PHYTOPLANKTON DYNAMICS OF TWO NORTH CAROLINA COASTAL PLAIN SWAMPS: SPECIES COMPOSITION, SEASONAL PERIODICITY AND IMPACT OF WASTEWATER DISCHARGE

MARY BETH H. SUTTON

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PHYTOPLANKTON DYNAMICS IN TWO NORTH CAROLINA COASTAL PLAIN SWAMPS: SPECIES COMPOSITION, SEASONAL PERIODICITY, AND RESPONSE TO WASTEWATER DISCHARGE

Mary Beth H. Sutton

INTRODUCTION

Wetland Values

Wetlands are valuable ecosystems which serve to interface land and water systems. Saturation of the soil and type of vegetation are major criteria which define wetlands (Cowardin, et al. 1979). These ecosystems support diverse plant and animal communities and the magnitude of primary productivity in wetlands is of global importance. In addition, wetlands provide sanctuary to many threatened and endangered species of plants and animals. Wetland ecosystems also have many valuable hydrologic functions. In palustrine forested wetlands, commonly called swamps, the inundation of the soil varies with the season and the amount of precipitation and runoff. One of the predominant values of wetlands is their capacity to serve as sites of water retention and flood control. They are also traps for suspended sediments and nutrients, thus improving the water quality downstream (Carter, et al.,1979). Because of their potential to improve water quality, wetlands have also been used as tertiary treatment for municipal wastewater discharge (Brinson and Westall, 1983; Richardson and Nichols, 1986). However, such uses are inappropriate if using the wetland as a site for sewage treatment will alter the valuable ecologic and hydrologic functions of the wetland.

Nutrient Removal By Wetlands

Many studies have been done on wetlands receiving sewage effluent, but none has conclusively shown that any wetland has the unlimited capability to remove nutrients and suspended solids from wastewater without detrimental effects on the wetland itself. Many studies have shown that the concentrations of nutrients in the water are reduced downstream of wetlands, although the wetlands seem to have a limited capacity to retain the nutrients. For example, some wetlands have become phosphorus-saturated and have lost their nutrient retention capacity (Dodd, et al., 1985; Nichols, 1983). Other wetlands are not suited for tertiary treatment and will export nutrients in similar concentrations to those entering the wetland (Schwartz and Gruendling, 1983).

The mechanisms of nutrient removal are physical and chemical as well as biological. Simple dilution plays a major role in many cases. Interaction with the sediments is thought to be one of the most important processes involved, but perhaps this mechanism may be limited by the amount of nutrients the sediment can adsorb (Nichols, 1983). Biological uptake can also be an important mechanism, but this is also limited to certain types wetlands or the time of year supporting the highest rates of primary productivity (Klopatek, 1978; Mudroch and Capobianco, 1979). Uptake by non-woody macrophytes (e.g. Carex sp., Typha sp., Scirpus sp.) occurs at a higher rate than by trees, and springtime blooms of attached filamentous algae can take up nutrients at a rate comparable to macrophytes. Both Atchue, et al. (1983) and Brinson, et al. (1981) found that the late winter/early spring filamentous algae bloom in swamps accounted for as much nutrient uptake as the herbaceous macrophytes. This finding is particularly significant since it would allow swamps to retain nutrients before the summer growing season began (Atchue,et al., 1983). Kuenzler, et al. (1980) and Yarbro, et al. (1984) also found a significant phosphorus retention by the filamentous algae in Creeping Swamp on the Coastal Plain of North Carolina. In contrast, phytoplankton is generally not a major factor in nutrient uptake.

Biological uptake occurs during the growing season. After fall dieback of leaves and emergent macrophytes occurs, the nutrients are once again returned to the water, although at this time the nutrients are typically released in a different chemical form than at the time of uptake. The retention and subsequent release of nutrients by emergent vegetation are beneficial in improving water quality. The nutrients retained in the emergent vegetation are not available for excessive algal growth in the growing season, there is typically more water available for dilution in the dormant season, and the nutrients are often re-released in forms unavailable to algae, such as in lignins, cellulose or other plant material (Nichols, 1983).

It appears that the hydrology of the wetland is one of the most important factors in determining the capacity of a wetland to take up nutrients since it determines, among other things, the contact time between the incoming nutrients, the biota and the sediments. Unfortunately, wetland hydrology can also be difficult to quantify. It is particularly difficult in swamps with many braided channels which can flood a width of several kilometers with a few centimeters of water. Every wetland has its own hydrological system, so it appears that to determine the feasibility of sewage disposal in a particular wetland one must first study its hydrology, chemistry, and biology.

Algal Response to Nutrient Loading

In other water bodies, particularly lakes and rivers, the response of biological communities to pollutant loading has been well studied. Many investigators have found that nutrient inputs, such as from a wastewater discharge, cause an increase in the biomass of the phytoplankton and attached filamentous algae. For example, Wager and Schumacher (1970) found an increase in the suspended algal biomass, particularly in cyanophytes and chlorophytes, downstream of a sewage effluent discharge into the Susquehanna River (New York). Olsen and Willen (1980) found that the phytoplankton biomass in Lake Vattern (Sweden) increased with increased nutrient loading but decreased after improved sewage treatment reduced the wastewater and nutrient loads. The changes in algal biomass were also accompanied by shifts in species composition, from oligotrophic species, mainly diatoms, to eutrophic species, primarily blue greens, and then back to oligotrophic species following nutrient diversion. The well known eutrophication and subsequent decrease in phytoplankton biomass of Lake Washington were also due to increased and decreased wastewater and nutrient loading (Edmondson and Lehman, 1981). A number of investigators artificially increased the nutrient concentrations in ponds and lakes and found higher suspended algal biomass after increasing the nutrients (for example, Schindler, 1974; DeNoyelles and O'Brien, 1978).

<u>Predictive Models</u>: Eutrophication, evidenced by increased nutrients and phytoplankton biomass, has become a prime concern of those involved in lake management. Many of the eutrophication studies use the phytoplankton biomass as estimated by chlorophyll <u>a</u> (chl<u>a</u>) concentrations and correlate the changes in chl<u>a</u> to changes in nutrients and other factors (OECD, 1982). Dillon and Rigler (1974), Canfield (1983), and Smith (1982) developed models which predict chl<u>a</u> concentrations from changes in nutrient concentration or nutrient loading in the lake. Jones, et al. (1984) have developed similar models for prediction of chl<u>a</u> concentrations in streams. Models predicting summer biomass (Smith 1985, Smith, et al. 1987) and relative biomass (Smith 1986) of nuisance blue-green algae in lakes have also been developed.

Community Structure: Studies of wetland phytoplankton, on the other hand, are very rare, particularly for the Coastal Plain blackwater swamps. In two studies in glacially formed peat bogs, diatoms and desmids dominated the phytoplankton (Hayward, 1957; Duthie, 1965). A Lake Champlain marsh was similarly dominated by diatoms (Schwartz and Gruendling, 1985). The phytoplankton in the Porter Ranch Peatland (Michigan) was dominated by desmids and other chlorophytes (Kasischke, 1974). Two studies have been done on the phytoplankton of the Great Dismal Swamp in Virginia and North Carolina. Marshall and Poore (1971) found desmids and diatoms dominated the summer phytoplankton community while Atchue, et al. (1983) found the phytoplankton in 1980 to be dominated by diatoms (*Pinnularia* sp.; *Eunotia* sp.; *Cymbella* sp.; *Tabellaria* sp.). Other abundant algae which they found included cyanophytes. (*Oscillatoria* sp.; *Lyngbya* sp.), the chlorophyte, *Closterium* sp., and the chrysophyte, *Mallomonas* sp. Whitford and Schumacher (1963) did an extensive survey of the phytoplankton of North Carolina rivers and streams including the slow-flowing brown water streams in the Coastal Plain. They also found diatoms and desmids dominated the phytoplankton community although chrysophytes (*Dinobryon* sp. and *Synura* sp.) and chlorophytes (*Eudorina* sp. and *Pandorina* sp.) were also fairly abundant. Cryptophytes were abundant in shallow, acidic, blackwater lakes in Finland which have similar water quality to swamps (Ilamvirta, 1983; Arvola, 1983).

Biological Response to Pollution: Studies of the effect of pollution on the phytoplankton of wetlands are also very uncommon. Stevens Brook Marsh (northern New York), which received sewage effluent discharge, was dominated by greens, bluegreens, and euglenoids (Schwartz and Gruendling, 1985). A number of studies, however, have examined the effects of wastewater on the growth of filamentous algae. Richardson and Schwegler (1986) performed bioassays *in situ* using the attached filamentous alga Cladophora sp., and found significantly increased growth rates near the sewage outfall.

Practical Implications

In the coastal plain of North Carolina and many other coastal states, small communities do not have the financial resources necessary to upgrade their sewage treatment facilities, although the Clean Water Act requires that they have tertiary treatment of their sewage. Since many of these communities are situated near swamps, the possibility of using the swamps as tertiary treatment would be a financially feasible way of meeting the EPA standards for effluent water quality. The state of Florida grants wetland disposal permits only after the state Department of Natural Resources has made a 1-year study to determine the potential effects the effluent disposal might have on the wetland (Larry Schwartz, Florida DNR, pers. comm. 1986). Although the blackwaters of the coastal plain swamps generally have low concentrations of nutrients, low conductivity, and low productivity (Kuenzler, et al. 1980), the dissolved oxygen concentrations are naturally so low that the addition of wastewater could cause anoxic conditions to occur. The lowest natural oxygen conditions also occur during the summer when the flow rate of the swamp streams might be zero. The ecological implications of wastewater discharge into specific swamps and the possibility of nutrient saturation also must be investigated.

The state of North Carolina has been considering permitting of wetland discharge for some time and has been studying a number of sites which were granted temporary wetland discharge as research sites. The EPA determined there were many more wetland dischargers in North Carolina than are permitted as such (EPA, 1983). Two of the sites specially permitted to allow for research on the effectiveness of Coastal Plain swamps for tertiary treatment were the subjects of study by researchers at the University of North Carolina. One study investigated the nutrient retention by the swamp and the effect on the woody vegetation in one swamp (Kuenzler, 1987). The research presented here was conducted in conjunction with the study by Kuenzler (1987) mentioned above. The goals of this report were:

1. Characterization of the species composition and seasonal distribution of phytoplankton in two Coastal Plain swamps.

2. Characterization of the species composition and seasonal distribution of algae in the oxidation pond at Clarkton, NC.

3. Determination of the spatial variation in phytoplankton downstream of the effluent input and the relation of the variation to physical and chemical factors.

4. Comparison of the relation of the chlorophyll and nutrients in swamps to other water bodies via use of empirical models.

5. Determination of the importance of the phytoplankton community structure and algal biomass in swamp water quality management.

METHODS

Samples were collected once a month from all stations. One grab sample was collected for each of the nutrient analyses. Dissolved oxygen, pH, water temperature and air temperature were determined while in the field. Nutrient analyses of filterable reactive phosphorus, nitrite+nitrate, and ammonium via E.P.A. approved spectrophotometric methods were performed in our laboratory until after August 10, 1985, after which they were done in the analytical laboratory of the N.C. Department of Environmental Management. Additional analyses performed by the D.E.M included total phosphorus, total kjeldahl nitrogen, chloride, biological oxygen demand, and fecal coliforms. A detailed explanation of the methods and the results of the nutrient data can be found in the report by Kuenzler (1987).

Phytoplankton Counting Methods

Collection: At each station, two grab samples in 125 ml containers were collected from just beneath the water's surface. Within one hour, one of the bottles was preserved with Lugol's solution. The other sample was kept alive. Both samples were kept on ice and in the dark until analysis.

Examination: The live samples were examined within 3 days. 15 ml of the live sample was spun down in the centrifuge at the highest speed. The supernatant was decanted off the material at the bottom. The algae were resuspended in the remaining drop left in the tube which was then placed on a microscope slide to identify the live algae, especially the flagellates.

The dead samples were examined using settling chambers. 1-30 ml of the fixed sample was settled for quantitative identifications. The samples were settled at least 1 hour for every 5 ml to insure complete settling. (Lund, et al., 1958).

Counting Methods: After settling, the samples were examined using a Unitron inverted microscope. First, the bottom of the chamber was scanned at a low power to search for large, infrequent species. Then at a higher power (200x-450x), the phytoplankton along transects of the bottom were identified and counted until at least 100 specimens of the dominant species had been counted or at least 300 specimens had been counted. If the phytoplankton was very sparse and 300 specimens were not likely to be found, either one half or the entire bottom would be counted. The number of fields were counted and the counts converted to the number of cells/ml.

Biovolume estimates of most species were determined by either Dr. Peter Campbell or the biological lab at the DEM. Those biovolumes not available from these sources were determined measuring the dimensions of the algal cell and estimating its volume using standard geometric formulas. The total biovolume at each station was determined by multiplying the cells/ml by volume estimates of the cells (Lund, et al., 1958).

Verification of the counting was made by recounting a number of samples and comparing the results with the first count. Aid in identification was obtained from Drs. Edward J. Kuenzler, Max Hommersand and Peter C. Campbell. Phytoplankton keys used included those of Prescott (1962), Whitford and Schumacher (1984), Cocke (1967), Reimer and Patrick (1966), Huber-Pestalozzi (1951), and an unpublished work by Dr. Campbell.

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Diatoms: 15 ml of samples in which diatoms were among the dominant species were spun down at high speed in the centrifuge. The supernatant was decanted and the remaining organic matter was placed on a slide and burned off at high temperature. A drop of Hyrax and a coverslip were then added to the slide. After the slides were cooled, the dominant species of diatoms were identified. The proportions of the different species were determined from the quantitative counts (Peter Campbell, pers. comm., 1986).

Data Analysis

Data handling and graphics were done on a Leading Edge Model D personal computer using LE Twin, Lotus 1-2-3 and Systat software packages.

The percent change in dilution of the sewage in the swamps was estimated to give an approximation of the variation in water volume in the swamp stream. This was accomplished by comparing the chloride concentration at stations downstream of the effluent input to those of the effluent. The equation used to estimate the percent change in dilution was:

$$WVOL=(1-(C_i-C_c/C_e-C_c))*100$$

where C_i is the chloride concentration at the station, C_c is the chloride concentration of the control station, and C_e the chloride concentration of the effluent. This calculation gave the change in dilution of the chloride.

Similarity indices were calculated to give an indication of the biological similarity among stations. The calculation used the total biovolumes of the phytoplankton species present at each station. The equation is the PSC percent similarity index modified to include biovolume (Washington, 1984).

$$PSC=100-0.5\quad|a-b|$$

where a and b are, for a given species, the percentages of the total sample biovolumes, A and B, which each species represents.

Stepwise multiple regression analyses were performed on the two year data set to see if any of the physical or chemical parameters which were measured, such as water temperature, the variation in water volume present in the swamp, or different species of phosphorus and nitrogen, could account for most of the variance in chlorophyll *a* concentrations. Systat software was used for these procedures.

SITE DESCRIPTIONS

Lewiston-Woodville

The Lewiston-Woodville sewage treatment plant is located beside Highway 42/11 in Bertie County and discharges approximately 0.1 MGD of effluent directly into the Cashie River. The sewage treatment plant is an extended aeration package plant designed to overtreat the sewage by having low loading rates and long detention times during the aeration treatment. It is a simple activated sludge plant which, when operated properly, can give very satisfactory treatment (J.C.Lamb,III personal communication,1986). However, when the sludge is not removed from the plant on a regular basis, it will be discharged with the effluent. This can cause problems for swamp dischargers.

A new sewage treatment facility is planned to be constructed between the summer of 1986 and the summer of 1987. It will be an activated sludge plant which discharges its effluent into the swamp using a perforated pipe.

The Cashie River at the point of effluent input is actually a cypress-gum swamp which is inundated for most of the year. During summer drydown, the stream becomes intermittent and sewage accounts for all of the flow for approximately 300 meters below the effluent input. The forest is dominated by tupelo gum, black gum and red maple. Bald cypress is also present, as is sweet gum, cottonwood, green ash, and holly. *Saururus cernuus* (Lizard's Tail), *Polygonum* sp. and *Carex lupulina* are the most abundant herbaceous macrophytes.

The Cashie River interconnects with the Roanoke River as they both empty into the Albemarle Sound. The area of the watershed above the effluent input is 62.1 km^2 and the river's watershed area above the sampling site farthest downstream is 110 km^2.

There were up to 9 stations sampled around the effluent input on the Cashie River and on its tributaries (Figure 1).

1) Station 1 was 120 m upstream of the sewage input above Hwy 42/11. The swamp was closely bounded and encroached upon by agricultural fields to the east and extensive timber cutting to the west. Since the cutting occurred, the swamp forest was reduced to approximately 50 m wide. There was no water present at this station during the summer drydown.

2 & 2A) Station 2 was in the swamp directly in the path of the sewage flow, about 2 m away from the effluent pipe. It was in one of the braided channels of the swamp. For about four months, the sewage flow was blocked by a fallen tree which diverted the flow to another channel. During this time we sampled the new sewage route as Station 2A, also about 2 m from the effluent pipe. When the sludge built up so much that it blocked the sewage flow to Station 2A, the sewage stream was rediverted back to Station 2. During dry weather, some of the sewage also flows upstream and under the highway bridge, as evidenced by a dye study performed by the DEM (Lewiston-Woodville special study report,1985) and by our water quality data (Kuenzler,1987).

3) Station 3 was about 80 meters downstream of the effluent input. The vegetation was much the same, but more cypress trees were present. The main stream is very shallow here (<0.3m). When flooded, the swamp is nearly 1 km wide.

4) Station 4 was about 200 meters downstream of the effluent input in the main channel of the swamp, which was up to 0.7 m deep. Macrophytes were common, particularly <u>Saururus cernuus</u>. The stream and forest here contained many fish, turtles, dragonflies, damselflies, and numerous birds (e.g. kingfishers, herons, gnatcatchers, vireos, and anhingas).

5) Station 5 was about 3.2 km downstream of the effluent input and was near the junctions of many tributaries. Therefore, the swamp was very wide and deep at this point. This site was less encroached upon by agricultural fields and seemed undisturbed. This site is approximately 50 m upstream of the junction of the Cashie River and the Whatom Swamp. It was also about 600 m downstream of the joining of the LD tributary from the west. We observed that the swamp here provided habitat for many animals and birds such as muskrat, raccoon, deer, heron, prothonotary warblers, kingfishers, anhingas, pileated woodpeckers, yellow bellied sapsuckers, red headed woodpeckers, red eyed vireos, blue gray gnatcatchers, barred owls, and many others.

6) WS was the station at which we monitor the Whatom Swamp. It was about 50 m upstream of the bridge on SR1205. Many trees had recently fallen, presumably because of strong winds, and the swamp was closely bounded by corn fields.

7) Station 5 was the furthest station downstream and was 4.5 km from the sewage input. It appeared to be fairly undisturbed by humans since there were many very large tupelo and cypress trees here draped with spanish moss. The flow was affected for a number of months at the end of the study when a beaver dam backed up the water considerably. The dam also caused a significant rise in water level at Station 5. The site was 30 m upstream of the bridge over SR1219.

8) Station LD was a dredged tributary to the Cashie which drained part of Lewiston-Woodville and all of the N.C. Agricultural Experiment Station and its fields. It was a small tributary whose flow doubled or trebled during heavy runoff from the adjacent concrete roadside ditches. It was about 30 m downstream of Hwy 42/11 in the field beside the highway.

Clarkton

The sewage treatment facility at Clarkton is an oxidation pond which previously discharged into a small ditch at a rate of about 0.1 MGD. The ditch joined the swamp system about 750 m downstream. The discharge system was altered in May, 1985 when pipes and pumps were installed to carry the effluent to Brown Marsh Swamp where it was being discharged by a spray aeration system.

An oxidation pond is generally 3 to 5 feet deep and can reduce the BOD and suspended solids in the wastewater by 75 to 85% utilizing a complex combination of treatment methods. The detention time for a simple oxidation pond should be as long as 30 days with a one acre pond serving 200 to 300 people. Processes included in this treatment include settling of suspended matter, aerobic and anaerobic digestion of organic matter, and further reduction in BOD by biochemical reactions. Oxygen is primarily provided by the photosynthetic activities of the algae which grow abundantly in the pond. (J.C. Lamb, pers. comm., 1986). The single lagoon at Clarkton is also sporadically aerated by a small boat being driven around it. The abundance of algae proves to be a problem in small streams and swamps where discharge of great amounts of algae increases the stress on the discharge ecosystem.

The Brown Marsh/Elkton Swamp system forms the Red Hill Swamp which is a tributary to the Waccamaw River. The area of the watershed above the effluent input is 235 km^2 and the river's watershed to the last sampling station is approximately 300 km^2.

There were up to 12 stations sampled around the previous discharge site and along the swamp system and its tributaries (Figure 1).

1) BMS was on the Brown Marsh Swamp approximately 0.8 km upstream of the spray aeration system. It is a gum-cypress swamp with an abundance of red maple,

tupelo gum, black gum and ash with some cypress; details of tree abundances are given in Kuenzler (1987). The sampling site was about 40 m north of Hwy 211. The swamp was very shallow here, never exceeding 0.3 m deep during our sampling and often being completely dry.

2) ES was on Elkton Swamp about 45 m north of Hwy 211. We sampled near the head of a deep pool which often still had water when the swamp became intermittent during summer drydown. The Elkton and Brown Marsh Swamps are probably joined upstream of these sites at a railroad bridge. Therefore, both were considered to be control stations for the study.

3)EFF was the effluent sample taken directly from the wetwell of the treatment plant.

4) Station A was the first station sampled downstream of the sprayers in the swamp. It was approximately 30 m south of the cross in the sprayer pipes. The swamp here is primarily tupelo gum, black gum, cottonwood, ash, red maple and cypress. Before the spraying began, a lush undergrowth of macrophytes was also present. The sampling occurred in the deepest part of the stream, which reached a maximum depth of 0.4 m. The sludge from the effluent accumulated here in an unbroken blanket.

5)Station 1A was a small channel which formed during periods of higher water and branched off Brown Marsh Swamp just below the main pipe of the spray system. At times this channel also received part of the effluent, but on most sampling dates this station appears to be undisturbed. The sampling point was marked by a break in a raised railway bed and the swamp forest here was comprised of tupelo gum, red maple and some cypress.

6) Station B was 170 m downstream of the effluent discharge in a shallow (maximum depth of 0.4 m) tupelo gum-dominated area. The sludge also formed a blanket beyond this point until this stream rejoined the Elkton Stream again

at 228 m below the sprayers.

7) Station C was 320 m downstream from the sprayers, after the junction of the two branches and below a deep pool at the junction. The tupelo gum/cypress swamp was wider and the water deeper here. An old raised railway bed with big gaps in it marked the site. Even the deeper sections of this part of the swamp became isolated pools during the drought of the study year.

8) RHS was 4.5 km downstream of the sprayers on the Red Hill Swamp. The swamp system is about 1.6 km wide at this point and has many braided channels. The sampling point was on the main channel about 50 m above the second bridge from the east on SR 1700. Tupelo gum, cypress, and red maple dominated and many of the cypress knees reached a height of 1.4 m. Macrophytes include <u>Cyperus</u> sp. and <u>Saururus</u> <u>cernuus</u>. One time during the sampling period, this swamp was reduced to a series of small pools.

9) SS was the sampling station on a tributary to the Brown Marsh Swamp called Slades Swamp. It has a watershed area of 41 km^2 and the joining of Slades and Brown Marsh Swamps forms the Red Hill Swamp. Slades Swamp is a very shallow swamp with abundant <u>Saururus</u> <u>cernuus</u>. The trees are mostly tupelo gum and red maple. The sampling site is about 40 m upstream of the bridge on SR 1758.

10) UT was the station on the unnamed tributary which flowed beside the sewage lagoon and into which the effluent was previously discharged. It is a dredged ditch which also drains a number of agricultural fields.

11) BFCR was the station on Big Foot Creek which previously flowed through a forest which had been clear cut near the beginning of our sampling period (probably winter 1985). It is a shallow, blackwater creek and is very responsive to heavy rainfall events which cause surges in its flow. BFCR and UT join to form Big Foot Swamp. It is a small swamp and was only flooded once during the sampling period.

12) BFB was the station on the main channel of Big Foot Swamp about 15 m below the junction of UT and BFCR. Its sediments are very deep and sticky and we often sunk up to our knees while trying to sample. Part of the sediments are likely residual sludge from the sewage effluent. The channel is dredged out past our sampling point. The Big Foot Swamp joins Brown Marsh Swamp about 1 km above its junction with Slades Swamp.

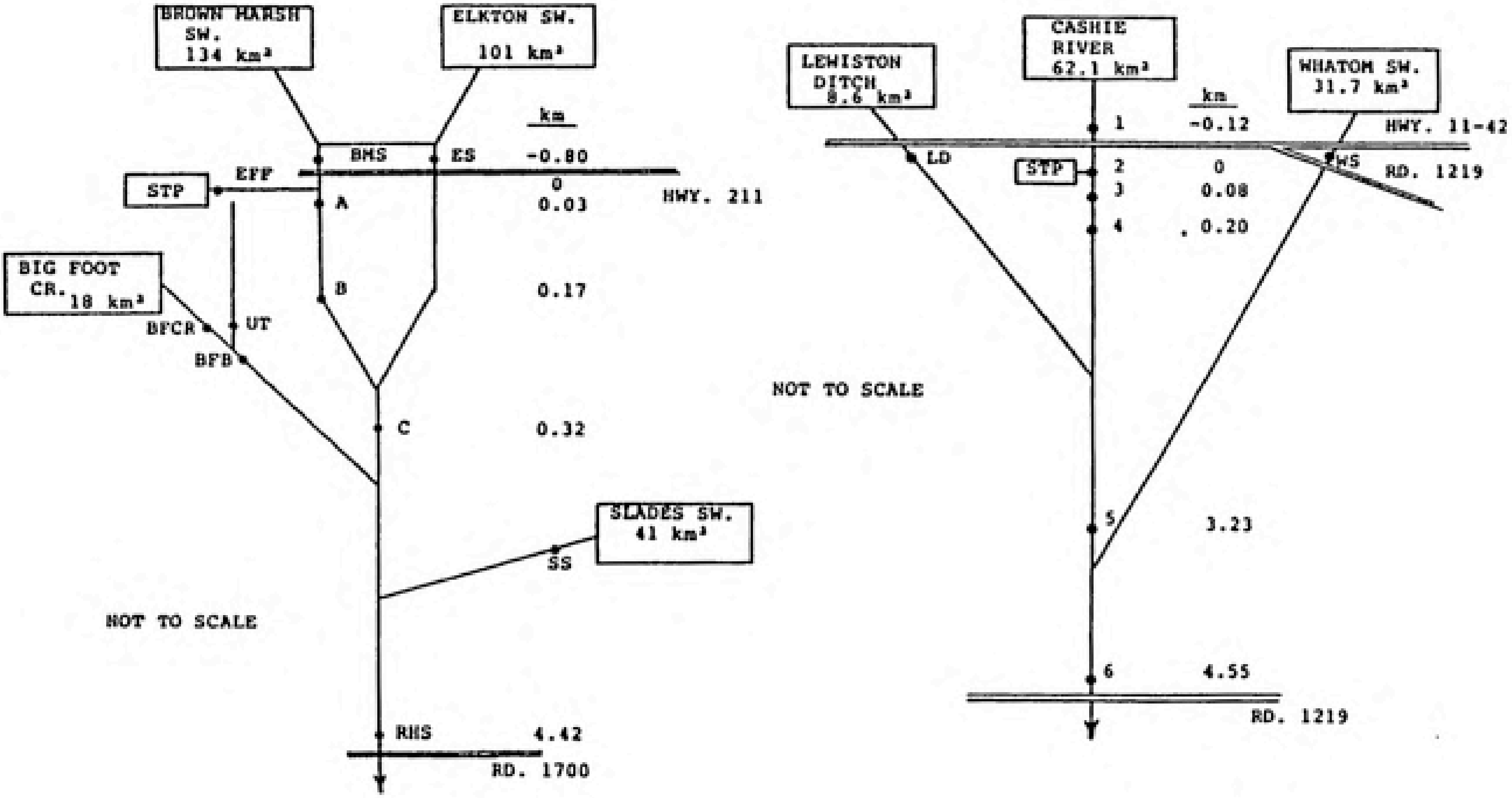


Figure 1. Diagrammatic maps of the Brown Marsh Swamp, the Cashie River, and their tributaries, with watershed areas, sampling stations, and distances between stations. (Kuenzler, 1987)

RESULTS

Natural Swamp Phytoplankton Community Structure

Total phytoplankton volumes were generally low in the two blackwater swamp streams. For the Cashie River control stations, 1 and 6, the phytoplankton biovolume ranged from 6.1×10^3 um^3/ml in November to a maximum of 1.64×10^7 um^3/ml in June. The median value was 5.1×10^5 um^3/ml, the mean value was 2.1×10^6 um^3/ml, and all of the values over 1×10^6 um^3/ml occurred from May through September. The lowest biovolumes occurred during the winter months when the amount of water in the swamps was high. For the Brown Marsh Swamp control stations, BMS, ES and RHS, the phytoplankton biovolume ranged from 7.2×10^4 um^3/ml in August to 1.4×10^7 um^3/ml in September. The median value was 5.0×10^5 um^3/ml and the mean was 1.6×10^6 um^3/ml . There was much more scatter in the biovolume data in the Cashie River, but lower values generally occurred in the cooler months, except for June and August, when more water than the summertime norm was in the swamps.

Both swamps also exhibited seasonal patterns in the species composition of the phytoplankton communities. The Cashie River phytoplankton was dominated by the Euglenophyceae from May through October, but the dominance pattern was more complicated in the cooler months when smaller cryptophytes, chrysophytes and chlorophytes vied for dominance (Figure 2A). One species of the Chloromonadophyceae dominated in April. The same general pattern was exhibited by the community of the Brown Marsh Swamp (Figure 2B). However, in summer the euglenophytes shared dominance with other classes, primarily cryptophytes and chrysophytes. The winter assemblages were dominated by cryptophytes and chrysophytes, but they were more complex, and euglenophytes, bacillariophytes, and chlorophytes were also important.

Analysis of the control site species composition in both swamps showed that the most important genera by percent composition by biovolume were *Trachelomonas* sp., *Cryptomonas* sp., *Euglena* sp., and *Synura* sp. (Figures 3, 4, and 5); they often comprised over 75% of the total biovolume sampled. Certain species within these genera were consistently important at both swamps. These include *Trachelomonas volvocina*, *Trachelomonas hispida*, *Cryptomonas marssonii*, *Cryptomonas erosa*, *Euglena chlamydomorpha*, and *Synura uvella*. Other genera which played an important role in the Brown Marsh Swamp were *Chromulina* sp., *Phacus* sp., *Nitzschia* sp., *Polycystis* sp., *Chilomonas* sp., *Closterium* sp., *Chlamydomonas* sp., *Mallomonas* sp. and *Pheaster* sp.(Figure 4). The spring was a time of major transition, particularly at the Cashie River. From January to April, 1986, the dominant genus in the Cashie River phytoplankton community changed every month (Figure 5). These dominants included *Synura* sp., *Pheaster* sp., *Pleurotaenium* sp., and *Gonyostomum* sp. When up to eight genera were included, they nearly always accounted for over 75% of the total biovolume sampled. In the Cashie River, other important genera include *Phacus* sp., *Nitzschia* sp. and *Chlamydomonas* sp.(Figure 3).

Although filamentous and attached algae were not systematically examined in this study, they were very important in both swamps in the spring. Some of the genera which grew extensively before canopy closure in the spring were the chlorophytes *Oedogonium* sp., *Spirogyra* sp., *Zygnema* sp., and *Mougeotia* sp. and the xanthophyte *Tribonema* sp.

Sewage Lagoon Phytoplankton Community Structure

The sewage lagoon at Clarkton also displayed marked seasonal variation. Excluding the April sample which was taken in the stream into which the effluent was discharged, phytoplankton biomass varied from 1.94×10^8 um^3/ml in

September to 3.1x10^6 um^3/ml in March. The mean of the 11 months was 5.2x10^7 and the median was 4.0x10^7. All of the values over 5.0x10^7 occurred in the warm season, between June and September. The Euglenophyceae dominated the lagoon phytoplankton community for half of the year, in the months of January, May, June, October, November, and December. In July through September, the Cyanophyceae dominated the community and in February, March, and April the Chlorophyceae dominated (Figure 6). In every month except August, one class constituted over half of the biovolume of the lagoon phytoplankton community.

Analysis of the lagoon data showed that the most important genera, by biovolume percent composition, were *Euglena* sp., *Oocystis* sp., *Oscillatoria* sp., *Arthrospira* sp. and, in June only, *Pandorina* sp. (Figure 7). The species within these genera which occurred most frequently were: *Euglena gracilis*, *E. pisciformis*, *Oocystis parva*, *Oscillatoria limosa*, *O. chlorina*, *Arthrospira jenneri*, and *Pandorina morum*. Other genera which were important in the lagoon phytoplankton community include the chlorophytes *Actinastrum* sp., *Ankistrodesmus* sp., *Coelastrum* sp., *Chlorella* sp., and the colorless euglenophyte *Menoidium* sp. The species which were most common in these genera were *Actinastrum hantzschii*, *Ankistrodesmus falcatus*, *Coelastrum microporum*, *Chlorella vulgaris*, and *Menoidium pellucidum*. Many species of the genus *Scenedesmus* sp. were also commonly present, including *S. quadricauda*, *S. opoliensis*, *S. bijuga* var. *alternans*, *S. acuminatus*, and *S. dimorphus*. *Nitzschia* sp. was only important in the sample taken from the receiving stream.

Spatial Variation Within the Impacted Swamps

Each of these swamp systems received a point source input of sewage effluent from a different type of treatment plant. The Lewiston-Woodville treatment plant primarily added nutrients and suspended solids to the Cashie River swamp stream while the Clarkton plant also added large amounts of algae to the Brown Marsh Swamp from its oxidation pond. These differences in the treatment systems should result in different phytoplankton communities downstream of the input.

Cashie River

Biomass: At the Cashie River, the effluent had little effect on the phytoplankton relative to the control site. Although there was rarely much phytoplankton within 2 m of the effluent pipe, higher total biovolumes were found further downstream after the effluent stream became more fully mixed with the swamp waters (Figure 8). The biomass of phytoplankton did not appear to be overtly affected by the wastewater input since total biovolumes at sites up- and down-stream of the effluent input were nearly always greater than the effluent site, suggesting simple dilution. In addition, the patterns of total biovolume varied widely with the highest biovolumes occurring at various stations and sampling dates. The particular months when the biovolume of one genus or species at a station was greater than 40% of the total biovolume for that station were:

OCTOBER	1985	Station 1	44%	Cryptomonas
NOVEMBER	1985	Station 2	89%	Chlamydomonas
MARCH	1986	Station 5	48%	Pleurotaenium
APRIL	1986	Station 5	48%	Nitschia

In the winter months, there was less biovolume found at the stations, and the biovolume at Station 2 was commonly close to or slightly larger than the next station downstream. However, in many months of the year, two main patterns emerged in the biovolumes downstream of the effluent input. In June, August, September, January, and March, the total biovolume had a gradual increase to Station 6, the last station downstream of the wastewater input. In July, October, and April, the maximum biovolume was found at Station 5. However, the patterns in total biovolume were not consistent for more than two consecutive months.

Community Structure: The structure of the phytoplankton community of the Cashie River did not show any consistent variation downstream from the effluent input. Similarity indices based on all species showed that Stations 1, 3, and 4 were very similar as were Stations 5 and 6, whereas Station 2 was very different from the others.

Brown Marsh Swamp

Biomass: At Brown Marsh Swamp, where the sewage treatment system continually discharged algae as well as suspended solids and nutrients into the swamp stream, a clear pattern of biovolume change was seen downstream of the sewage input by the spray diffuser system. In all months sampled, except the first month that sewage was discharged into the swamp, the algal biovolume found in the swamp decreased downstream of the input (Figure 9). In the cooler months, the drop in phytoplankton biovolume downstream from the sprayers occurred very rapidly and often dropped down to background swamp stream conditions within 300 m downstream of the sprayers .

Community Structure: The spray diffuser system began distributing effluent into the Brown Marsh Swamp in early May, 1985. The initial impact on the the phytoplankton community structure was that the natural phytoplankton community was displaced by the lagoon phytoplankton. The contrast of the similarity of station A to the effluent and controls from April to May illustrates the change in species composition (Figures 10 and 11). In April, the sample from station A contained a mixed, diverse community very similar to upstream or control stations (Figure 10). After the spraying began in May, the community was composed primarily of *Euglena gracilis*, *E.pisciformis*, and other members of the lagoon community (Figure 10). The percent similarity of station A to the control stations in April was 47% whereas in May the similarity to the control stations was only 8%. Conversely, the similarity of station A to the effluent in April was only 12% but in May it was 76% similar to the effluent.

The species composition of the phytoplankton displayed a marked pattern downstream of the sprayers. While the area within 100m was generally dominated by species found in the sewage lagoon, farther downstream the natural phytoplankton community of the swamp again became dominant (Figure 12). In the summer, the change in algal dominants downstream is not evident at the class level since the euglenophytes dominate both the lagoon and the swamp stream. A change from only the genus *Euglena* to a combination of many species of *Trachelomonas* and *Euglena* occurs in the swamp stream. A number of species of the genera *Phacus* and *Lepocinclis* were also present in the swamp stream in lower numbers. In addition, only two species of *Euglena* were found in the lagoon, *Euglena gracilis* and *E. pisciformis* while there were many species of the four euglenophyte genera found in the swamp stream. Among those species commonly found in the swamp stream are *Trachelomonas volvocina*, *T.hispida*, *T.granulosa*, *T.lacustris*, *T.acanthostoma*, *T.horrida*, *Euglena proxima*, *E.acus*, *E.tripteris*, *E.chlamydomorpha*, *E.sprirogyra*, *Phacus longicauda*, *P.orbicularis*, *P.curvicauda*, *P.inflexus*, *P.acuminatus*, *P.helikoides*, *P.pleuronectes*, *Lepocinclis ovum*, *L.steinii*, and *L.fusiformis*.

In the cooler months, the effluent algae did not dominate as far downstream as in the warmer months. Percent similarity of phytoplankton communities at different stations to the effluent also shows the change in species composition downstream of the sprayers (Figure 11). In the warmer months, the stations within 300m of the effluent were generally more than 75% similar to the lagoon but that dropped to about 50% similar or less in the cooler months. Similarity to control stations show the opposite pattern (Figure 10).

Blooms of cyanobacteria (Oscillatoria sp.) and purple photosynthetic sulfur bacteria (Chromatium sp.) commonly occurred below the sprayers in the spring and summer, covering the bottom of the swamp with dark blue-green mats or pink patches. The cyanobacterial blooms commonly extended for over 50m. In July at station B, Oscillatoria spp. (primarily Oscillatoria limosa) accounted for 48% of the total phytoplankton sample collected. Another bacteria present in the swamp stream below the sprayers was the "sewage fungus", Sphaerotilus natans, which would form long white filaments on top of the water and on the bottom of the stream. There were also occasional phytoplankton blooms of species not found in the sewage lagoon. For example, at RHS in June and ES in October, Microcystis sp. respectively accounted for 49% and 45% of the total phytoplankton sample at that station.

Variation in Chlorophyll a Concentrations

Stepwise multiple regression analysis was performed on the chlorophyll and physical and chemical data, in order to determine if the concentration of chlorophyll covaried with any of the water quality parameters which were measured and to see if predictive models could be formulated for swamp stream chlorophyll concentrations.

Cashie River: The Cashie River chlorophyll values were generally very low. A relatively small amount of the the variation in the chlorophyll concentrations was accounted for by any of the different nutrient concentrations and physical characteristics which were measured. Water temperature was a significant ($p<0.01$) factor, which alone accounted for 31.3% of the chlorophyll variance. The variation in two nutrient concentrations, those of total phosphorus and nitrite+nitrate, were also significant factors. The multiple regression model obtained utilizing all three factors is Equation 1.

$$(1)\quad \mathrm{LOGCHLA} = -0.141 + 0.467\ \mathrm{TOTP} - 0.309\ \mathrm{LOGNOX} + 0.039\ \mathrm{WTEMP} \quad R^2=0.421\ P<.05$$

The season of the year and the nutrient combined to account for about half of the variance in the chlorophyll concentrations of the Cashie River.

Brown Marsh Swamp: The variance in the Brown Marsh Swamp chlorophyll concentrations was also significantly related to total phosphorus ($p<0.05$). Total phosphorus(TP) alone accounted for 61% of the chlorophyll variance for all stations and sampling dates (Equation 2)

$$(2)\quad \mathrm{LOGCHLA} = 1.768 + 0.786\mathrm{LOGTP} \qquad R^2=0.61$$

When only the data from the main stem sampling stations were used, the model obtained included phosphate and nitrite+nitrate (Equation 3). Both total phosphorus and total nitrogen were also significant, but more variance was accounted for by phosphate and nitrite+nitrate.

$$(3)\quad \mathrm{LOGCHLA} = 2.571 + 0.454\mathrm{LOGNOX} + 0.394\mathrm{LOGPO4} \qquad R^2=0.65$$

For further analyses, the data was then divided into summer and winter data sets, the summer being defined by water temperatures >= 20 C, but no significantly different models were obtained. The variation in water volume, as estimated by chloride concentration, also was a significant factor and alone accounted for 27% of the chlorophyll variance. When it was added to the multiple regression model, however, it was not significant. The nutrients, particularly nitrite+nitrate and orthophosphate, played the major role in accounting for the variance in the chlorophyll concentrations in the Brown Marsh Swamp.

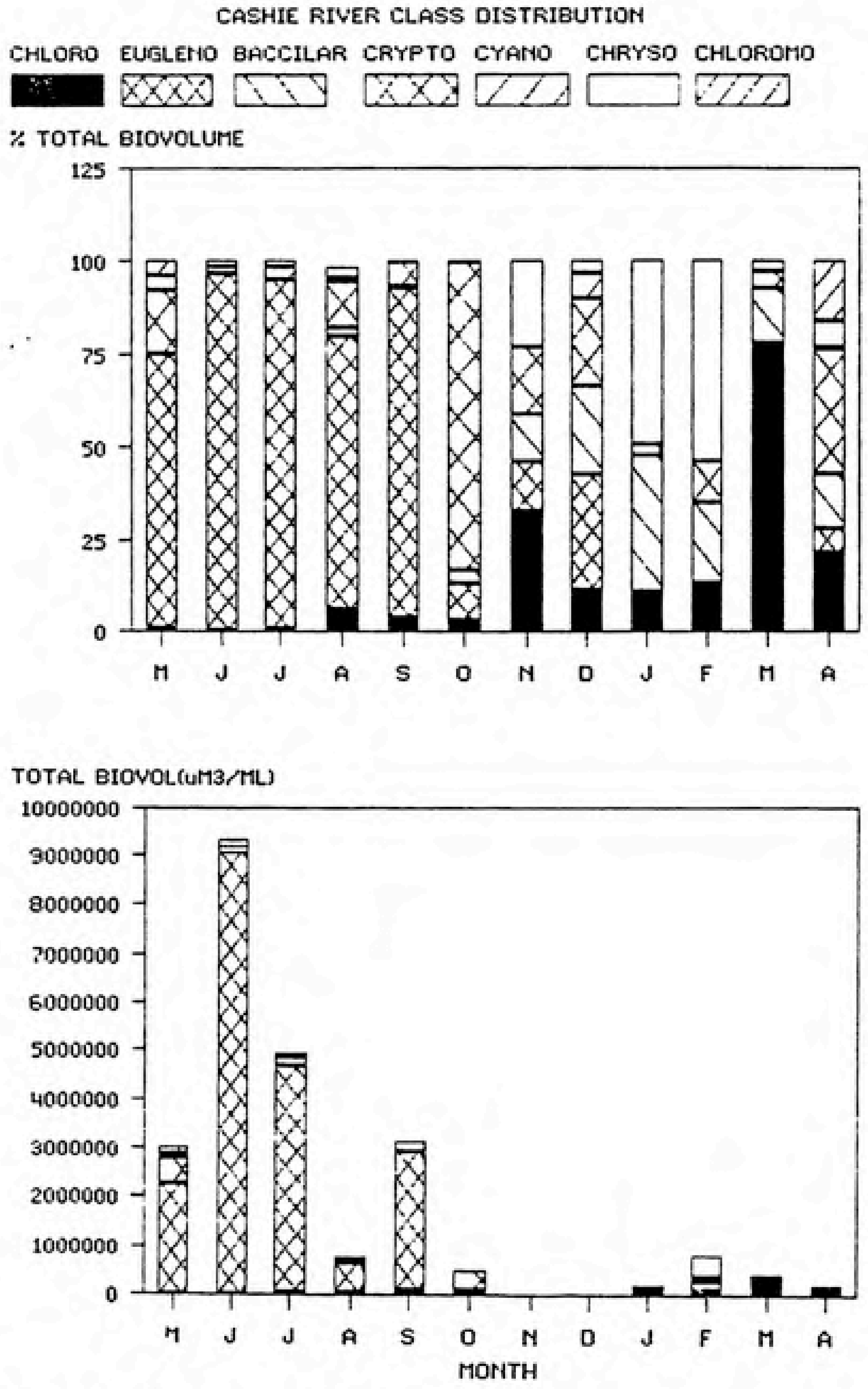


Figure 2A. Cashie River Phytoplankton Class Distribution.

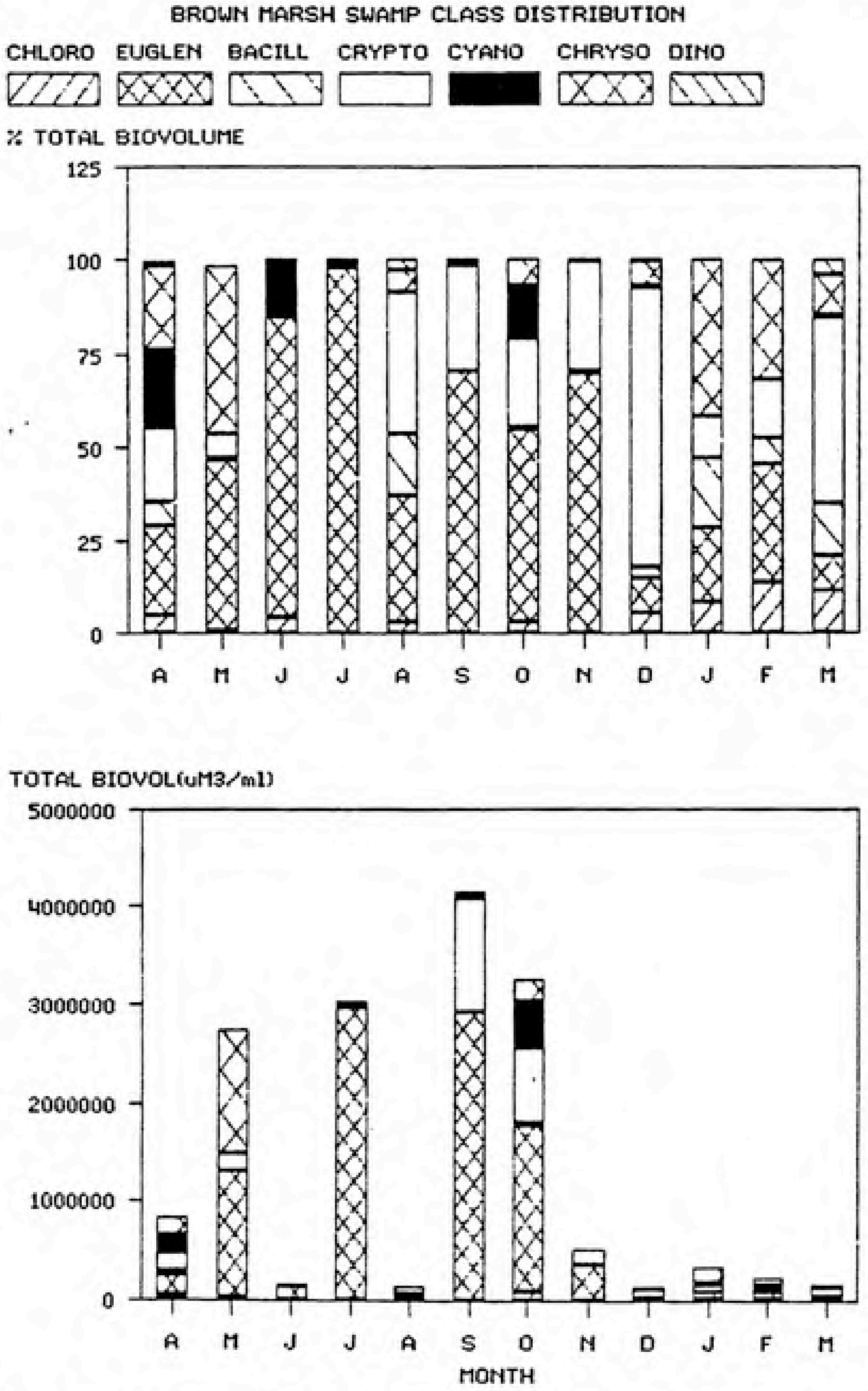


Figure 2B. Phytoplankton class distribution at Brown Marsh Swamp

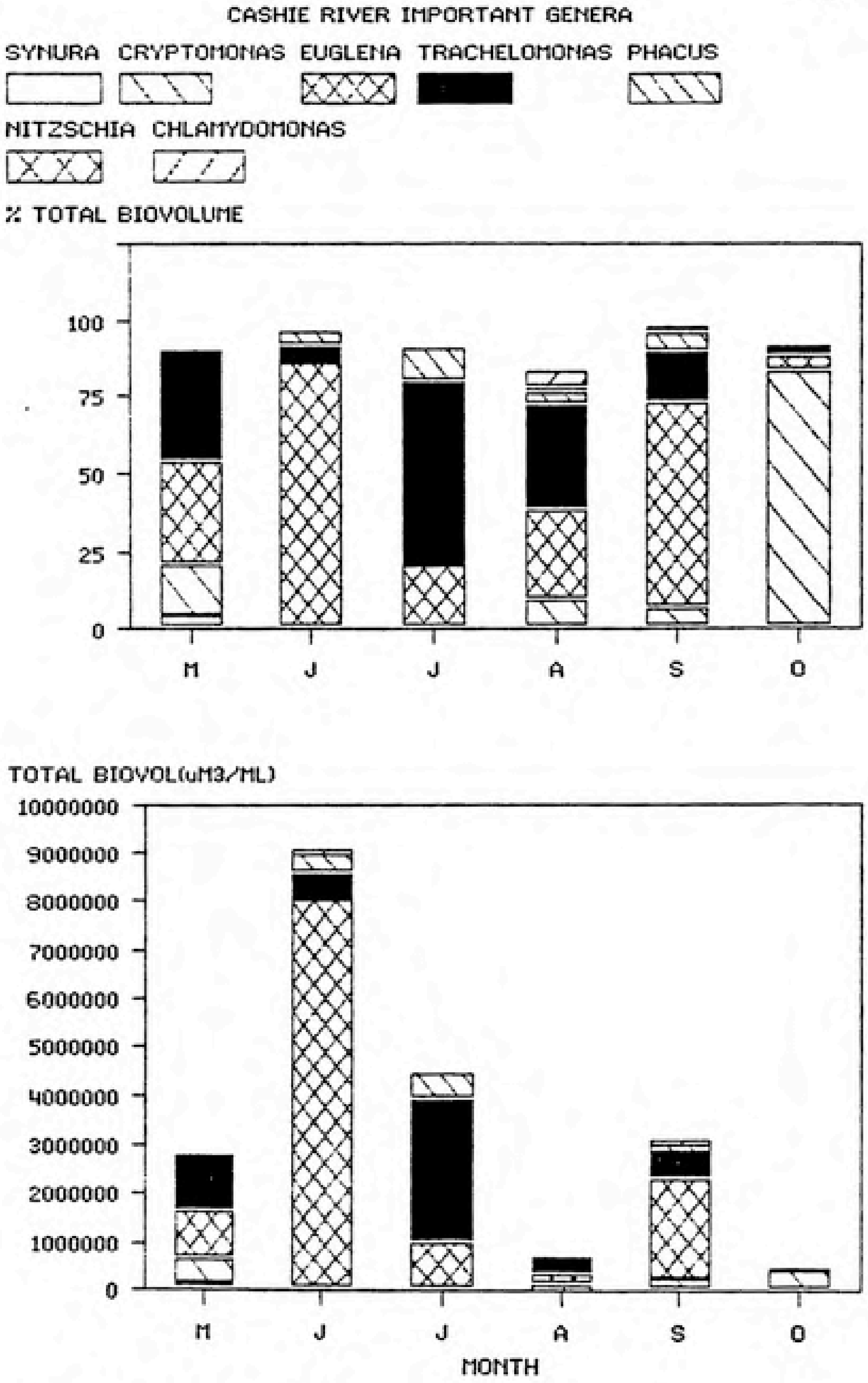


Figure 3A. Distribution of Important Genera in the Cashie River.

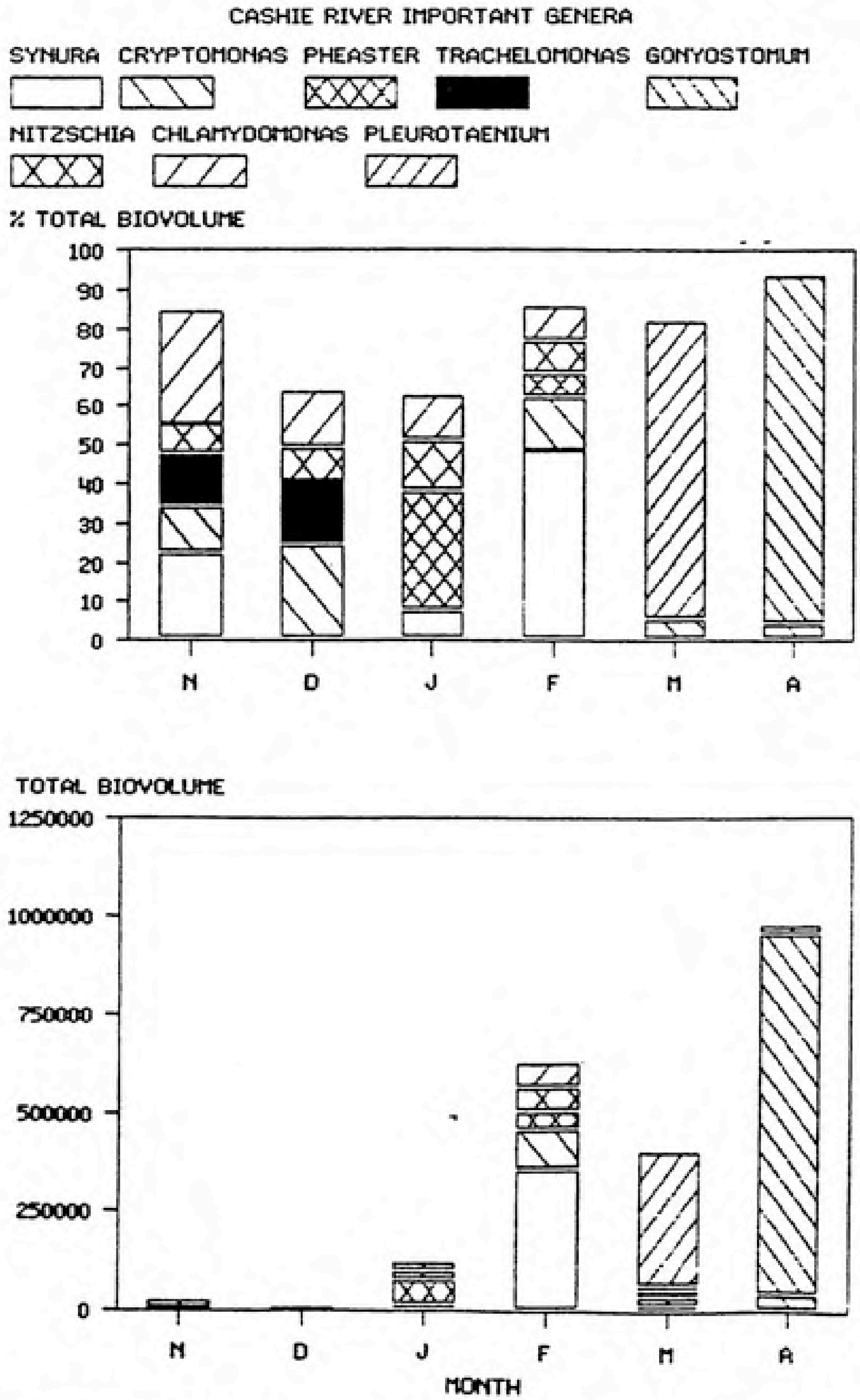


Figure 3B. Distribution of Important Genera in the Cashie River.

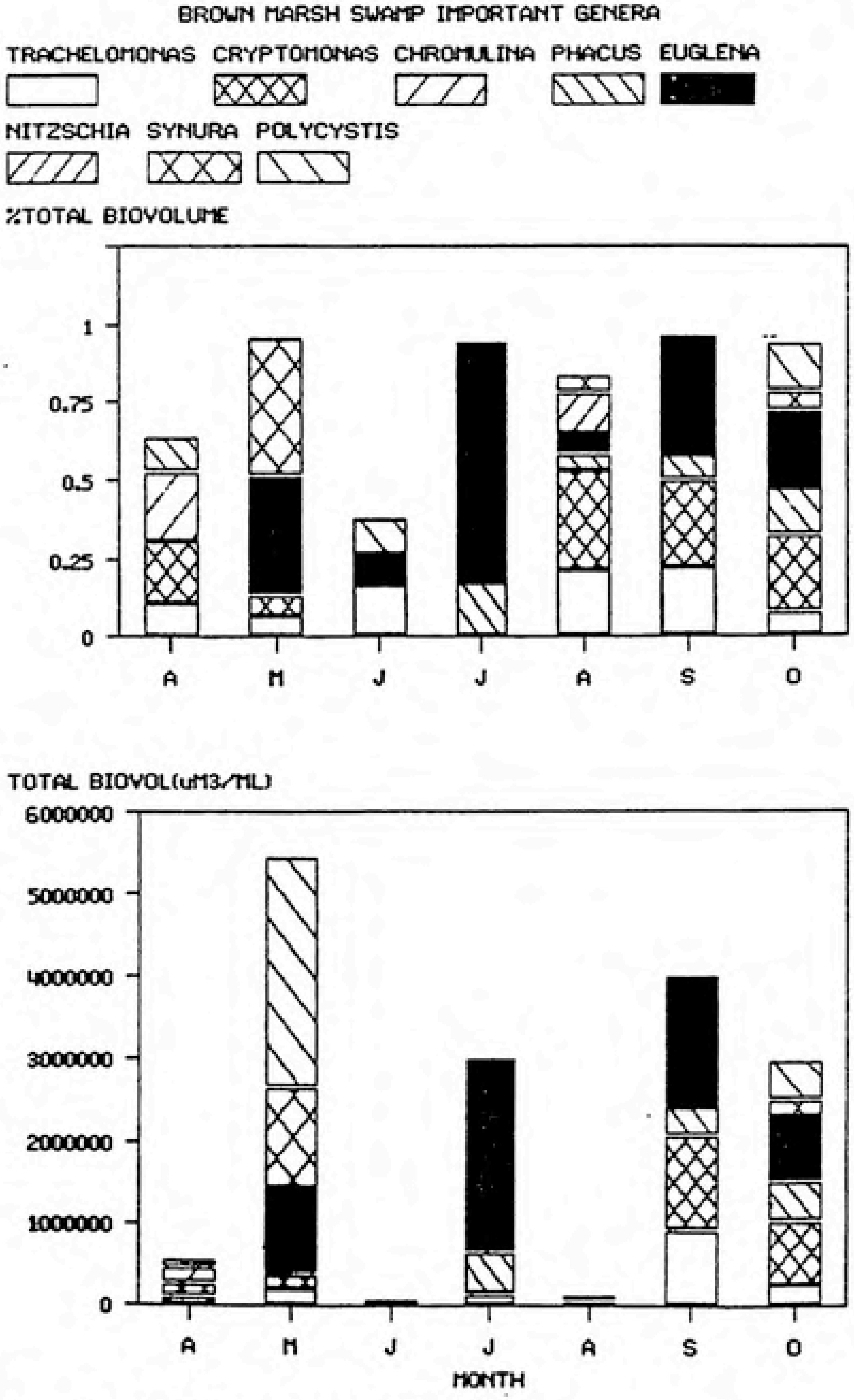


Figure 4A. Important genera of control stations in Brown Marsh Swamp.

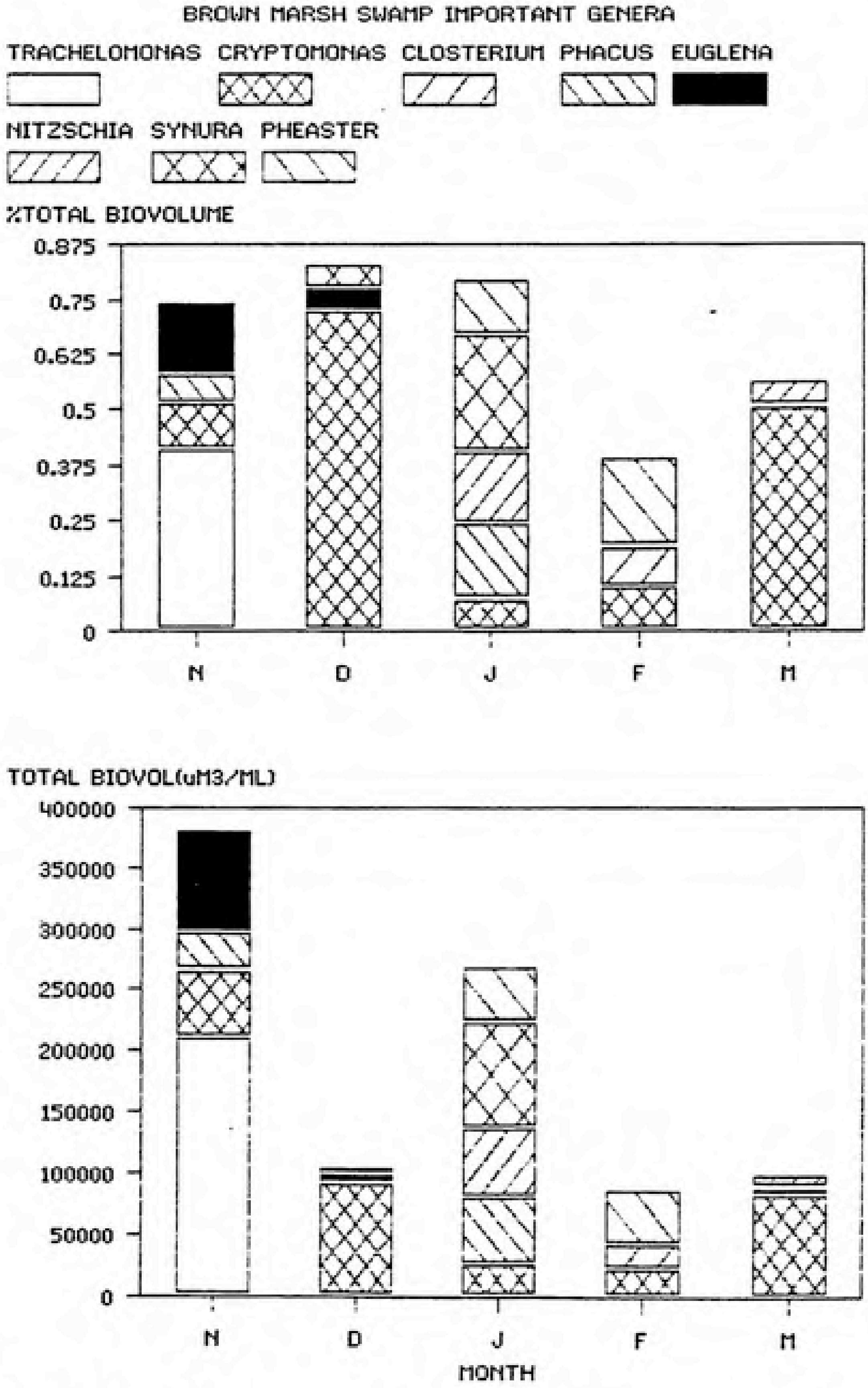


Figure 4B. Important genera of control stations in Brown Marsh Swamp.

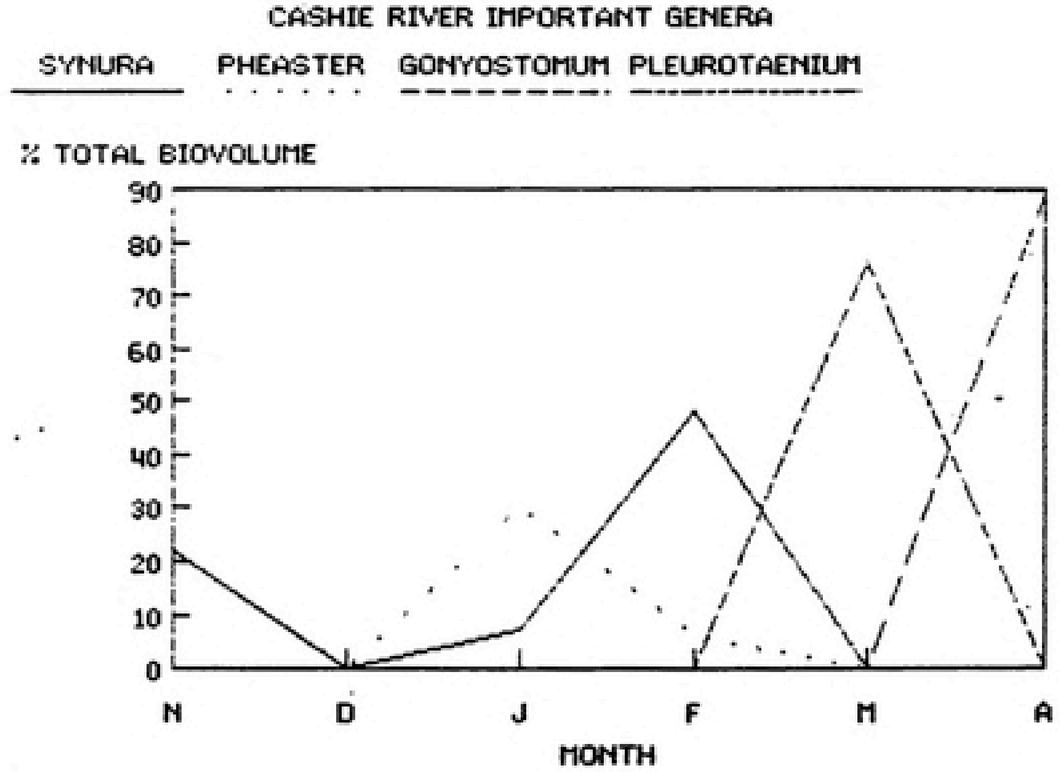


Figure 5. Distribution of Important Genera in the Cashie River.

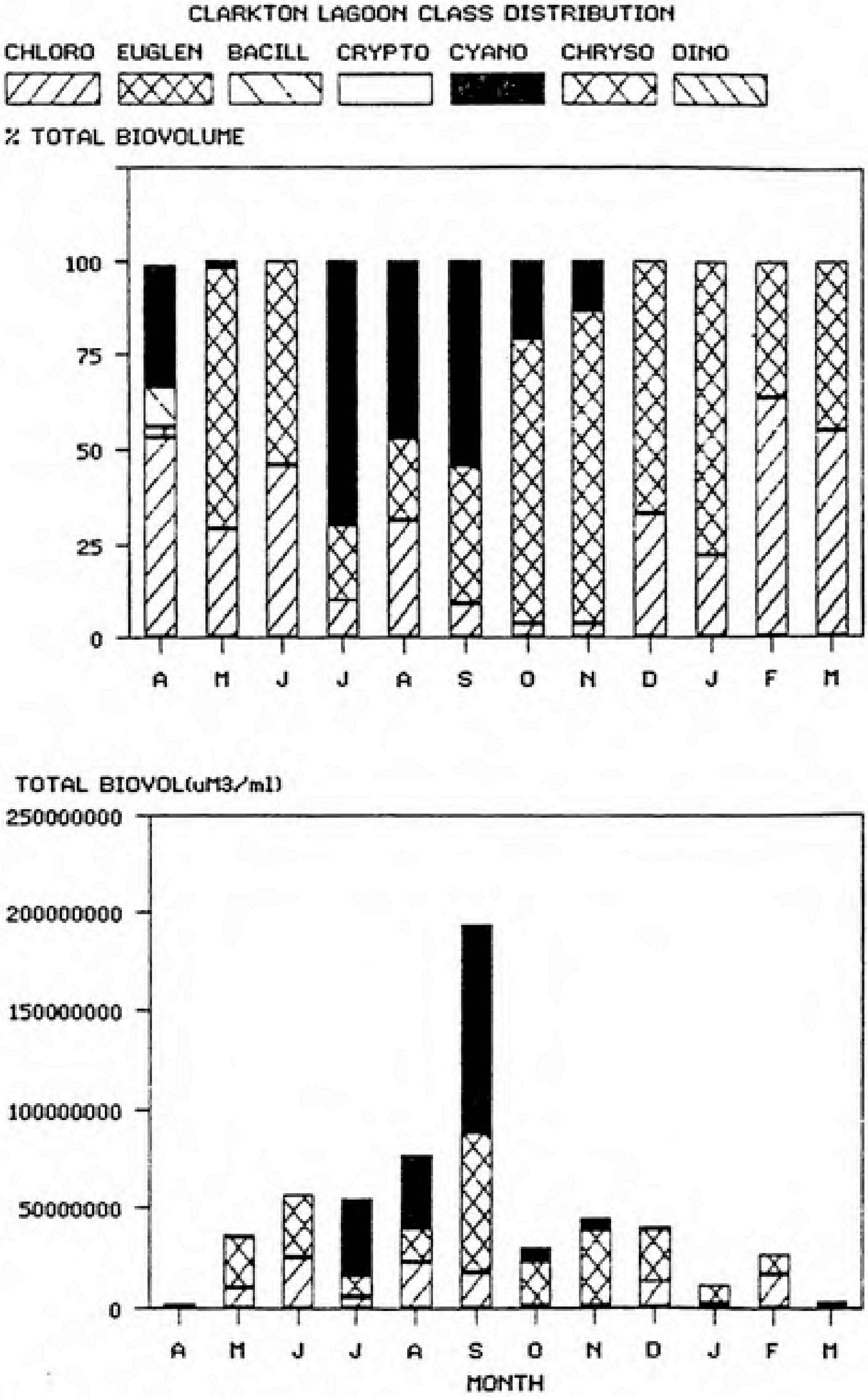


Figure 6. Clarkton Sewage Lagoon
Algal Class Distribution

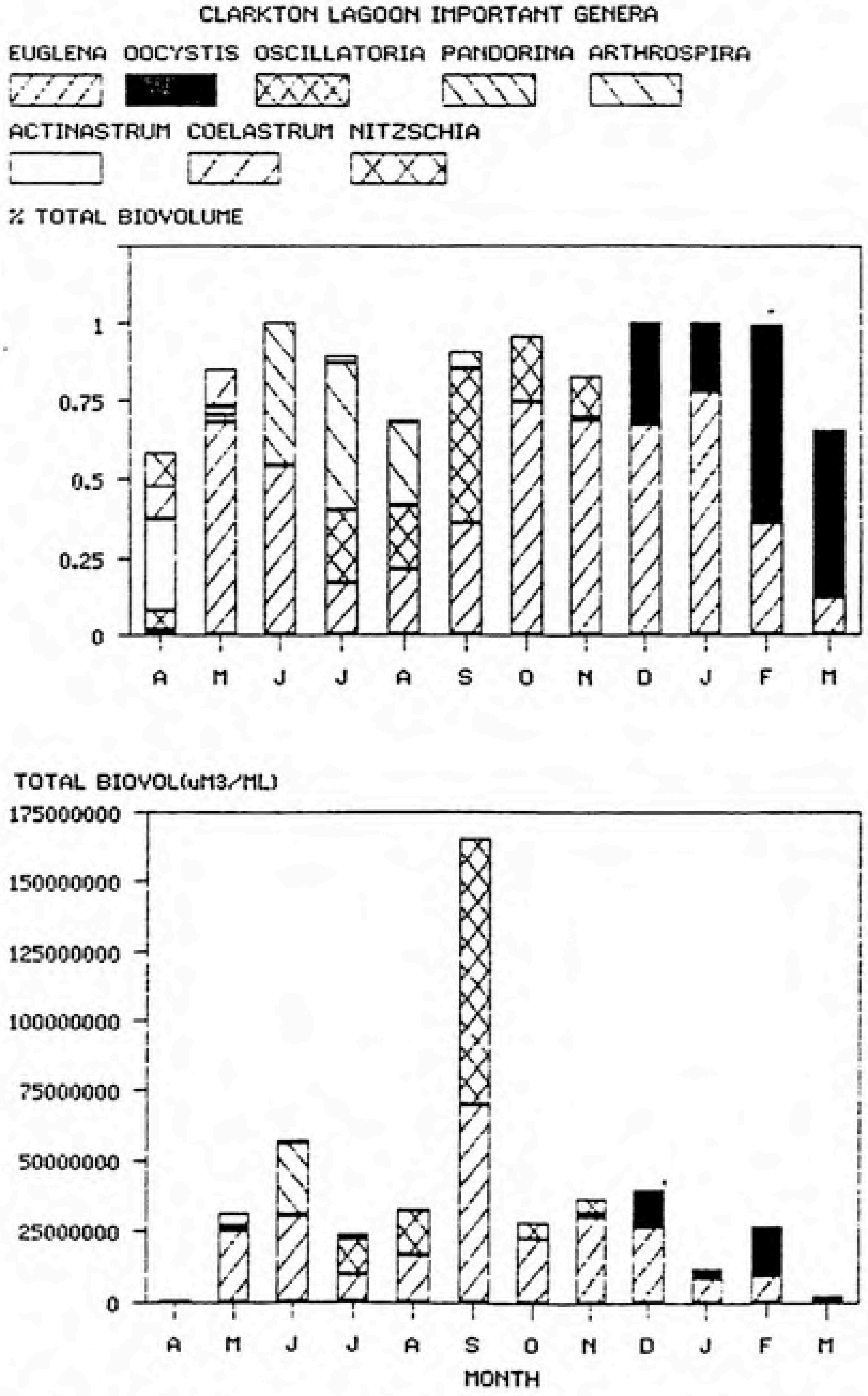


Figure 7. Important genera of Clarkton's sewage lagoon.

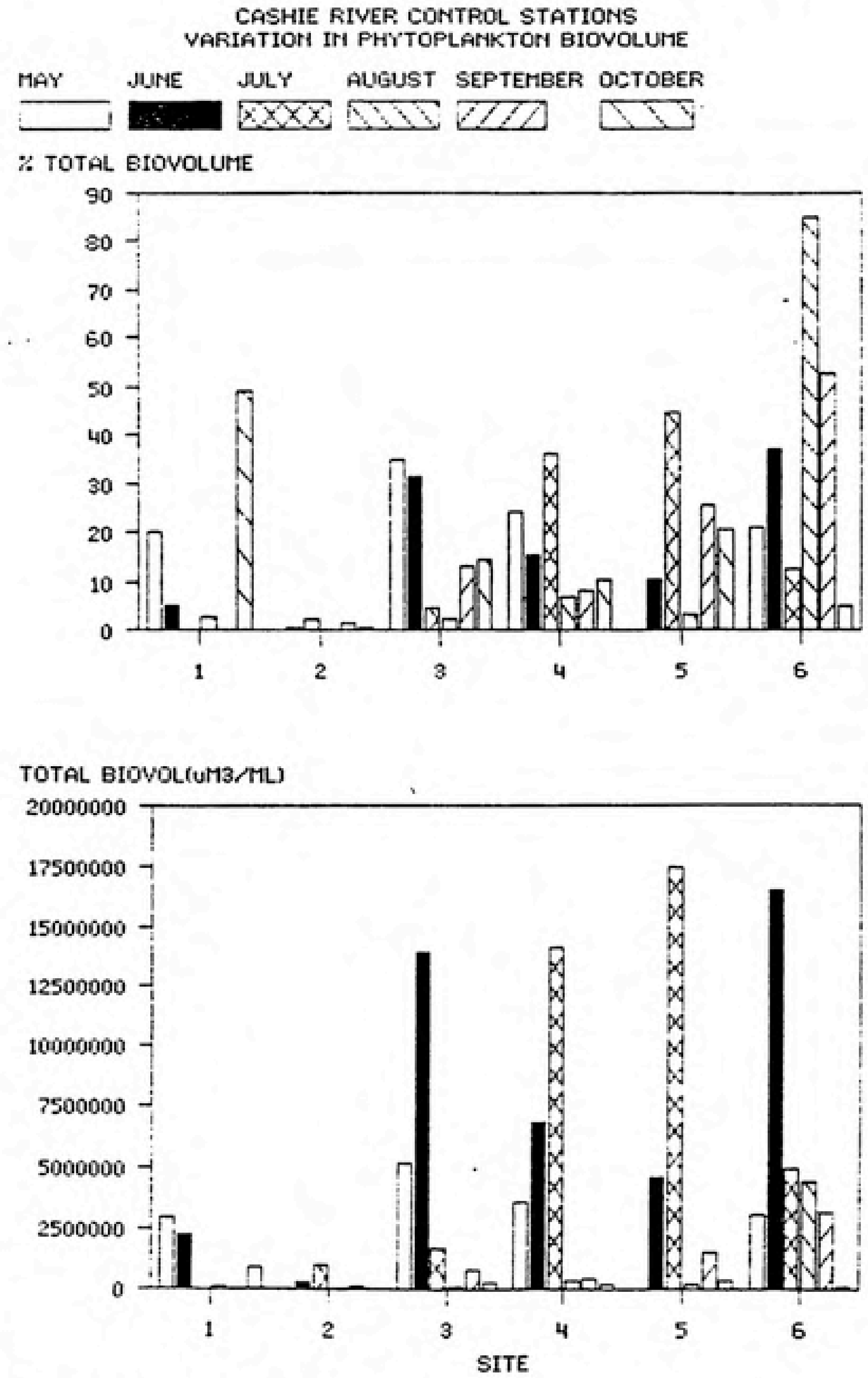


Figure 8A. Phytoplankton biovolume variation at stem stations.

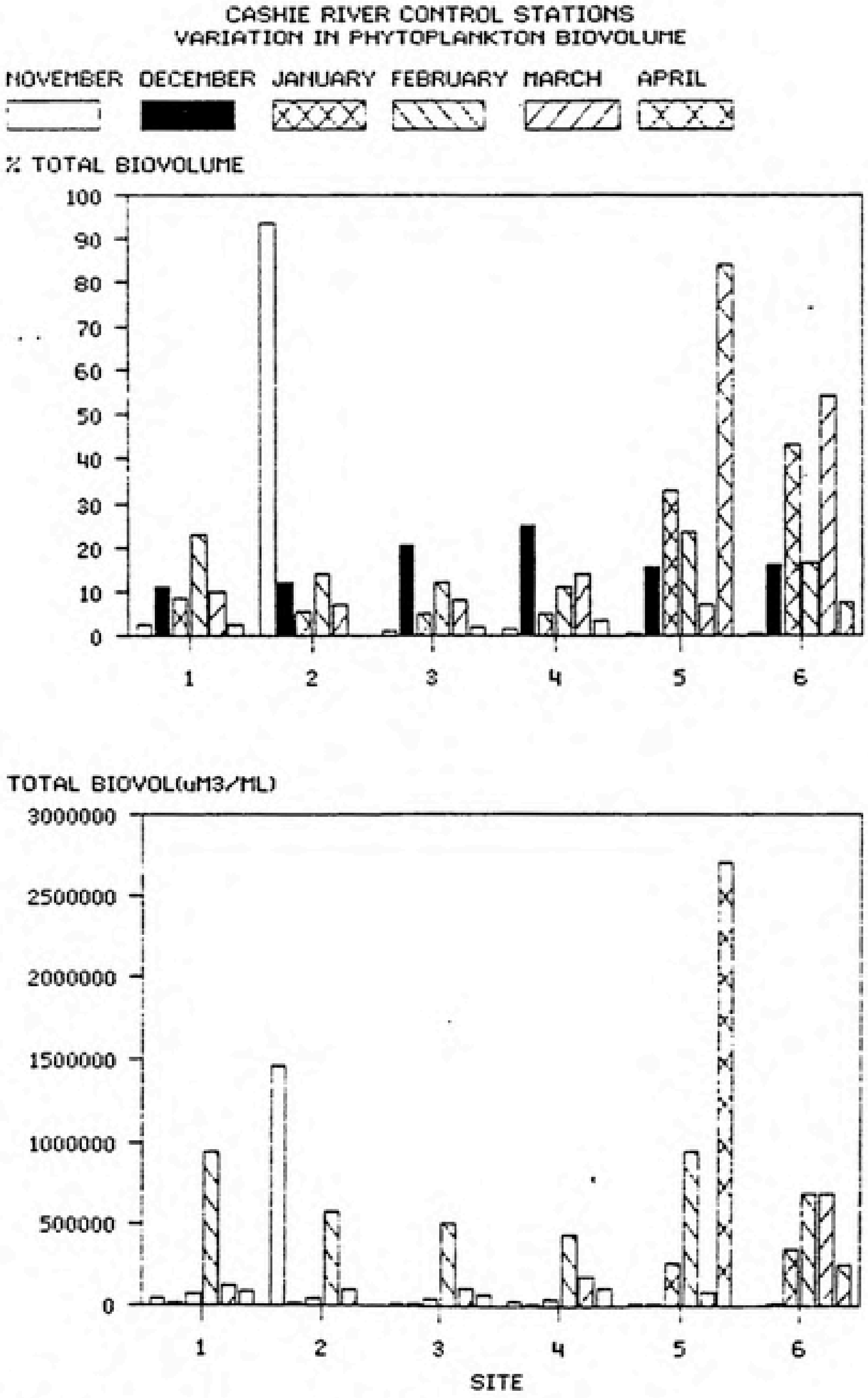


Figure 8B. Phytoplankton biovolume variation at stem stations.

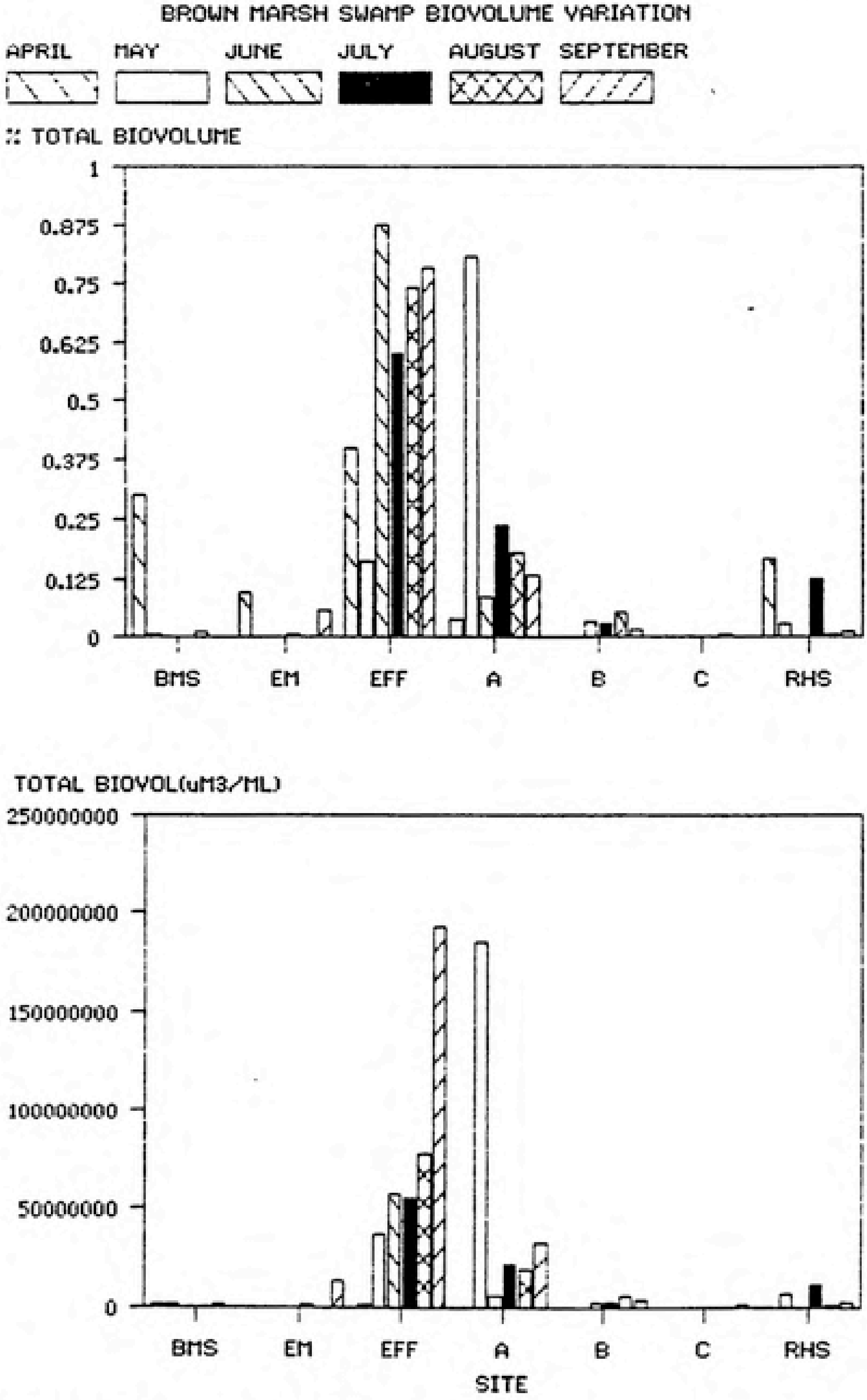


Figure 9A. Phytoplankton biovolume variation at stem stations.

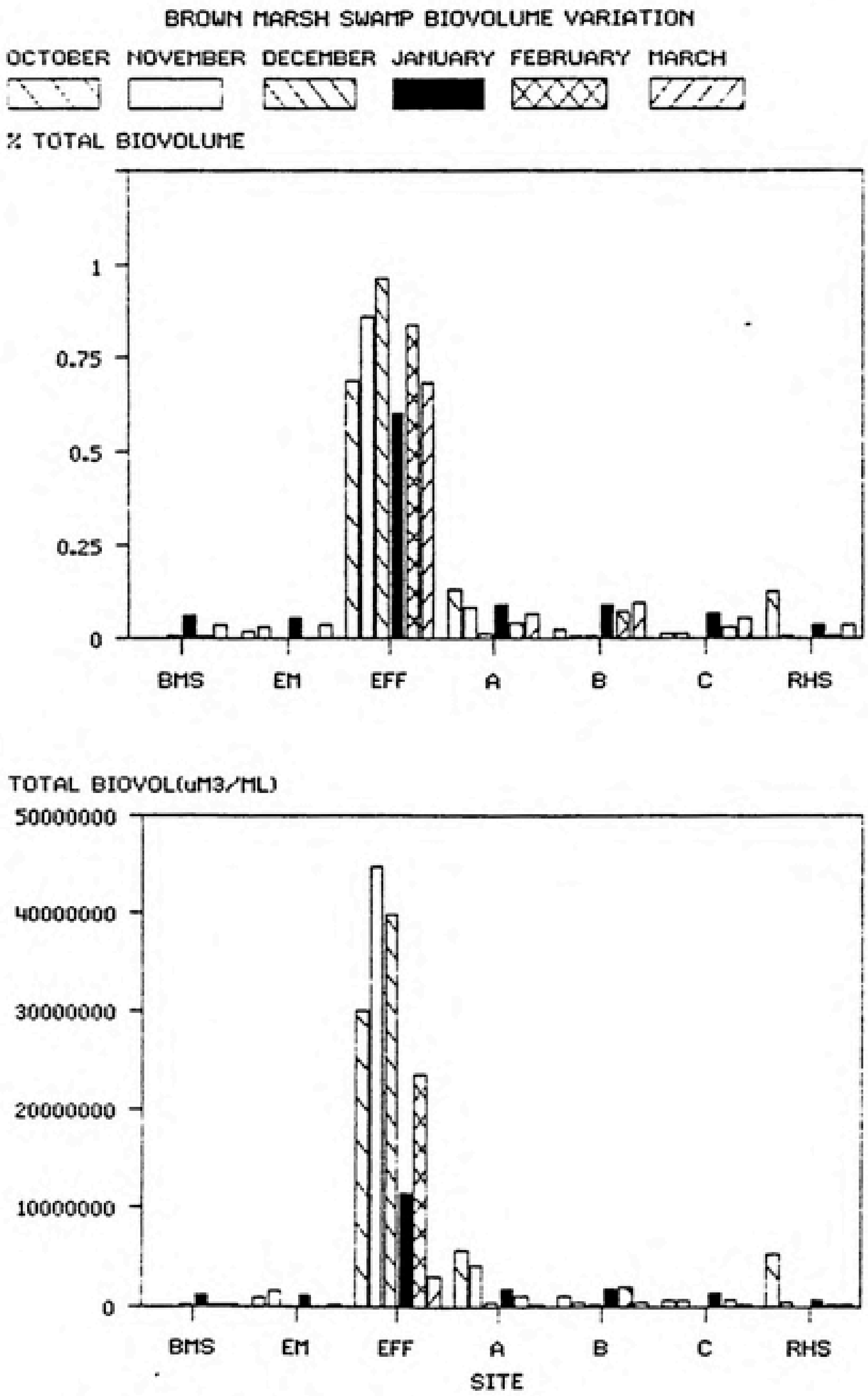


Figure 9B. Phytoplankton biovolume variation at stem stations.

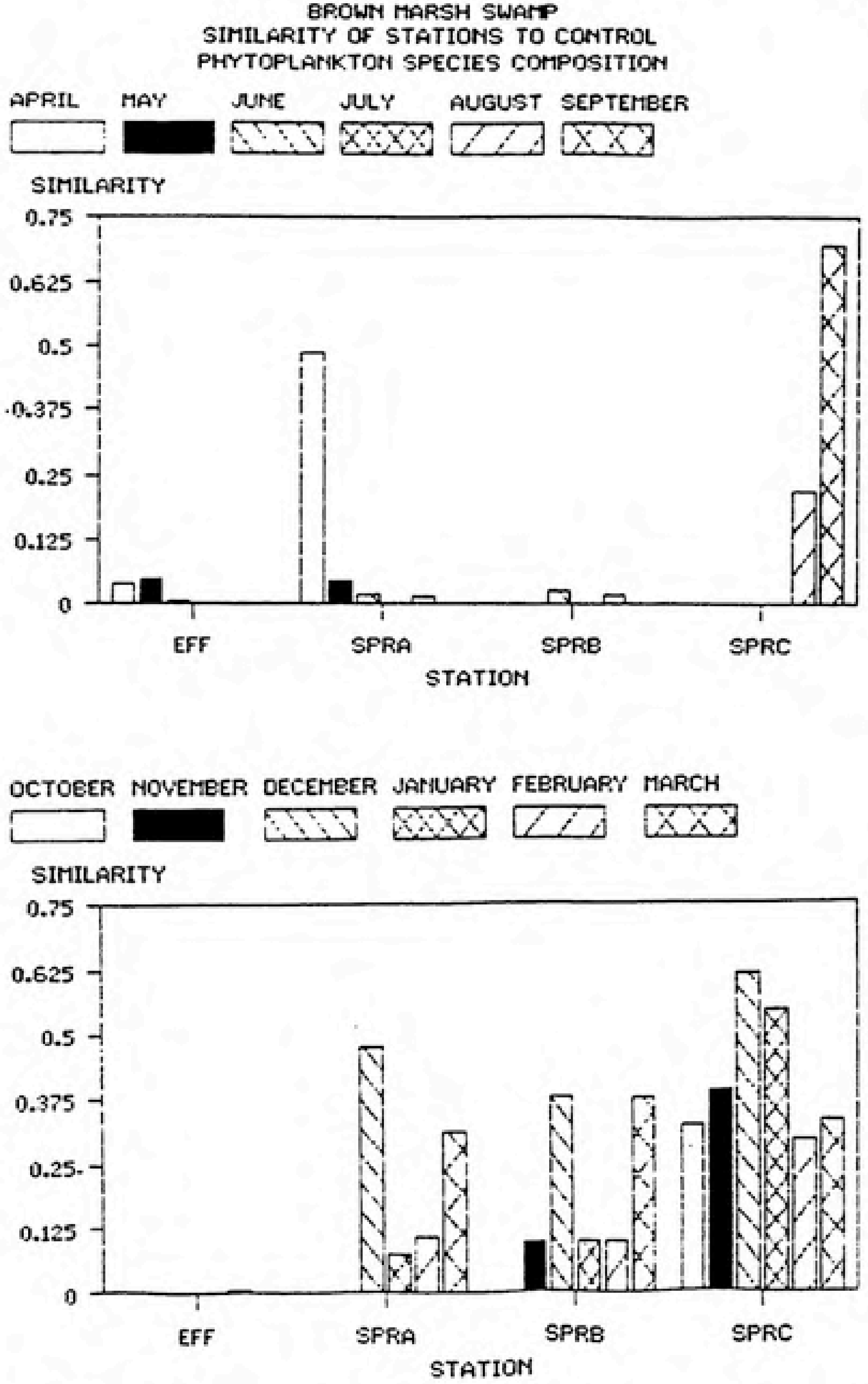


Figure 10. Brown Marsh Swamp. Similarity of phytoplankton species composition at downstream stations to that of control stations.

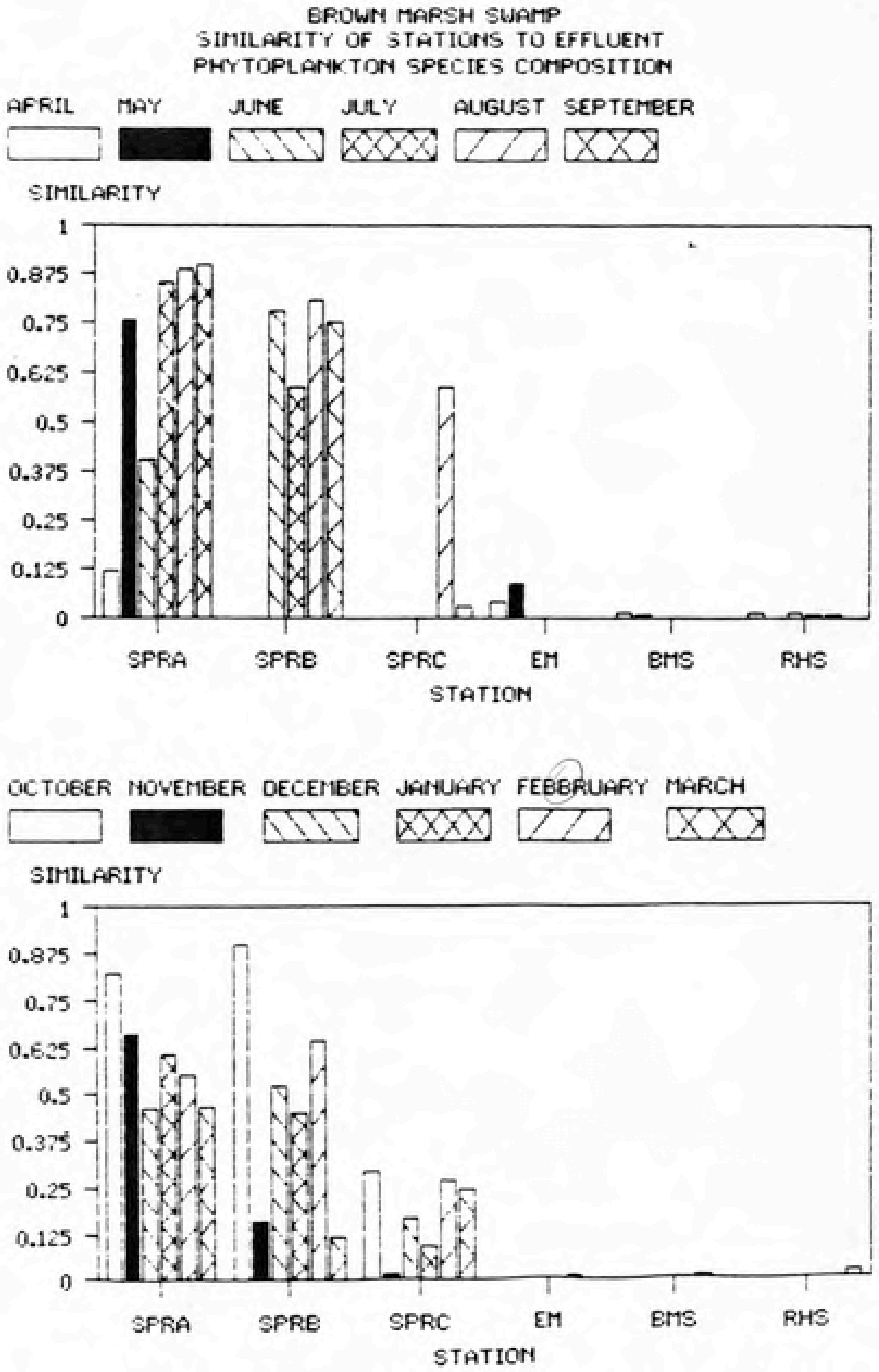


Figure 11. Brown Marsh Swamp. Similarity of phytoplankton species composition at downstream and control stations to that of the sewage lagoon.

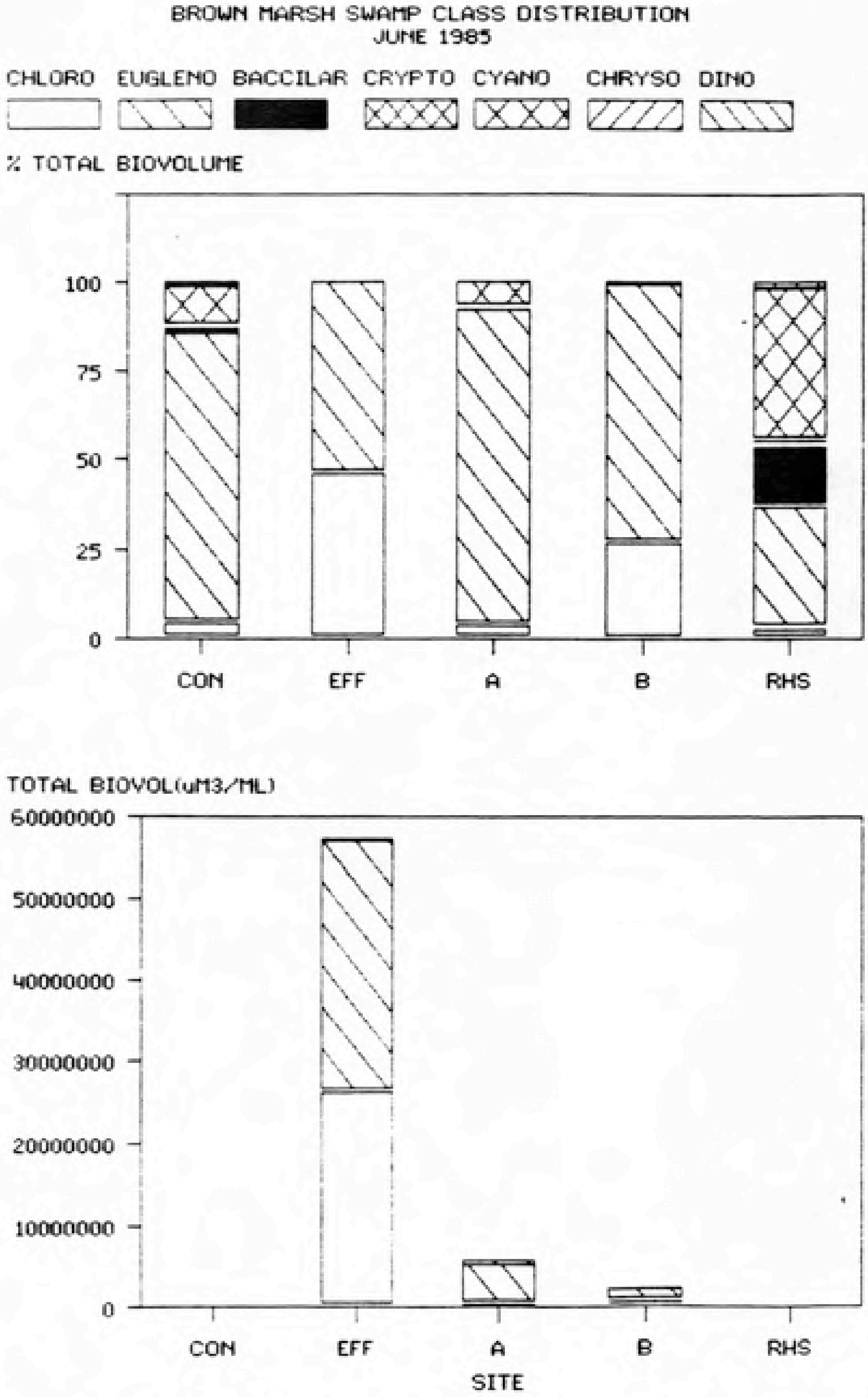


Figure 12. Brown Marsh Swamp June 1985
Phytoplankton Class Distribution

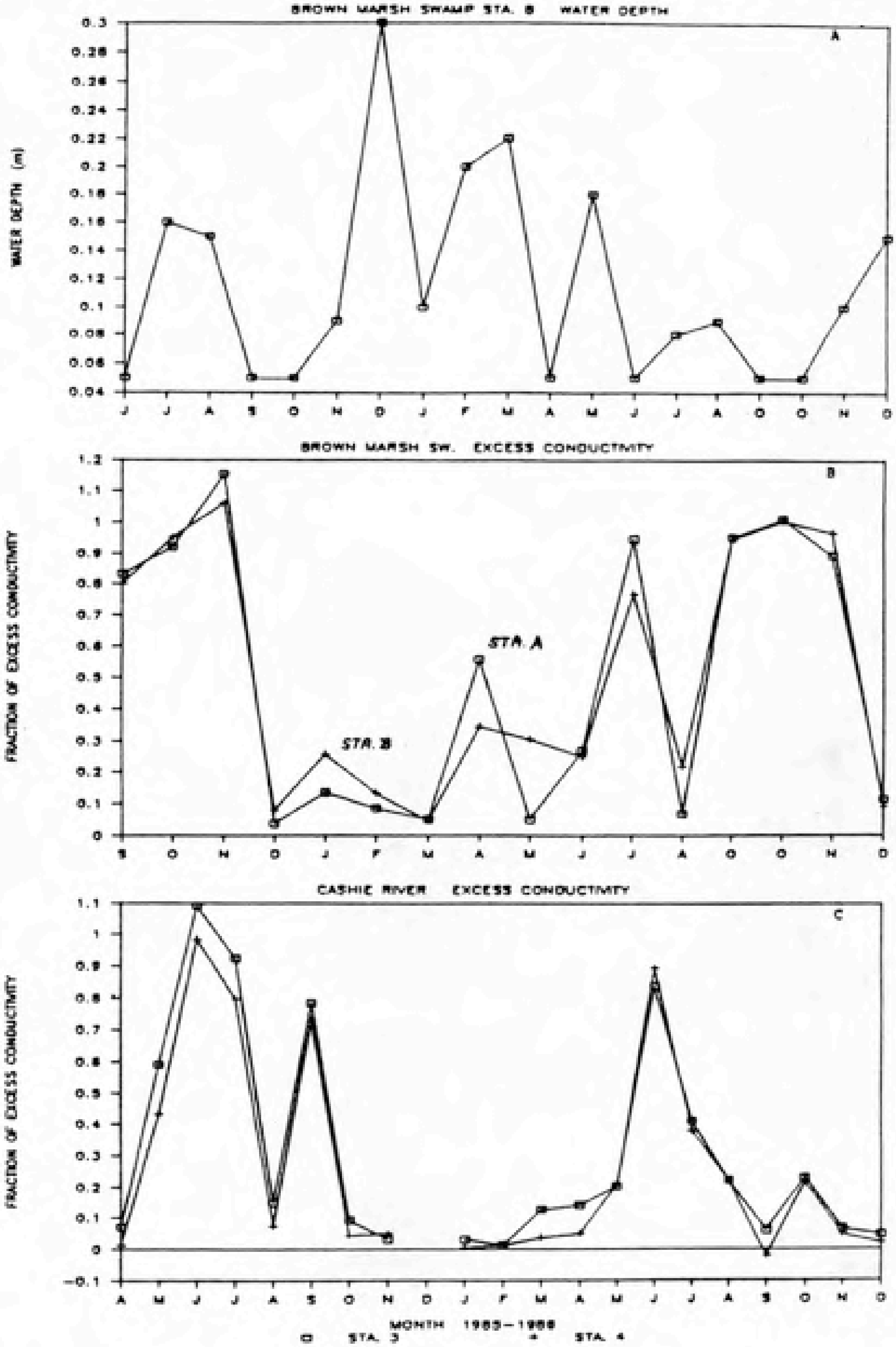


Figure 13. **Station B water depth (A) and excess conductivity (B) at Brown Marsh Swamp; excess conductivity in the Cashie River (C).** (Excess conductivity estimates water volume; Kuenzler, 1987)

DISCUSSION

Phytoplankton Species Composition of the Unimpacted Swamps

Comparison to Previous Studies: Similarities observed in phytoplankton community composition between the Brown Marsh Swamp and the Cashie River differed from those communities observed in other wetlands. In the Cashie River and other blackwater rivers in the Coastal Plain of North Carolina, Whitford and Schumacher (1963), in the only other study of wetlands with flowing water, found many of the same genera as found in this study, although in different frequencies. However, other studies, including two in the Great Dismal Swamp, described very different phytoplankton communities (Table 1). Other studies consistently found that diatoms played major role in the algal flora whereas in the Brown Marsh Swamp and the Cashie River, they only were abundant for a short time in the spring (Figures 2A and 2B). Only one station on the Cashie River, Station 5, always had diatoms, mainly long filaments of *Eunotia pectinalis*. This species was commonly found by Whitford and Schumacher (1963). In addition, the Cryptophyceae dominated in both swamps many months of the study year but were not even mentioned by Whitford and Schumacher. However, their enumeration methods did not allow for identification of very small flagellates, so it is possible cryptophytes were missed in the counting. Ilmavirta (1982) and Arvola (1983) found cryptophytes dominated the phytoplankton of shallow, acidic, brownwater lakes in Finland, whose summer water chemistry is very similar to the winter water chemistry in these swamps. The euglenophyte dominance found in the Cashie River and the Brown Marsh Swamp in the summer (Figures 2A and 2B) has not been noted in other swamp phytoplankton communities, although Dawes and Jewett-Smith (1985) did find *Euglena acus* to be common in the summer marsh drydown in Florida (Table 1).

Since the Brown Marsh Swamp and the Cashie River also experience summer drydown, the warm temperatures and shallow water could allow for dominance by the euglenophytes.

Phytoplankton community succession: In community succession, the species which can maintain the highest rate of net increase under the given environmental conditions is the one which is most likely to dominate (Harris, 1986). In phytoplankton community dynamics, some of the many factors which work together to determine what species will dominate a certain environment include light availability, including penetration into the water, insolation, and day length, nutrient availability, flushing rate, and competition between the species (Reynolds, 1984). Because no two swamps are the same, these variables provide different combinations of factors which affect the viability of particular phytoplankton species.

In summer, the water in both the Cashie River and the Brown Marsh Swamp was very warm, up to 27 C, and the flow was very slow or completely stopped, evidenced by crude flow measurements and, in many cases, an intermittent stream. The swamps dried down to the point that some of the sampling stations were without water. The water in the swamp often became a series of above-ground pools only connected by subsurface water. It became highly concentrated with organic acids as evidenced by very dark color. During these conditions, often in very shallow warm water, euglenophytes dominated (Figures 2A and 2B). They are known to thrive in highly organic conditions and need plenty of light for their larger-sized cells to survive (Fogg, 1965). Palmer (1969) noted certain species of Euglena and Phacus were highly tolerant of organic pollution and may therefore find the highly organic swamp waters suitable habitats.

During the colder months, more water was present in the swamps resulting in more diluted organics, evidenced by less color, higher flushing rates, and less nutrients (Figure 13). The days were also shorter and insolation was lower than in summer. When these conditions occurred, the smaller-celled, flagellated cryptophytes and chrysophytes dominated (Figures 2A and 2B). Due to their larger surface area to volume ratios and lower light and metabolic requirements, these taxa typically are capable of surviving harsher winter conditions (Reynolds, 1984). Cryptomonas, Pheaster, and sometimes Synura were in the water when no other genus was present in any significant number (Figures 3 and 4). When the days became longer and the water warmer, certain chlorophytes, including Chlamydomonas and Closterium appeared. Diatoms peaked in abundance and biovolume in the late winter/early spring when phytoplankton typically experience an increase with the lengthening days and warming waters (Figures 2A and 2B). Diatom abundance in lakes has been shown to be inversely related to temperature (Tilman and Kiesling, 1984). This seemed to be the case in the swamps since the highest numbers of diatoms were found in the colder early spring. Diatoms often occupy this niche in water bodies because of their capacity for overwintering, their somewhat higher surface area to volume ratios and their capacity for growth at lower temperatures and insolation (Reynolds, 1984). The chloromonad, Gonyostomum semen, also dominated for a period later in the spring (Figure 3).

Another factor important to phytoplankton community dynamics is the springtime growth of filamentous algae which typically occurs in swamps before the canopy closes. Brinson, et al. (1981) and Atchue, et al. (1983) both found that the productivity and nutrient cycling of this spring growth of filamentous algae was comparable to that of emergent macrophytes. Because of their growth habit and larger size, these extensive masses of filamentous algae would seem have a high light requirement for growth which would restrict their appearance to times in the spring when the temperatures and day lengths combine to form optimal conditions before the canopy closes. In this period they are perhaps the most important producers in the swamp (Atchue, et al., 1983).

Oxidation Pond Species Composition and Seasonal Variation

The phytoplankton community of the oxidation pond at Clarkton also displayed seasonal variation, though the community was not as complex as the natural swamp stream communities. Wiedeman (1965) found similar species in oxidation ponds in Texas. Palmer's (1969) list of algal species tolerant of highly organic conditions included nearly all of the species found in the oxidation pond. The seasonal variation of the dominating species is also dependent on algal growth limiting factors. Wiedeman (1965) concluded that temperature was the most important factor influencing the seasonal succession of algae in oxidation ponds. Light availability, as estimated by day length and insolation, also varies seasonally, as does the amount of precipitation which could dilute the nutrients in the pond. Tilman and Kiesling (1984) showed that bluegreen biovolume increased with increasing temperature but that greens reached a maximum at about 15 C. They also showed the importance of the interaction of many factors which influence species succession. The absence of Oocystis in the summer relative to its dominance all winter could be due in part to competition for light, as well as to the increasing temperature (Figure 7). The cyanophytes and euglenophytes could also thrive in the higher temperatures (Reynolds, 1984; Palmer, 1969).

Spatial Variation of Phytoplankton Taxa

Cashie River: Spatial variation among the sampling stations is also affected by the interaction of various factors which limit the growth or survival of the phytoplankton. The input of sewage effluent into the Cashie River supplies an overabundance of nutrients which could possibly result in an algal bloom, but blooms did not occur just downstream of the effluent input (Figure 8). Other factors at the Cashie River seemed to offset or delay the possible effects of the nutrients. The river is relatively shallow (<1m deep) and is susceptible to wide variations in flow due to runoff from precipitation events. The reaction of the river to precipitation was rapid (within two hours) and caused the clear, slow-flowing brown water stream to become deeper, swifter and muddier than before the storm. An increased flow rate over the typically slow-flowing swamp stream could wash out the established phytoplankton community as well as the sludge deposited on the swamp floor by the wastewater. Increased flow also would dilute the nutrient concentrations below the outfall. The sediment load of the stream immediately after a storm was enough to shade out the algae. The sewage effluent contained a large load of suspended solids which caused the water turbidity to be very high just downstream of the effluent input. Secchi disk readings were usually between 0.05 and 0.15 meters and maximum turbidity was 171 NTU at Station 2. This could block out some of the light required for an algal bloom. In a number of months, higher algal biomass occurred at Stations 5 and 6, the farthest ones downstream (Figure 8). These biovolume increases could be due to the increased nutrient load on the swamp and a slower response time of the phytoplankton community because of the high turbidity of the water near the outfall and flow variations.

The growth of phytoplankton at the Cashie River did not seem to be stimulated or retarded by the input of the wastewater, except at Stations 5 and 6. The change in community structure from station to station was minimal and more likely due to the individual conditions at each station. As Jones, et al.(1984) noted for streams in the Midwest, physical conditions in lotic systems often account for more of the chlorophyll variance than do nutrient concentrations and during high flow situations, nutrients may not be limiting. For example, Station 5 was at the confluence of a number of tributaries, it was fairly deep, and its community structure more closely resembled those of blackwater rivers as described by Whitford and Schumacher (1963) than did Station 1, upstream of the effluent input, where the river was very shallow and closely bordered by agricultural fields. Lumbering had recently moved closer to the channel at Station 1. This station was much more subject to variation in streamflow due to rainfall events than Station 5, most likely because of a combination of smaller size and encroachment of agriculture and lumbering. In addition, a beaver dam built about 4 km downstream of Station 5 and 300 m downstream of Station 6 affected both of these stations after January 1986. Both stations continually contained more water and had slower flows after this time and their phytoplankton communities became very similar to each other. The slower flows at these stations all year could contribute to the higher phytoplankton concentrations found here, since longer residence times allow for more cell doubling and use of available nutrients. Overall, it appeared that the possible effects due to the nutrient input were balanced or delayed by other factors, reducing the effects on the phytoplankton community structure at the various stations on the Cashie River.

Brown Marsh Swamp: The input of the algae from the oxidation pond made Brown Marsh Swamp water very different from the Cashie River water. As noted by Tilman and Kiesling (1984), however, the effects of various environmental factors combine to determine which species will have the greatest competitive advantage. Since the lagoon algae were primarily nonmotile, it seems logical that losses due to sedimentation would be important in determining how far downstream the lagoon species would dominate. At times, however, it was obvious that lagoon algae became established in the shallows of the swamp and the swamp came to resemble another oxidation pond rather than a swamp stream (for example, the blooms of Oscillatoria limosa at Station B). At station A, lagoon algal species dominated the phytoplankton community to the exclusion of the swamp stream phytoplankton. Occasionally, taxa found in the natural stream would be present in countable numbers. During 4 to 6 months of the year, Station BMS, the station just upstream of the sprayers, was dried out; thus the effluent sprayed into the swamp provided a greater volume of water than did the swamp stream. Therefore, the effluent's abundant algae would also dominate the phytoplankton community at Station A. Farther downstream, at Stations B and C, other factors became important. At Station B, the swamp stream was shallow and much of the suspended solids sedimented out along this stretch to form a layer of sludge, averaging about 20 cm, on the bottom of the stream. Blooms of the cyanophyte, Oscillatoria sp., occurred here in the warmer months, indicating the high nutrient status of these waters. Cyanophytes require fairly abundant nutrients, particularly phosphorus, to gain competitive advantage. It has been shown that bluegreens tend to dominate when nitrogen to phosphorus ratios are low (Smith 1983). Although a low N to P ratio was not present for the swamp stream, blooms of cyanophytes could be supported below the sprayers in the Brown Marsh Swamp where phosphorus and nitrogen were both plentiful. This happened particularly during times of low flow conditions, which generally occurred from July through October resulting in total nitrogen concentrations ranging from 2 to 9 mg/l and total phosphorus concentrations ranging from 1 to 7 mg/l.

The blooms of Chromatium sp., the photosynthetic purple sulfur bacterium, were indicative of stagnant, anoxic conditions rich in reduced sulfur and organic matter (Jorgensen 1977; 1982; Jorgensen and Fenchel, 1974). During times of Chromatium sp. growth, the only noticeable flow originated from the sprayers. The presence of Sphaerotilus natans, the bacterium often erroneously called "sewage fungus" because it forms visible filaments, is also indicative of highly organic conditions where oxygen is available. It grows best at temperatures between 5 and 20 C and will form white mats covering the bottom of highly polluted waters (Rheinheimer, 1974). At the Brown Marsh Swamp, white mats of Sphaerotilus natans were visible on the bottom of the stream and filaments were floating on the water's surface from about 30 m below the sprayers to over 200 m downstream of the sprayers from May to October. This was one indication the swamp had come to resemble a sewage lagoon.

The variation in the flow rate and the volume of water in the swamp stream appeared to be very important factors in determining the phytoplankton community and the extent of lagoon algal dominance downstream of the sprayers. The main factors which seemed to determine the phytoplankton community at Station C were the flow rate and sedimentation rate of the lagoon algae. Where the branch of Brown Marsh Swamp which received the sewage joined with the main stem of the swamp about 50 m above station C, the swamp stream became more than a meter deep, as compared with 20 to 30 cm deep in the other branch. Since retention times are longer in deeper waters, given a constant width, and since lagoon algae were only present at Station C in times of high flow (Figures 10, 11, and 13; Appendix), sedimentation of lagoon algae was probably an important loss process at this point in the swamp stream. Many authors have found that water retention time is a major factor in determining the phytoplankton abundance in water bodies. Dillon (1975) found that high flushing rates and short retention times could counteract the positive effects of high phosphorus loadings on chlorophyll concentrations. Schindler (1978) also found a high proportion of the variance in chlorophyll concentrations in the IBP lakes could be accounted for once water renewal time was included in his model. Jones, et al. (1984) found that the concentration of algal cells in Midwestern streams was fairly constant throughout the year when change in the water volume in the streams was considered, but that cell density was not constant due to the variation in stream discharge among seasons. Unfortunately, the hydrology of swamps is extremely hard to quantify. For these swamps, the variation in water volume was estimated from conservative factors, such as chloride concentration and conductivity (Figure 13; Kuenzler,1987). The hydrology of every swamp is different and is one of the most important factors in determining a swamp's suitability for receiving wastewater effluent (Carter, et al., 1979).

Modelling of Chlorophyll Concentrations and Other Parameters

Cashie River: The regressions of chlorophyll against several physical and chemical parameters added insight to the variance in the phytoplankton volumes. At the Cashie River, nearly half of the variance in chlorophyll was accounted for by two nutrients, total phosphorus and nitrite+nitrate, and water temperature. The sampling stations were fairly close to the headwaters of the Cashie River. The station upstream of the sewage treatment plant had no surface water for most of the summer. There were also a number of seeps and springs associated with this river (Jay Sauber, NCDEM, personal communication). Due to the low stream order and proximity of foresting and farming, the stations were subjected to rapid flushing after an intense rainfall event. The water temperature variation is also associated with the change in the volume of water in the stream since the highest temperatures, lowest water volumes, and highest phytoplankton volume occurred in the summer. Variation in water volume was not significant when added to this multiple regression. Since the nitrogen to phosphorus ratios were generally above 10 (see data in Kuenzler, 1987), indicating phosphorus limitation, it is reasonable that total phosphorus is a significant factor in accounting for the variance in chlorophyll concentrations. The water temperature and phosphorus availability are likely the major limiting factors in the phytoplankton growth in this part of the Cashie River.

Brown Marsh Swamp: At the Brown Marsh Swamp, the variance in chlorophyll was also accounted for primarily by nutrient concentrations. Although variation in water volume alone explains 27% of the variance, when coupled with any of the nutrients, it is not significant. Total phosphorus alone accounts for 60% of the variance in chlorophyll of all the sampling stations and orthophosphate alone accounts for 57% of the variance. Two models were developed using nitrite+nitrate and these two phosphorus concentrations and they were not significantly different. The model with orthophosphate and nitrite+nitrate accounted for more of the variance in the main stem stations. However, when the data is split up by season, total phosphorus again becomes more important and is coupled with nitrate-nitrite nitrogen to explain between 59% and 67% of the chlorophyll variance. It is not evident whether these parameters simply covary or if there is indeed a causal relationship between the nutrients and chlorophyll. It is more likely the former, particularly since phosphate and nitrate are the most reactive forms of the nutrients and are removed from the swamp stream faster than other nutrient forms and also because both the chlorophyll and nutrients are being diluted downstream. This nutrient removal is accompanied by the loss of lagoon algae from the water column (Figures 9 and 11), thus the decrease in chlorophyll concentrations. The importance of water volume is highly related to flushing rate which affects the distance the lagoon algae dominate downstream of the sprayers.

Comparison to Published Models: Since flushing rate and the amount of water in the swamp appear to be such important factors in determining the fate of the phytoplankton communities, a comparison was done between the measured chlorophyll concentrations in the swamp and predicted concentrations from a number of chlorophyll nutrient models developed for lakes and streams. Conceptually, the variation in chlorophyll concentrations in swamp waters would be more like the variation found in lotic than lentic systems due to the slow flushing action. The models tested are summarized in Table 2. Since the lake models tested were based on growing season data, the swamp stream data from the growing season was also compared to the lake models resulting in relationships not significantly different from ones found using the entire data set, which are presented here.

At the Cashie River, none of the models tested were appropriate predictors of the swamp stream phytoplankton concentrations (Figure 14). All of them predicted much higher concentrations than were actually present. The model including only total phosphorus by Jones, et al. (1984) was the best predictor, although it accounted for less than 20% of the variance and consistently predicted values bigger than those observed. This finding is consistent with the Cashie River modelling since most of the variance in the Cashie River chlorophyll was accounted for by temperature and nutrients. Similarly, for the Brown Marsh Swamp, the model of Jones, et al. (1984) was the best predictor (Figure 15). The regression between the actual and predicted chlorophyll values had an R^2 of 0.62. The Jones TP model was also most like the one generated from this swamp data set (Equation 2 in text). All of the other models predicted the chlorophyll values to be much larger than the observed values. The other models did, however, significantly account for a large amount of the swamp stream chlorophyll variance, although not as accurately as

Jones' model. Since Jones' model for streams predicts the swamp chlorophyll values better than the other models tested, it seems these swamp waters resemble streams more than lakes, although they do have characteristics of both lentic and lotic systems.

Jones, et al. (1984) states that stream chlorophyll concentrations are less predictable by the nutrient concentrations than lake and reservoir chlorophyll concentrations because the physical variability of the stream plays a major role in the growth of phytoplankton. Their data indicates that export processes in streams would have a large effect on the nutrient assimilation capacity of the phytoplankton. With this in mind, the variability in swamp stream phytoplankton concentrations should also be affected by export processes occurring in the stream. Wylie and Jones (1986) found that observed chlorophyll concentrations in Missouri wetlands were much lower than concentrations predicted by chlorophyll-nutrient models for lakes. Although the wetlands studied were greentree reservoirs which were periodically inundated and contained high concentrations of suspended solids, the study also shows that wetland chlorophyll concentrations are not dependent only on nutrients, as the present study also shows. For managers to sufficiently predict algal response to nutrient loading in wetland waters, much more data is needed so that the major factors, other than nutrients, which affect variation in chlorophyll concentration can be elucidated and added to predictive models.

CONCLUSIONS

1. SEASONAL VARIATION OCCURS IN SWAMP STREAM PHYTOPLANKTON COMMUNITIES. DIFFERENT SWAMPS MAY HAVE SIMILAR BUT NOT EXACTLY THE SAME COMMUNITIES DUE TO THE UNIQUE CHARACTERS OF SWAMP SYSTEMS. THE TWO SWAMPS STUDIES HAVE DIVERSE PHYTOPLANKTON COMMUNITIES WITH THE CLASSES EUGLENOPHYCEAE, CRYPTOPHYCEAE, AND CHRYSOPHYCEAE BEING THE MOST IMPORTANT.

2. OXIDATION PONDS ALSO EXHIBIT SEASONAL VARIATION IN THE ALGAL COMMUNITY STRUCTURE AND ARE DOMINATED BY FEW SPECIES IN THE CLASSES CHLOROPHYCEAE, EUGLENOPHYCEAE AND CYANOPHYCEAE.

3. THE CHANGES IN THE PHYTOPLANKTON COMMUNITIES IN EACH SWAMP DOWNSTREAM OF THE EFFLUENT INPUT SITE WERE MOSTLY DEPENDENT ON THE TYPE OF SEWAGE TREATMENT AND THE INDIVIDUAL PHYSICAL AND CHEMICAL CHARACTERISTICS OF EACH SWAMP. REGRESSION MODELS INDICATE THAT PHYSICAL AND CHEMICAL FACTORS COMBINED TO ACCOUNT FOR MOST OF THE VARIANCE IN THE PHYTOPLANKTON BIOMASS AS ESTIMATED BY CHLOROPHYLLa. MORE OF THE VARIANCE IN CHLOROPHYLL WAS ACCOUNTED FOR BY NUTRIENTS IN THE BROWN MARSH SWAMP THAN IN THE CASHIE RIVER.

4. THE SWAMP STREAMS IN THIS STUDY REACTED MORE LIKE STREAMS THAN LAKES IN THE ALGAL RESPONSE TO NUTRIENTS WHEN COMPARED TO PUBLISHED MODELS. FOR USEFUL PREDICTIVE MODELS TO BE DEVELOPED, MORE DATA IS NEEDED TO DETERMINE THE FACTORS WHICH COMBINE WITH NUTRIENT CONCENTRATIONS TO ACCOUNT FOR THE VARIATION OF CHLOROPHYLLa CONCENTRATIONS IN WETLAND WATERS.

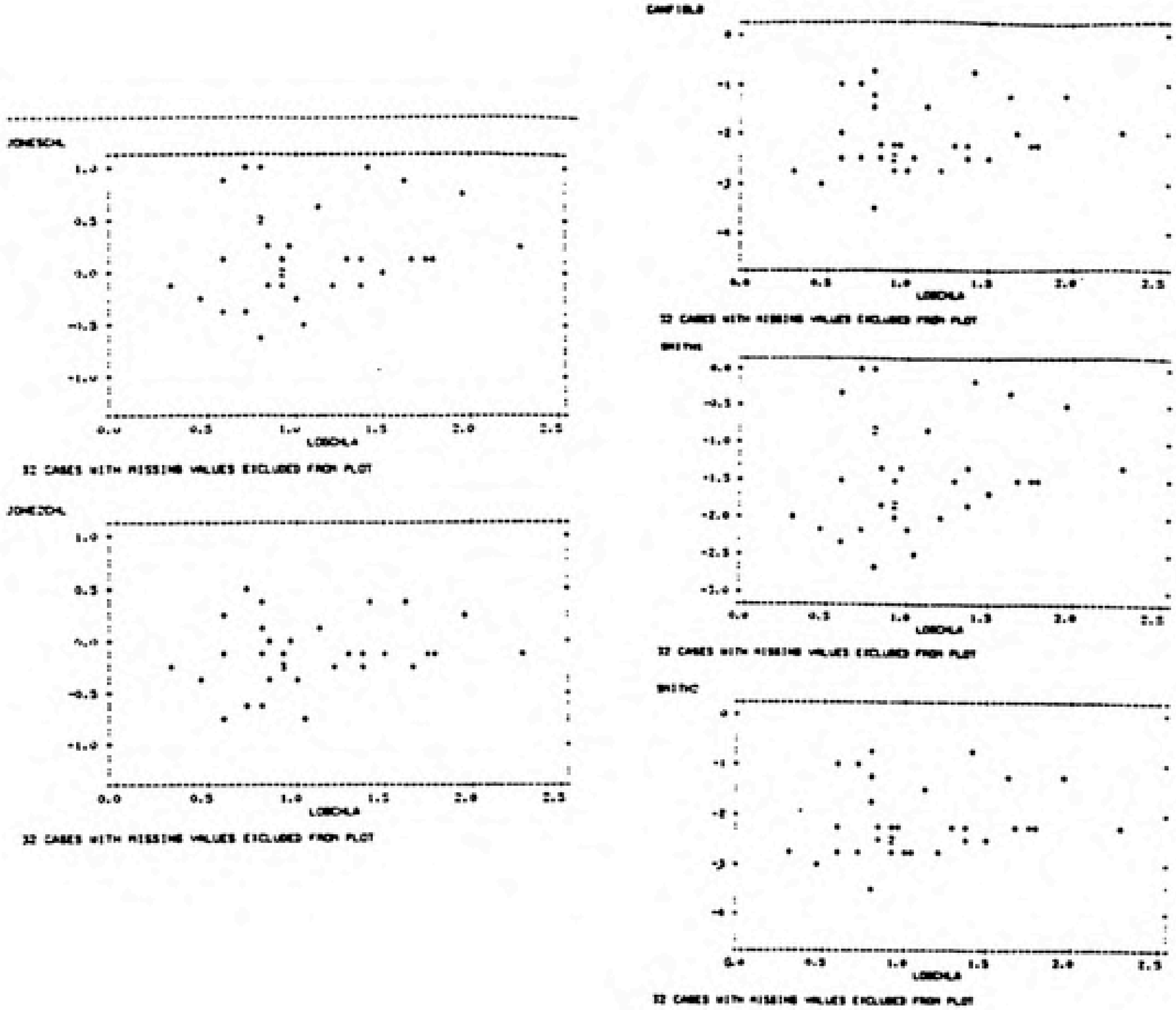
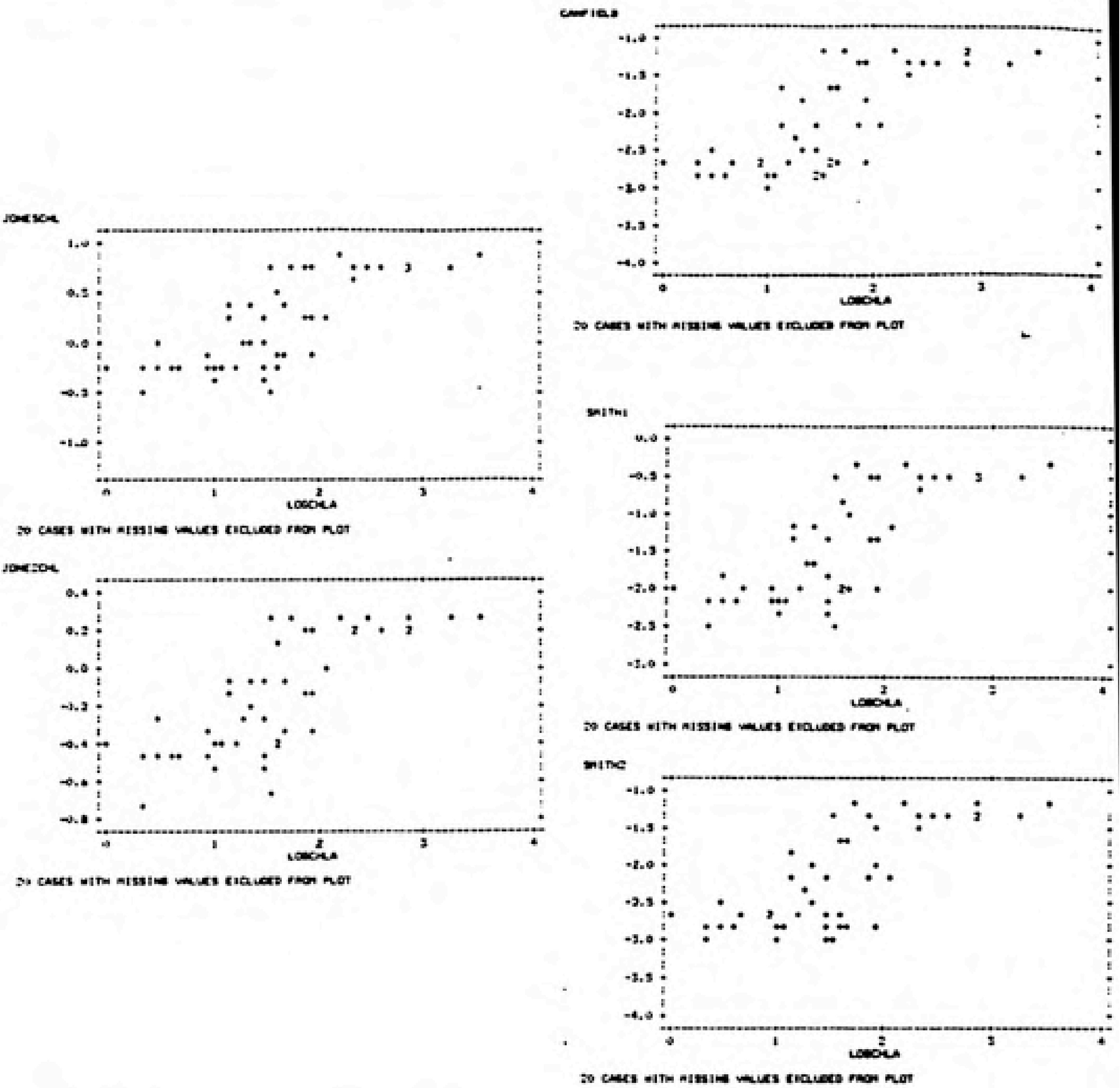


Figure 14. Cashie River. Prediction of chla in swamp streams by published models. Concentrations of chla found in the swamp streams were regressed against chla concentrations predicted by published models. LOGCHLA = log(measured chla) (Table 2).



20 CASES WITH MISSING VALUES EXCLUDED FROM PLOT

20 CASES WITH MISSING VALUES EXCLUDED FROM PLOT

20 CASES WITH MISSING VALUES EXCLUDED FROM PLOT

20 CASES WITH MISSING VALUES EXCLUDED FROM PLOT

20 CASES WITH MISSING VALUES EXCLUDED FROM PLOT

Figure 15. Brown Marsh Swamp. Prediction of chla in swamp streams by published models. Concentrations of chla found in the swamp streams were regressed against chla concentrations predicted by published models. LOGCHLA = log(measured chla) (Table 2).

TABLE 1
DOMINANT PHYTOPLANKTON GENERA OF UNIMPACTED SWAMPS

CASHIE RIVER AND BROWN MARSH SWAMPS, NORTH CAROLINA, 1985-6

WINTER:	SPRING:	SUMMER:
Cryptomonas	Mallomonas	Euglena
Euglena	Nitzschia	Trachelomonas
Chlamydomonas	Eunotia	Cryptomonas
Synura	Chlamydomonas	Phacus
Pheaster	Cryptomonas	Synura
Phacus	Closterium	Microcystis
	Pleurotaenium	

COASTAL PLAIN BLACKWATER RIVERS/SWAMPS NORTH CAROLINA
(Whitford and Schumacher, 1963)

WINTER/SPRING	SUMMER:
Melosira	Melosira
Eunotia	Eunotia
Asterionella	Eudorina
Synedra	Closterium
Tabellaria	Pleurotaenium
Synura	Staurastrum
Dinobryon	Synura
Fragillaria	Dinobryon

GREAT DISMAL SWAMP-LAKE DRUMMOND SUMMER 1970
(Marshall and Poore, 1971)

DOMINANT:	OTHERS FOUND:
Asterionella	Scenedesmus
Melosira	Ankistrodesmus
Closterium	Arthrodesmus
Staurastrum	Coelastrum
	Pinnularia
	Synedra
	Cryptomonas
	Phacus

GREAT DISMAL SWAMP JAN-NOV, 1980
(Atchue, Day and Marshall, 1983)

DOMINANT:	OTHERS FOUND:
Eunotia	Cymbella
Pinnularia	Tabellaria
Mallomonas	Lyngbya
Oscillatoria	periphytic algae

ACID MARSH WEST-CENTRAL FLORIDA 1981
(Dawes and Jewett-Smith, 1985)

WINTER:	SPRING:	SUMMER:
Hyalotheca	Closterium	Chlamydomonas
Dinobryon	Zygnema	Euglena
Zygnema	diatoms	Eudorina
Gymnodinium	cryptomonads	Mallomonas

TABLE 2

MODELS PREDICTING CHLOROPHYLLa CONCENTRATION WITH NUTRIENT CONCENTRATIONS

Model	Source	Prediction
1) $\mathrm{Log\ CHL}\underline{a} = -1.517 + 0.653 \log \mathrm{TP} + 0.548 \log \mathrm{TN}$	Smith, 1982	summer/fall #
2) $\mathrm{Log\ CHL}\underline{a} = -2.488 + 0.374 \log \mathrm{TP} + 0.935 \log \mathrm{TN}$	Smith, 1982	annual mean #
3) $\mathrm{Log\ CHL}\underline{a} = -2.49 + 0.269 \log \mathrm{TP} + 1.06 \log \mathrm{TN}$	Canfield, 1983	annual mean #
4) $\mathrm{Log\ CHL}\underline{a} = 0.1 + 0.39 \log \mathrm{TP} + 0.34 \log \mathrm{TN}$	Jones,et al.,1984	summer/fall *
5) $\mathrm{Log\ CHL}\underline{a} = -0.09 + 0.39 \log \mathrm{TP}$	Jones,et al., 1984	summer/fall *

*=models for streams #=models for lakes

KEY (for graphs):
MODEL 1) = SMITH1
2) = SMITH2
3) = CANFIELD
4) = JONESCHL
5) = JONE2CHL

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