121.30	3.05	0	12.26	76.80
	LSW	2.05	36.0	-	68	66.52	1.43	0	12.33	24.31

Table 55. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig.19 on 9 October 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	12.45	5.0	6.50	50	85.19	2.17	54.66	3.30	6.18
	LSW	5.80	17.5	6.80	57	65.76	2.08	33.27	7.76	10.26
12	HSW	12.10	5.0	6.60	50	103.53	2.26	46.57	3.95	8.93
	LSW	5.60	18.0	6.80	63	97.26	3.72	54.31	6.89	11.01
12A	HSW	11.40	5.0	6.25	51	89.89	2.34	37.76	3.76	6.70
	LSW	5.65	19.0	6.84	57	16.95	.23	9.03	6.01	9.45
13	HSW	11.15	5.0	6.67	44	100.26	2.70	48.02	5.55	9.52
	LSW	4.00	21.0	6.81	60	115.48	3.81	11.34	9.55	15.03
14	HSW	7.60	13.0	6.70	42	112.18	2.57	52.49	5.88	9.82
	LSW	4.20	20.0	6.84	55	77.94	2.10	35.01	9.04	16.14
14A	HSW	9.50	11.0	6.70	39	131.01	3.56	26.40	6.70	11.76
	LSW	3.95	18.0	6.75	67	163.44	10.69	231.87	3.58	7.96
14B	HSW	11.85	8.5	6.70	42	119.99	2.79	28.69	6.10	10.27
	LSW	3.60	22.0	6.78	68	159.10	6.53	15.36	13.91	23.87
15	HSW	11.90	9.0	6.74	41	112.16	2.93	60.99	6.61	11.01
	LSW	3.40	22.0	6.80	49	46.09	.99	14.11	5.00	8.04

Table 56. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 9 November 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	8.10	6.0	7.60	44	111.21	2.63	64.24	6.18	14.61
	LSW	4.80	15.0	7.40	43	98.27	2.88	40.70	8.65	16.89
12	HSW	7.50	7.0	7.59	41	116.59	2.52	52.58	6.97	15.34
	LSW	4.75	18.0	7.37	70	74.36	4.06	67.22	9.59	17.80
12A	LSW	7.20	8.0	7.57	39	122.72	2.46	53.81	7.86	15.79
	LSW	6.35	16.0	7.40	59	17.37	.88	14.42	7.13	11.87
13	HSW	5.90	10.5	7.53	36	129.64	2.77	66.41	9.22	17.62
	LSW	3.80	19.0	7.33	67	97.15	4.43	147.28	8.75	14.88
14	HSW	5.75	10.5	7.53	38	123.42	2.83	56.12	11.16	19.81
	LSW	4.20	18.5	7.40	56	39.26	1.85	24.33	8.65	14.79
14A	HSW	5.00	11.0	7.45	39	127.27	3.01	83.33	9.32	17.35
	LSW	3.80	18.0	7.30	91	168.50	10.78	368.43	4.77	9.40
14B	HSW	5.25	11.0	7.45	36	140.48	2.61	52.51	10.48	18.53
	LSW	3.75	20.0	7.40	68	74.46	3.36	197.59	15.72	25.11
15	HSW	5.00	11.0	7.43	42	114.69	3.01	90.17	10.48	18.08
	LSW	3.75	22.5	7.40	54	39.31	1.21	18.46	7.66	12.96

Table 57. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 9 December 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	12.10	2.0	7.75	35	78.63	1.70	25.88	5.28	10.58
	LSW	9.65	9.0	7.50	45	118.08	1.88	33.96	7.41	14.11
12	HSW	11.70	4.0	7.72	35	84.75	1.52	20.75	6.20	12.35
	LSW	8.35	11.0	7.45	37	112.98	2.23	36.50	6.78	13.23
12A	HSW	11.25	4.0	7.70	33	90.90	1.54	19.10	7.11	14.46
	LSW	8.05	12.0	7.60	40	40.05	.80	9.28	3.48	6.09
13	HSW	11.20	3.0	7.70	34	96.31	1.76	23.70	13.31	19.67
	LSW	7.15	13.0	7.45	45	121.51	3.39	71.47	10.02	18.52
14	HSW	10.90	4.0	7.70	34	94.84	1.84	17.91	10.55	20.46
	LSW	7.65	15.0	7.60	38	77.39	2.33	36.43	8.81	15.79
14A	HSW	11.00	4.0	7.75	32	109.07	1.74	13.87	8.13	15.70
	LSW	7.25	12.0	7.60	51	156.45	3.41	98.53	3.00	6.09
14B	HSW	10.95	4.0	7.75	33	158.02	1.76	17.30	10.02	19.23
	LSW	6.30	20.0	7.50	58	147.93	7.27	249.26	40.32	79.38
15	HSW	10.75	4.0	7.75	30	60.00	1.72	19.63	8.47	16.23
	LSW	6.55	18.0	7.70	36	2.80	1.64	13.94	3.15	5.38

Table 58. Dissovled oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channet Sites shown in Fig. 19 on 16 February 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	-	-	-	-	-	-	-	-	-
	LSW	-	-	-	-	-	-	-	-	-
12	HSW	11.85	3.5	6.45	28	56.14	.63	6.93	1.36	5.59
	LSW	-	-	-	-	-	-	-	-	-
12A	HSW	-	-	-	-	-	-	-	-	-
	LSW	-	-	-	-	-	-	-	-	-
13	HSW	11.65	3.0	6.48	25	55.20	.59	11.52	1.36	6.45
	LSW	8.50	8.0	6.37	20	85.48	2.10	39.78	1.68	12.37
14	HSW	11.55	3.0	6.50	26	59.62	.55	6.28	1.50	5.91
	LSW	7.95	4.5	6.37	20	77.43	1.91	13.05	1.73	5.59
14A	HSW	11.80	3.0	6.48	27	58.99	.68	9.70	1.68	5.91
	LSW	6.90	13.5	6.40	50	166.90	3.95	98.17	2.28	4.62
14B	HSW	11.20	3.0	6.48	26	60.30	.89	18.68	2.28	7.74
	LSW	6.75	9.5	6.38	25	63.91	1.18	11.81	2.60	4.48
15	HSW	11.80	3.0	6.47	28	86.36	.64	10.95	1.82	5.91
	LSW	8.35	8.0	6.37	20	76.14	1.85	25.03	2.18	4.84

Table 59. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 24 March 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	12.00	2.6	7.10	37	61.76	1.13	49.42	3.90	9.19
	LSW	10.50	6.0	7.10	35	122.09	2.58	58.60	8.25	14.81
12	HSW	11.40	3.0	7.10	33	64.20	1.18	50.54	4.74	10.11
	LSW	10.00	8.0	7.10	29	126.79	2.82	45.35	5.63	11.54
12A	HSW	12.85	3.4	7.10	34	103.41	1.42	44.41	5.63	12.67
	LSW	8.25	12.0	7.10	30	50.93	1.37	32.70	5.28	13.86
13	HSW	11.40	6.0	7.15	30	114.97	1.84	41.22	8.35	17.06
	LSW	7.80	9.0	7.00	32	90.38	3.22	59.50	3.26	6.64
14	HSW	11.00	5.3	7.15	30	115.86	1.77	50.12	7.95	15.94
	LSW	6.50	12.0	7.10	29	89.67	.90	32.46	2.96	6.54
14A	HSW	9.80	3.8	7.15	28	132.00	1.94	62.13	8.15	17.68
	LSW	5.60	13.0	6.90	55	269.91	.80	155.59	2.47	5.62
14B	HSW	9.40	5.8	7.15	30	123.21	1.87	51.59	8.40	16.45
	LSW	5.80	12.0	7.10	47	77.81	.17	24.37	2.76	5.62
15	HSW	9.10	5.2	7.20	28	107.62	1.68	51.73	8.25	16.14
	LSW	6.90	10.0	7.10	23	108.00	1.27	31.23	2.96	5.72

Table 60. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and p at stream channel Sites shown in Fig. 19 on 23 April 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	8.90	1.0	7.52	46	58.37	4.71	24.85	3.77	11.77
	LSW	8.50	4.8	-	40	69.88	7.15	30.94	6.79	22.01
12	HSW	9.20	3.0	7.50	47	57.18	4.53	23.79	3.25	12.43
	LSW	8.60	5.0	-	44	73.23	8.73	39.26	8.34	19.81
12A	HSW	9.20	1.0	7.45	47	55.56	4.65	34.11	4.39	14.64
	LSW	6.00	21.1	-	50	18.77	1.08	18.40	5.14	14.31
13	HSW	9.00	1.0	7.42	46	58.68	4.92	35.34	4.74	17.39
	LSW	5.80	10.0	-	56	65.58	11.47	92.73	10.51	23.55
14	HSW	8.90	1.5	7.40	45	64.77	4.80	29.75	5.08	14.97
	LSW	6.00	9.0	-	58	54.68	9.78	93.21	11.99	24.76
14A	HSW	8.70	1.5	7.40	43	69.49	5.31	34.36	6.68	16.18
	LSW	4.20	11.5	-	77	90.16	10.57	78.23	4.28	11.22
14B	HSW	8.70	2.5	7.40	45	67.59	4.62	33.43	4.85	13.64
	LSW	3.90	15.0	-	101	19.14	13.83	489.43	26.45	39.29
15	HSW	8.50	2.0	7.40	44	63.13	4.74	37.13	5.25	17.72
	LSW	6.40	11.0	-	39	36.88	5.04	7.35	5.88	11.77

Table 61. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 20 May 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	9.00	2.0	7.30	30	61.71	2.02	2.56	3.53	8.24
	LSW	7.70	9.5	7.33	41	93.36	4.68	59.83	12.49	25.54
12	HSW	7.90	2.0	7.40	32	68.53	2.51	3.84	3.64	7.62
	LSW	5.97	15.5	7.25	52	98.27	7.63	49.81	11.41	23.17
12A	HSW	7.90	6.0	7.33	32	76.67	2.36	0	4.23	10.19
	LSW	6.60	13.5	7.30	58	10.67	1.37	26.16	8.04	13.69
13	HSW	8.20	6.0	7.23	32	87.81	3.39	10.10	7.77	16.27
	LSW	5.70	15.5	7.20	64	132.43	11.58	118.30	15.32	26.67
14	HSW	8.70	5.0	7.27	32	87.78	3.54	11.98	8.69	19.26
	LSW	5.75	15.5	7.26	54	103.68	9.71	104.42	17.11	30.07
14A	HSW	8.40	6.0	7.30	31	92.50	3.37	6.49	10.92	21.32
	LSW	4.30	17.5	7.10	82	154.69	13.26	164.14	7.28	16.06
14B	HSW	8.50	7.0	7.25	31	91.23	3.41	11.17	10.10	18.23
	LSW	4.60	22.5	7.18	92	204.33	30.72	173.63	40.32	81.26
15	HSW	8.70	7.0	7.29	31	102.53	3.65	12.99	10.48	19.57
	LSW	5.25	14.5	7.32	45	73.79	2.53	27.52	5.70	6.18

Table 62. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 16 June 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	6.55	6.0	-	64	77.90	1.93	0	1.62	3.95
	LSW	3.48	18.0	-	56	74.80	7.44	173.34	11.82	31.04
12	HSW	6.43	4.5	-	53	77.25	2.13	0	1.56	7.22
	LSW	3.90	17.0	-	61	73.76	2.94	31.73	12.39	30.18
12A	HSW	6.25	4.0	-	57	83.12	2.17	0	1.93	5.59
	LSW	4.25	27.0	-	69	7.65	7.44	39.49	8.01	23.13
13	HSW	4.38	10.0	-	53	96.98	5.15	10.83	5.93	11.18
	LSW	3.13	23.5	-	76	51.59	7.87	79.90	19.84	39.46
14	HSW	4.38	26.0	-	108	91.25	3.40	0	4.68	11.18
	LSW	3.00	19.5	-	83	53.09	3.63	26.62	21.83	42.92
14A	HSW	4.18	9.5	-	45	101.52	4.72	3.78	5.18	11.99
	LSW	3.35	34.0	-	100	66.82	8.12	142.87	8.41	44.77
14B	HSW	4.30	8.5	-	47	75.20	4.29	43.06	4.68	10.90
	LSW	2.58	30.5	-	102	76.97	12.01	191.97	25.81	79.41
15	HSW	3.90	11.0	-	47	99.57	5.33	0	5.50	12.81
	LSW	2.95	23.0	-	91	45.23	1.90	0	9.15	25.60

Table 63. Disolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 14 July 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	6.70	6.5	6.50	29	70.20	2.26	7.29	2.39	4.79
	LSW	6.10	21.0	6.80	55	62.40	5.38	0	8.21	24.02
12	HSW	6.10	3.4	6.45	39	70.34	2.50	10.81	3.21	6.39
	LSW	5.45	13.0	6.70	55	60.14	6.98	0	8.94	24.52
12A	HSW	6.40	6.5	6.45	40	71.74	3.75	0	4.27	9.73
	LSW	6.20	16.0	6.75	63	13.88	1.04	2.63	8.71	19.16
13	HSW	5.70	7.0	6.40	39	80.10	4.30	21.49	6.02	13.59
	LSW	4.20	20.0	6.70	67	50.85	4.65	0	14.14	37.46
14	HSW	5.20	7.0	6.40	40	83.12	4.91	6.05	6.43	13.59
	LSW	4.28	20.0	6.70	64	43.46	3.43	.35	14.55	37.96
14A	HSW	5.15	7.0	6.40	38	86.50	5.73	21.41	7.43	19.19
	LSW	2.80	27.0	6.45	106	64.57	7.94	0	5.93	15.43
14B	HSW	5.40	8.5	6.45	38	84.91	5.90	33.91	8.31	22.26
	LSW	3.60	25.0	6.60	105	47.77	6.16	90.05	26.09	113.89
15	HSW	4.85	9.0	6.45	37	91.34	5.90	32.32	8.31	17.73
	LSW	-	20.0	6.65	56	42.15	1.89	2.04	5.83	15.80

Table 64. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 26 September 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	7.20	4.0	–	47	95.44	3.66	0	3.90	9.88
	LSW	5.70	10.5		89	93.46	3.30	13.41	7.75	16.70
12	HSW	7.10	4.0	–	45	96.02	3.81	0	4.08	11.88
	LSW	5.40	6.0		146	95.54	4.31	27.95	4.40	16.20
12A	HSW	7.00	5.0	–	44	97.86	4.08	0	4.63	12.76
	LSW	5.30	14.5		141	25.54	.08	0	4.95	20.64
13	HSW	5.80	7.0	–	45	107.53	4.70	1.06	6.42	15.76
	LSW	3.52	16.0		134	91.93	4.60	33.80	10.60	20.70
14	HSW	5.20	8.0	–	44	115.73	4.79	0	7.20	16.54
	LSW	3.65	14.5		175	59.54	2.64	4.44	9.73	18.80
14A	HSW	4.60	7.0	–	45	121.54	5.30	0	7.29	16.88
	LSW	3.70	12.5		115	94.54	4.51	59.75	4.59	10.40
14B	HSW	5.00	5.0	–	46	111.00	4.85	0	7.10	71.90
	LSW	2.52	14.0		74	144.85	7.39	97.43	27.40	82.76
15	HSW	–	9.0	–	39	124.76	5.43	4.42	8.81	18.76
	LSW	2.90	17.5		71	46.90	1.46	0	4.22	8.90

Table 65. Dissovled oxygen, CO_2, pH, alkalinity, inorganic N and P at stream channel Sites shown in Fig. 19 on 29 October 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
11	HSW	-	5.0	-	22	71.31	1.70	44.95	5.35	13.52
	LSW	11.00	11.0	-	32	104.78	2.29	5.95	8.67	17.06
12	HSW	-	10.0	-	25	70.33	2.47	5.04	5.97	14.96
	LSW	11.00	12.0	-	39	102.10	3.10	22.59	9.80	18.08
12A	HSW	-	5.0	-	25	85.07	1.84	5.48	6.68	14.80
	LSW	7.80	15.0	-	39	27.86	.87	.17	3.83	8.88
13	HSW	12.00	6.0	-	26	78.85	1.80	8.38	7.06	16.80
	LSW	6.80	15.0	-	66	96.73	5.03	158.40	13.76	22.84
14	HSW	12.50	5.0	-	27	77.52	1.88	35.70	8.57	17.44
	LSW	7.00	14.0	-	50	72.64	3.24	55.09	14.02	21.90
14A	HSW	12.00	6.0	-	25	79.06	1.92	15.07	8.05	18.56
	LSW	6.80	16.0	-	106	134.72	6.04	431.21	2.60	6.26
14B	HSW	12.00	5.0	-	36	78.88	1.86	33.11	8.24	19.66
	LSW	5.45	14.0	-	68	178.81	1.70	244.17	31.08	32.76
15	HSW	-	5.0	-	26	82.20	2.19	38.36	8.38	20.72
	LSW	5.95	15.0	-	44	42.86	1.90	1.53	3.55	7.22

than upstream sites near the effluent study area. Differences between hsw and lsw levels were generally 2-3 mg L^{-1} during the summer, but increased to as much as 8 mg L^{-1} in the early fall when the macrophytes were rapidly decomposing.

Carbon dioxide levels also followed expected seasonal patterns. They were consistently 2-4 time higher at lsw then at hsw, with the highest values occurring during the summer monthes when oxygen levels were at their lowest levels. Sites 11 and 12 generally had the lowest CO_2 levels, but Site 13, immediately downstream from the study site, had values comparable to Site 12A that drained a section of marsh not receiving sewage.

pH ranged from 6.10 to 7.75 with winter and spring values being generally higher than summer and fall values. On a given sample date, pH levels at hsw and lsw were similar and site differences were negligible. Total alkalinity ranged from 30-80 mg $CaCO_3$ L^{-1} and rarely exceeded 100 mg $CaCO_3$ L^{-1} except at Site 14A which received seepage from a nearby sludge lagoon.

Nitrate - N was consistently higher at hsw than at lsw during the summer with especially dramatic differences appearing at Site 12A. The picture at other times of the year was more mixed with Sites 13, 14A, and 14B, the latter draining directly from the effluent study area, often having more NO_3-N at lsw than at hsw. In all cases, however, lsw NO_3-N levels were considerably reduced by the time they reached Sites 11 and 12 some distance downstream from the study site. Nitrite -N values were generally less than 10 μg. at N L^{-1}, with lsw values usually higher than lsw values, especially downstream from the study site. Values were usually low except at Sites 13, 14, 14A, and 14B where summer levels in >200 μg• at N L^{-1} were found on several occasions at lsw.

Phosphorus levels at all Sites were consistently higher at lsw than hsw. Site 11 had the lowest values while Sites 13, 14A, 14B usually exceeded all other sites by 5-10 μg• at P L^{-1} except in February 1976 when effluent application was suspended for the winter.

Enclosure studies

Results of water quality studies in the experimental enclosures are given in Tables 66-79. At hsw the high marsh was typically covered with 10 to 30 cm of water while at lsw the surface was completely drained except for isolated pockets of water. On three dates, 9 October 1975 9 November 1975 and 16 June 1976, flood tide waters did not cover the high marsh surface in the study area.

Hsw dissolved oxygen levels followed the same seasonal patterns found for stream waters, but were always 2-4 μg L^{-1} lower than dissolved oxygen levels at Site 14 in the stream channel immediately downstream from the study area. Lsw surface dissolved oxygen values were almost always lower than hsw values with summer and fall values generally two to five fold lower. On several dates in the summer, dissolved oxygen was not detectable at the wetland surface at lsw.

Carbon dioxide levels at hsw were generally less than 20 μg L^{-1} when the wetland surface was inundated and almost always lower than at lsw. The most dramatic differences between hsw and lsw values occurred at Sites 1 and 2 which received effluent only when the high marsh was flooded. In these enclosures, summer carbon dioxide levels in excess of 60 μg L^{-1} were recorded at lsw. Comparison of tide cycle curves for

Table 66. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in treatment ares on 27 June 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	4.50	9.5	7.00	42	93.31	5.20	56.13	18.91	37.80
	LSW	1.40	40.0	6.70	107	0	3.38	137.68	26.32	57.76
2	HSW	4.10	10.0	6.95	45	91.45	9.23	142.37	28.64	83.51
	LSW	.70	67.0	6.60	115	0	1.54	206.31	38.99	130.46
3	HSW	4.30	10.5	7.00	39	73.14	6.84	39.90	15.93	42.81
	LSW	.90	26.0	7.10	128	104.32	24.76	299.86	61.72	182.86
4	HSW	3.90	10.5	7.00	39	88.76	6.90	59.83	20.96	44.04
	LSW	1.15	22.5	7.00	116	60.93	17.49	646.55	49.00	136.03
5	HSW	3.60	10.0	6.90	44	102.58	9.43	139.80	28.04	57.42
	LSW	1.90	33.0	6.90	131	27.99	13.78	514.95	35.56	98.12
6	HSW	3.60	11.0	7.00	45	86.75	9.01	130.57	20.24	56.75
	LSW	.50	44.5	6.65	132	0	12.03	503.97	44.41	133.80
7	HSW	3.35	13.0	6.90	56	102.88	13.89	197.67	29.70	83.40
	LSW	1.35	41.5	6.50	56	0	.14	12.34	27.10	56.86
8	HSW	3.30	10.5	7.00	42	100.76	8.09	97.54	24.83	54.75
	LSW	.65	35.0	6.50	77	0	.47	24.06	25.49	51.29

Table 67. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in treatment areas on 10 July 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	4.10	11.0	6.65	46	84.36	3.13	176.90	7.67	22.68
	LSW	.20	47.0	6.80	119	75.00	12.96	138.74	24.83	80.65
2	HSW	3.60	14.0	6.70	57	94.31	5.76	201.16	29.30	85.62
	LSW	.08	55.0	6.50	130	16.44	6.32	186.85	26.76	99.25
3	HSW	3.85	10.5	6.65	46	87.27	6.60	26.67	14.51	28.80
	LSW	.35	32.5	7.10	130	91.89	18.83	433.73	80.95	146.25
4	HSW	4.10	10.5	6.60	47	61.94	5.65	39.16	14.04	29.80
	LSW	.55	31.5	7.60	131	51.94	39.42	454.10	70.09	124.10
5	HSW	3.90	10.0	6.70	48	64.97	6.19	100.00	22.74	50.70
	LSW	.25	28.0	6.80	129	19.70	10.43	462.22	30.63	81.70
6	HSW	3.95	11.5	6.70	50	55.92	6.09	160.92	20.04	69.94
	LSW	.50	37.0	6.80	115	46.63	8.48	347.07	70.30	128.20
7	HSW	3.20	15.5	6.70	54	100.04	8.48	98.39	30.00	88.63
	LSW	.33	23.5	6.55	64	2.87	2.44	36.54	17.79	45.50
8	HSW	3.20	16.0	6.20	52	106.40	8.53	254.87	30.23	88.74
	LSW	.18	46.5	6.70	83	7.25	1.77	14.93	23.60	78.58

Table 68. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in treatment areas on 11 August 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	3.30	15.0	-	53	173.33	5.61	33.32	45.85	76.90
	LSW	0	62.0	-	108	.75	.16	130.29	57.38	133.20
2	HSW	3.25	15.0	-	57	196.78	7.73	67.24	63.42	120.15
	LSW	0	63.0	-	115	1.57	2.70	219.83	97.90	189.81
3	HSW	2.75	15.0	-	51	163.42	6.03	83.33	43.11	80.10
	LSW	.10	40.0	-	106	12.87	4.11	170.38	74.80	163.17
4	HSW	2.40	14.0	-	53	102.07	5.68	23.05	36.42	66.16
	LSW	0	50.0	-	117	4.83	2.63	76.40	76.04	138.20
5	HSW	3.35	14.0	-	50	126.13	4.98	24.45	37.71	61.20
	LSW	1.0	42.0	-	114	6.79	3.92	183.55	63.79	116.55
6	HSW	2.65	14.0	-	57	160.31	7.54	39.43	50.99	80.10
	LSW	.65	36.0	-	106	66.00	12.19	220.61	138.07	249.75
7	HSW	2.45	16.0	-	51	88.80	4.91	.10	33.42	68.09
	LSW	1.25	17.5	-	69	13.32	0	.37	26.14	60.27
8	HSW	2.35	18.0	-	48	136.79	4.41	9.76	23.82	42.93
	LSW	1.85	45.0	-	48	3.53	.16	0	20.96	47.12

Table 69. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 9 October 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	8.10	11.0	6.90	45	271.72	7.79	108.38	23.41	53.57
	LSW	.65	40.0	6.70	55	117.24	4.95	254.86	26.35	55.80
2	HSW	7.40	15.0	6.90	59	325.24	14.23	289.23	33.92	69.19
	LSW	.30	39.5	6.75	115	29.92	2.39	409.90	49.66	96.72
3	HSW	9.20	34.0	6.85	100	160.68	7.70	381.37	31.26	66.22
	LSW	.55	44.0	6.75	130	116.32	7.30	403.54	39.47	70.68
4	HSW	.15	22.5	6.90	71	208.60	7.84	369.59	36.86	64.73
	LSW	.25	23.5	6.82	88	402.43	12.83	385.08	48.56	78.12
5	HSW	7.00	14.5	6.92	45	200.65	7.47	134.88	20.66	50.59
	LSW	.20	34.5	6.84	111	97.94	5.95	404.48	31.67	58.03
6	HSW	5.80	21.5	6.90	87	352.44	12.16	344.68	47.92	81.84
	LSW	.85	20.5	6.84	54	595.29	14.85	364.69	48.29	81.84
7	HSW	6.10	19.5	6.90	50	156.16	5.09	62.11	12.71	20.46
	LSW	1.90	23.0	6.90	46	9.29	.19	25.84	6.65	14.36
8	HSW	.65	17.0	6.92	35	149.64	5.76	53.32	10.10	17.26
	LSW	1.40	24.0	6.86	49	14.18	1.27	55.87	13.77	24.55

Table 70. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 9 November 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	1.70	40.0	7.40	100	21.95	4.63	406.91	35.00	91.30
	LSW	1.10	30.0	7.52	101	19.28	2.41	395.31	40.40	86.74
2	HSW	4.00	28.0	7.40	124	70.74	14.73	562.19	46.74	134.21
	LSW	.30	37.0	7.60	130	0	3.11	498.56	46.22	130.56
3	HSW	.45	51.0	7.23	130	27.65	3.71	373.33	43.33	118.69
	LSW	.75	29.0	7.60	120	40.62	6.36	496.28	47.43	94.04
4	HSW	2.00	29.0	7.34	107	48.29	6.01	539.25	41.55	102.26
	LSW	.90	22.5	7.60	104	46.74	8.31	510.29	42.29	111.39
5	HSW	.35	15.0	7.46	90	68.47	8.68	451.93	36.16	86.74
	LSW	2.75	21.5	7.55	103	106.23	17.92	452.30	46.74	125.19
6	HSW	2.50	22.0	7.46	97	221.49	11.29	535.55	47.79	114.13
	LSW	1.65	22.0	7.52	96	228.67	14.37	571.00	46.37	112.30
7	HSW	1.90	19.0	7.50	56	13.20	2.44	126.46	15.35	28.03
	LSW	3.05	23.0	7.52	62	6.47	1.43	115.20	26.20	52.77
8	HSW	1.15	51.0	7.36	95	1.55	0	162.35	18.86	46.56
	LSW	.75	30.0	7.44	82	.97	.60	119.20	26.99	55.69

Table 71. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 9 December 1975. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	8.10	10.0	7.55	83	367.17	13.58	400.74	77.92	128.77
	LSW	6.60	9.0	7.75	60	191.42	9.17	302.08	33.40	80.26
2	HSW	7.45	10.0	7.75	59	205.25	8.78	272.82	56.24	79.38
	LSW	6.90	16.0	7.70	99	244.23	11.09	422.17	73.57	143.77
3	HSW	5.40	10.0	7.75	79	264.29	6.97	408.64	80.88	127.89
	LSW	6.30	24.0	7.70	118	232.82	12.21	500.16	68.24	140.24
4	HSW	4.25	10.0	7.85	74	249.85	5.84	409.44	76.52	123.48
	LSW	2.40	18.0	7.70	122	292.67	17.81	491.44	96.32	179.05
5	HSW	8.05	10.0	7.82	63	263.16	5.97	340.42	61.56	102.31
	LSW	5.10	13.0	7.60	110	215.00	16.13	505.62	87.12	163.17
6	HSW	4.40	10.0	7.75	88	262.68	5.15	409.92	78.02	127.89
	LSW	4.40	13.0	7.70	114	275.76	11.56	546.56	90.56	163.17
7	HSW	8.45	8.0	7.80	42	140.34	3.25	137.20	35.43	66.15
	LSW	3.95	17.0	7.40	45	29.13	1.99	65.88	15.00	23.64
8	HSW	10.00	6.0	7.75	33	97.23	2.39	25.89	28.65	41.45
	LSW	2.55	19.0	7.40	50	18.16	1.05	56.69	11.76	18.52

Table 72. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 16 February 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	11.55	4.6	6.52	27	62.08	.61	15.37	1.82	6.67
	LSW	7.25	10.5	6.40	40	15.67	.52	69.15	14.91	33.90
2	HSW	11.52	4.9	6.49	28	61.68	.76	20.53	2.05	6.99
	LSW	4.30	10.5	6.34	40	9.71	1.52	104.26	22.71	55.96
3	HSW	10.15	5.0	6.46	25	85.28	1.18	24.62	3.83	11.30
	LSW	3.05	13.0	6.36	36	14.85	2.12	114.37	27.46	97.93
4	HSW	10.85	4.8	6.45	26	72.41	1.01	16.49	2.62	8.60
	LSW	1.65	18.0	6.31	56	9.15	.86	120.52	25.91	69.95
5	HSW	11.00	5.0	6.47	24	80.11	.95	18.99	2.60	9.14
	LSW	2.95	20.0	6.32	63	15.15	.63	180.37	39.73	96.85
6	HSW	9.25	4.7	6.42	27	78.33	1.01	18.60	3.10	12.91
	LSW	1.80	18.5	6.33	75	5.57	.86	227.61	82.93	206.63
7	HSW	11.35	3.9	6.43	26	73.27	.76	14.03	1.82	6.99
	LSW	1.75	13.5	6.37	33	19.78	1.14	34.30	7.57	17.21
8	HSW	11.50	3.6	6.43	27	64.65	.70	21.44	1.82	6.45
	LSW	7.05	15.5	6.37	27	14.74	1.33	40.31	6.93	19.90

Table 73. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 24 March 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	10.60	5.1	7.05	27	131.34	1.94	169.10	9.48	23.40
	LSW	4.10	10.0	7.00	48	20.94	1.41	66.71	21.64	47.21
2	HSW	11.60	5.0	7.05	26	129.28	2.06	135.16	9.48	24.11
	LSW	4.30	17.0	6.90	65	15.71	2.25	99.04	42.99	89.73
3	HSW	11.60	5.9	7.05	29	128.21	2.21	101.95	10.57	22.27
	LSW	3.55	13.0	7.00	42	26.15	.99	66.06	49.42	106.90
4	HSW	10.70	6.1	7.05	24	132.00	1.94	110.42	10.22	25.14
	LSW	1.75	18.0	6.95	62	17.35	.71	72.61	42.20	94.12
5	HSW	10.60	4.9	7.05	26	141.48	2.06	88.79	10.22	21.87
	LSW	4.00	19.0	7.00	37	15.54	.90	55.16	29.55	69.29
6	HSW	11.50	4.1	7.05	28	105.54	2.29	120.37	11.31	23.40
	LSW	5.70	17.0	6.80	86	21.39	1.51	169.40	109.61	245.28
7	HSW	11.65	6.0	7.05	26	85.56	2.34	91.67	9.29	19.41
	LSW	3.80	17.0	6.90	40	17.54	.33	48.44	22.83	34.95
8	HSW	12.80	5.0	7.05	30	138.26	2.32	91.11	9.29	21.15
	LSW	2.70	18.0	6.95	30	18.80	.56	25.76	9.53	20.33

Table 74. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 23 April 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	8.70	3.8	7.50	44	79.25	5.91	138.96	14.68	33.57
	LSW	8.10	14.0	-	129	0	22.37	380.55	40.39	62.19
2	HSW	8.80	5.2	7.60	56	96.63	9.36	275.41	41.48	54.81
	LSW	7.95	19.5	-	171	46.67	36.75	646.07	54.34	140.68
3	HSW	12.00	1.8	7.60	67	153.55	53.63	567.31	47.54	101.38
	LSW	6.20	16.5	-	188	70.67	53.36	771.64	66.85	142.33
4	HSW	10.20	4.2	7.45	56	103.49	21.71	297.49	40.16	56.03
	LSW	6.45	11.8	-	195	116.52	69.00	784.35	81.48	177.44
5	HSW	9.60	5.0	7.45	53	101.54	17.78	236.16	33.71	46.23
	LSW	3.75	19.2	-	119	130.02	62.99	569.98	50.62	114.15
6	HSW	8.80	4.0	7.45	50	88.42	13.68	157.42	35.14	51.62
	LSW	2.40	19.5	-	171	109.14	20.17	581.51	57.54	147.17
7	HSW	8.80	4.5	7.40	52	103.59	8.39	191.64	33.59	47.55
	LSW	2.95	25.0	-	74	5.31	1.08	47.49	26.68	44.69
8	HSW	8.80	5.5	7.40	35	90.72	9.36	136.55	14.05	36.10
	LSW	4.30	28.0	-	65	4.48	.87	16.18	20.39	39.29

Table 75. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 20 May 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	4.60	13.0	7.35	83	169.78	20.05	72.40	74.88	143.89
	LSW	2.20	26.0	7.30	107	8.10	6.40	324.84	54.55	122.76
2	HSW	9.00	11.0	7.40	117	233.56	22.36	71.51	70.47	162.74
	LSW	1.65	27.0	7.30	134	1.69	6.10	301.54	73.84	179.11
3	HSW	7.50	16.0	7.26	98	171.21	55.49	31.14	76.07	146.98
	LSW	6.10	13.5	7.35	137	174.61	45.92	333.89	90.09	179.11
4	HSW	7.40	20.0	7.30	116	198.73	20.42	84.98	55.02	118.34
	LSW	5.70	12.5	7.30	107	221.14	57.39	313.42	82.65	156.35
5	HSW	3.60	29.0	7.35	160	18.42	16.29	79.37	68.57	196.21
	LSW	7.90	15.5	7.30	111	154.08	74.45	289.32	88.46	179.11
6	HSW	5.50	24.0	7.40	115	106.32	39.02	59.85	66.94	128.64
	LSW	1.60	27.5	7.30	170	11.13	10.21	410.61	87.10	221.14
7	HSW	4.40	25.0	7.40	40	72.68	6.10	0	13.25	18.33
	LSW	1.90	32.0	7.35	51	1.97	2.36	28.89	14.23	33.26
8	HSW	2.55	36.0	7.45	30	3.51	4.02	1.16	16.41	31.20
	LSW	2.15	51.5	7.30	46	1.41	2.36	34.33	26.19	69.83

Table 76. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 16 June 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	.30	26.5	-	106	230.41	7.51	201.09	16.81	46.22
	LSW	.28	57.0	-	137	.17	4.92	95.23	58.17	117.51
2	HSW	3.53	27.0	-	115	-	17.44	211.86	16.81	68.86
	LSW	0	54.0	-	135	0	10.71	157.41	40.88	150.91
3	HSW	1.40	17.5	-	125	127.28	18.79	22.00	18.25	62.45
	LSW	.55	18.0	-	129	145.41	24.46	214.04	42.59	160.81
4	HSW	3.38	19.5	-	111	154.32	24.18	134.36	22.62	72.40
	LSW	.20	52.5	-	154	51.21	16.10	187.99	26.84	199.15
5	HSW	2.15	19.0	-	88	126.34	11.81	149.84	13.25	42.95
	LSW	3.45	15.5	-	-	108.50	36.72	0	28.20	195.44
6	HSW	.55	30.5	-	153	57.35	4.52	317.68	21.18	42.95
	LSW	1.80	30.0	-	152	44.62	11.60	50.21	43.93	175.68
7	HSW	2.13	18.5	-	76	153.68	10.21	117.15	8.25	39.81
	LSW	0	79.0	-	131	2.01	.38	58.06	25.93	112.56
8	HSW	3.15	22.5	-	62	97.19	7.67	89.22	5.50	17.99
	LSW	.35	36.0	-	100	3.39	.60	28.74	28.37	79.16

Table 77. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 14 July 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	4.50	9.5	6.90	42	80.34	5.55	47.27	11.12	22.53
	LSW	1.00	46.0	6.35	36	16.43	1.62	364.08	45.07	241.36
2	HSW	3.80	14.5	6.30	54	96.29	9.71	134.75	28.15	79.19
	LSW	1.15	58.0	6,35	55	22.79	5.26	606.04	50.45	262.77
3	HSW	3.80	11.5	6.45	43	85.91	8.14	59.86	21.24	51.59
	LSW	2.55	28.0	6.45	47	99.02	18.97	688.68	49.49	241.36
4	HSW	3.95	12.5	6.40	41	83.76	8.26	48.75	16.38	38.39
	LSW	2.40	28.0	6.70	46	102.84	19.00	688.68	69.20	249.83
5	HSW	3.40	13.0	6.40	42	102.51	9.98	66.54	22.47	53.06
	LSW	1.80	47.5	6.65	58	25.00	4.97	590.62	48.31	249.83
6	HSW	3.00	10.0	6.30	61	136.02	13.03	198.61	40.67	75.72
	LSW	1.95	28.0	6.65	46	64.43	7.15	620.35	47.35	218.58
7	HSW	3.10	13.0	6.45	43	125.83	13.21	74.39	23.29	53.06
	LSW	1.90	44.5	6.95	85	6.59	.69	1.04	21.39	108.92
8	HSW	2.50	16.5	6.50	43	117.14	11.75	85.22	18.67	37.86
	LSW	1.05	85.0	6.70	57	6.99	2.64	29.39	22.90	120.62

Table 78. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 26 September 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	4.50	9.5	-	46	122.22	5.98	0	13.54	29.44
	LSW	1.55	26.5	-	52	261.56	8.41	0	42.41	109.00
2	HSW	3.80	9.5	-	47	183.31	8.11	65.70	23.73	63.88
	LSW	1.15	63.0	-	54	21.30	1.17	5.47	50.85	159.00
3	HSW	3.30	11.0	-	47	142.74	6.90	35.82	20.98	44.00
	LSW	7.50	10.0	-	49	170.14	19.65	0	45.30	149.00
4	HSW	3.50	12.0	-	52	160.67	8.00	52.47	25.57	67.76
	LSW	1.00	20.0	-	57	99.77	7.09	0	52.87	166.00
5	HSW	2.45	13.5	-	59	145.57	7.56	110.62	27.36	83.76
	LSW	1.22	45.0	-	49	23.99	2.25	0	54.52	184.00
6	HSW	2.65	16.5	-	75	206.63	10.37	227.47	39.75	117.76
	LSW	1.50	17.0	-	66	189.85	14.39	0	50.58	150.00
7	HSW	2.70	15.0	-	44	100.71	7.32	36.73	27.86	62.10
	LSW	1.55	21.0	-	62	21.40	2.36	0	28.96	58.70
8	HSW	2.50	-	-	48	160.64	6.77	0	14.18	31.76
	LSW	1.25	22.0	-	47	12.60	.39	0	21.38	62.80

Table 79. Dissolved oxygen, CO_2, pH, alkalinity, inorganic N and P in the treatment areas on 29 October 1976. Values are for morning high slack water (HSW) and afternoon low slack water (LSW).

Site	Tide	D.O. mg L^{-1}	CO_2 mg L^{-1}	pH	Alkalinity mg $CaCO_3$ L^{-1}	NO_3-N ug.at N L^{-1}	NO_2-N ug.at N L^{-1}	NH_3-N ug.at N L^{-1}	Reactive P ug.at P L^{-1}	Total P ug.at P L^{-1}
1	HSW	12.30	18.0	-	89	383.39	13.66	535.40	49.85	55.20
	LSW	3.25	27.0	-	94	76.99	4.20	294.31	34.83	96.02
2	HSW	12.10	12.0	-	94	139.43	8.76	520.59	46.86	86.40
	LSW	2.82	13.0	-	120	43.62	7.10	560.85	48.19	111.89
3	HSW	-	15.0	-	117	77.68	8.72	520.60	45.16	92.80
	LSW	7.95	9.0	-	117	168.67	9.03	311.79	52.93	116.49
4	HSW	-	16.0	-	132	131.99	14.85	654.51	34.73	147.20
	LSW	6.80	10.0	-	126	153.41	16.19	757.87	32.93	111.88
5	HSW	-	20.0	-	107	32.90	1.86	441.96	29.23	80.80
	LSW	9.40	7.0	-	133	250.13	41.35	-	43.78	130.14
6	HSW	-	16.0	-	137	172.01	12.42	724.01	50.28	84.80
	LSW	5.10	14.0	-	142	90.02	13.39	62.84	42.31	142.64
7	HSW	-	20.0	-	50	15.21	.83	72.68	24.69	49.60
	LSW	3.90	17.0	-	53	8.59	1.01	54.04	24.59	53.16
8	HSW	-	41.0	-	75	9.66	.79	138.94	35.02	54.40
	LSW	5.20	36.0	-	79	4.64	.50	66.13	34.07	87.28

carbon dioxide and dissolved oxygen (Figure 20) shows that carbon dioxide levels increased gradually to a maximum immediately before flood tide water inundated the high marsh while dissolved oxygen declined rapidly to very low levels immediately after ebb tide waters retreated from the wetland surface.

pH values in the experimental enclosures closely paralleled those found for the watershed. As with watershed values, pH was similar at hsw and lsw and site differences were negligible. Total alkalinity values at hsw were also similar to watershed values. Values at lsw were often two to four fold higher at Sites 1-6 receiving effluent, especially during the summer months.

Nitrate N showed very different responses depending on the treatment regime. Both the tapwater control (Site 7) and the no treatment control (Site 8) had hsw NO_3-N levels at or above those found at Site 14 immediately downstream from the study area. Lsw levels at these sites were markedly lower, often approaching zero. The pattern of these changes through a tide cycle closely followed changes in dissolved oxygen (Figure 20). On most dates Sites 1 and 2 which received sewage only when the wetland was inundated showed NO_3-N patterns very similar to the control sites. In contrast, Sites 3, 4, 5, and 6 were variable in their response with lsw NO_3-N levels at times being higher than hsw levels. The general trend, however, was for lower NO_3-N values at lsw during the summer months. In February and March when effluent was not being applied NO_3-N values were remarkably similar at all sites with hsw values being four to eight fold higher than lsw values.

Nitrite N levels were generally <10 μg·at N L^{-1} at hsw. Lsw NO_2-N values were always lower at control Sites 7 and 8, but often higher at the sites receiving sewage. Values at lsw were especially elevated prior to the macrophyte growing season (April and May 1976) when NO_2-N levels >40 μg·at N L^{-1} were noted at several treatment sites. During February and March 1976 when sewage was not being applied NO_2-N levels were <2.50 μg·at N L^{-1} and were virtually identical to watershed values.

Ammonia N was quite variable ranging from undetectable to >700 μg·at N L^{-1}. Summer control values (Sites 7 and 8) were generally five to ten fold lower than those for sites receiving effluent. During the summer and fall hsw values were usually lower than lsw values at sites receiving sewage, but higher at the control sites.

Reactive P and TOTAL P values were almost always higher at lsw than hsw. The greatest differences between hsw and lsw phosphorus levels appeared at Sites 3, 4, 5, and 6 which received sewage for nine or more hours during each tide cycle. Unlike nitrogen, lsw phosphorus levels remained high during February and March when effluent was not being applied to the wetland.

Flux Studies

Results of the tide cycle nutrient budget studies are presented in Tables 80-82. Except for NO_2-N, nutrient flux patterns were basically the same for the two experimental sites receiving sewage and the no treatment 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 held 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

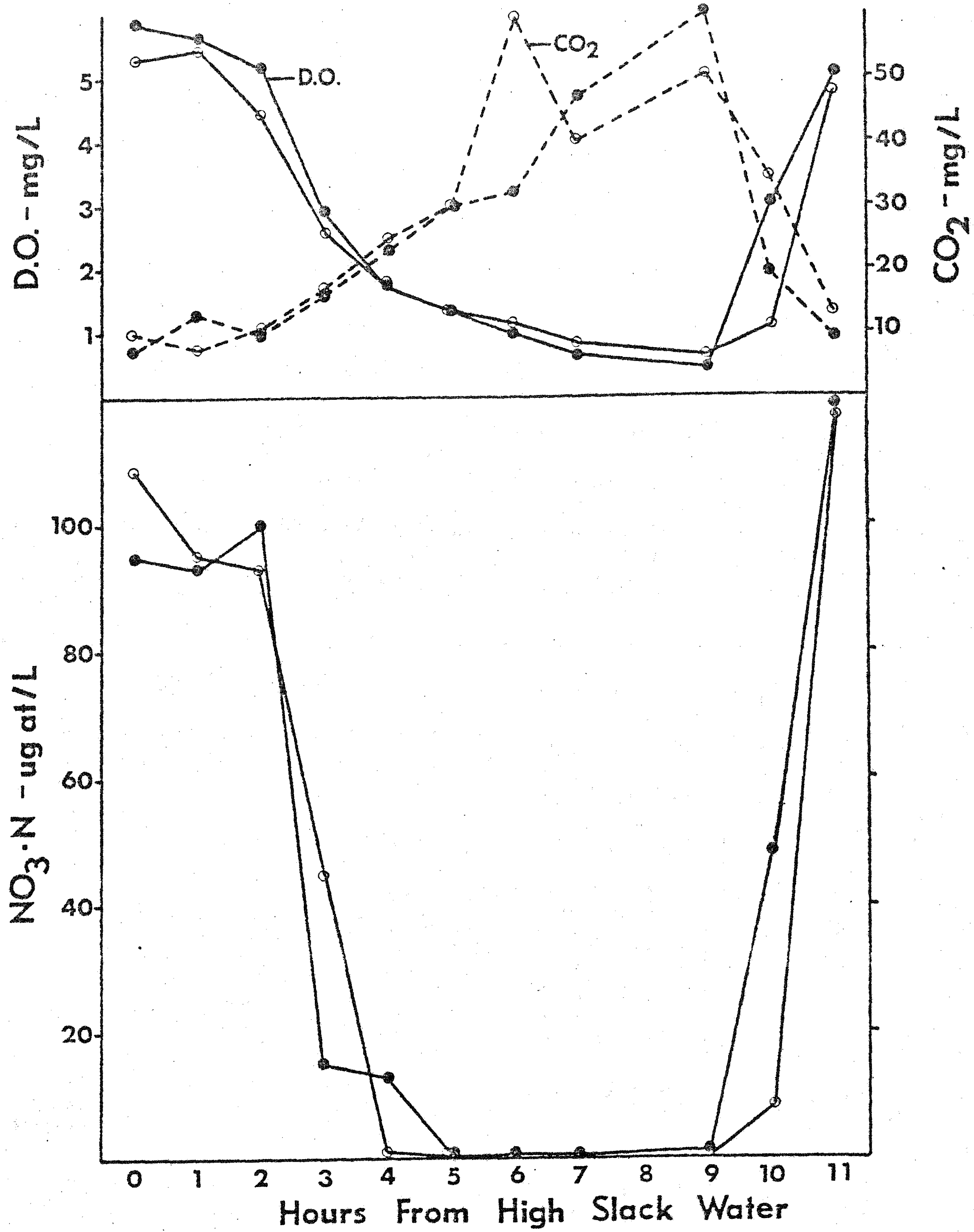


Fig. 20. Changes in dissolved oxygen, carbon dioxide and nitrate during one complete tide cycle beginning with high slack water for two wetland sites.

Table 80. Flux of N and P for Site 5 (continuous spray application at 12.5 cm day^{-1}) during complete tide cycles on five dates in 1977. All values are in grams. Parenthesis around flux values indicate a net loss from the enclosure during the study interval.

	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 81. Flux of N and P for Site 6 (continuous spray application of 5.0 cm day^{-1}) during complete tide cycles on five dates in 1977. All values are in grams. Parenthesis around flux values indicate a net loss from the enclosure during the study interval.

	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 82. Flux of N and P for Site 8 (no treatment control) during complete tide cycles on five dates in 1977. All values are in milligrams. Parenthesis around flux values indicate a net loss from the enclosure during the study interval.

	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	3.699	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	243.255	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

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 received. In contrast, the high marsh appears to export up to 50% more phosphorus than received during a given tide cycle during the late spring and early summer.

11. DISCUSSION

It has been demonstrated that natural and man-made wetlands are capable of performing some tertiary treatment functions (Tourbier and Pierson 1976, Ewel and Odum 1978), Tilton and Kadlec 1979, Whigham and Bayley 1979, Zoltek et al. 1979, Farnham 1974, Fetter et al. 1978, Sloey et al. 1979, Stanlick 1976, Valiela et al. 1975, Boyt et al. 1977). In instances where successful wastewater renovation seems possible, the wetlands are characterized by the presence of a thick, primarily peat, organic substrate (Whigham and Bayley 1979). This implies that the most active assimilatory component of most wetlands is the substrate where nutrients are either biologically processed or sorbed. The addition of wastewater often produces an increase in primary production but the vegetation does not appear to be as significant in removing and storing nutrients as is the substrate (Zoltek et al. 1979, Tilton and Kadlec 1979, Ewel and Odum 1978, Richardson et al. 1978).

The proximate factors that are responsible for removal of nutrients within the substrate are not well known (Kadlec 1979), but most of the biological activity seems to be due to heterotrophic activity of microorganisms (Zoltek et al. 1979). Wetlands seem to be particularly well suited for removing nitrogen from wastewater. Denitrification is important in waterlogged wetland substrates and seems to account for most of the nitrogen losses (Patrick et al. 1976, Zoltek et al. 1979). Denitrification results in losses to the atmosphere of N_2 and/or gaseous oxides of nitrogen. The fate of phosphorus in wetlands is less clear and there seems to be more variation (Fetter et al. 1978) in the ability of different types of wetlands to assimilate phosphorus. Because there is no atmospheric component to the phosphorus cycle its removal would seem to be restricted to biological assimilation, sorption, or chemical precipitation. Zoltek et al. (1979) found that phosphorus removal was very efficient in a peat based Florida wetland and their mass balance studies indicated that most of the phosphorus was sorbed in the peat substrate with a smaller fraction being assimilated in plant biomass. They actually had difficulty, however, locating the phosphorus in the substrate. Ewel and Odum (1978), studying Florida Cypress Dome wetlands, had similar difficulties and could not account for all of the phosphorus that was added to the wetland. Only a small percentage was sorbed in the peat substrate and plant biomass. They were able to sample another Cypress wetland that had been receiving wastewater and found that as much as 43% of the phosphorus was stored in Cypress root tissues. Other authors (Klopatek 1975, 1978, Prentki et al. 1978, Kitchens et al. 1975) have suggested that macrophytes could account for significant amounts of phosphorus immobilization in wetlands. In most instances, the substrate seems to be the primary compartment in which phosphorus is stored.

When temporal factors are considered, some wetlands may be capable of long-term storage of phosphorus (Kadlec 1979, Boyt et al. 1977, Odum and Ewel 1978, Tilton and Kadlec 1979). This seems to be especially true for temperate zone wetlands that have peat substrates and that occur in areas where the climate is not characterized by harsh winter conditions when the entire wetland would be frozen. Wetlands that are located in areas where winters are severe seem to be able to store phosphorus for part of the year with strong seasonal pulses of phosphorus release, especially in the spring after the wetland thaws (Fetter et al. 1978). The short-term storage and then release of phosphorus, therefore, seems to be a normal characteristic of certain types of wetlands (Sloey et al. 1978). Wetlands with predominantly inorganic substrates also seem less capable of storing phosphorus (Whigham and Bayley 1979). In wetlands, such as the Hamilton Marshes, where decomposition rates are very high (Odum 1978, Odum and Heywood 1978, Simpson et al. 1978, Whigham et al, in review) the flushing may occur at the end of the growing season rather than in the spring after the wetlands thaws.

Although poorly understood, hydrologic characteristics of wetlands are undoubtedly very important in regulating functional processes and efficient processing of wastewater will only be possible when the nutrient uptake and hydraulic capacity of the wetlands are not exceeded (Kadlec 1979, Gosselink and Turner 1978, Sloey et al. 1978). Hydrologically, Delaware River freshwater tidal wetlands are in high energy environments (Odum et al. 1974) that are characterized by a large tidal amplitude (@ 2-3 meters) that results in an almost complete twice daily flushing of the wetland. The wetland surface is drained for approximately 18 hours daily yet, because of the consistently large tidal amplitude, the surface is flooded by almost every flood tide (Whigham and Simpson, personal observation). Because of these hydrologic characteristics, there are substantial differences between the Hamilton Marshes and other freshwater wetlands where wastewater application has been studied. We believe the results that will now be discussed and compared can be explained by three factors, the hydrologic characteristics of the Hamilton Marshes, the presence of substrates that are primarily inorganic except for a thin organic surface litter layer, and the fact that the wetland receives water from a very eutrophic riverine system.

Standing crop biomass and estimated macrophyte net primary production did not increase as a result of applying secondarily treated wastewater (Tables 2-12). These results contrast with those of other researchers who have found significant increases in primary production (Zoltek et al. 1979, Ewel and Odum 1978, Boyt et al. 1977, Tilton and Kadlec 1979, Richardson et al. 1978, Chapin et al. 1975, Fetter et al. 1978). Most of the cited studies were conducted in wetlands with peat substrates and most of the wetlands received water from oligotrophic sources. In contrast, the Hamilton Marshes are located in a portion of the Delaware River that is characterized by water that receives a large organic and inorganic nutrient load from diffuse and point sources (Walton and Patrick 1973, Whigham and Simpson 1976a). The Hamilton Marshes, consequently, have had a long exposure to water with elevated nutrient levels and the vegetation is probably not nutrient limited. We have found (Whigham et al. 1978, Whigham and Simpson 1977) that these wetlands are among the most productive along the east coast. If this assumption is correct, then it seems likely that the addition of wastewater would cause only minor changes in rates of primary production.

Kadlec (1979) and Odum and Ewel (1978) have suggested that species changes could be expected as a result of nutrient loading in wetlands. The most significant treatment effects on vegetation of the Hamilton Marshes were decreases in species diversity (Table 13) and increased concentration of N and P in tissues of plants in the treated areas (Tables 2-10). The decrease in species diversity was due to elimination of annual species that, most likely, were killed by prolonged exposure to chlorinated effluent (Whigham and Simpson 1975). Chlorination was required by the State of New Jersey and, although we did not perform experiments on the effects of chlorine, our conclusions seem justified for several reasons. There was a differential response in the treated areas and only one species (<u>Impatiens capensis</u>) was eliminated from the areas (Sites 1 and 2) that were sprayed for two 3 hour periods daily. At the opposite extreme, all annuals except <u>Polygonum arifolium</u> were killed in the areas (Sites 5 and 6) that were continually sprayed. Similar results occurred in Sites 3 and 4 that were sprayed for 9 hours out of each tide cycle for an overall daily exposure time of 18 hours. The response was not simply due to addition of water because no species were removed from control Site 7 that received 12.5 cm of tap water daily. The net effect of species removal was that the areas sprayed with effluent almost always had less standing crop biomass than the control sites (Tables 2-11). Because the N and P content of plants in the treated areas was significantly higher (Tables 2-10), there were few differences in total standing crops of N and P when comparisons were made between the treatment and control sites. Increased N and P concentrations have been found in all instances where wastewater had been added to wetlands (Ewel and Odum 1978, Tilton and Kadlec 1979, Zoltek et al. 1979, Sloey et al. 1978). An argument could be developed that increased production rates would have occurred had the chlorine been removed prior to application. However, because of the eutrophic nature of Delaware River water and because we have documented that the Hamilton Marshes are among the most productive wetlands on the east coast, we doubt that additional studies would produce significantly different results.

Although there were no significant changes in primary production, there were interesting seasonal response patterns for biomass and nutrient standing stocks. Figures 21-23 show seasonal trends of biomass, TOTAL N, and TOTAL P for selected sites for 2 years of the study. Site 2 (Fig. 21) received wastewater for 2 daily periods of 3 hours of application each at a rate of approximately 12.5 cm per day. There was a sharp decline in biomass, TOTAL N, and TOTAL P after the third sampling date. This response was due to suppression of annual species at the site and elimination of one species, Impatiens capensis. Biomass and TOTAL N remained significantly lower throughout the remainder of the growing season while TOTAL P in the vegetation was not significantly less than at the control sites. In 1976, the dramatic early season decline in biomass did not occur and TOTAL N and TOTAL P were not significantly less than the control sites. Although species diversity at Site 2 was lower in 1976 (Table 13), biomass and standing stocks of nutrients remained high because the perennials (primarily Peltandra virginica, Acorus calamus, and Sagittaria latifolia) did not experience the mid-summer die-back that we have observed to occur

Fig. 21. Seasonal patterns of standing crop biomass, TOTAL N, and TOTAL P for Site 2 which received 12.4 cm of wastewater daily during two 3 hour spray periods. Data for control Site 8 are shown for comparison. All values are means ± 1 standard error of the mean.

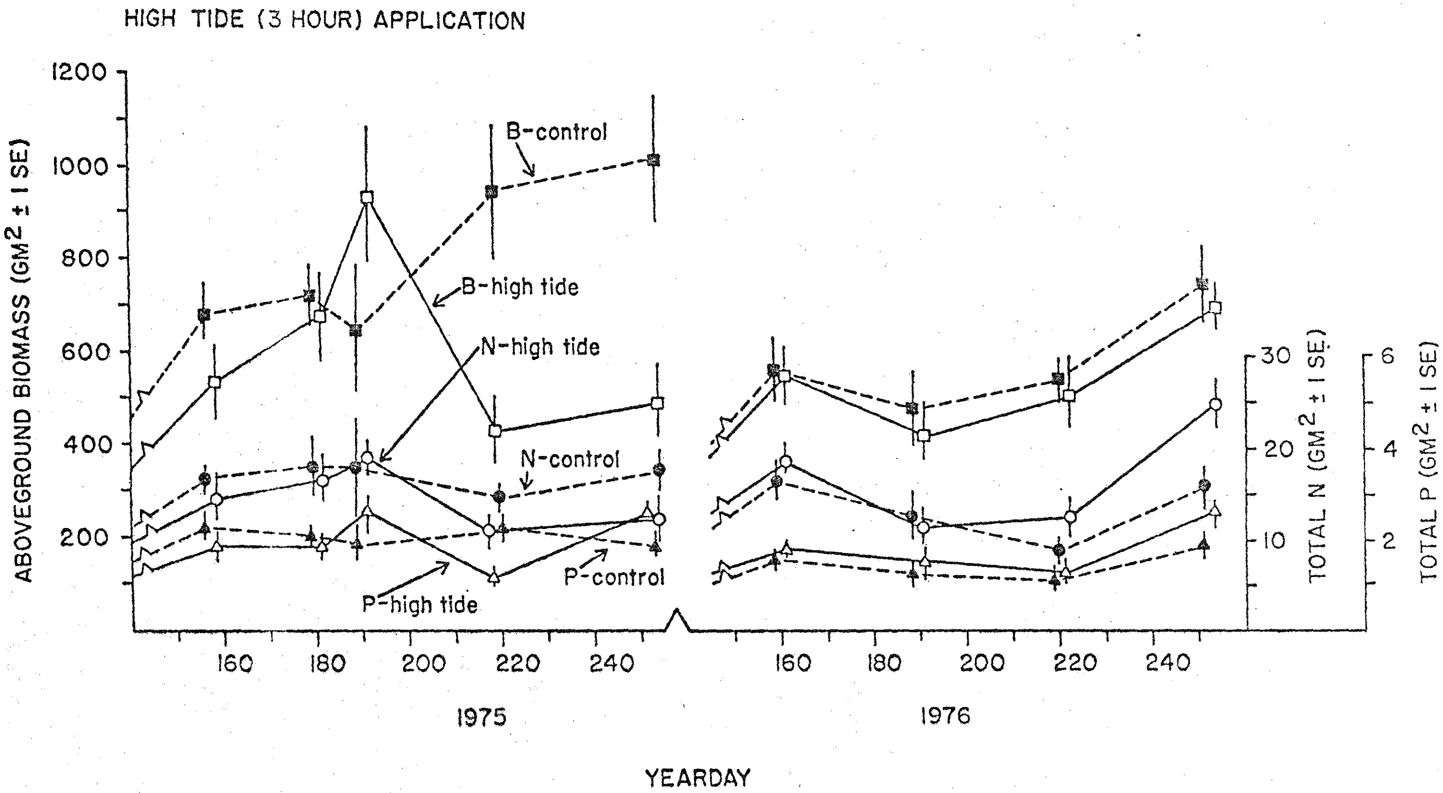


Fig. 22. Seasonal patterns of standing crop biomass, TOTAL N, and TOTAL P for Site 4 which received 12.5 cm of wastewater daily during two 9 hour spray periods. Data for control Site 8 are shown for comparison. All values are means ± 1 standard error of the mean.

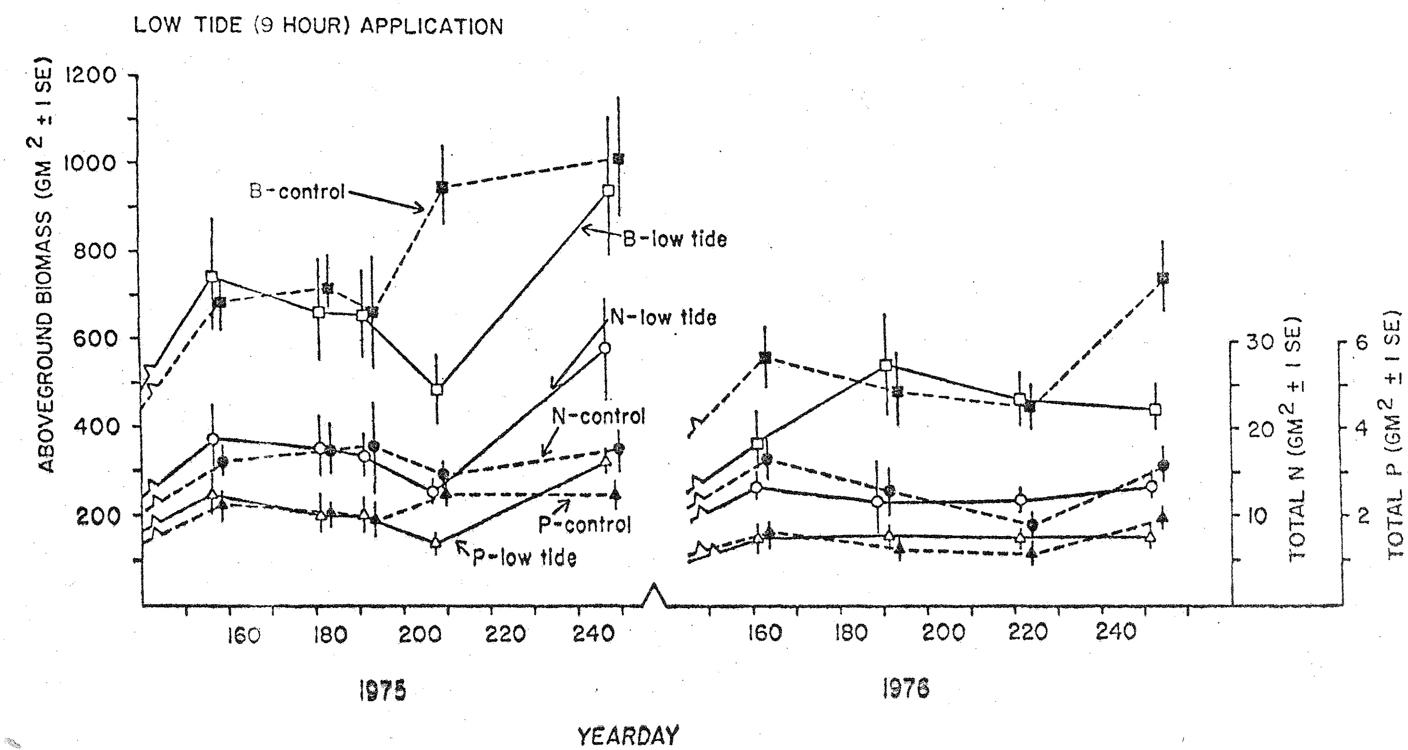
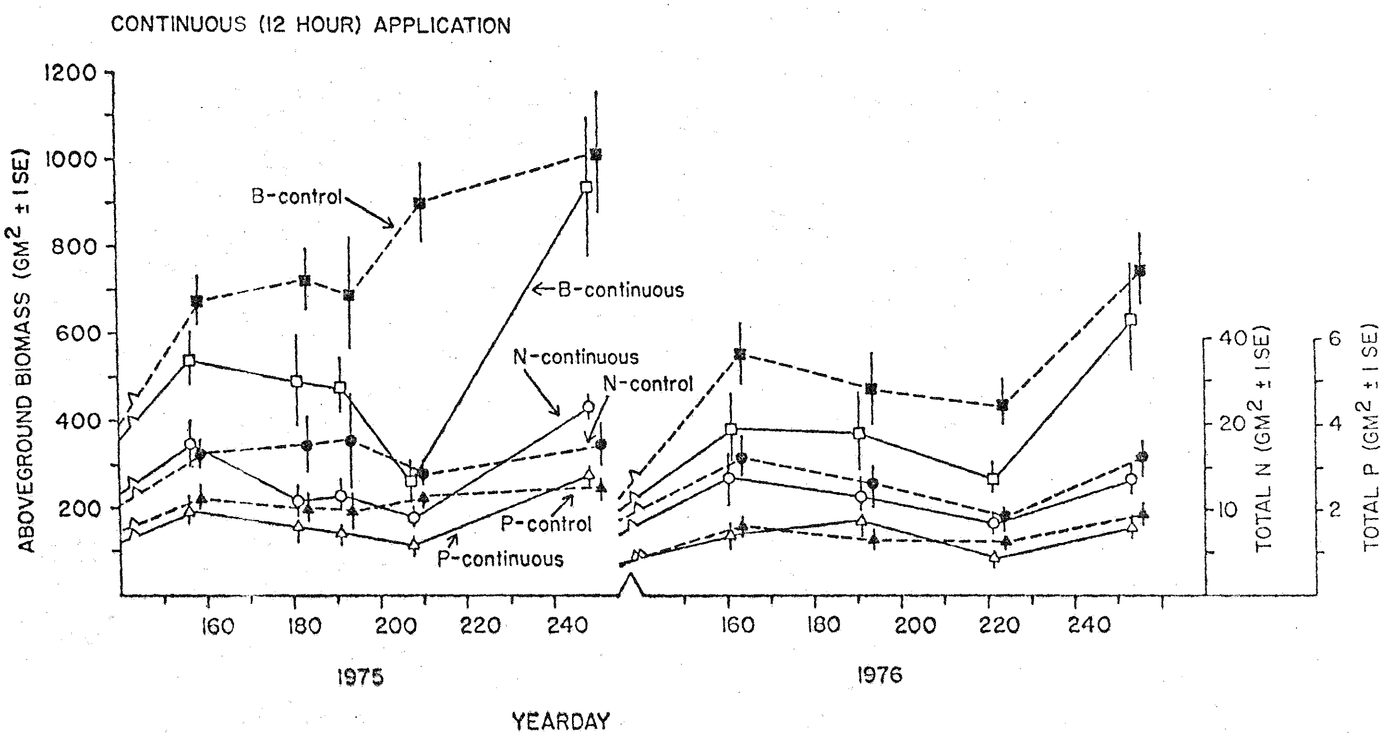


Fig. 23. Seasonal patterns of standing crop biomass, TOTAL N, and TOTAL P for Site 6 which received 12.5 cm of wastewater daily during a continuous spray regime. Data for control Site 8 are shown for comparison. All values are means ± 1 standard error of the mean.



yearly in the Hamilton Marshes (Whigham et al. 1978).

Figure 22 shows the yearly seasonal parameters for the same variables at Site 4. The same sharp decline in biomass occurred after the third sampling date in 1975. Biomass recovered by the end of the growing season with most of the biomass being found in the perennials cited above and one annual, Polygonum arifolium. TOTAL N and TOTAL P also recovered by the end of the 1975 growing season. Seasonal patterns of biomass and nutrient standing stocks accumulation at this site were similar to those described for Site 2 in 1977 with the exception that biomass was slightly less at the end of the growing season.

Figure 23 shows biomass and nutrient patterns at Site 6 which received wastewater continuously. The patterns are almost identical to those described for Site 4 with distinct seasonal variations, compared to the control sites in 1975 and very little variation in 1976. At all 3 sites, we interpret the 1976 patterns to be due to responses of the plant community. Although there were fewer species in the treatment sites, the remaining individuals produced more per capita biomass than did individuals at the control sites where plant densities were much higher.

We did not consider belowground biomass during this study. There have been very few studies of belowground biomass in freshwater wetlands (Barko and Smart 1978, Prentki et al. 1978, Klopatek et al. 1978, Whigham and Simpson 1978) but there is evidence (Ewel and Odum 1978) that significant increases in belowground storage of nutrients may follow the application of wastewater. We believe that there were no changes in belowground storage of nutrients in the treated areas because, as stated elsewhere, we believe that Hamilton Marsh vegetation seems to be producing biomass at about the maximum possible rate.

Surface litter and the first 2 cm of substrate were the most active components of this wetland system. There were significant increases in N and P concentrations of both confined and unconfined litter as well as increases in absolute amounts of total nitrogen, nitrate, ammonia, and total phosphorus (Tables 20-22 and 26-26). Richardson et al. (1978), working in a peat based wetland, also found that litter was an important component in the immobilization of nutrients in wetlands. There are few comparative data from studies of wetlands with a relatively thin surface litter layer and an underlying substrate that is primarily inorganic. Brinson (1977) found immobilization of N and P in the litter layer of a North Carolina swamp forest while Fetter et al. (1978) found significant retention of nutrients in a Wisconsin wetland. In the latter study, they did not determine how much phosphorus was immobilized within the wetland but did find large concentrations of phosphorus in stream sediments.

The importance of litter in the Hamilton Marshes was also documented by the tide cycle nutrient budget studies (Tables 80-82). Inputs of NH_3-N, NO_3-N, and TOTAL N were greater than outputs and those patterns held for sites that received either 5 cm or 12.5 cm of effluent daily or no water (Site 8). Most of the wastewater that was applied seemed to have a short retention time on the wetland surface. We saw no evidence that effluent infiltrated into the substrate which was always waterlogged just below the litter layer. Because most of the tidal water and wastewater runoff was direct overland flow, reductions in nutrients would most likely be the result of interactions between the water and the surface litter. Hunt and Lee (1976) found similar results for overland flow situations. The fact that nutrient concentrations did not increase in the substrate would also indicate that most of the nutrient removal occurred in the litter zone. The experimental work with epibenthic algae (Section 6) shows that those organisms respond very rapidly to the addition of wastewater and their increased growth would certainly be responsible for assimilation of some nutrients within the litter zone.

Retention of nutrients in the litter would not provide long-term storage in freshwater tidal wetlands. Our studies of unconfined litter (Tables 26-36), litter in litter bags (Tables 20-22; also see Odum and Heywood 1978), litter metabolism studies (Tables 24 and 25) and water quality studies (Tables 52-79 and Simpson et al. 1978) all indicate that nutrients in litter are quickly released at the end of the growing season. Our earlier water quality studies (Simpson et al. 1978) clearly showed sharp increases in nutrient concentrations in ebbing tidal water after the first killing frosts. There were also associated increases in dissolved carbon dioxide which indicates an increase in heterotrophic activities throughout the wetland. Nutrients are released by leaching of soluble materials and also by heterotrophic decomposition of the litter (Whigham et al., in review).

Unlike many of the peat based systems that have been treated with wastewater (Tilton and Kadlec 1979, Zoltek et al. 1979, Ewel and Odum 1978), nutrient concentrations and standing stocks did not change in the first 50 cm of substrate as a result of wastewater applications in the Hamilton Marhses. We believe that this is primarily due to the fact that the substrate has been exposed for a long time to water from the Delaware River that has been quite high in nutrients. Also, the substrate in the portion of the wetland where this study was conducted, typical of the entire wetland, is low in organic matter (20.7 ± 2.5%). Whigham and Bayley (1979) found that nutrient retention seems to be restricted primarily to wetlands with substrates that contain larger amounts of organic matter. This has been documented in recent papers by Tilton and Kadlec (1979), Zoltek et al. (1979), and Ewel and Odum (1978).

12. CONCLUSIONS

In summary, results of this study indicate that Delaware River freshwater tidal wetlands do not accumulate N and P in the vegetation or sediments, but do accumulate, on a short-term basis, nutrients in the litter. Four factors seemed to be most important in describing results of this study. First, the effluent that was applied was chlorinated as required by the State of New Jersey. The vegetation was stressed by contact with the chlorine and the degree of damage to the vegetation was related to the length of time that the plants, primarily annuals, were exposed to the chlorine. Even in areas where the stress was severe, there were significant overall community responses so that there were few differences between the treated and control sites even though there were differences in the floristics. Second, litter decomposition rates for macrophytes is very high in freshwater tidal wetlands (Whigham et al., in review, Odum and Heywood 1978) and nutrients that would be stored in vascular plants are rapidly leached following senescence of perennials and death of annuals. For most species, decomposition is essentially complete before the onset of the next growing season. Thus, although the litter is an active site for nutrient immobilization, it does not provide for long-term nutrient storage. Third, the wetland that we studied was a pulsed system and the high marsh was flooded and drained twice daily. While flood and ebb tide water seemed to move over the wetland surface as sheet flow, the flows were substantially greater (Whigham and Simpson 1975) than those that normally occur in most other types of freshwater wetlands. This, combined with the high rate at which we applied wastewater, meant that the wastewater was not in contact with the high marsh surface for long periods of time. Sloey et al. (1978) have suggested that the most efficient systems of wastewater treatment would require that contact periods be as prolonged as much as possible. Fourth, it seems likely that vegetation in this wetland is not nutrient limited due to the eutrophic nature of Delaware River water. Consequently, it seems unlikely that any of the biological components would show enhanced growth and/or nutrient retention once wastewater was added.

13. PUBLICATIONS

Good, R.E., D.F. Whigham and R.L. Simpson. 1978. Freshwater Wetlands: Ecological Processes and Management Potential. Academic Press, New York.

Whigham, D.F. and R.L. Simpson. 1977. Growth, mortality and biomass partitioning in freshwater tidal wetland populations of wild rice (*Zizania aquatica* var. *aquatica*). Bull. Torrey Bot. Club. 104:347-351.

Whigham, D.F. and R.L. Simpson. 1978. Nitrogen and phosphorus movement in a freshwater tidal wetland receiving sewage effluent. Pp. 2189-2203. *In* Coastal Zone '78. American Society of Civil Engineers, NY.

Whigham, D.F., J. McCormick, R.E. Good and R.L. Simpson. 1978. Biomass and primary production of Middle Atlantic Coast freshwater tidal wetlands. Pp. 3-20. *In* Freshwater Wetlands: Ecological Processes and Management Potential. Good, R.E., D.F. Whigham, and R.L. Simpson (eds.) Academic Press, New York.

Simpson, R.L., D.F. Whigham, and R. Walker. 1978. Nutrient movements in freshwater tidal wetlands. Pp. 243-257. In Freshwater Wetlands: Ecological Processes and Management Potential. Good, R.E., D.F. Whigham, and R.L. Simpson (eds.). Academic Press, New York.

Whigham, D.F. and R.L. Simpson. 1978. The relationship between aboveground and belowground biomass of freshwater tidal wetland macrophytes. Aquatic Botany. 5:355-364.

Simpson, R.L., D.F. Whigham, and K. Brannigan. 1979. The mid-summer insect communities of freshwater tidal wetland macrophytes. Bull. N.J. Acad. Sci. 24:22-28.

Whigham, D.F., R.L. Simpson, and M.A. Leck. 1979. The distribution of seeds, seedlings, and established plants of arrow arum (Peltandra virginica (L) Kunth) in a freshwater tidal wetland. Bull. Torrey Bot. Club. 106:193-199.

Lee, K.W., R.J. Natuk, R.L. Simpson and D.F. Whigham. 1977. Effects of sewage on the soil algae of a freshwater tidal marsh. Paper presented at annual meeting Phycological Society of America.

Sickels, F.A., R.L. Simpson, and D.F. Whigham. 1977. Decomposition of vascular plants in a Delaware River freshwater tidal marsh exposed to sewage spray irrigation. Paper presented at annual meeting New Jersey Academy of Science.

Natuk, R.J. and K.W. Lee. 1977. Soil algae of a freshwater tidal marsh. Paper presented at annual meeting New Jersey Academy of Science.

Correll, S.A. and K.W. Lee, 1977. Growth response of three chlorophycean algae to cross-gradients of light intensity and temperature. Paper presented at annual meeting New Jersey Academy of Science.

Simpson, R.L., D.F. Whigham and F.A. Sickels. 1977. Decomposition of vascular plants in a Delaware River freshwater tidal marsh. Paper presented at Ecological Society of America.

Natuk, R.J. and K.W. Lee. 1978. Response of soil algae of a freshwater tidal marsh to the removal of the vascular plants. Presented at annual meeting New Jersey Academy of Science.

Whigham, D.F. and R.L. Simpson. 1978. Nitrogen and phosphorus movemnet in a freshwater tidal wetland receiving sewage effluent. Paper presented at symposium meeting Coastal Zone '78.

Simpson, R.L. and D.F. Whigham. 1978. The impact of treated sewage on water quality of a Delaware River freshwater tidal wetland. Paper presented at Meeting American Society of Limnology and Oceanography.

Whigham, D.F. and R.L. Simpson. 1978. Aboveground and belowground biomass relationships of freshwater tidal wetland macrophytes. Paper presented at annual meeting Ecological Society of America.

Whigham, D.F. and R.L. Simpson. 1979. Effects of sewage spray irrigation in a freshwater tidal wetland. I. Primary production and nutrient standing stocks. Paper presented at annual meeting Ecological Society of America.

Simpson, R.L., D.F. Whigham, and F. Sickels. 1979. The effect of sewage spray irrigation in a freshwater tidal wetland. II. Decomposition studies. Paper presented at annual meeting Ecological Society of America.

14. LITERATURE CITED

American Society of Agronomy, Inc. 1965. Methods of soil analysis. Part 2. Chemical and microbiological properties. American Society of Agronomy, Madison, Wisconsin.

American Public Health Association. 1971. Standard methods for the examination of water and wastewater. 13th ed. American Public Health Association, Inc. New York.

Barko, J.W. and R.M. Smart. 1978. The growth and biomass distribution of two emergent freshwater plants, Cyperus esculentus and Scirpus validus, on different sediments. Aq. Bot. 5:109-117.

Bischoff, H.W. and H.C. Bold. 1963. Phycological Studies. IV. Some soil algae from Enchanted Rock and related algal species. Univ. Texas Publs., No. 6318.

Bonasera, J., J. Lynch, and M.A. Leck. 1979. Comparison of the allelopathic potential of four marsh species. Bull. Torrey Bot. Club. 10-:217-222.

Boyt, F.L., S.E. Bayley, and J. Zoltek, Jr. 1977. Removal of nutrients from treated municipal wastewater by wetland vegetation. Jour. Water Poll. Control Fed. 49:789-799.

Brinson, M.W. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecology. 58:601-609.

Brown, R.M., Jr., and H.W. Bischoff. 1962. A new and useful method for obtaining axenic culture of algae. Phycol. News Bull. 15:43-44.

Chapin, F.S., III, K. van Cleve, and L.L. Tieszen. 1975. Seasonal nutrient dynamics of tundra vegetation at Barrow, Alaska. Arctic and Alpine Res. 7:209-226.

Edwards, P. and C. Van Baalen. 1970. An apparatus for the culture of benthic marine algae under varying regimes of temperature and light intensity. Bot. Marina. 13:42-3.

Ewel, K.C. and H.T. Odum. 1978. Cypress swamps for nutrient removal an wastewater recycling. In: Advances in water and wastewater treatment: Biological nutrient removal. W.P. Wanielista and W.W. Eckenfelder, Jr. (eds.) Ann Arbor Sci. Publ. Inc., Ann Arbor Michigan. pp. 181-198.

Farnham, R.S. 1974. Use of organic soils for wastewater infiltration. In: Histosols: Their characteristics, use and classification. Soil. Sci. Soc. Am. Spec. Publ. No. 6. pp. 111-118.

Fetter, C.W., Jr., W.E. Sloey, and F.L. Spangler. 1978. Use of a natural marsh for wastewater polishing. J. Water Poll. Control Fed. 50:290-307.

Golterman, H.L. 1969. Methods for chemical analysis of freshwaters. IBP Handbook No.8. Blackwell Scientific Publications, Oxford, England.

Gosselink, J.G. and R.E. Turner. 1978. The role of hydrology in freshwater wetland ecosystems. In: Freshwater wetlands: Ecological processes and management potential. R.E. Good, D.F. Whigham, and R.L. Simpson (eds.) Academic Press, New York. pp. 63-78.

Grant, R.R., Jr. and R. Patrick. 1970. Tinicum Marsh as a water purifier. In: Two studies of Tinicum Marsh, Delaware and Philadelphia Counties, Pa. J. McCromick, R.R. Grant, Jr. and R. Patrick (eds.) The Conservation Foundation, Washington, D.C. pp. 105-123.

Halldal, P. and C.S. French. 1956. The growth of algae in crossed gradients of light intensity and temperature. Carnegie Instit. Washington Year Book. 55:261-5.

Halldal, P and C.S. French. 1958. Algal growth in crossed gradients of light intensity and temperature. Plant. Physiol. 33:249-52.

Hoshaw, R.W. and J.R. Rosowski. 1973. Methods for microscopic algae. In: Handbood of phycological methods: Culture methods and growth measurements. J.R. Stein (ed.) Cambridge Univ. Press. New York. pp. 87-104.

Hunt, P.G. and C.R. Lee. 1976. Land treatment of wastewater by overland flow for improved water quality. In: Biological control of water pollution. J. Tourbier and R.W. Pierson, Jr. (eds.) Univ. Pennsylvania Press. Philadelphia, Pa. pp. 151-160.

Kadlec, R.H. 1979. Wetlands for tertiary treatment. In: Wetland functions and values: The state of our understanding. American Water Works Association. St. Paul, Minn.

Kitchens, W.M., Jr., J.M. Dean, L.H. Stevenson and J.H. Cooper. 1975. The Santee Swamp as a nutrient sink. In: Mineral cycling in Southeastern ecosystems. F.G. Howell, J.B. Gentry and M.H. Smith. (eds.) ERDA Symposium Series Conference - 740513. pp. 349-366.

Klopatek, J. 1975. The role of emergent macrophytes in mineral cycling in a freshwater marsh. In: Mineral cycling in Southeastern ecosystems. F.G. Howell, J.B. Gentry and H.M. Smith. (eds.) ERDA Symposium Series Conference - 740513. pp. 367-393.

Klopatek, M.J. 1978. Nutrient dynamics of freshwater riverine marshes and the role of emergent macrophytes. In: Freshwater wetlands: Ecological processes and management potential. R.E. Good, D.F. Whigham, and R.L. Simpson. (eds.) Academic Press, New York. pp. 195-216.

Leck, M.A. and K.J. Graveline. 1979. The seed bank of a freshwater tidal marsh. Amer. J. Bot. 66:1006-1015.

Lee, K.W. and H.C. Bold. 1974. Phycological studies. XII. Characium and some Characium like algae. Univ. Texas Publs., No. 7403. pp. 127.

Odum, H.T., B.J. Copeland, and E.A. McMahan, eds. 1974. Coastal ecological systems of the United States. Conservation Foundation, Washington, D.C. 4 Vols.

Odum, W.E. 1978. The importance of tidal freshwater wetlands in coastal zone management. In: Coastal Zone 78. American Society of Civil Engineers, New York. pp. 1196-1203.

Odum, W.E. and M.A. Heywood. 1978. Decomposition of intertidal freshwater marsh plants. In: Freshwater wetlands: Ecological processes and management potential. R.E. Good, D.F. Whighham and R.L. Simpson. (eds.) Academic Press, New York. pp. 89-98.

Olson, J.S. 1963. Energy storage and decomposers in ecological systems. Ecology. 44:322-332.

Patrick, W.H., Jr., R.D. Delanne, R.M. Engler, and S. Gotoh. 1976. Nitrate removal from water at the watermud interface in wetlands. EPA-600/3-76-042. Ecological Research Series.

Peet, R.K. 1975. Relative diversity indices. Ecology. 56:496-498.

Prentki, R.T., T.D. Gustafson, and M.S. Adams. 1978. Nutrient movement in lakeshore marshes. In: Freshwater wetlands: Ecological processes and management potential. R.E. Good, D.F. Whigham, and R.L. Simpson. (eds.) Academic Press, New York. pp. 169-194.

Simpson, R.L., D.F. Whigham, and K. Brannigan. 1979. The mid-summer insect communities of freshwater tidal wetland macrophytes, Delaware River estuary, New Jersey. Bull. New Jersey Acad. Sci. 24: 22-28.

Simpson, R.L., D.F. Whigham, and R. Walker. 1978. Seasonal patterns of nutrient movement in a freshwater tidal marsh. In: Freshwater wetlands: Ecological processes and management potential. R.E. Good, D.F. Whigham and R.L. Simpson. (eds.) Academic Press, New York. pp. 243-258.

Sloey, W.E., F.L. Spangler and C.W. Fetter, Jr. 1978. Management of freshwater wetlands for nutrient assimilation. In: Freshwater wetlands: Ecological processes and management potential. R.E. Good, D.F. Whigham and R.L. Simpson. (eds.) Academic Press, New York. pp. 321-340.

Sommers, K.E. and D.W. Nelson. 1972). Determination of total phosphorus in soils: A rapid perchloric acid digestion procedure. Soil Sci. Soc. Amer. Proc. 26:902-904.

Stanford, G., J.N. Carter, E.C. Simpson, Jr., and D.E. Schwaninger. 1973. Nitrate determination by a modified conway microdiffusion method. J.A.O.A.C. 56:1356-1368.

Stanlick, H.T. 1976. Treatment of secondary effluent using a peat bed. In: Freshwater wetlands and sewage effluent disposal. D.L. Tilton, R.H. Kadlec and C.J. Richardson. (eds.) Univ. Michigan, Ann Arbor, Mich. pp. 257-268.

Strickland, J.D.H. and T.R. Parson. 1968. A practical handbook of seawater analysis. Fish Res. Bd. Can. Ottawa.

Tilton, D.L. and R.H. Kadlec. 1979. The utilization of a freshwater wetland for nutrient removal from secondarily treated waste water effluent. J. Enut. Qual. 8:328-334.

Tourbier, J. and R. Pierson, Jr. 1976. Biological control of water pollution. University of Pennsylvania Press. Philadelphia, Pa.

Walton, T.E., III and R. Patrick. 1973. Delaware River estuarine marsh survey. In: Delaware estuary system: Environmental impacts and socio-economic effects. Philadelphia Academy of Sciences. Philadelphia, Pa.

Whigham, D.F. and S.E. Bayley. 1979. Nutrient dynamics in freshwater wetlands. In: Wetland functions and values: The state of our understanding. American Water Works Association. St. Paul, Minn.

Whigham, D.F., J. McCormick, R.E. Good, and R.L. Simpson. 1978. Biomass and primary production in freshwater tidal wetlands of the middle Atlantic coast. In: Freshwater wetlands: Ecological processes and management potential. R.E. Good, D.F. Whigham, and R.L. Simpson. (eds.) Academic Press, New York. pp. 3-20.

Whigham, D.F. and R.L. Simpson. 1975. Ecological studies of the Hamilton Marshes. Progress Report of the period June, 1974 - January, 1975. Rider College, Biology Department, Lawrenceville, New Jersey.

Whigham, D.F. and R.L. Simpson. 1976a. The potential use of freshwater tidal marshes in the management of water quality in the Delaware River. In: Biological control of water pollution. J. Tourbier and R.W. Pierson, Jr. (eds.) University of Pennsylvania Press, Philadelphia, Pa. pp. 173-186.

Whigham, D.F. and R.L. Simpson. 1976b. Sewage spray irrigation in a Delaware River freshwater tidal marsh. In: Freshwater wetlands and sewage effluent. D. Tilton, J. Kadlec and C.J. Richardson. (eds.) University of Michigan, Ann Arbor, Mich. pp. 119-144.

Whigham, D.F. and R.L. Simpson. 1977. Growth, mortality, and biomass partitioning in freshwater tidal wetland populations of wild rice (Zizania aquatica var. aquatica). Bull. Torrey Bot. Club. 104: 347-351.

Whigham, D.F. and R.L. Simpson. 1978. The relationship between aboveground and belowground biomass of freshwater tidal wetland macrophytes. Aq. Bot. 5:355-364.

Whigham, D.F. and R.L. Simpson. 1978. Nitrogen and phosphorus movement in a freshwater tidal wetland receiving sewage effluent. In: Coastal Zone '78. Am. Soc. Civil Engineers, New York. pp. 2189-2203.

Whigham, D.F., R.L. Simpson, and M.A. Leck. 1979. The distribution of seeds, seedlings, and established plants of arrow arum (Peltandra virginica (L) Kunth) in a freshwater tidal wetland. Bull. Torrey Bot. Club. 106:193-199.

Whigham, D.F., R.L. Simpson, and F.E. Sickels. In review. Decomposition of vascular plants in a freshwater tidal wetland. J. Ecology.

Wiedeman, V.E., P.L. Walne, and F.R. Trainor. 1964. A new technique for obtaining axenic cultures of algae. Can. J. Bot. 42:958-959.

Yarish, C. 1976. Polymorphism of selected marine chaetophoraceae (Chlorophyta). Br. Phycol. J. 11:29-38.

Zoltek, J., Jr., S.E. Bayley, A.J. Hermann, L.R. Tortora, and T.J. Dolan. 1979. Removal of nutrients from treated municipal wastewater by freshwater marshes. Center for Wetlands. University of Florida, Gainesville, Fla.

SELECTED WATER RESOURCES ABSTRACTS

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16. *Abstract* The effects of sprayingchlorinated secondarily treated sewage on a Delaware River freshwater tidal wetland for three years was studied. Macrophyte net primary production was significantly lower in the experimental sites receiving sewage than in the no treatment controls in 1975 but not in 1976 or 1977. Diversity of annuals was reduced in the experimental sites largely due to the elimination of annuals. Although percent N and P were generally high in the vegetation of experimental sites, there was little difference inTotal N and Total P between treatments and controls. Macrophyte decomposition rates were little affected by sewage application. Substrate N and P were not significantly different between sites, but surface litter of the experimental sites accumulated N and P. Epibenthic algae may contribute to this accumulation. Water quality studies showed the high marsh to be metabolically active. Tide cycle flux studies indicated that up to 40% of the N added to the wetland was assimilated during the late spring - early summer period. Conversely, there was a net loss of P from the wetland.

These results are compared with thoseof similar studies in other wetlands. It is concluded that the strongly pulsed tidal regimes of the wetland, the low organic content substrate, and theeutrophic nature of Delaware River waters contribute to the inability of the wetland to efficiently assimilate nutrients from sewage.

17a. *Descriptors* Nutrient removal*, Sewage treatment*, Tidal marshes*, Freshwater marshes*, Marsh plants*, Soil algae*, Litter*, Decomposing organic matter*, Primary productivity*, Chlorophyll*, Dissolved oxygen*, Carbon dioxide*, Nitrogen*, Phosphorus*, Soil*, Water pollution control, Waste assimilative capacity, Biomass, Chlorophyta, Chrysophyta, Euglenophyta, Cyanophyta, Nitrates, Nitrites, Ammonia, Delaware River.

17b. *Identifiers*

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