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Seasonal Phytoplankton Composition in the Pagan River, Virginia: A Nutrient Enriched River

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ABSTRACT

This river is characterized as a nutrient enriched system with annual mean levels of total nitrogen and phosphorus at 1.8 and 0.8 mg L^{-1} respectively. Three phytoplankton maxima occurred during the year at concentrations of 10^7 to 10^8 cells L^{-1}. Other algal populations had distinct periods of abundance, which varied seasonally in magnitude and time of development. Turbidity levels were high, with a mean secchi depth of 0.4 m. When compared to other regional rivers within the Chesapeake Bay drainage basin, the Pagan River had similar, but greater phytoplankton abundance, in addition to higher nutrient levels and lower secchi depths.

INTRODUCTION

The Pagan River is a 16.9 km long tributary of the James River in southeastern Virginia (Figure 1). It is a nutrient enriched river, with a drainage basin of approximately 148 to 172 km^2 (Kuo et al., 1976; Rosenbaum and Neilson, 1977). A largely agricultural area is within the river basin, with more than 1,000 hectares of marsh along its route. The town of Smithfield, with a population of approximately 4,800 is located 8 km upstream. The river receives nutrients from a variety of sources that include two meat processing plants, the Smithfield Sewage Treatment facility, agricultural drainage, and street storm sewer runoff from the town of Smithfield.

Kuo et al. (1976) found the Pagan River well mixed, having little vertical stratification occurring seasonally, with tidal currents up to 30.5 cm sec^{-1} and little freshwater runoff into the river basin (<0.28 m^3 sec^{-1}). Rosenbaum and Neilson (1977) conducted a short term study of the Pagan River. They noted chlorophyll "a" levels were high, with some readings approaching 140 µg L^{-1}, and the highest concentrations upstream. The dissolved oxygen was low during the pre-dawn slack tide, often below 3-4 mg L^{-1}. However, at other times the surface water was supersaturated with dissolved oxygen. They reported fecal coliform levels increasing upstream, reaching an excess of 200 MPN/100 mL. Rosenbaum and Nielson (1977) associated poor water quality problems in the Pagan to discharge from the local sewage treatment plant and two meat packing plants in Smithfield. These two plants discharged approximately 5,447 kg of 5-day carbonaceous biochemical oxygen demand (BOD) and about 13,200 kg of nitrogenous BOD daily in 1976. The loads from non-point sources were also large, but intermittent. Some of the increased oxygen demand may also be due to a high benthic oxygen demand (Rosenbaum and Neilson, 1977). This occurs when various organic materials from different discharges, and from dead phytoplankton, coat the benthic substrate of the river. As this material decomposes, it places an additional oxygen demand on the surrounding water.

No phytoplankton studies have been conducted in the Pagan River, however, phytoplankton populations in the James River have been reported by Woodson (1959,

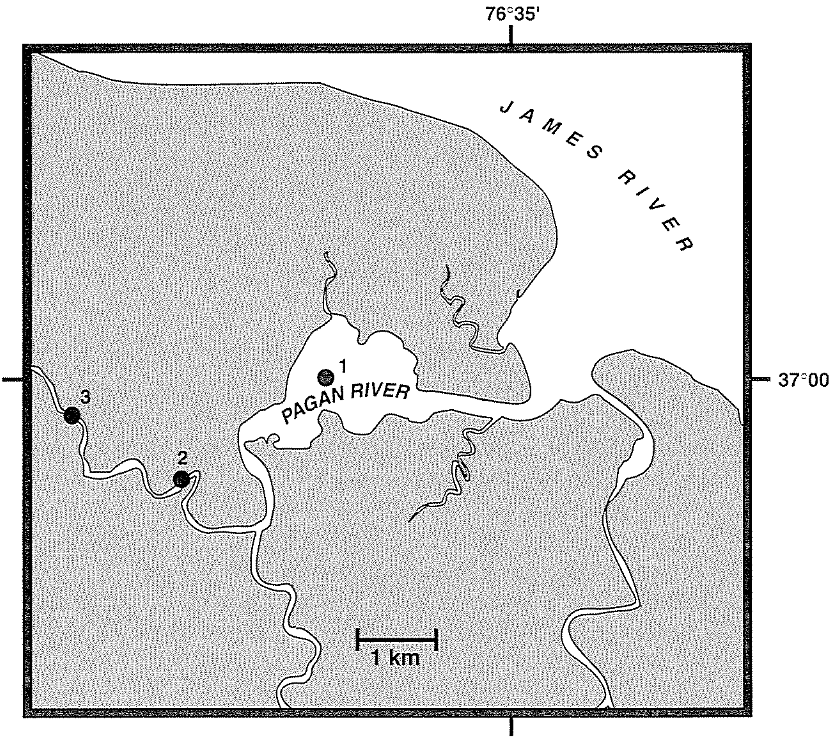

FIGURE 1. Station locations in the Pagan River

1960), Marshall (1967a, 1967b, 1968), and Filardo and Dunstan (1985). These studies have characterized the James river flora as dominated by diatoms and a variety of phytoflagellates, with spring population peaks of 3 x 10^6 cells L^{-1}.

The objectives of the study were to identify the seasonal phytoplankton composition and seasonal abundance patterns in this nutrient enriched river, and to identify relationships between the flora and nutrient levels in this estuary.

METHODS

Monthly replicate samples (500 mL) were collected at the surface (<1 m) from September 1992 through October 1993 at three stations in the Pagan River (Figure 1). Station PG1 is downstream of both the meat packing and sewage treatment plants which are located adjacent to the river. Station PG2 is between these two sites, with station PG3 farther upstream. The samples were fixed with five mL of Lugol's solution

TABLE 1. Results of a one-factor, model II analysis of variances on surface water salinity from the three monthly sampling sites on the Pagan River from October 1992 to September 1993. (DF= degrees of freedom, SS= sum of squares, MS= mean sum of squares, F= F-calculated statistic, P= probability of chance).

			Salinity		
Source	DF	SS	MS	F	P
Among Stations	2	217.4	108.7	5.39	< 0.01
Within Station	33	666.1	20.18	------	------

(Verduin, 1962) when collected. These samples were later processed in the laboratory using a series of settling and siphoning procedures over a 72 hour period, with 10% buffered formalin (4 mL) added as a preservative. The samples were examined using a modified Utermöhl method and procedures described by Marshall (1984), using a Zeiss Opton inverted plankton microcsope.

On station, measurements of water temperature, salinity, pH, and conductivity were determined with a Hydrolab® Surveyor II. Water transparency was recorded on station using a Secchi disk (18 cm diam.). Supplementary water quality data of nutrient levels were provided by the Virginia Department of Environmental Qualtiy (VDEQ, 1990).

Multiple analyses of variances (MANOVA) were conducted on the physical water parameters to determine if significant temporal and spatial differences existed. A one-factor analyses of variance (ANOVA) was conducted on phytoplankton abundances to determine if these values differed significantly between station locations. A non-hierarchal cluster analysis (Gauch, 1979) was used to group VDEQ stations based on similarities in the physical water parameters. The SPSS version of Discriminant Function Analysis (Nie et al., 1975) was performed on the data to determine whether clusters found were statistically distinct from one another.

RESULTS

Water Parameters

Surface water temperatures in the Pagan River ranged from 4.33 to 29.19 ^{o}C (Seaborn, 1994). The temperature decreased from a peak in October to a 12 month low in February, then increased rapidly into spring (March). A MANOVA indicated no statistically significant temperature differences between the stations ($P > 0.01$). Average salinity in the Pagan River ranged from 0.8 ppt in January and March to 12.1 ppt in September. The mean station salinities were statistically significant ($P < 0.01$), ranging from 3.3 to 9.0 ppt (Table 1). Secchi depth readings were low at all stations, averaging 0.4 m, with a range from 0.2 (April) to 0.8 m (December). The 12 month low was associated with the spring diatom pulse. Values for pH remained stable throughout the study. The river was slightly alkaline with an average pH of 7.36, with pH increasing upstream (Table 2).

Dissolved oxygen was measured during midday sampling and ranged from 13.07 mg L^{-1} in April to 4.78 mg L^{-1} in July. Levels were high during fall and winter and decreased into spring and summer. A marked reduction occurred between April and

TABLE 2. Monthly means for physical water parameters at three Pagan River Stations between October 1992 and September 1993.

	Station 1	Station 2	Station 3
SALINITY (ppt)	9.0	4.4	3.3
pH	7.15	7.41	7.53
DISSOLVED O_2 (mg L^{-1})	9.50	8.97	9.46
TOTAL N (mg L^{-1})	1.217	1.913	2.227
TOTAL P (mg L^{-1})	0.478	0.826	0.891
SECCHI DEPTH (m)	0.4	0.4	0.4

May at station PG2, located between the meat and sewage treatment plants, having the lowest oxygen values (Table 2).

Total nitrogen and phosphorus levels had mean concentrations of 1.79 and 0.73 mg L^{-1}, respectively. The total nitrogen and total phosphorus maxima were highest upstream (PG3), and lowest downstream (PG1) (Table 2). These differences between stations were statistically significant for both nitrogen and phosphorus. Seasonally, the highest levels (TN 3.5, TP 1.3 mg L^{-1}) occurred in summer for both nitrogen and phosphorus. These nutrient concentrations were much higher than those in other regional rivers. For instance, in the Nansemond River the total mean nitrogen and total phosphorus, for the same time period, were 0.94 and 0.19 mg L^{-1}, respectively (Shomers, 1988).

Additional water quality parameters were provided by VDEQ from 11 stations in the Pagan River. These parameters and their means over the sampling period included the following: ammonia (0.249 mg L^{-1}), nitrite (0.137 mg L^{-1}), nitrate (0.486 mg L^{-1}), BOD (3.71 mg L^{-1}), total suspended solids (TSS) (9137.69). A cluster analysis grouped 11 VDEQ stations in the Pagan according to these parameters, as well as temperature, salinity, dissolved oxygen, pH, total nitrogen (TN), and total phosphorus (TP). The three monthly phytoplankton stations of this study corresponded to three of the 11 VDEQ stations (Stations PG1.1, PG5.4, PG7.4). The results indicated the Pagan River has three distinct water quality regions; one located below the meat and sewage treatment plants, one between these plants, and one upstream from these plants (Seaborn, 1994). The specific differences of these three regions are seen in Figure 2. They indicate increased salinity and TSS are associated with PG1, whereas, these values decrease upstream at stations PG2 and PG3. At these stations there are increased levels of TN, TP, DIN, and BOD.

Phytoplankton Patterns

A total of 151 taxa were identified in the study (Seaborn, 1994). These represented 9 classes of phytoplankton: 65 Bacillariophyceae, 27 Dinophyceae, 23 Chlorophyceae, 17 Cyanobacteria, 7 Cryptophyceae, 5 Euglenophyceae, 5 Chrysophyceae, 1 Prasinophyceae, and 1 Prymnesiophyceae. Another category not mentioned here, is the

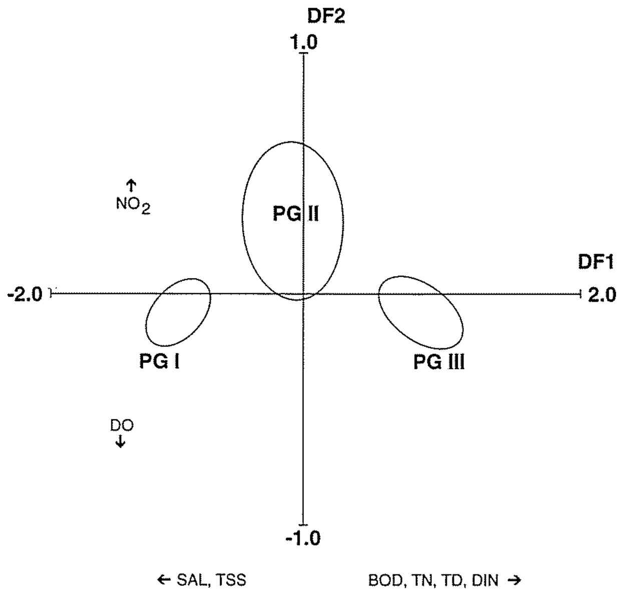

FIGURE 2. Confidence ellipses for canonical discriminant relationships between the three stations (Station 1 = PG1, etc.) regarding water quality parameters in the Pagan River.

TABLE 3. Results of a one-factor, model II analysis of variances on phytoplankton abundance by station location for the three monthly sampling sites on the Pagan River. (DF=degrees of freedom, SS= sum of squares, MS= mean sum of squares, F= F-calculated statistic, P= probability of chance).

		Phytoplankton Abundance			
Source	DF	SS	MS	F	P
Among Stations	2	9.5×10^{15}	4.8×10^{15}	2.24	0.10 <> 0.25
Within Station	33	1.0×10^{16}	2.1×10^{15}	-----	

autotrophic picoplankton, with cells that were ubiquitous in the samples and are discussed by Seaborn (1994) and Davis et al. (1997).

The overall abundance of phytoplankton was tested with one-way ANOVAS, but they did not identify significant differences in concentrations for station locations (Table 3). Although variation in phytoplankton abundance among stations was not significant, stations PG3 and PG1 consistently had the highest and lowest abundances, respectively (Figure 3).

The total cell concentrations exhibited a trimodal pattern of abundance. There was an initial peak in October (1.3×10^8 cells L^{-1}) which decreased in winter to a March low (2.9×10^6 cells L^{-1}). A second major peak (2.6×10^7 cells L^{-1}) occurred in April,

TABLE 4. Average monthly values of total phytoplankton in the Pagan River and other regional rivers (James and Elizabeth data from CBMP; Nansemond from Shomers, 1988; Lafayette from Purcell, 1973), in numbers of cells per liter.

Group	Pagan	James	Elizabeth	Nansemond	Lafayette
Diatom	$1.25x10^7$	$9.90x10^6$	$4.03x10^6$	$6.63x10^5$	$6.67x10^5$
Dinoflagellate	$6.48x10^5$	$4.20x10^4$	$4.92x10^5$	$6.60x10^4$	$2.77x10^5$
Cyanobacteria	$1.37x10^7$	$7.67x10^6$	$1.59x10^5$	$2.53x10^4$	$1.42x10^4$
Chlorophyte	$9.81x10^5$	$6.18x10^6$	$1.63x10^5$	$2.66x10^4$	$1.88x10^3$
Cryptomonad	$1.39x10^6$	$8.22x10^5$	$7.34x10^5$	$4.78x10^5$	$3.41x10^5$
Euglenoid	$6.24x10^4$	$2.49x10^3$	$2.67x10^3$	$3.17x10^4$	$1.44x10^4$
Chrysophyte	$4.00x10^3$	$3.42x10^4$	$0.89x10^0$	$2.61x10^3$	0
Miscellaneous	$1.31x10^6$	$1.49x10^5$	$7.19x10^5$	$3.73x10^6$	$1.46x10^4$
Totals	$3.06x10^7$	$2.48x10^7$	$6.30x10^6$	$5.02x10^6$	$1.33x10^6$

and was mainly due to the spring diatom pulse. This was followed by a third pulse in August (4.2×10^7 cells L^{-1}). The mean abundance of phytoplankton in the Pagan River was higher than that reported from other regional rivers (Table 4). Their average monthly concentrations in the Pagan were more than in other local rivers. The assemblages in the Pagan were dominated by cyanobacteria, diatoms, and cryptomonads. Whereas, in the other four rivers, diatoms and cryptomonads were the dominant flora.

MAJOR PHYTOPLANKTON COMPONENTS

Bacillariophyceae

The diatoms were the most abundant phytoplankton during the study (excluding the autotrophic picoplankton component). They were also the most diverse phytoplankton category, composing 41% of the taxa identified. The most abundant species included *Cyclotella choctowhatcheeana* (*C. caspia*), *Leptocylindricus minimus*, *Skeletonema costatum*, and *Skeletonema potamos*. The diatoms exhibited three distinct peaks during the study period. The largest was in fall, followed by others in spring and late summer (Figure 3). Cell concentrations were highest in October with a mean concentration of 4.9×10^7 cells L^{-1}, and greatest upstream at station 3, with a concentration of 1.1×10^8 cells L^{-1}. Cell numbers then decreased into in March, at a level of 1.8×10^6 cells L^{-1}, with *Leptocylindricus minimus* the most abundant species.

Following the winter low, there was a second pulse in April which was associated with a marked increase in water temperature. Concentrations were at levels of 2.1×10^7 cells L^{-1}. Diatom levels were highest upstream (Station PG3) and lowest downstream (Station PG1). Common species at this time were *Cyclotella choctowhatcheeana*, *Cyclotella striata*, *Navicula* spp., *Skeletonema potamos*, and *Synedra* spp.

During summer months the diatom abundance gradually increased until reaching a third peak in August of 8.9×10^6 cells L^{-1}. There was no statistical difference in diatom concentration according to station location during this peak. Prominent species

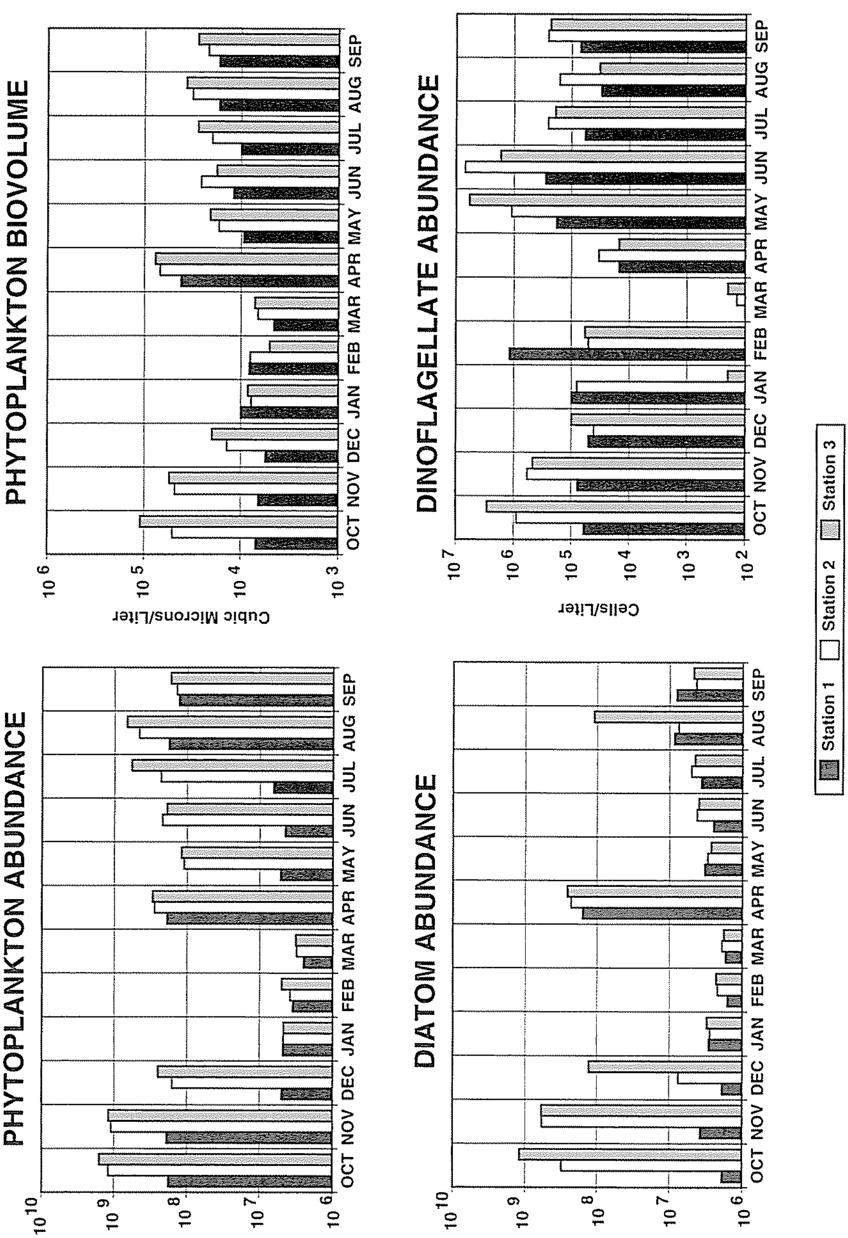

FIGURE 3. Phytoplankton abundance and biovolume comaprisons for stations in the Pagan River.

included *Cyclotella choctowhateeana*, *Cyclotella striata*, *Cylindrotheca closterium*, *Leptocylindricus minimus*, *Skeletonema costatum*, *Skeletonema potamos* and *Thalassiosira* spp.

Dinophyceae

The dinoflagellate concentrations ranged from a mean abundance of 2.9×10^6 cells L^{-1} (June), to 1.1×10^2 cells L^{-1} (March). The concentration of dinoflagellates was widely variable throughout the sampling period. A major development occurred at station PG1 in February when a bloom of *Heterocapsa triquetra* reached 1.2×10^7 cells L^{-1}. This species was not found in any appreciable abundance at the other stations indicating a possible salinity barrier for the organism. The dominant species during the summer and fall was *Gymnodinium danicans*. In general, dinoflagellates were a major component of the phytoplankton throughout the year, with highest concentrations occurring in late spring and summer.

Other Categories

The chlorophytes were a common and diverse component of the phytoplankton throughout the study. They were represented by a variety of species which included *Chlorella* spp., *Dictyosphaerium pulchellum*, and *Selenastrum minutum*. Three peaks occurred, the largest was in late fall (October and November). This development was mainly upstream, with an average concentration of 3.3×10^3 cells L^{-1}. A second smaller peak was in April during the spring diatom pulse. A third larger peak occurred in late summer (July and August) of 2.6×10^3 cells L^{-1} at the upstream station (PG3).

The cyanobacteria concentrations exhibited a pattern that generally followed the water temperature, with lowest numbers in winter and highest in summer. Prominent species included *Chroococcus* spp., *Dactylococcopsis raphidioides*, *Merismopedia tenuissima*, *Merismopedia elegans*, *Microcystis aeruginosa*, *Microcystis incerta*, and *Phormidium* spp. The 12 month maxima occurred in October and was predominantly composed of *Microcystis incerta* at 6.8×10^7 cells L^{-1}.

The cryptomonads were ubiquitous and had concentrations that were never lower than 1.0×10^5 cells L^{-1}. They produced two small peaks at the upstream stations in October and May. The common species were *Chroomonas amphioxeia, Chroomonas pusilla*, *Cryptomonas erosa*, and *Cryptomonas erosa* var. *reflexa*.

Other phytoplankton categories included the Euglenophyceae , Prasinophyceae, and the Prymnesiophyceae. However, these groups all contributed less than 10% to the total cell counts throughout the year.

Biovolume

Phytoplankton biovolume in the Pagan River mimicked the phytoplankton abundance pattern (Figure 3). This is mainly due to diatoms being the most abundant phytoplankton group and possessing relatively large cell volumes when compared to other phytoplankton. The second most abundant contributor to biomass was the dinoflagellates, especially during spring and summer. There were three periods of biovolume maxima, with the largest in fall at a mean station value of $5.1 \times 10^4\ \mu^3\ L^{-1}$, with PG3 having the highest values ($9.4 \times 10^4\ \mu^3\ L^{-1}$). This was followed by a second peak in early spring, mainly due to the diatoms. A third and smaller peak occurred in late summer with combined means of $2.8 \times 10^4\ \mu^3\ L^{-1}$.

DISCUSSION

The Pagan River represents a highly nutrified river having high concentrations of total nitrogen and total phosphorous, with the mean annual TN:TP station ratios of 2.4:1 and 2.5:1. Phytoplankton concentrations are higher in the Pagan River than in other regional rivers, (e.g. Elizabeth, James, Lafayette, and Nansemond rivers). Although many environmental parameters (e.g. rainfall, sunlight, temperature) were similar for these rivers, the differing factor appears to be the higher level of nutrients in the Pagan River. The phytoplankton community is exposed to comparatively higher levels of nitrogen and phosphorus than in these other rivers. The two main causes of the increased nutrient levels appear to be agricultural runoff and outflow from meat packing and sewage treatment plants in the local watershed.

Marshall and Lacouture (1986) reviewed long term patterns of phytoplankton populations in the Chesapeake Bay and indicated an increasingly abundant number and diversity of species have occurred in recent times. They concluded this trend was a result of increasing eutrophication, through nutrient addition, within the Bay. This rate of eutrophication in the Chesapeake Bay is enhanced by inputs from many smaller sites, such as the Pagan River.

It is not known whether the future reduction of nutrient (TN,TP) effluents into the Pagan River by the two meat packing plants and the sewage treatment plant will reduce the abundance of phytoplankton. Sufficient amounts of nutrient enhancement may be delivered to the Pagan River from various agricultural sources within its watershed and continue to support high phytoplankton concentrations. This influence is noted in the present results, which indicate station PG3, located above the three plants and their effluent entry into the river, has the highest phytoplankton concentration. Although some nutrient enhancement into the station PG3 area may occur from downstream commercial and industrial sources during tidal action, it appears additional enrichment to these waters comes from the surrounding watershed, including the adjacent wetlands and agricultural lands upland to station PG3.

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