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NUTRIENT AND MULTI-SPECIES CRITERIA STANDARD FOR THE CHOWAN RIVER, NORTH CAROLINA

By

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ABSTRACT

An investigation of changes in nutrient concentrations, phytoplankton biomass, and environmental parameters in the Chowan River Complex (CRC) was conducted from October 1978 through December 1981.

The response of phytoplankton to a given concentration of a given nutrient was determined using a growth response ratio (RR) for each nutrient relative to chlorophyll-a and algal wet weight biomass.

Species of the three genera that periodically bloom in the river were isolated and a minimum nutrient requirement for each was determined. The results suggest that the CRC is in excess of necessary nutrients for moderate algal growth.

In the order of descending nitrogen requirements for initiating cyanophyceae algal growth, the species were: Microcystis, Anabaena and Aphanizomenon. Initiating PO_4 concentrations depended upon the physiological state of the species and the light and temperature regime to which they were exposed.

Using the extent to which RR_{NO_3}, RR_{NH_4} and RR_{OP} exceed the efficiency level of 1.0 per chlorophyll-a, reductions of 48% NO_3, 23% NH_4 and 27% OP would be required for algal biomass (as chloro-a) to be reduced to 40 µg/l; the margin determined as the maximum desirable concentration for the CRC.

Because blue-green algae are "luxury consumers" of PO_4, both PO_4 and nitrogen should be reduced simultaneously.

These results are discussed as they might relate to management of the CRC.

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SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

An analysis of nutrient data taken weekly over a two-year, two-month span within the Chowan River complex (CRC) (26 Oct 78 - 18 Dec 80) indicated that all measured nutrients in the river were in excess for phytoplankton growth needs throughout the two-year study. This suggests that a need exists for nutrient reductions to the system. A critical question, therefore, was answered: which of the phytoplankton growth requiring nutrients must be reduced? An answer to the question was examined physiologically, ecologically and statistically using the data-set generated over the time frame stated above which included: (1) phytoplankton biomass, numbers, bio-volume, and types; (2) chlorophyll-a analysis; (3) periodic sediment and nutrient analysis; and (4) environmental parameters of known importance to the productivity of an aquatic ecosystem.

A growth response ratio (RR) for each growth nutrient using chlorophyll-a and algal wet weight biomass (WWB) was determined for both total biomass and blue-green algal biomass (biomass/nutrient). The RR concept was important because it negated intrasystem particulars such as flow, temperature, pH, etc. Further, it permitted a gross determination, under variable conditions, as to the response of the algae to a given nutrient.

The available nutrient ratio (N:P) was determined and found to be more important than nitrogen alone or phosphorus alone. In fact, the N:P ratio was found to be a key factor in determining nutrient reduction needs to the CRC.

Union Camp (UC) effluent, a continuous controversial topic, was utilized to assay its effect on algal growth. The effluent was a better than adequate growth medium, either at 100% UC concentration or if log-reduced in water from the upper Nottoway River, for both blue-green and green algae (endemic Chowan

species). It appeared that the Chowan River algal species have adapted to the effluent. Species either isolated from other aquatic systems or ordered from algal-culture commercial sources did not similarly respond to the UC effluent.

Hydrogen ion concentration (-log, pH) played a role at the extremes in the river. However, water temperature was the most influential factor (given the state of the river that existed) on the growth of algae. Moderate (16°-24°C) temperatures were preferred by the green algae; moderate to low (20°-5°C) were preferred by the diatoms; high (25°-32°C) were preferred by the blue-green algae. However, dominant diatoms were able to persist throughout the year, as were many green algae. Temperature at its lower end (below 10°C) had a devastating effect on blue-green algal growth. As a result, they usually sporolated and overwintered in the sediment beds. There was one exception; one species (new to the river Aphanizomenon ovata) was found at pulse-bloom WWB concentrations at 8°C subsequent to a nitrogen spill two weeks prior in the river.

Water hydrology due to flow, wind and tidal effects was often confusing. Flow reversals increased dispersion of nutrients in three-fourths of the river toward the lower reach. Therefore, an accurate determination of nutrient source and loading as measured by nutrient input, water column and flow rate was almost impossible. Thus the calculation of the sources of nutrients that were not directly measured from the site could be as correct as 95% or as incorrect as 50%. Also, the precise location of the collection sites is another parameter related to phytoplankton numbers, biomass and taxa diversification. Nevertheless, station C13 near Colerain, NC was unique. It was the most productive algal site on the river. Studies may utilize this site as the ultimate potential.

The algal community structure has shifted over the last 10 years. There

are more and different Cyanophyceae (blue-green algae) and diatoms in the system. Ten (10) mg/l WWB constituted a visual bloom when all species were collectively considered. This figure could vary if the algal community structure changes. Likewise, 1 mg/l of a single growing filamentous blue-green alga constituted a visual bloom. These WWB quantities were compared with the 40 µg/l chlorophyll-a standard set by NRCD-DEM. Thus, a determination of nutrients or nutrient reduction that would not exceed either biological standard was deduced.

Anabaena, Aphanizomenon and Microcystis were isolated from the surface of Chowan sediments and subsequently assayed for nutrient requirements (NO_3, NH_4, PO_4). Different species of these genera were initially assayed. However, only Anabaena circinalis, aphanizomenon flos-aquae and Microcystis marina are discussed with respect to Chowan River nutrients.

In the order of descending nitrogen requirement for initiating growth the species are: Microcystis, Anabaena and Aphanizomenon.

Conclusions

1. Response Ratios (RR) are above 1.0 for summer lower reach averages for RR_{NH_4}, RR_{NO_3}, and RR_{OP}; however, they are low in winter.

2. The RR_{NO_3} is the highest in the summer lower reach; thus the Chowan River/chlorophyll-a is the most sensitive to nitrogen.

3. Using the extent to which RR_{NO_3}, RR_{NH_4} and RR_{OP} exceed the efficiency level of 1.0 per chlorophyll-a, reductions of 48% NO_3, 23% NH_4 and 27% OP would equal a 40 µg/l margin. For 30 µg/l chlorophyll-a reductions, NO_3 = 61%, NH_4 = 42% and OP = 27%.

4. Wet weight biomass/nutrient, OP, NH_4 and NO_3, in the Chowan River is more sensitive to OP, NH_4 and NO_3, in that order. Therefore, river reduction levels should be 27.8%, 26.5% and 18.5%, respectively.

5. To achieve a 10 mg/l WWB, reductions are 72.0%, 71.1% and 68.7%, OP, NH_4 and NO_3, respectively.

6. If reduction in nutrients for blue-green algae are considered apart from other algae, nutrient levels of 90.7% NH_4, 90.9% NO_3 and 89.7% OP appear necessary to achieve the "no bloom conditions" in this river.

7. The three blue-green algae genera are "luxury consumers" of PO_4.

Recommendations

1. Reductions in both phosphorus and nitrogen should be done simultaneously.

(a) Neither nitrogen nor phosphorus should be reduced alone.

(1) Rationale: A reduction in phosphorus alone would reduce algal biomass. However, a reduction in total biomass would decrease competition for nutrients, thus nitrogen levels would increase. An increase in nitrogen levels would favor the growth of Microcystis. This would create a situation more damaging than currently exists.

(2) Rationale: A reduction in nitrogen alone would favor an increase in other algae, in particular flagellates. It is not known if a specific organism may develop that would be detrimental to the system, say Peridinium (dianoflagellates). While nitrogen fixation is important, algal communities have not been shown to bloom with N_2-fixation as the only source of nitrogen.

2. The ratio between nitrogen and phosphorus must be made such that diverse species will compete for each. Thus, no species or groups of species would gain an advantage.

3. Reductions by percent of both nutrients, nitrogen and phosphorus, as indicated in the conclusions and text, is highly recommended.

INTRODUCTION

During the late spring/early summer of 1978 the Chowan River (Figure 1), located in northeastern North Carolina experienced an extensive proliferation of the small "pulse" blooms of 1976 and 1977 (54) (Figures 1A and 1B) (57). The 1978 massive bloom was similar in location to a previous massive bloom of 1972. However, both quantitatively and qualitatively, the two blooms were distinctively different. The five dominant species of 1972, Anabaena circinalis, Anabaena aequalis, Anabaena flos-aquae, Aphanizomenon flos-aquae and Microcystis aeruginosa were either replaced in dominance by others within the group or were not important as a dominant in 1978. The magnitudes of biomass during 1978 exceeded that of 1972 and the total number of cells were either more diverse, greater in number or less in number depending on the particular location in the river. In addition, there was a greater intensity of blue-green algal species present in 1978 than seen in 1972.

Public interest in the river's water quality was triggered by the sudden appearance of the 1978 bloom. Strong public opinion indicted a local industry which had been previously implicated by the State of North Carolina as a causative agent of the 1972 massive bloom.

The attention given by the local communities and business interest in the area plus the concern expressed by NRCD stimulated a series of new studies on the river system. An interesting aspect of the 1978 bloom that suggested a need for new studies was information by one researcher (54) that approximately two weeks prior to the 1978 bloom, algal biomass and nutrient conditions at three stations (Table A, Figure 2, C3A, C13 and C16) did not indicate the presence of bloom species or nutrients beyond the concentrations found in the period between the years 1975 through 1977 (not to include the small areas where pulse blooms had occurred).

TABLE A

CHOWAN STATIONS

		River Mile from Va. Line	D.O. - Temp. - pH alk.-light	P&N - Water	Chlorophyll	Phytoplankton	P&N - Sediment	Spores - Sediment
C-1	Nottoway River above mouth at US 258.		W	W	W	W		
UC-1	Union Camp discharge			W				
C-1A	Discharge canal from Union Camp.		W	W	W	W		
C-1B	Blackwater River at horseshoe bend above Union Camp		W	W	W	W		
C-2	Blackwater River 300 yds. above mouth.		W	W	W	W		
C-2A	Buckhorn Creek at Riddick Landing.		W	W	W	W		
C-2B	Somerton Creek 100 yds. above mouth.		W	W	W	W		
C-2B1	Chowan At Gatlington Landing.	4.0	W	W	W	W		
C-2C	Chowan at 90° bend above Meherrin.	8.8	W	W	W	W		
C-2D	Meherrin River at horseshoe.		W	W	W	W		
C-2E	Meherrin River at Parker Ferry.		D	D	D	D		
C-2F	Potecasi Creek at mouth.		W	W	W	W		
C-3	Chowan 100 yds. above bridge at Winton.	13.3	W	W	W	W	M	W
C-3A	Chowan at Seaboard Railroad near Tunis. (Old C-RR).	16.2	W	W	W	W		
C-3B	Catharine Creek at Tunis boat ramp.		W	W	W	W		
C-4	Chowan mid-river at CF Industries pier.	17.8	W	W	W	W	M	W
C-4Z	Swamp drainage at downstream flag (sample on land)		W	W	W	W		
C-4C	Chowan 10' off bank at C-4Z		D	D	D	D	D	D

C-4A	Chowan on CF side at swamp at automatic sampler.	17.9	W	W				
C-5	Chowan below bend below CF Industries at Marker 27.	18.8	W	W	W	W		
C-5A*	Barnes Creek at mouth.							
C-6	Chowan just below Island Creek.	22.7	W	W	W	W		
C-6A	Wiccacon River at 1st bend above mouth.		W	W	W	W		
C-6B	Wiccacon at Tar River Landing		W	W	W	W		
C-7	Chowan 200 yds. below Wiccacon.	25.5	D	D	D	D	D	D
C-7A	Chowan River below Wiccacon at Marker 18	25.9	W	W	W	W		
C-8	Bennett Creek at 1st bend above mouth.		W	W	W	W		
C-9	Catharine Creek 100 yds. above mouth.		W	W	W	W		
C-11	Chowan 200 yds. below Holiday Island at Marker 12.	31.4	W	W	W	W	M	W
C-12	Chowan mid-channel at Dillard Creek (Indian Creek)	33.7	W	W	W	W		
C-13	Chowan mid-channel at Colerain.	37.1	W	W	W	W	M	W
C-14	Rockyhock Creek up into mouth.		W	W	W	W		
C-15	Chowan mid-channel at Rockyhock Creek.	44.2	W	W	W	W		
C-16	Chowan 50 yds. above NC 17 bridge.	48.2	W	W	W	W	M	W
C-17	Chowan 400 yds. below NC 17 bridge.	48.5	D	D	D	D	D	D
C-21	Edenton Bay 300 yards S of Edenton.		D	D	D	D	D	D

M=Monthly
W=Weekly
D=Discontinued

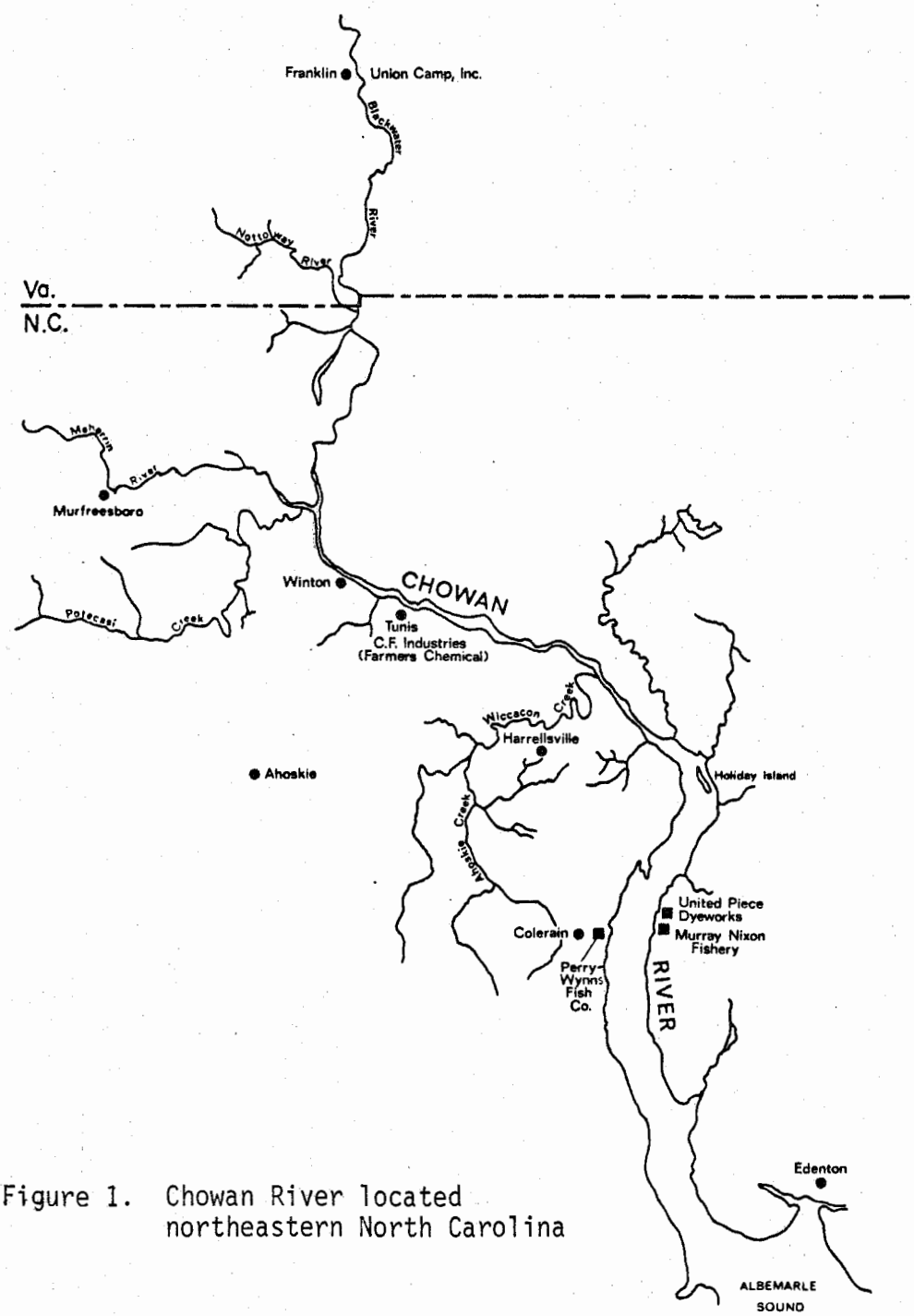


Figure 1. Chowan River located northeastern North Carolina

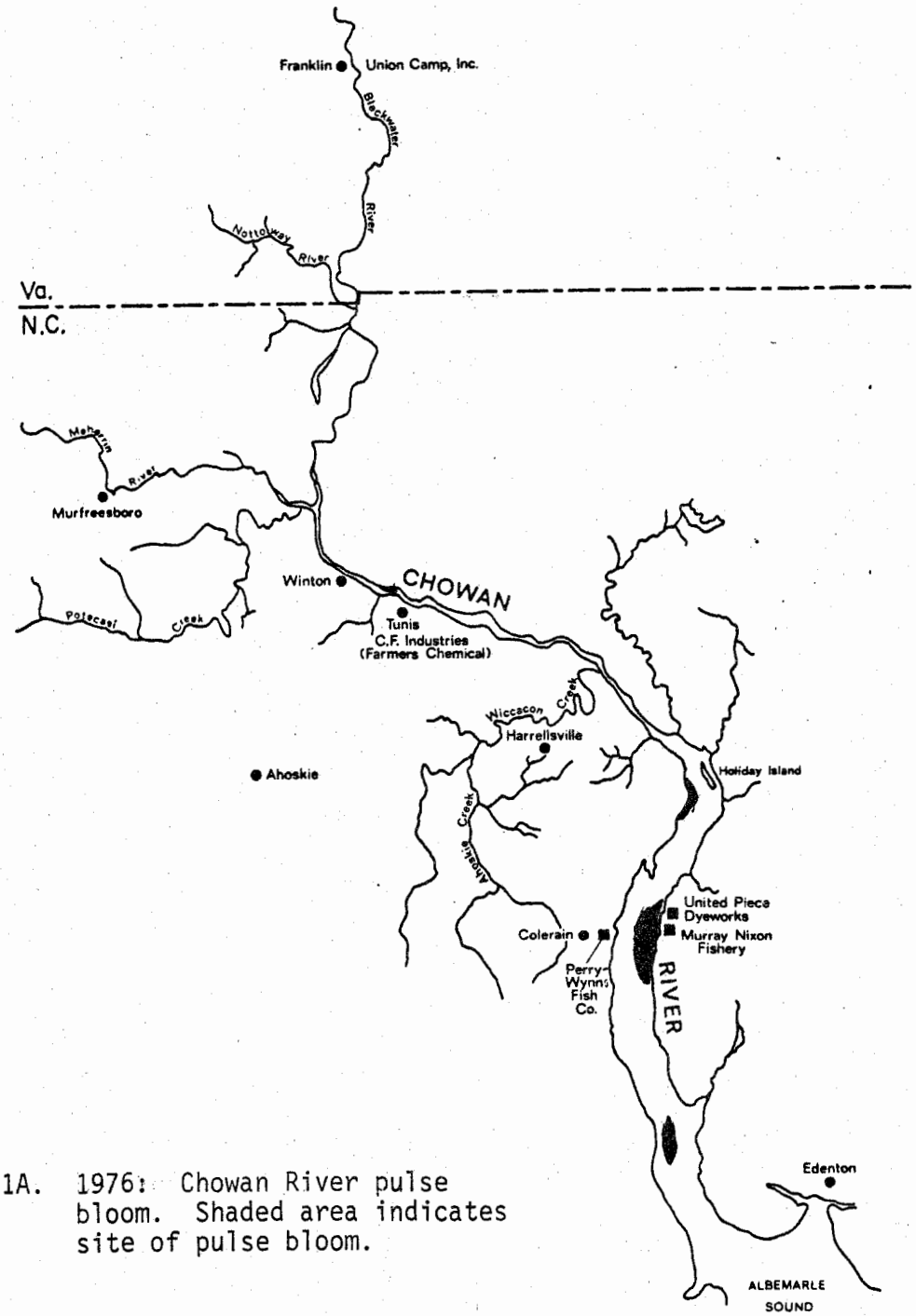


Figure 1A. 1976: Chowan River pulse bloom. Shaded area indicates site of pulse bloom.

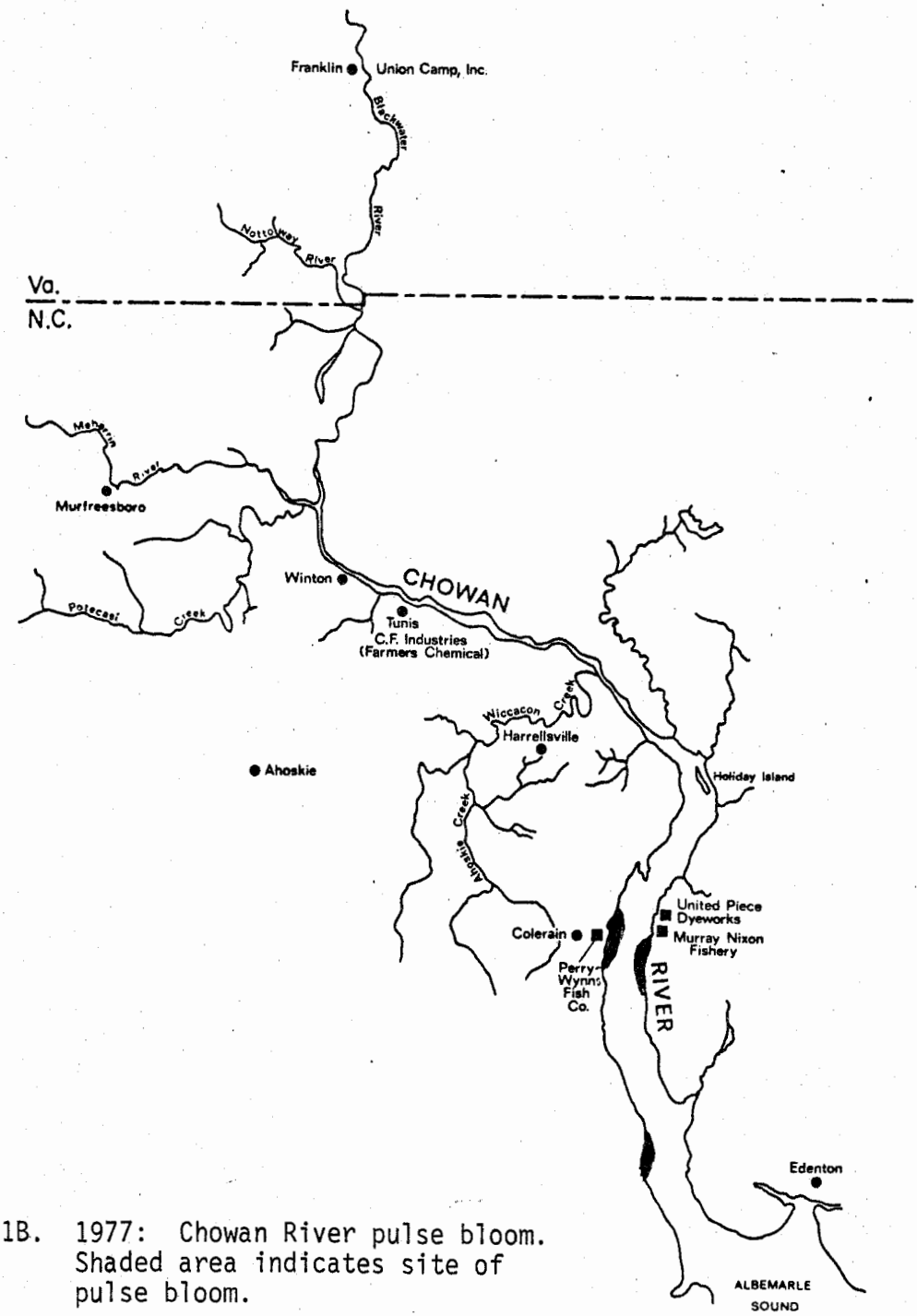


Figure 1B. 1977: Chowan River pulse bloom. Shaded area indicates site of pulse bloom.

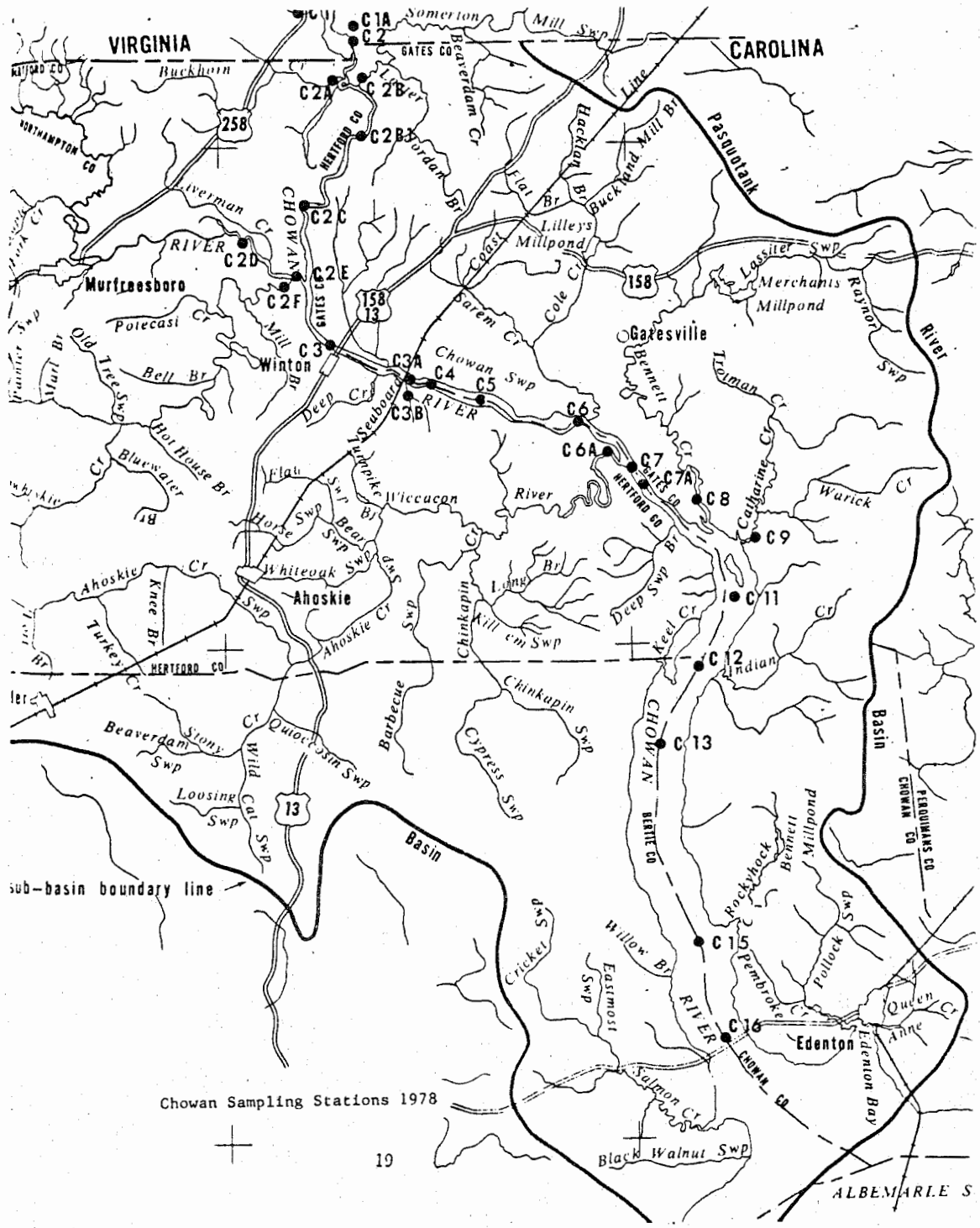


Figure 2: Chowan Sampling Stations 1978-1981

Several questions were asked by the local concerned citizens:

1. What triggered the massive bloom in such a short period of time? What mechanism?
2. As there seemingly was a quick build-up of nutrients in the lower reach of the river, what was the nutrients' source(s) and what were the nutrients of concern? Nitrogen? Phosphorus? Others?
3. What was the potential danger of the bloom and what could be done to prevent another? How long will it last? What should be expected?
4. How did the algae get into the system; was it by growth within the system or from run-off into the system?

Several public hearings were held in an attempt to give momentum to what was called the "clean-up" of the river. During the initial hearings, the interest of the discussion was one of blaming and denials. Therefore, very little was accomplished toward the initiation of or the support for an organized effort to answer the previously stated questions.

During the third public hearing one longtime Chowan River investigator (52A) gave the participants a "symbolic" cause/effect model of the historical profile of the river, subsequently called by the local residents the "Marble Story." This analysis sought to place responsibility for the then-current condition of the river across a wide spectrum of the public and over an extended period of time. The profile was implicating from individual households to corporate businesses; from the individual fisherman to the fish industry; from recreational users of the river to farmers in the river basin. The "Marble Story" seemingly gave some momentum to the idea that ultimately the river problem was a function of all who lived or worked in the area and all who used the river, directly or indirectly; all had to share somewhat in the blame.

The subsequent public hearings centered on how and when what could be done, would be done, and by whom; with reporting on what had been done, and organizing technical groups for support and policy making.

This study was undertaken at the request of the then Secretary and Deputy Secretary of the Department of Natural Resources and Community Development with the backing of the Governor of the State of North Carolina and the citizens' organization along the Chowan River.

The information reported here was deduced from a 20-month data set that was periodically (upon completion) given to the NRCD-DEM between October 1978 and July 1980.

The initial objective of this study was to generate a valid data set on nutrients and phytoplankton in the Chowan River. The nutrient data set produced by NRCD during and immediately following the 1972 bloom (1973-1974) proved to be invalid due to the limit of detection utilized for laboratory nutrient analysis. The specific objective was to utilize the data set in an effort to determine a nutrient standard for the river. The specific objective was initially aborted at the request of NRCD-DEM. However, it was understood that the data received by NRCD-DEM would be used to derive a nutrient standard for the river.

This report gives a summary of the data which suggests a range of conditions for consideration by management, the essence of which is a nutrient standard by suggested reductions in NH_4, NO_3 and PO_4 levels.

METHODS

The diversity of work encompassed in this report is such that specificity of procedures were included with the particular experiments concerned. The well-established and highly acceptable methods are given only as reference unless some degree of modification was undertaken.

All statistical analyses were derived from standard procedures developed as a computer package, the Statistical Analysis System (SAS) with the NCSU computer facility. However, some computer generated graphics were developed in association with additional programming or the use of other computer sets.

Sampling Stations

Twenty-five sampling sites were identified within the Chowan River Complex (CRC). The Chowan River, its tributaries and its two confluence-forming rivers, the Nottoway and the Blackwater, are considered in this work as the CRC.

The sites on the Chowan River proper were selected strategically on a spatial as well as from a "point-source" basis. A distance of equal proportions was established between each station except where the equal distance was not compatible with a point source (Table A). It was important to collect above and below each point source. The sites on the tributaries were located at the mouth or just up from the mouth of each tributary. Sites on the Blackwater River were arranged in accordance with the Union Camp (UC) point source, one above and one below the discharge area. Sites on the Nottoway were located up from the mouth of the river to a position where the confluence forming activity of this river with the Blackwater would not influence the discharge of the Nottoway from Virginia (Figure 2) or vice versa.

Each station in the CRC was sampled weekly beginning mid September 1978 and continuing through October 1980. During this period samples were collected to measure the following:

1. Nutrients: nitrogen (NO_2, NO_3, NH_4, TKN, TN), phosphorus (OP, TP), Cl.
2. Chlorophyll-a
3. Algal species and biomass

Environmental parameters were taken and recorded at the time they were measured from the boat. Most parameters were taken throughout the water column or, if not, they were measured at the water surface and at the water bottom. They were:

1. Temperature
2. pH
3. DO
4. COD
5. Conductivity
6. Alkalinity
7. Light (turbidity)

Analysis

All water samples were returned to NCSU for analysis. Chlorophyll-a analyses were done in the NCSU phycological laboratory with the aid of a Turner Fluorometer. Standard procedures were utilized as described in the Turner manual, 1978 (42A). Biomass estimates were based on the method of Utermohl (44A) using a phase contrast compound microscope. Nutrients were analyzed in the wet chemistry lab of the Department of Biological and Agricultural Engineering, NCSU, using the Technicon Auto-Spectrophotometric instrument (Industrial Method No. 100-70W. with the Technicon Autoanalyzer II methodology, 1973) and the preparation methods according to Standard Methods (41A). Sediment samples were taken both weekly and monthly. The weekly samples were taken for incubation and spore germination. The monthly samples were taken for

nutrient analysis. Analysis for nutrients of sediment samples were done by: 1. N.C. State Water Chemistry Lab, Cary Road, NC; and 2. the Soil Analytical Lab, Blue Ridge Road, Raleigh, NC.

Isolation of Algal Species

Sediment samples were incubated at temperatures ranging from 0°C to 40°C with continuous light in the range from complete darkness to 800 ft. c. Varying concentrations of nitrogen and/or phosphorus fortified Chowan River water or ASM-1 nutrient media were overlain on the sediment. When an algal species first appeared on the sediment surface, the species was isolated and reincubated either on nutrient fortified agar or in liquid medium. This process was repeated until unialgal species were obtained (56).

RESULTS AND DISCUSSION

Station Comparisions Based on Phytoplankton Response

Chlorophyll-a

Using Duncan's Multiple Range Analysis (DMR) (10, 11) station differences based on mean chlorophyll-a were grouped into seven (7) overlapping classes (Table I):

I. C-16, C-15, C-13*, C-12, C-9

II. C-8, C-9, C-11, C-12, C-15, C-16

III. C-7A, C-8, C-11

IV. C-6, C-6A, C-7A

V. C-2D, C-4, C-4A, C-5, C-6, C-6A

VI. C-1, C-2B, C-2C, C-2D, C-2F, C-3, C-3A, C-4, C-4A, C-5, C-6

VII. C-1, C-1B, C-2, C-2B, C-2C, C-2D, C-2F, C-3, C-3A, C-4, C-4A, C-5

As can be determined from Table I, the mean Chlorophyll-a concentrations are not arranged within sub-groups as indicated above. Station C-13* (Colerain) for example was not an overlapping station. It only appeared in the "A" grouping. The A and B groupings suggest that the river, from stations C-8 to C-16, while having some individualism, are wholistically similar. It is interesting to note that these stations comprise what we refer to as the "lower-Chowan."

Considering that all station numbers followed by a letter (C-1B, C-7A, etc) were either tributary or specially selected sites, it can be seen in Table I that the "upper-river" is also wholistic, if not uniform, from station to station. Thus, the data presented here treats the stations in the lower-river as a single responding unit and the stations in the upper-Chowan as a single responding unit.

TABLE I

DUNCAN'S MULTIPLE RANGE TEST RESULTS FOR CHLOROPHYLL-a (µg/l)

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

ALPHA LEVEL = .05 DF-2330 MS=332.977

GROUPING	MEAN	STATION
A	23.639	C13
B A	21.872	C15
B A	21.806	C9
B A	20.883	C16
B A	20.146	C12
B A C	18.081	C11
B C	17.277	C8
D C	13.631	C7A
E D	11.522	C6A
E F	9.558	C6
E G F	7.242	C4A
E G F	6.860	C5
E G F	6.558	C2D
E G F	6.480	C4
G F	5.506	C2F
G F	5.503	C3
G F	4.646	C3A
G F	4.064	C2B
G F	3.840	C1
G F	3.518	C2C
G	2.815	C2
G	2.701	C18

Algal Biomass

The Duncan's Multiple Range analysis was applied to wet weight biomass (WWB) in an attempt to make a "chlorophyll-a"--"WWB" comparison of the "likeness of the river" from station to station (Table II). Station C13 was not grouped, nor did it overlap according to wet weight algal biomass (WWB) with any of the other stations on the river. However, in general, the "lower Chowan" stations, as the "upper Chowan" stations, were grouped in amazingly similar aggregation. It is interesting to note that station C11 is more aligned with upper river stations according to biomass while it is grouped with the lower river station set when measured according to chlorophyll-a.

A most significant finding is shown in Table III. Again, using the DMR analysis test, the river stations were grouped according to the blue-green algal WWB. Stations C13 and C15 were grouped as a unit apart from stations C8, C9, C11, C12, and C16, unlike the DMR test using chlorophyll-a (Table I) and unlike the DMR test using WWB (Table II).

Blue-Green Algal Biomass

While blue-green algal wet weight biomass analyzed by the DMR test suggests that stations C13 to C15 were significantly alike, also were stations C16, C12, C14, C9, and C11. However, the latter were significantly different from C13 to C15 even though all stations were lower river stations. When the algal community structure data were analyzed it clearly showed that indeed the species makeup of stations C13 and C15 were similar, generally, in both species-bio-volume and the class of species present (Appendix III, IV). Likewise, species composition was similar within the C-group (Table III). The B-group suggested some overlapping between Station C15 and C16. Again, the species data during summer months when Aphanizomenon flos-aquae dominated the algal community, indicated this close relationship.

TABLE II

DUNCAN'S MULTIPLE RANGE TEST RESULTS FOR TOTAL BIOMASS (mg/l)

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05 DF=850 MS=101.169

GROUPING	MEAN	STATION
A	14.955	C13
B	8.582	C15
C B	7.378	C16
C B D	5.863	C12
C B D	5.384	C9
C E D	4.999	C14
C E D	4.804	C11
F E D	3.616	C7A
F E D	3.283	C6
F E	1.664	C4
F	0.852	C1

TABLE III

DUNCAN'S MULTIPLE RANGE TEST RESULTS FOR BLUE-GREEN BIOMASS (mg/l)

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

ALPHA LEVEL=.05 DF-723 MS-42.6961

GROUPING	MEAN	N	STATION
A	6.316917	80	C13
B A	4.418975	78	C15
B C	3.872917	71	C16
B C	3.479841	78	C12
B C	2.853389	75	C14
B C D	2.549391	58	C9
B C D	2.334669	72	C11
C D	1.228631	34	C6
D	0.246704	77	C4
D	0.108018	50	C1

Chlorophyll-a as well as algal wet weight biomass (Tables I and II, respectively), showed 6 to 7 different station groupings. Such groupings are indicative of the overlapping of either chlorophyll-a or wet weight algal biomass between some stations. However, blue-green algal WWB, Duncan Multiple Range test showed only four different groupings of the stations (Table III). It is interesting to note that Station C13 was never over-grouped with any other station.

Station Comparison Based on Nutrient Response

Ortho-Phosphorus (OP)

Shown in Table IV are the groupings of all stations sampled with respect to ortho-phosphorus mean concentrations, analyzed using the DMR test. Station C2, located in the upper section of the Chowan River complex (CRC) (250-300 yds up the Blackwater River above the confluence with the Nottoway River) was unique with respect to OP (Table IV). However, a greater uniformity of the stations was clearly shown. Group "F" represents the stations in the lower Chowan. This included station C13, which was unique in the chlorophyll-a and WWB DMR tests. Yet, with OP, C13 was linked to the lower Chowan Group. Thus, OP concentrations are divided in the river into upper and lower river groups (Table IV). Before removal from the data set, overlapped groupings express tributary sampling. However, when second order tributary stations were removed from the data set, the Chowan River complex stations were clearly delineated (Table IV).

It is noticeable that the positioning of the lower to upper Chowan station groupings are in reversed order to that shown by chlorophyll-a and WWB. Further, station C1B, while geographically located above Union Camp (UC), was nevertheless grouped at the lower end of the D-groupings (Table IV). Station C2, 250-300 yards above the mouth of the Blackwater River, but below UC discharge site, uniquely had the highest mean OP concentration.

TABLE IV

DUNCAN'S MULTIPLE RANGE TEST RESULTS FOR ORTHO-PHOSPHORUS (mg/l)

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

ALPHA LEVEL=.05 DF-2172 MS-9.4E-04

GROUPING		MEAN	N	STATION
	A	0.081786	84	C2
	B	0.065349	86	C2B1
	B	0.064195	87	C2C
	B	0.063908	87	C1
C	B	0.055523	86	C3
C	D	0.052679	84	C4A
C	D	0.052529	85	C3A
C	D	0.050706	85	C6A
C	D	0.050247	81	C2B
C	D	0.049277	83	C9
C	D	0.049186	86	C5
C	D	0.049048	84	C4
C	D	0.048571	84	C6
C	D	0.047941	85	C2D
C	D	0.046453	86	C7A
C	D	0.045893	84	C2F
E	D	0.042614	88	C1B
E	F	0.035882	85	C11
E	F	0.034824	85	C12
E	F	0.034706	85	C8
E	F	0.034080	87	C3B
	F	0.031824	85	C13
	F	0.031402	82	C14
	F	0.029048	84	C15
	F	0.028213	87	C16
	F	0.028082	73	C13A

In light of the B-groupings as opposed to the A-group, one would question the real source of OP to the river proper. Station C1B is more like stations C11, C12, C8, etc. However, no massive blue-green algal bloom has been reported in the area of the river covered by station C1B.

Nitrite-Nitrate Nitrogen (NO_3-N)

Station grouping as shown in Table V for NO_3-N were similar to the OP set. Group I, with the exception of C1, included the lower Chowan stations. It should be remembered that station C14, even though it has no letter designation, was a first-order tributary station at the mouth of Rocky Hock Creek. Therefore, the designation of C14 with the upper Chowan stations is not easily explained (Table V). Station C1 was inclusive in the lower Chowan group. However, C1 was located on the Nottoway River before the confluence with the Blackwater forming the origin of the Chowan River. Thus, C1 in essence, while belonging with the Chowan River complex, is not located in the Chowan River (Figure 3). All of the CRC sampling stations were included in the analysis for station-to-station comparison. When these data were analyzed without the tributary stations in the model, the Chowan River showed a remarkable "two-system" organization with respect to NO_3-N. Stations above C8 in one division (upper Chowan) and stations below C9 in another division (lower Chowan) (Table V). It was interesting to note that stations C4A, C1B and C14, group A, demonstrate the highest NO_3-N levels, even though they are geographically far removed. Equally as interesting was the DMR positioning in the I-group station C1, which is geographically located above the mouth of the Nottoway River at US #258. While the lower Chowan I-group low nitrogen level is perhaps an expression of nutrient uptake and algal blooms, no algal bloom and limited algal growth was found in all years in the Nottoway River (53). This suggests that low levels of nitrogen are entering the Nottoway River. Thus, the non-point

TABLE V

DUNCAN'S MULTIPLE RANGE TEST RESULTS FOR

NITRITE PLUS NITRATE NITROGEN (mg/l)

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

ALPHA LEVEL=.05 DF-2472 MS=.0313553

GROUPING	MEAN	N	STATION
A	0.344141	99	C4A
B A	0.305824	91	C1B
B A	0.293333	84	C14
B	0.285773	97	C3B
B C	0.260309	97	C2
B C	0.260108	93	C9
D C	0.214045	89	C2B
D E	0.192871	101	C5
D E F	0.188352	91	C2BA
D E F	0.186300	100	C4
D G E F	0.183700	100	C2C
H D G E F	0.178247	97	C6
H D G E F	0.171569	102	C3
H D G E F	0.170619	97	C2D
H D G E F	0.168800	100	C3A
H D G E F	0.162474	95	C7A
H G E F I	0.149381	97	C2F
H G E F I	0.142277	101	C11
H G E F I	0.140404	99	C6A
H G E F I	0.137475	99	C12
H G J F I	0.132172	99	C13
H G J F I	0.129949	98	C1
H G J I	0.125051	99	C16
H J I	0.120800	100	C15
J I	0.101918	73	C13A
J	0.077100	100	C8

source contribution of nitrogen from this river is questionable. However, C1B is above UC yet it has a high mean NO_3-N concentration and significantly compares with nitrogen mean concentrations around C.F. Industries. Thus, the large number of point sources on the Virginia section of the Blackwater should provoke questions concerning point and non-point sources of nitrogen from this area.

The B group (Table V) further suggests a closer examination of the source of nitrogen potential as revealed by these stations. In fact, the entire set of groupings suggests that a closer site examination be made relative to the sources of nitrogen. An analysis of land use by physical examination in light of these findings is necessary if definitive information is desired.

Ammonia-Nitrogen (NH_4-N)

The A-group stations (Table IV) form an interesting pattern. The A-group shows the highest mean ammonia concentrations of all the CRC stations. Yet, they are geographically quite a distance apart. In their geophysical location, each is uniquely located with respect to the CRC. Station C2 is below UC; station C3B and C4A are around C.F. Industries, with C4A in direct contact with the exploited forest area, now reduced to a grass field.

It is discernable that the lower Chowan stations, in particular C13 and C16, the two most bloom prone stations, are far removed from the A-group in NH_4-N highest mean concentrations. This is of interest since Hobbie and Stanley (24) indicated that ammonia was the nitrogen type of first preference to Chowan River algae.

Total Nitrogen -/- Kjeldahl Nitrogen (TN/TKN)

As can be seen in Tables VII and VIII, TN and TKN did not follow a pattern during the study period. However, a reasonable analysis might be drawn from a more detailed observation of the data.

TABLE VI

DUNCAN'S MULTIPLE RANGE TEST RESULTS FOR AMMONIA NITROGEN (mg/l)

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

ALPHA LEVEL=.05 DF-2475 MS=.0100059

GROUPING	MEAN	N	STATION
A	0.168010	98	C2
A	0.157474	97	C3B
A	0.150707	99	C4A
B	0.081485	101	C5
C B	0.080400	100	C4
C B	0.080055	91	C2B1
C B	0.078776	98	C6
C B	0.078150	100	C2C
C B D	0.076344	93	C9
C B D	0.071968	94	C7A
C B D	0.070000	100	C3A
C B D	0.069510	102	C3
C B D	0.056050	101	C11
C B D	0.064646	99	C12
C B D	0.046100	100	C8
C B D	0.062143	91	C1B
C B D	0.061212	99	C6A
C B D	0.061012	84	C14
C B D	0.054192	99	C13
C B D	0.053622	98	C16
C B D	0.050306	98	C2D
C B D	0.050278	90	C2B
C B D	0.047062	97	C2F

TABLE VII

DUNCAN'S MULTIPLE RANGE TEST RESULTS FOR TOTAL NITROGEN (mg/l)

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

ALPHA LEVEL=.05 DF=2470 MS=0.181282

GROUPING	MEAN	N	STATION
A	1.359462	93	C9
A	1.329072	97	C3B
B A	1.300404	99	C4A
B A	1.287143	84	C14
B A	1.287010	97	C2
B C	1.188681	91	C1B
B C D	1.172100	100	C8
E C D	1.093425	73	C13A
E C D	1.090909	99	C12
E C D	1.085354	99	C6A
E C D	1.080859	99	C13
E C D	1.077600	100	C15
E C D	1.075393	89	C2B
E C D	1.056162	99	C2C
E C D	1.052772	101	C11
E C D	1.050990	101	C5
E F C D	1.041978	91	C2B1
E F	1.036895	95	C7A
E F	1.021959	97	C6
E F	1.020515	97	C2F
E F	1.020408	98	C16
E F	1.008000	100	C4
E F G	0.968235	102	C3

TABLE VIII

DUNCAN'S MULTIPLE RANGE TEST RESULTS FOR TOTAL KJELDAHL NITROGEN (mg/l)

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

ALPHA LEVEL=.05 DF=2475 MS=0.157603

GROUPING	MEAN	N	STATION
A	1.099355	93	C9
A	1.095000	100	C8
B A	1.043299	97	C3B
B A C	1.025000	98	C2
B D A C	0.993810	84	C14
B D A C	0.991507	73	C13A
B D E C	0.956800	100	C15
B D E C	0.956263	99	C4A
B D E C	0.953434	99	C12
B D E C	0.948687	99	C13
B D E C	0.944949	99	C61
F D E C	0.910495	101	C11
F D E C	0.89622A	98	C16
F D E	0.882857	91	C1B
F D E	0.874421	95	C7A
F D E	0.874242	99	C2C
F D E	0.871134	97	C2F
F D E G	0.860556	90	C2B
F D E G	0.858119	101	C5
F D E G	0.853626	91	C2B1
F E G	0.842959	98	C6
F E G	0.821700	100	C4
F G	0.79667	102	C3

TKN includes NH_4-N and organic nitrogen (ON). Since station C3B was shown to be the second highest among mean concentration (Table VI) and third highest in TKN (Table VIII), it is logical to assume, due to location and WWB, that the TKN of station C3B is mostly NH_4-N. Likewise since C9 and C8 (Table VIII) were the highest TKN means concentration stations but were not particularly high NH_4-N stations (Table VI), it could be reasoned that NH_4-N and ON were moderately equal at these stations (Table VIII and Table VI). Algal species biomass (Appendix IV) indicates that station C9 and C8 were at bloom conditions (WWB) during 1979. This would suggest a high organic nitrogen concentration at these stations. However, an examination of stations throughout the reach of the CRC (Figures 3-7) suggests that the entire CRC was high in ON. This was true regardless of season of the year. Further, within the stations shown in Figures A-E, mean ON concentrations were only slightly below the mean TKN concentrations for these stations (Table VIII), but much higher than the mean NH_4-N (Table VI) concentrations. If most of the ON is a function of algal biomass, this would suggest a high utilization of NH_4-N and NO_3-N during all seasons of the year. The only difference would be a different algal community structure, due primarily to a temperature tolerance among the species. Thus, it seems reasonable to say that the entire CRC has exceeded its nutrient needs and remains so throughout the year. Only the specificity for high temperatures (14°C - 30°C) by Cyanophyta and the upper river high flow prevents a total CRC continuous blue-green algal bloom. It is arguable from a biological perspective that the CRC is now under the siege of a continuous algal bloom.

Station Comparative Summary

The efficiency of the stations in the river to respond both biologically and chemically as a "lower group" and an "upper group" (Lower Reach Stations; Upper Reach Stations) allowed for summarization of the data as an interpretable mass.

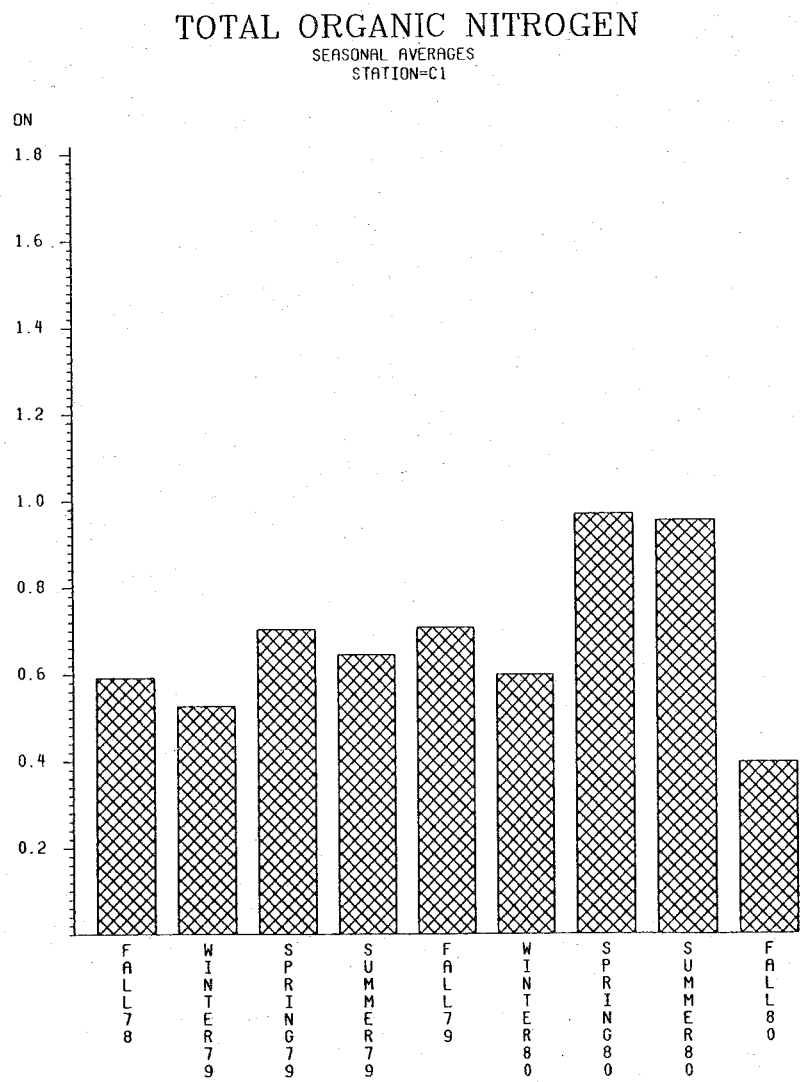


Figure 3 : Total Organic Nitrogen. Seasonal Averages, Station C1

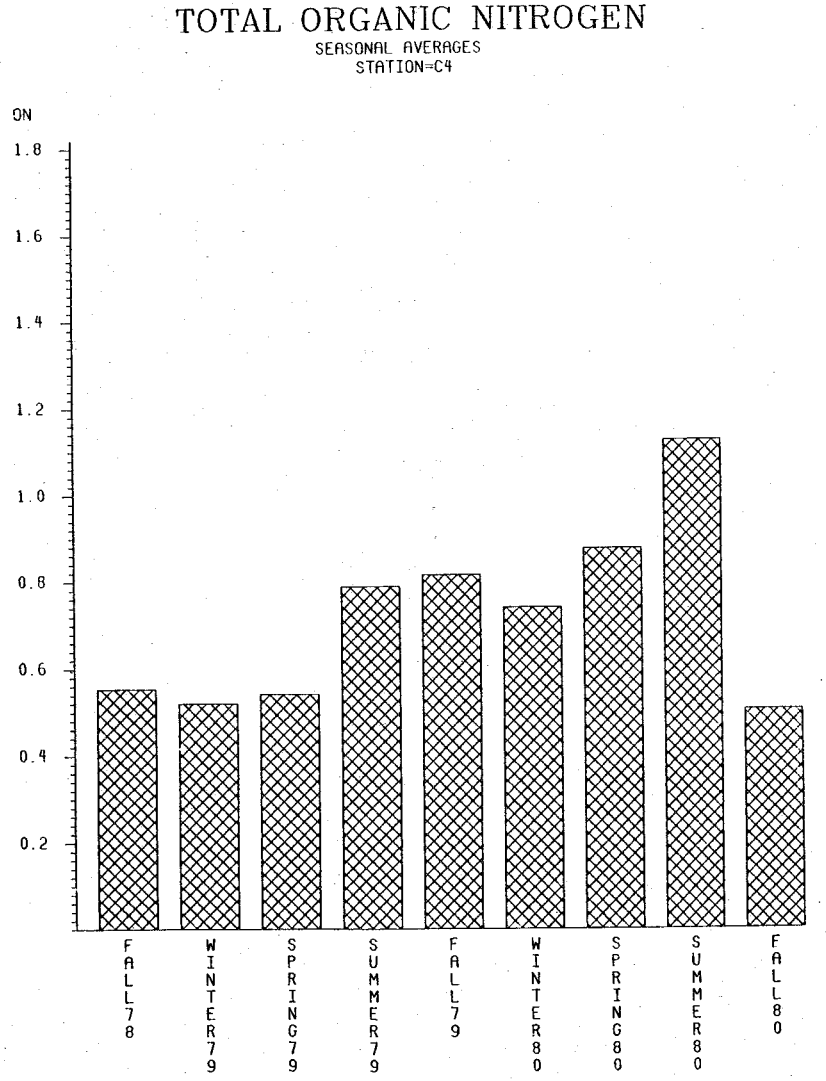


Figure 4: Total Organic Nitrogen. Seasonal Averages, Station C4

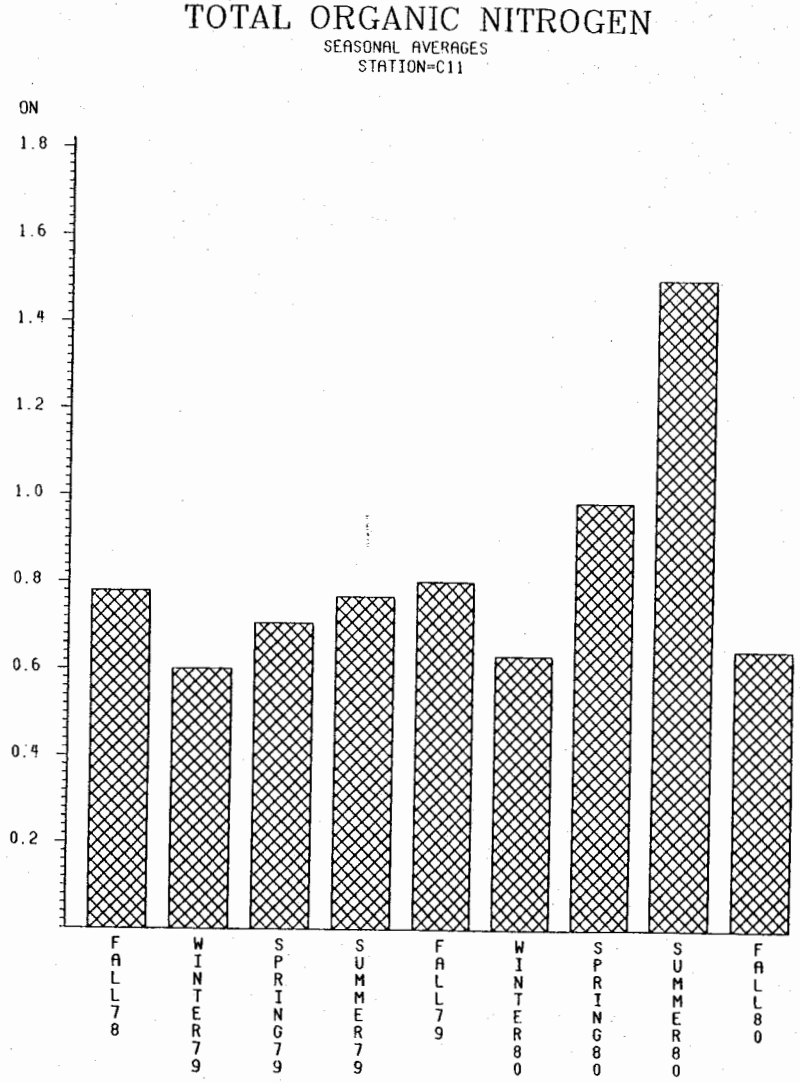


Figure 5: Total Organic Nitrogen. Seasonal Averages, Station C11

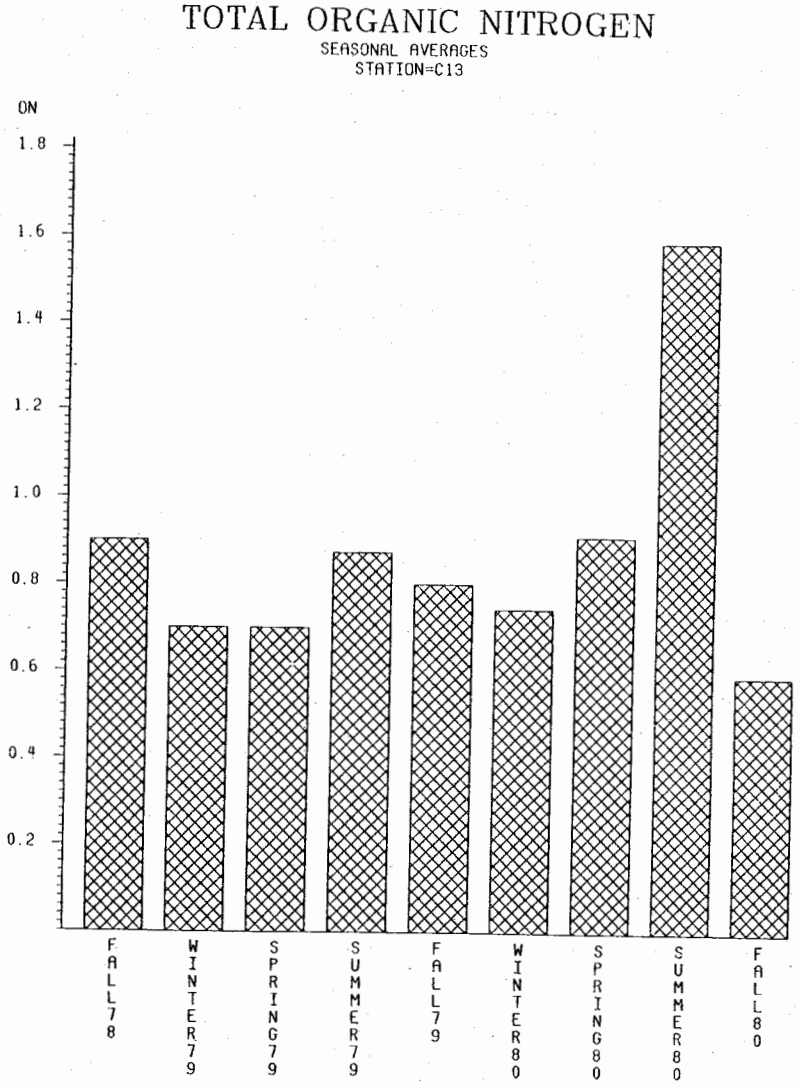


Figure 6: Total Organic Nitrogen. Seasonal Averages, Station C13

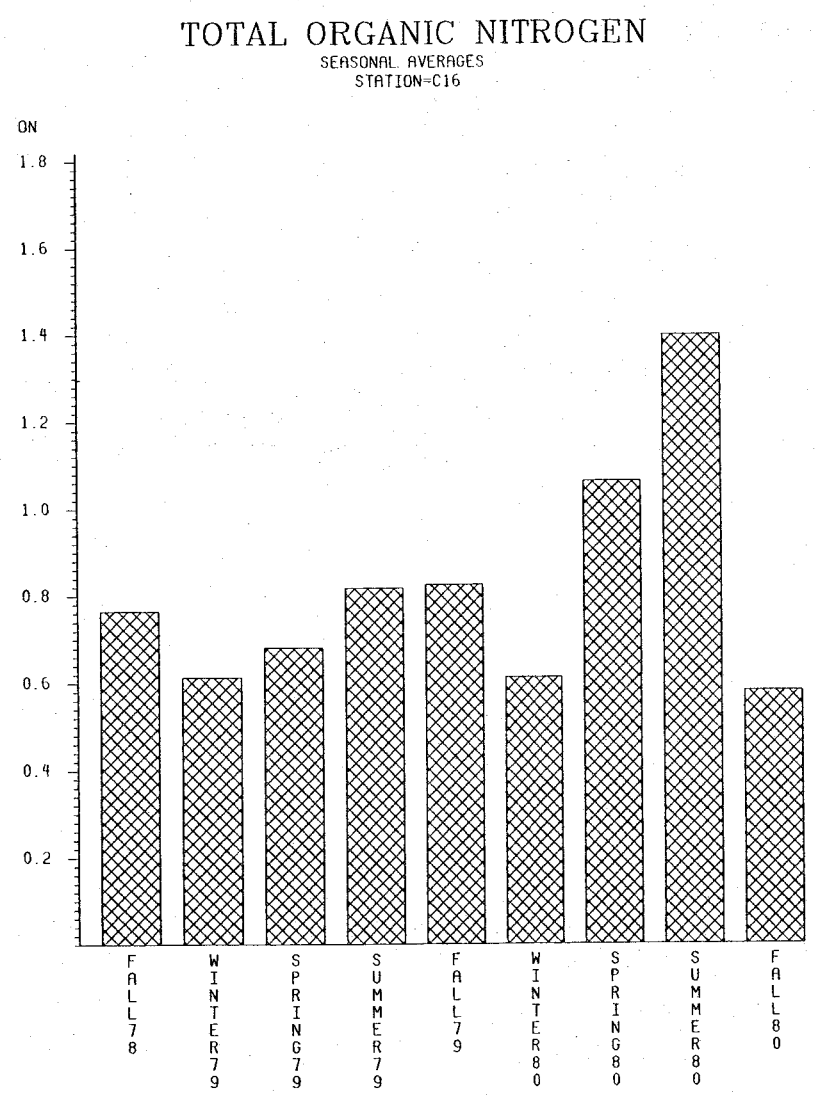


Figure 7 : Total Organic Nitrogen. Seasonal Averages, Station C16

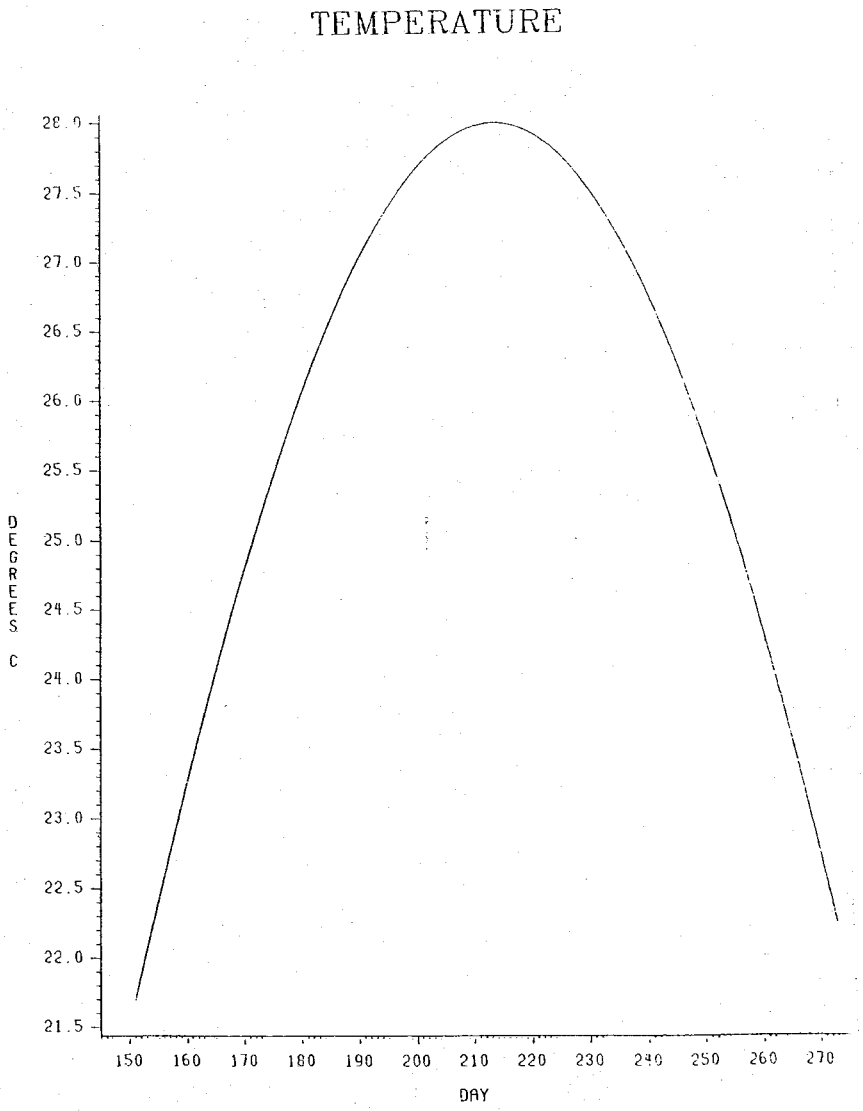
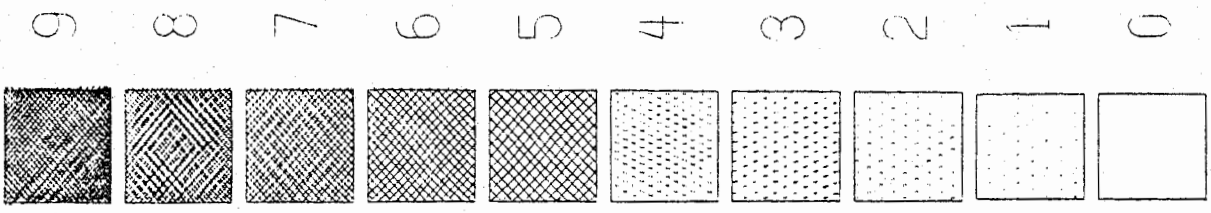


Figure 8: Temperature profile for the Chowan River, 1978-1981.



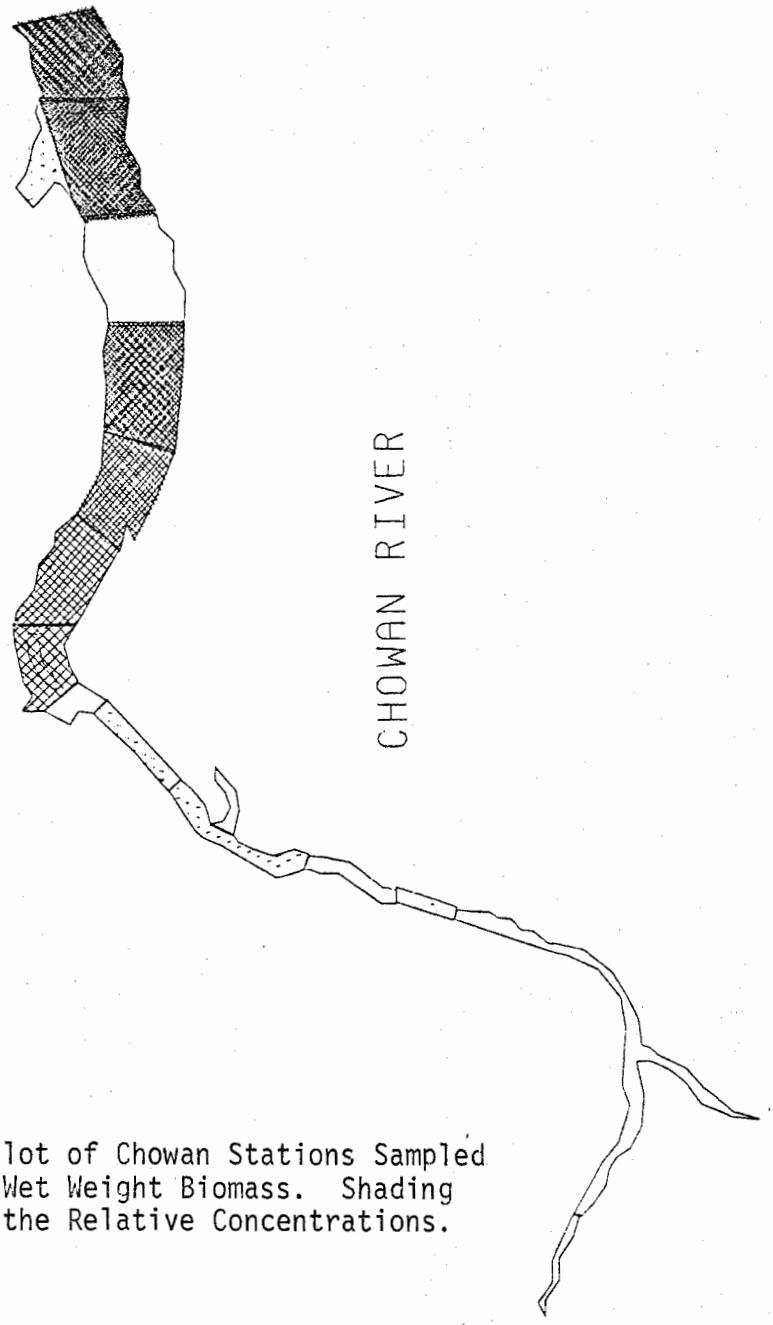


Figure 9: Computer Plot of Chowan Stations Sampled for Algal Wet Weight Biomass. Shading Indicates the Relative Concentrations.

Likewise given the chemical, ecological, hydrological and geophysical norms found in the system, temperature and changing hydrological conditions were clearly the major controlling factors for qualitative phytoplankton response (Figures 8-9).

Since temperature played a major role at its extremes and the blue-green algae of concern only respond after 14°C, temperature was considered in all analyses of phytoplankton.

Further, because the major problems in the Chowan River have historically been blue-green algal growth in the lower river reach, most of the data reported here considered only the stations in the A & B groupings (Table I, Figure 9).

In addition, the data were sub-divided into nine (9) seasons; three falls, two winters, two springs and two summers (Figures 10-15) and primarily only the mean of each parameter was considered.

Nutrient-Phytoplankton-Interaction

Chlorophyll-a

Forty micrograms chlorophyll-a per liter (40 µg/l) of river water has been established as the chlorophyll-a standard for the Chowan River (by NRCD, DEM).

Careful examination of Figures 10-15, encompassing the lower Chowan stations C11 to C16, revealed that during the years 1978-1980 the 40 µg/l level was reached seven (7) times. This occurred once at each station with the exception being station C13, where the mean chlorophyll-a exceeded the 40 µg/l in the fall season of 1978 and the summer season of 1980. The fall of 1978, which followed the dramatic 1978 summer bloom season, had a mean chlorophyll-a of 61 µg/l. The summer of 1980 was 51 µg/l.

It is interesting to note that by fall, 1978, station C16 had reduced its chlorophyll-a mean concentration from 46 µg/l as measured in June to 18.5 µg/l. During the summer of 1979 and 1980 mean chlorophyll-a concentrations were higher

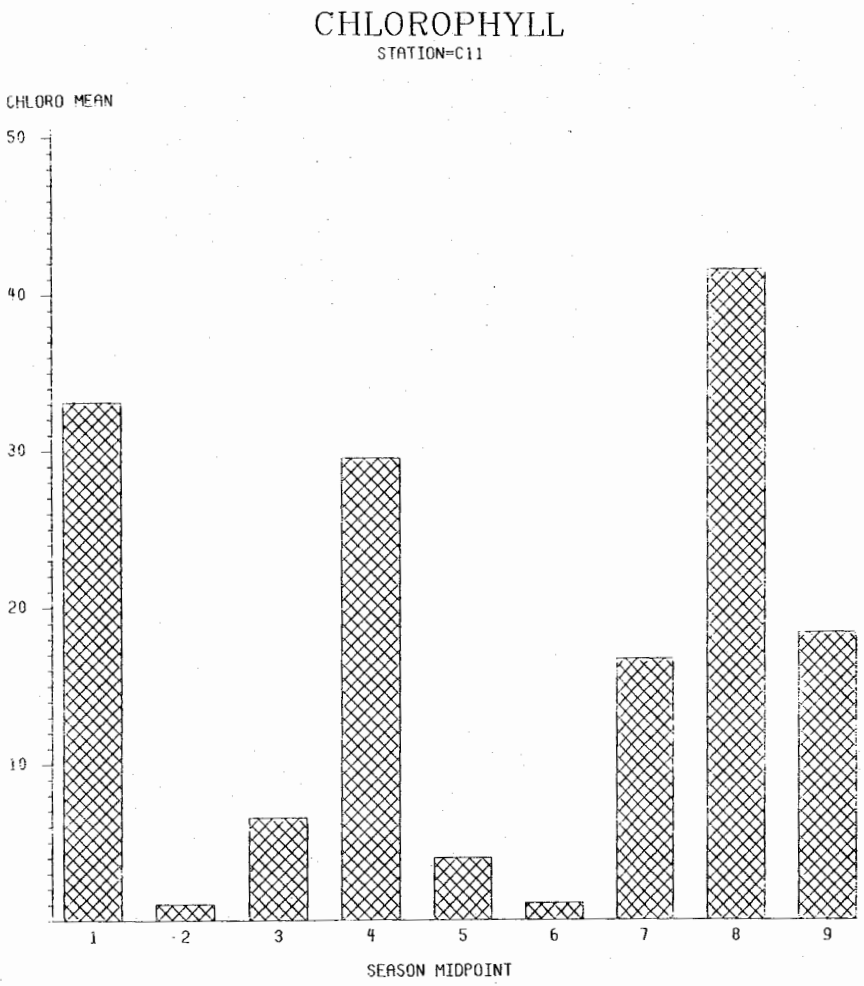


Figure 10: Chlorophyll-a Seasonal Averages, Station C-11

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

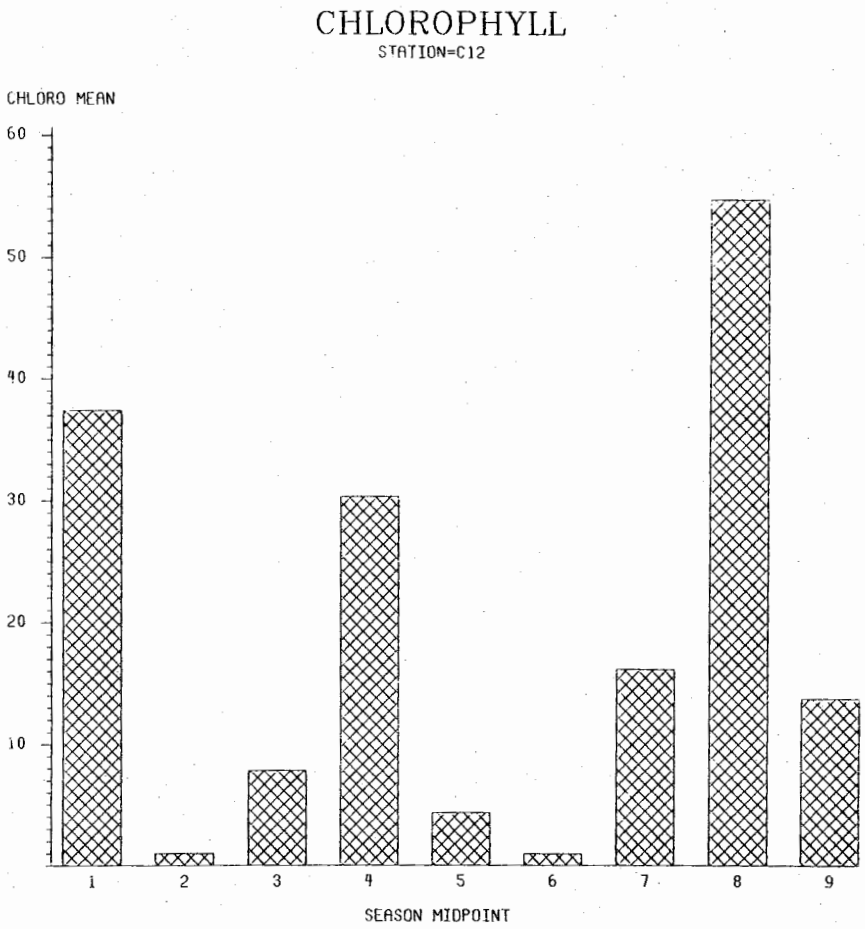


Figure 11: Chlorophyll-a Seasonal Averages, Station C-12

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

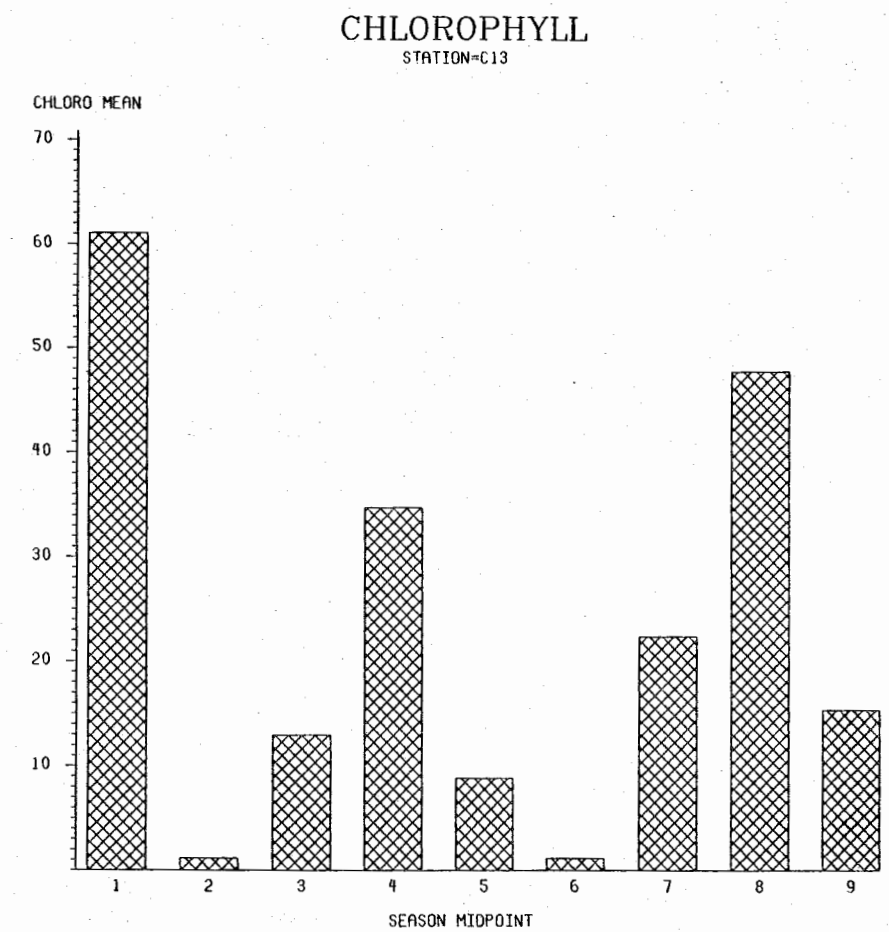


Figure 12: Chlorophyll-a Seasonal Averages C-13

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

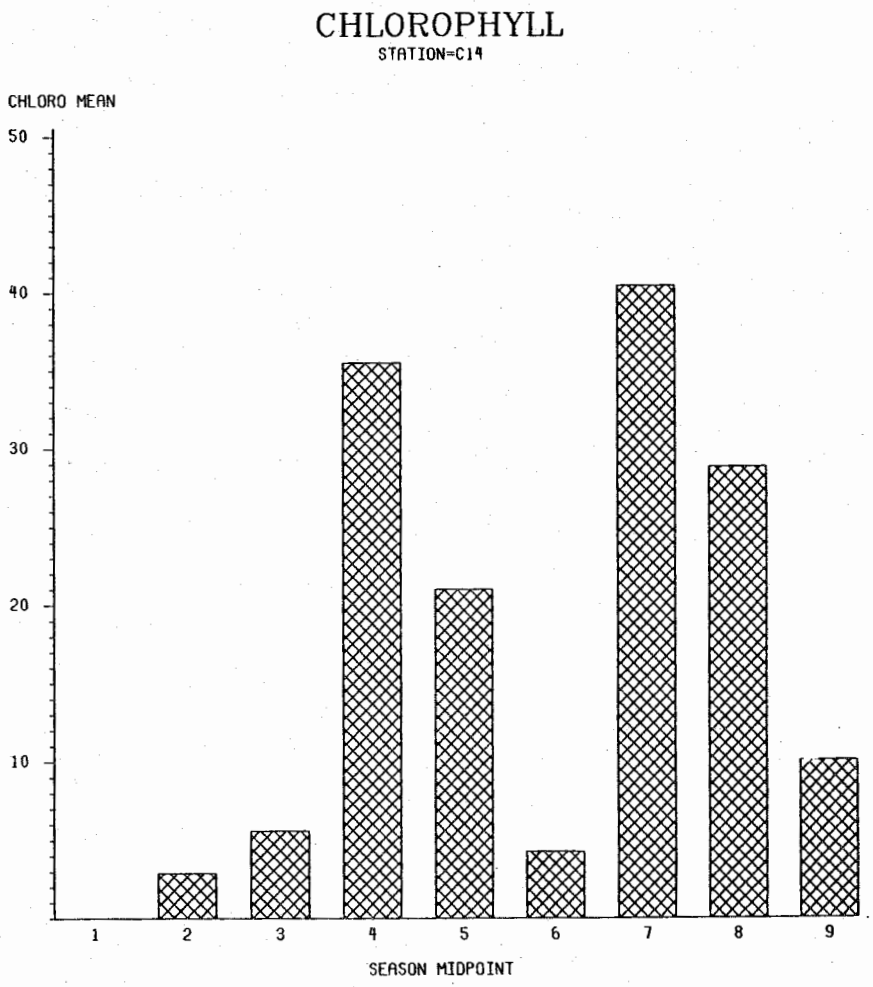


Figure 13 : Chlorophyll-a Seasonal Averages, Station C-14

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

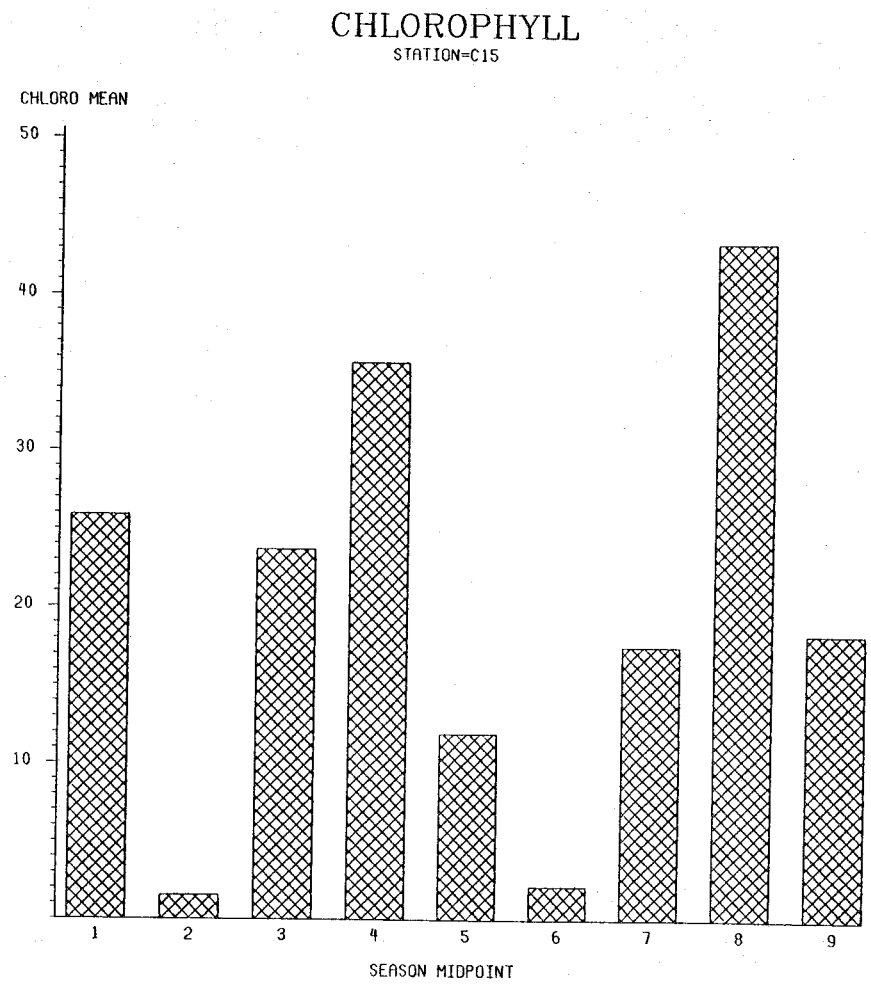


Figure 14 : Chlorophyll-a Seasonal Averages, Station C-15

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

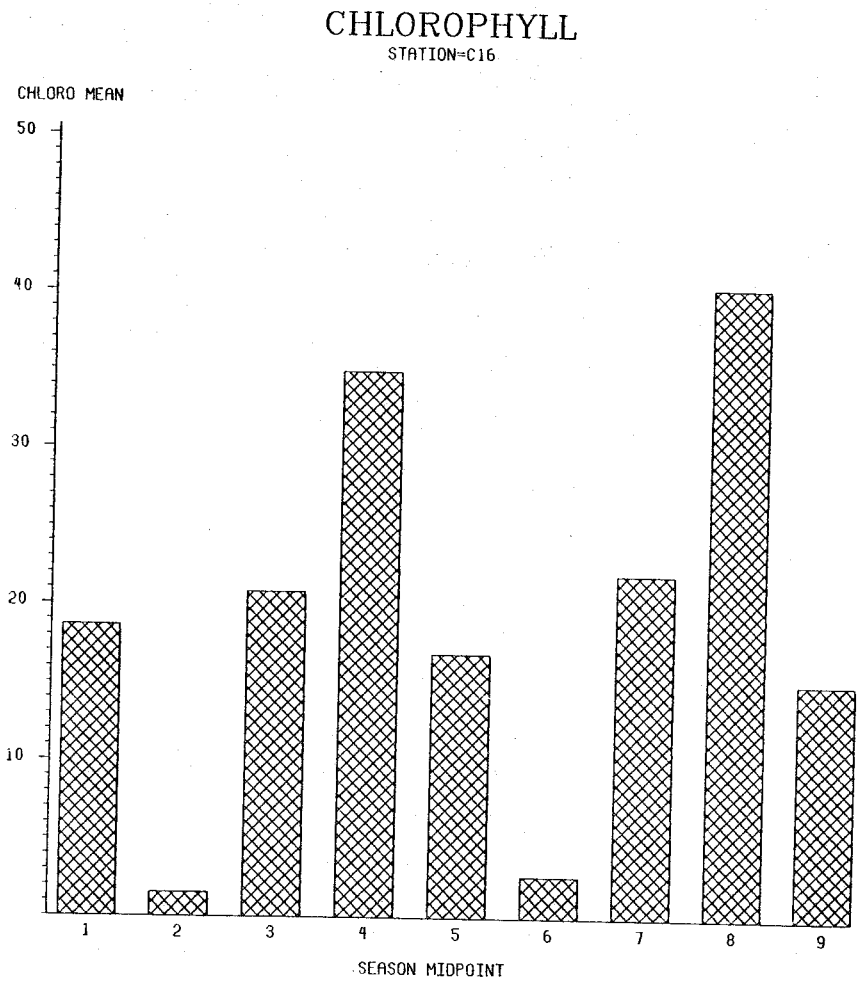


Figure 15: Chlorophyll-a Seasonal Averages, Station C-16

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

at C16 than any other station on the river. Even so, the mean concentrations barely reached 40 µg/l in 1980. In fact, the most expressive station during 1980 was C12, where chlorophyll-a mean concentrations reached 55 µg/l.

Wet Weight Algal Biomass (WWB)

A striking difference was seen when wet weight algal biomass (WWB) data were analyzed. Seasonal mean total wet weight biomass showed the same 1978, 1979 and 1980 summer pattern as was seen with chlorophyll-a. However, the comparative magnitude was far less for chlorophyll-a than for WWB (Figures 16-21). The data from station C13 were typical of observations made on the river, particularly during the fall 1978.

An examination of species data indicated that station C13 was dominated by blue-green algae (Figure 31). Thus, the difference between chlorophyll-a and WWB was perhaps the reduced chlorophyll-a content found in blue-green algae as compared to other species types, particularly the green algae. This is further suggested in Figures 22-23, C1, a station in which blue-green algae are almost absent from the system.

Since stations C13 and C16 are considered the chief problem areas and the most seriously affected algal stations, we decided to further examine the phytoplankton data at these stations in an effort to understand the chlorophyll-algal biomass-nutrient interaction.

Seasonal Mean Biomass Distribution

Figures 24-41 are representative of the groups (classes or divisions) of algae found during the various seasons. The total WWB of each group is indicated. In addition, the 360° circle depicts the percent of a given group of the whole. While these data are available for each station, only stations C13 and C16 are presented here. As stated before, these two stations are the most problematic and they are typical of the bloom stations (lower Chowan). Thus,

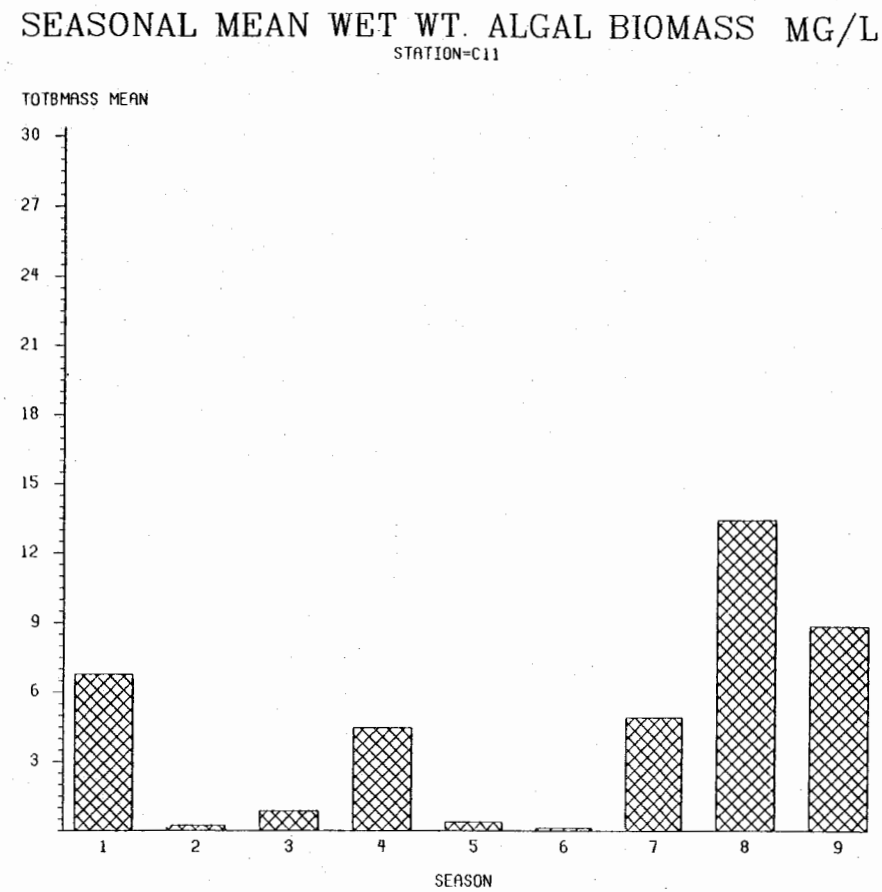


Figure 16: Seasonal Mean Wet Weight Algal Biomasses, mg/l. Station C-11

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

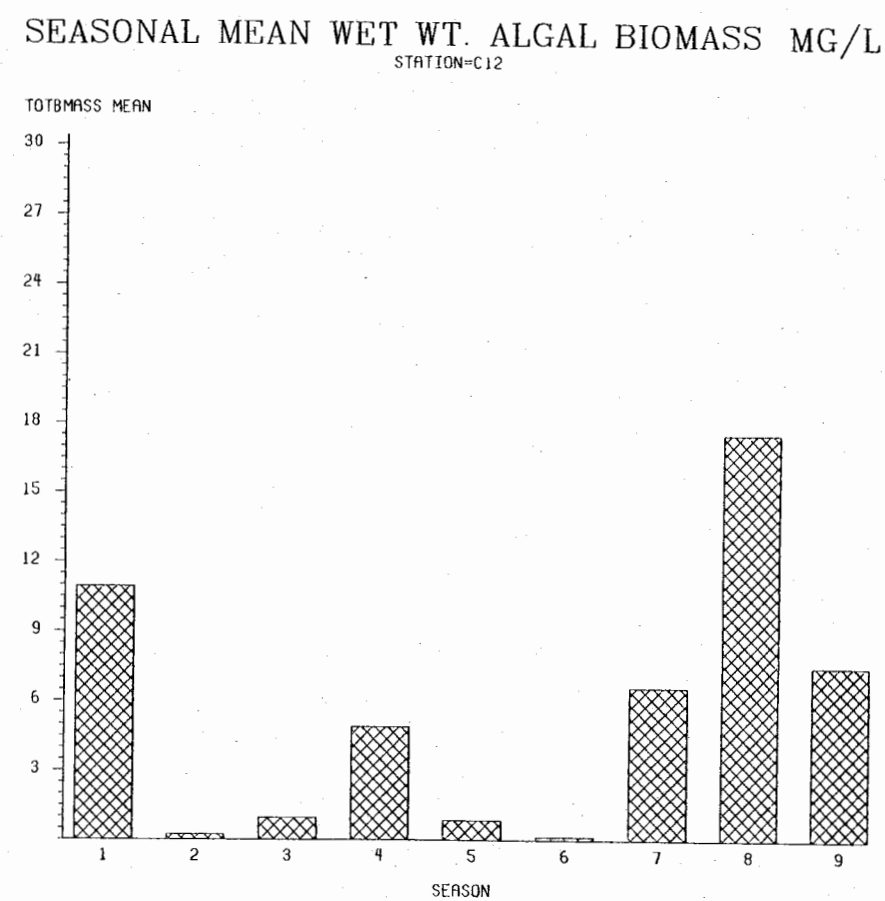


Figure 17: Seasonal Mean Wet Weight Algal Biomasses, mg/l. Station C-12

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

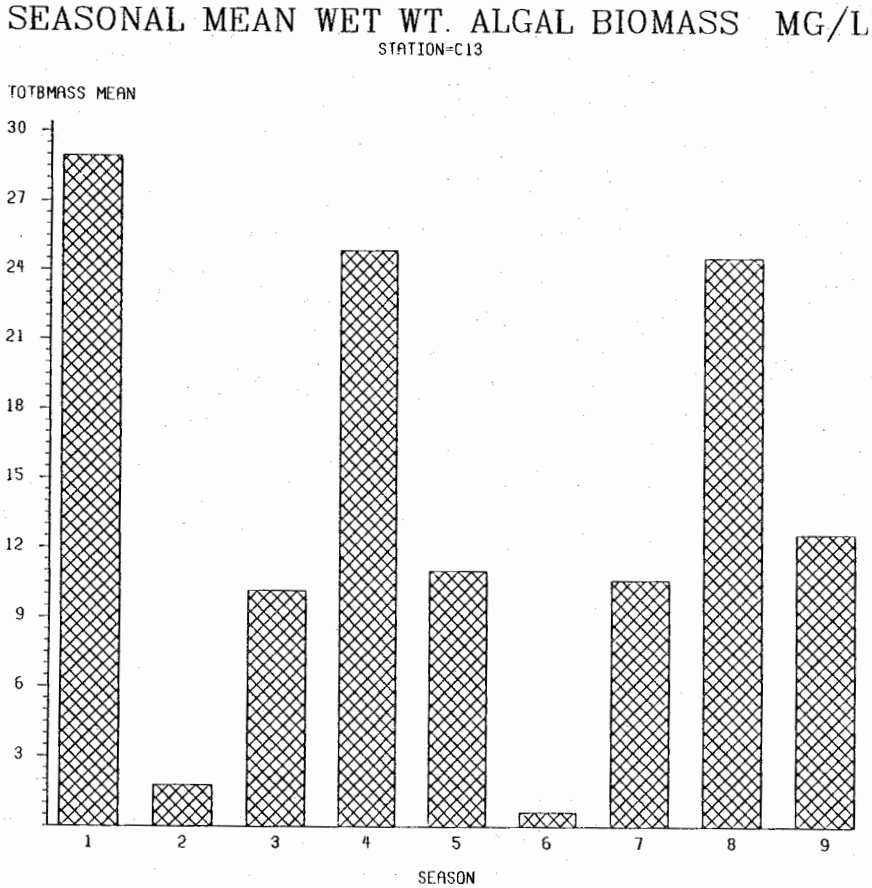


Figure 18: Seasonal Mean Wet Weight Algal Biomasses, mg/l. Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

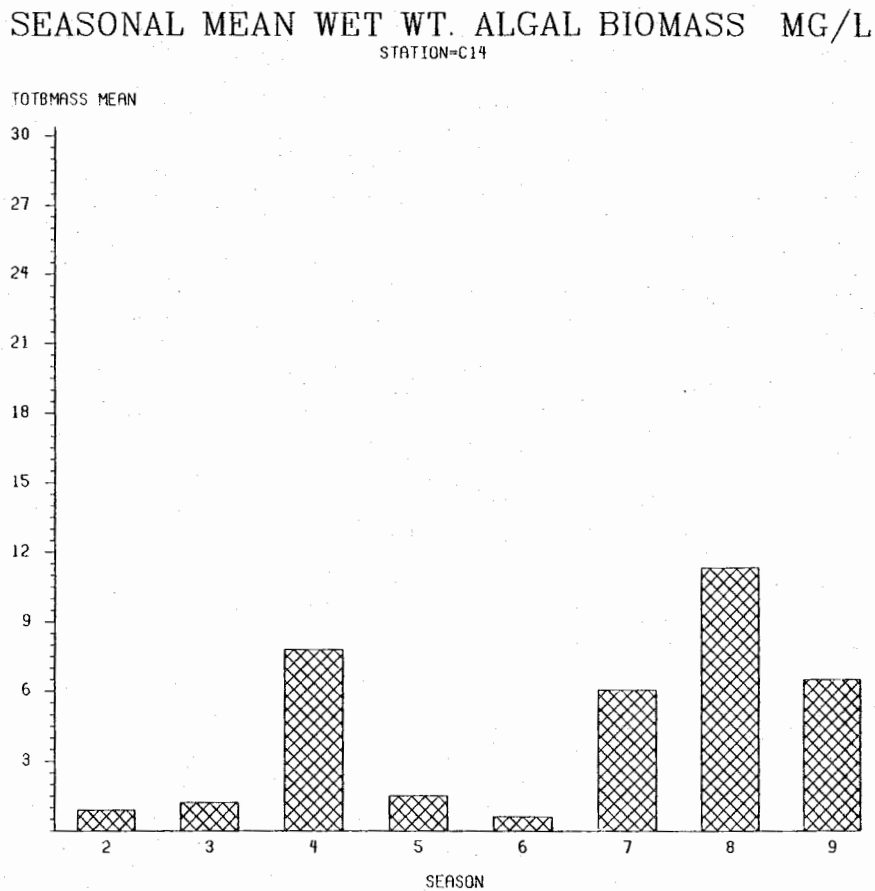


Figure 19: Seasonal Mean Wet Weight Algal Biomasses, mg/l. Station C-14

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

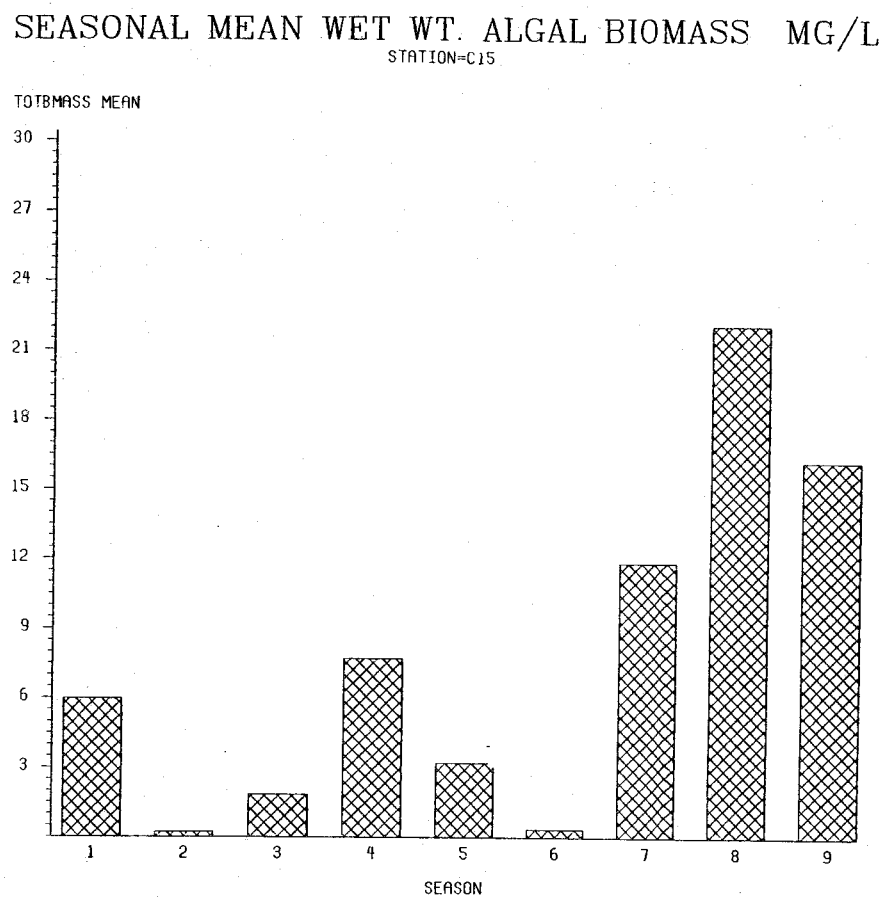


Figure 20: Seasonal Mean Wet Weight Algal Biomasses, mg/l. Station C-15

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

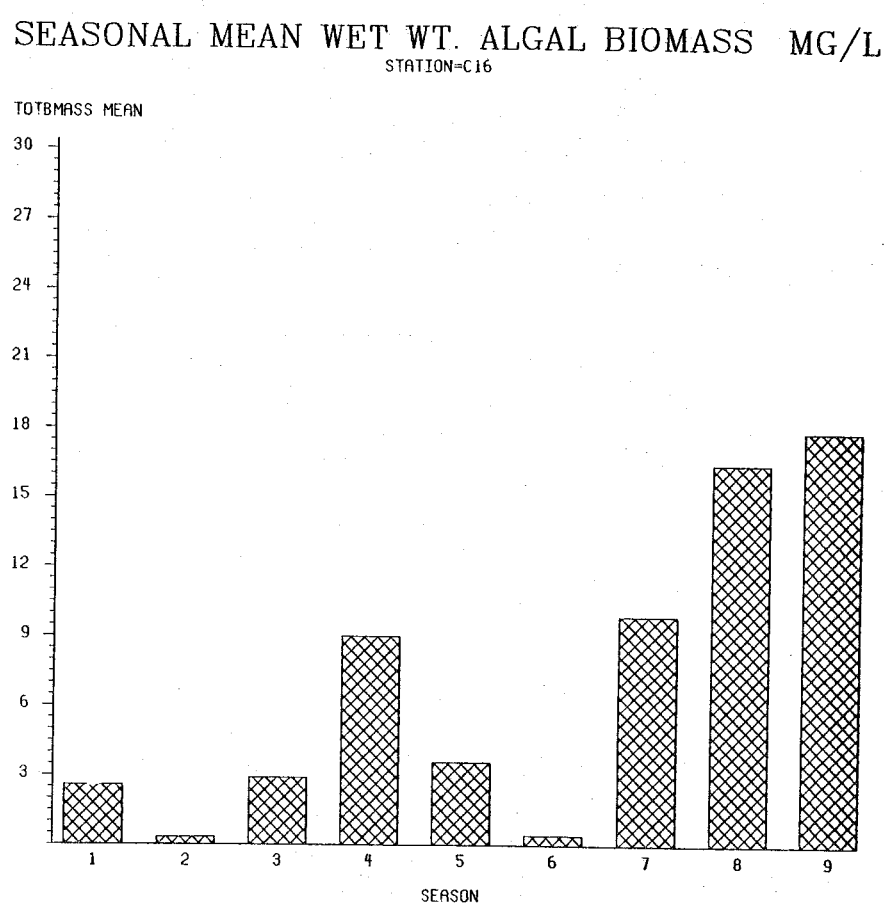


Figure 21: Seasonal Mean Wet Weight Algal Biomasses, mg/l. Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

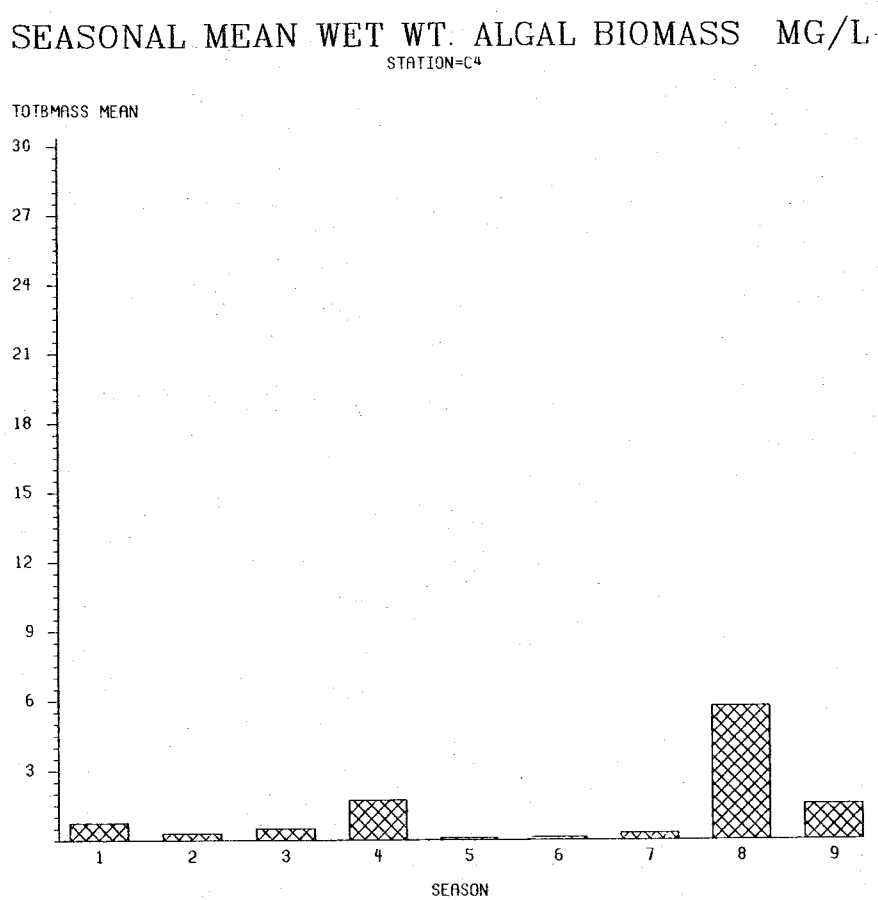


Figure 22: Seasonal Mean Wet Weight Algal Biomasses, mg/l. Station C-4

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

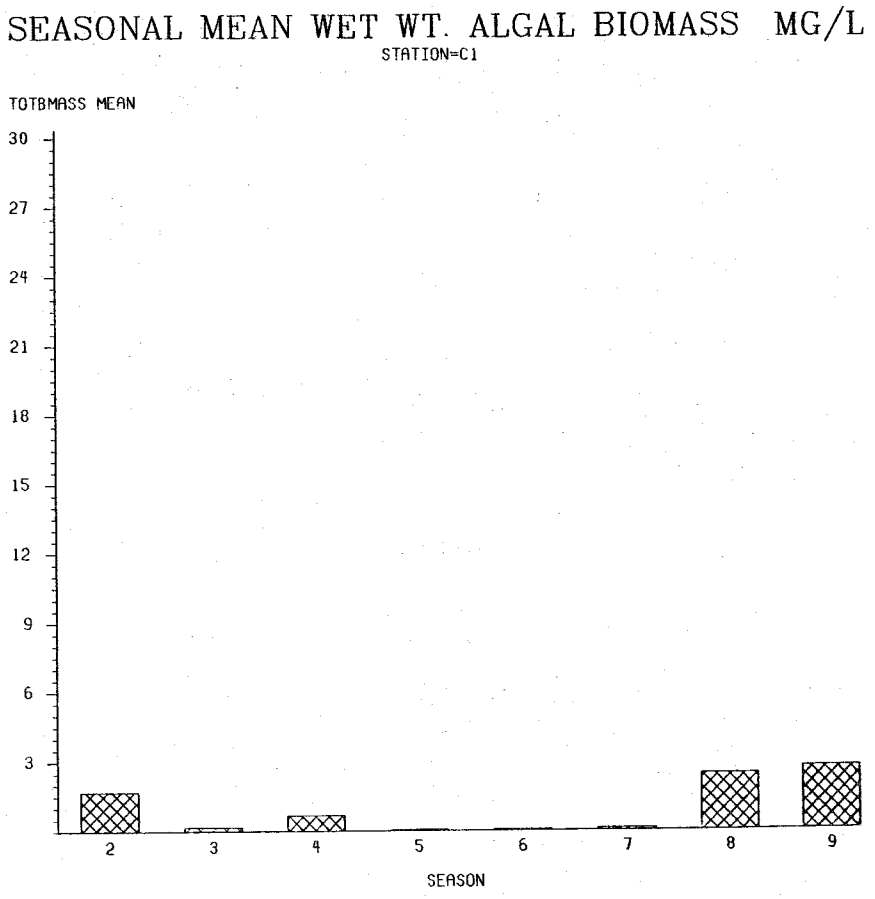


Figure 23: Seasonal Mean Wet Weight Algal Biomasses, mg/l. Station C-1

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

SEASONAL MEAN BIOMASS DISTRIBUTION
STATION=C13 SEASON=1
MEAN OF BIOMASS GROUPED BY DIVISION

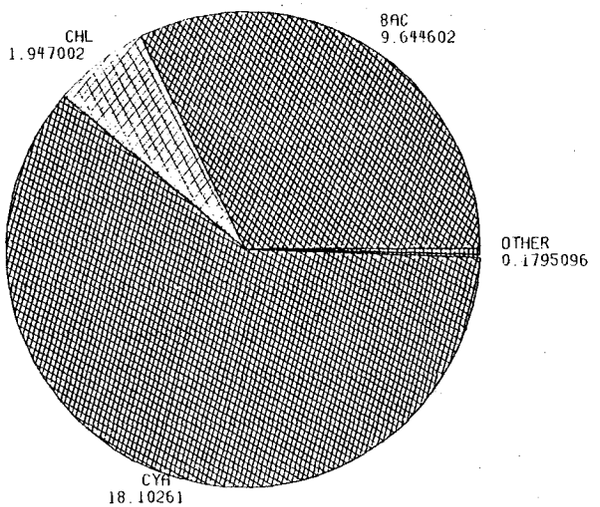


Figure 24: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-13, Season = Fall, 1978.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

SEASONAL MEAN BIOMASS DISTRIBUTION
STATION=C13 SEASON=2
MEAN OF BIOMASS GROUPED BY DIVISION

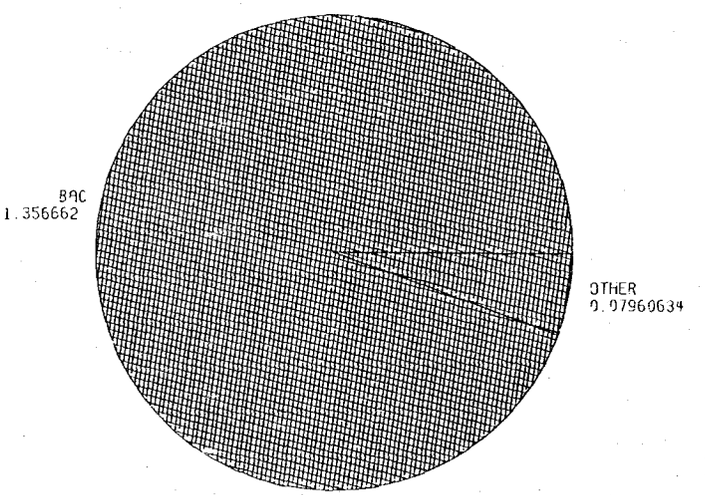


Figure 25: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-13, Season = Winter, 1979.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

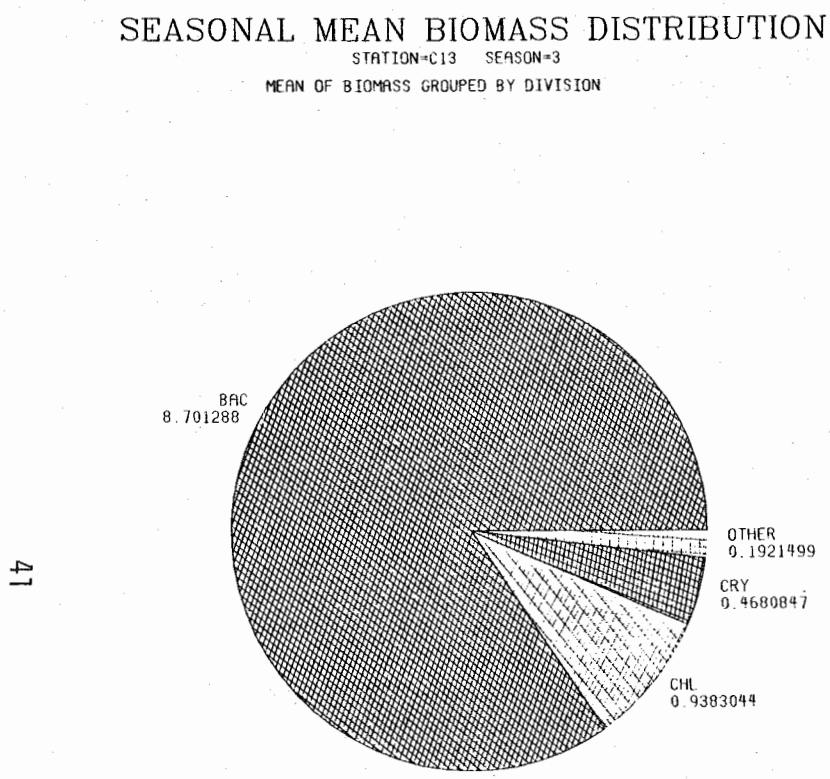


Figure 26: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-13, Season = Spring, 1979.

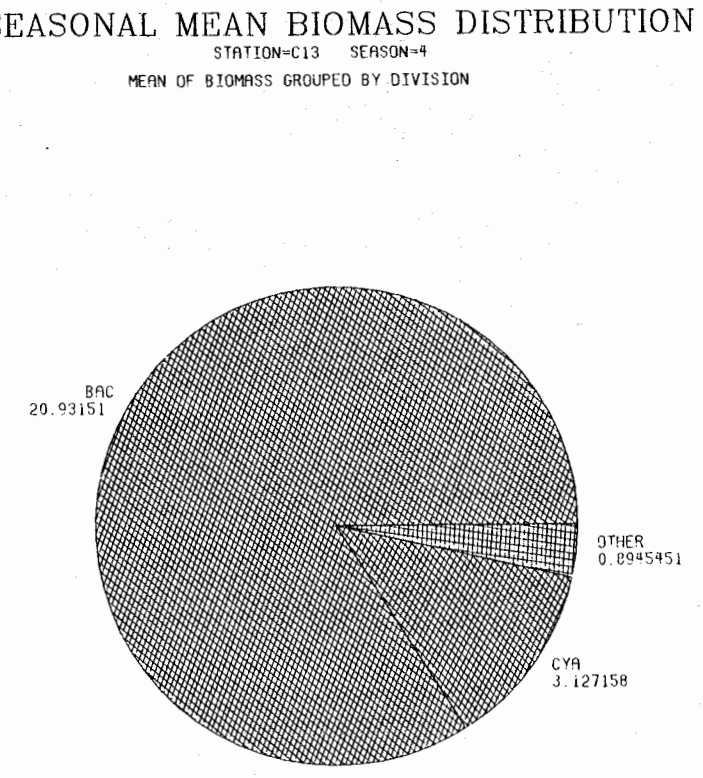


Figure 27: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-13, Season = Summer, 1979.

SEASONAL MEAN BIOMASS DISTRIBUTION
STATION=C13 SEASON=5
MEAN OF BIOMASS GROUPED BY DIVISION

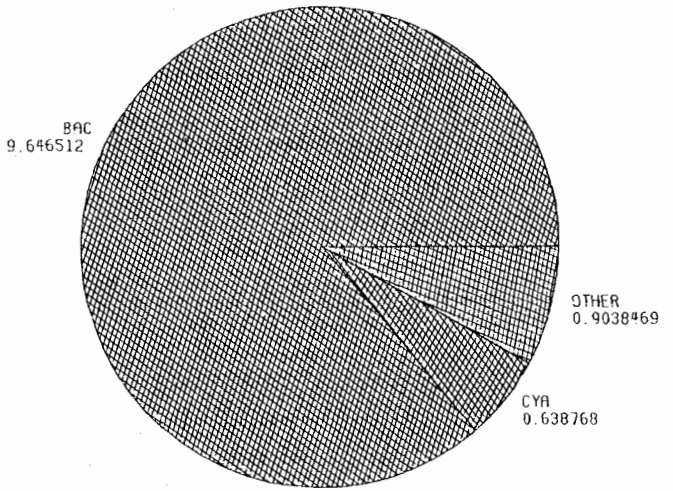


Figure 28: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-13, Season = Fall, 1979.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

SEASONAL MEAN BIOMASS DISTRIBUTION
STATION=C13 SEASON=6
MEAN OF BIOMASS GROUPED BY DIVISION

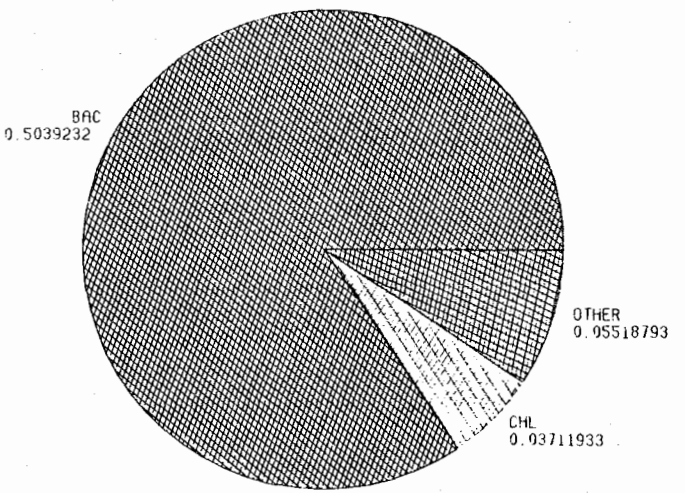


Figure 29: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-13, Season = Winter, 1980.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

SEASONAL MEAN BIOMASS DISTRIBUTION
STATION=C13 SEASON=7
MEAN OF BIOMASS GROUPED BY DIVISION

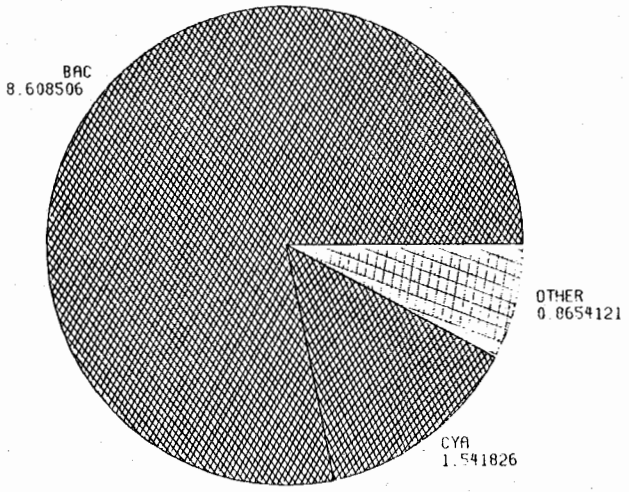


Figure 30: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-13, Season = Spring, 1980.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

SEASONAL MEAN BIOMASS DISTRIBUTION
STATION=C13 SEASON=8
MEAN OF BIOMASS GROUPED BY DIVISION

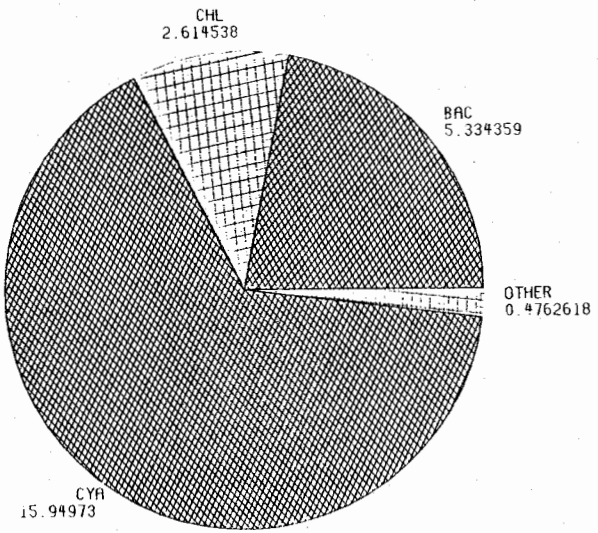


Figure 31: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-13, Season = Summer, 1980.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

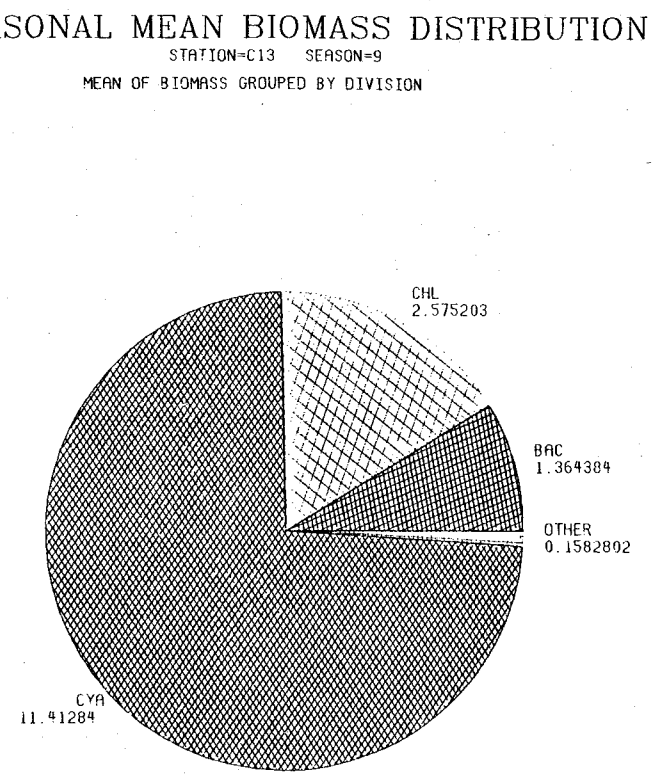


Figure 32: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-13, Season = Fall, 1980.

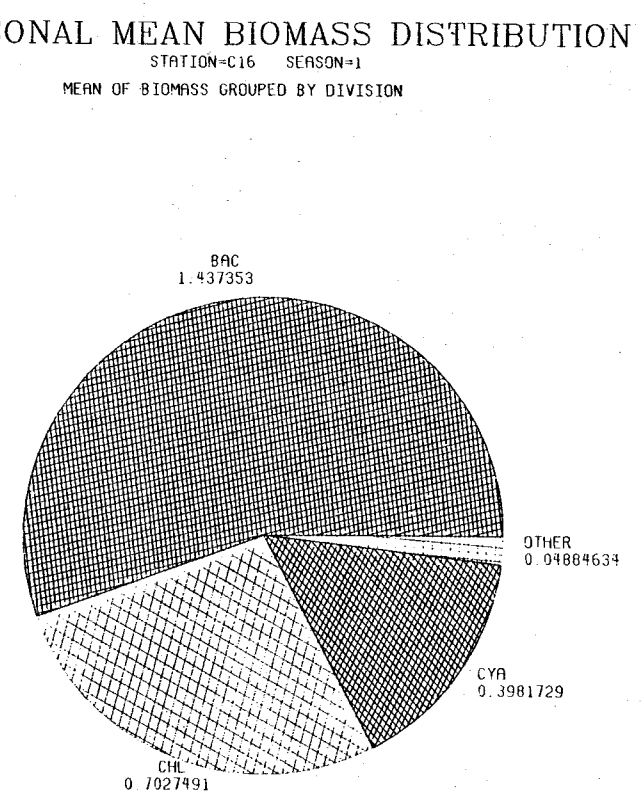


Figure 33: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-16, Season = Fall, 1978.

SEASONAL MEAN BIOMASS DISTRIBUTION

STATION=C16 SEASON=2

MEAN OF BIOMASS GROUPED BY DIVISION

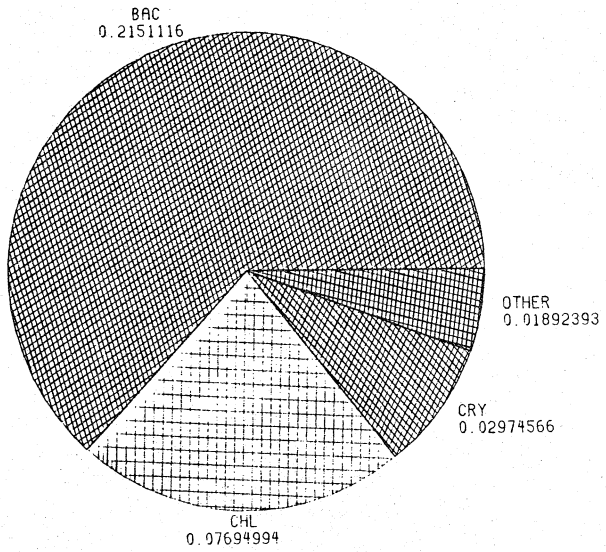


Figure 34: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-16, Season = Winter, 1979.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

SEASONAL MEAN BIOMASS DISTRIBUTION

STATION=C16 SEASON=3

MEAN OF BIOMASS GROUPED BY DIVISION

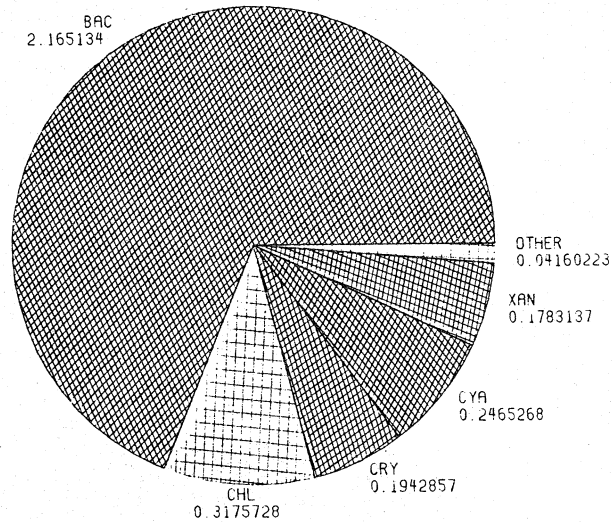


Figure 35: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-16, Season = Spring, 1979.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

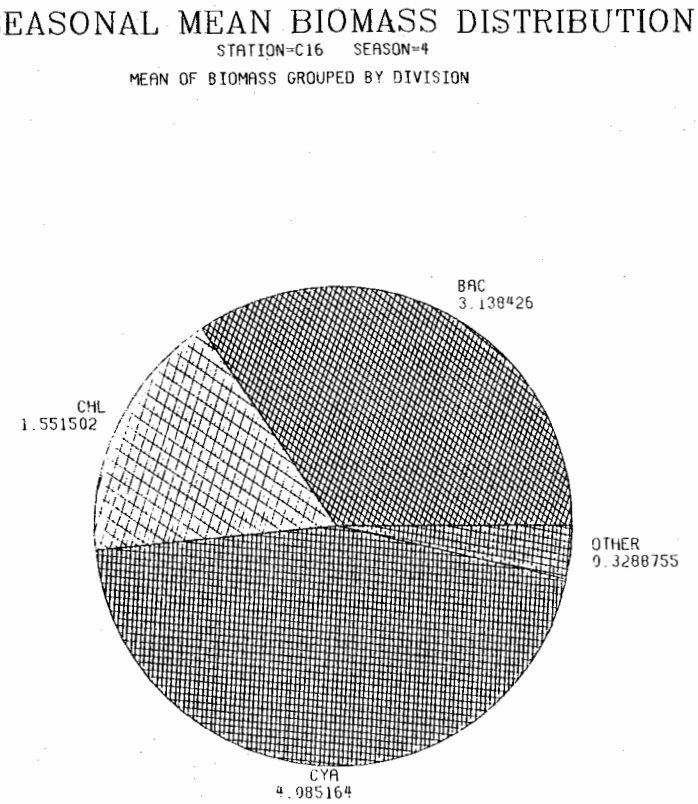


Figure 36: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-16, Season = Summer, 1979.

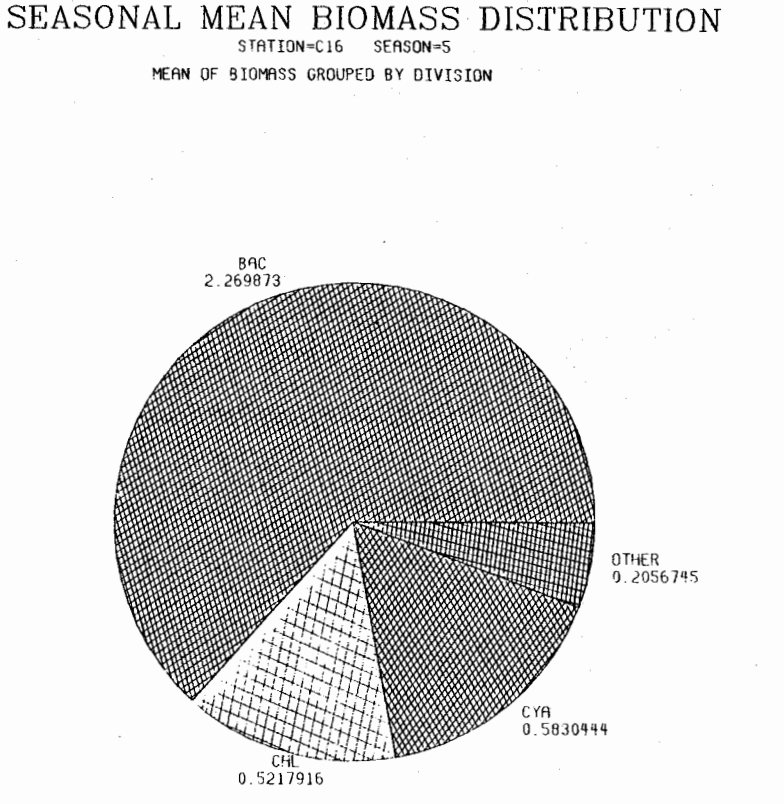


Figure 37: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-16, Season = Fall, 1979.

SEASONAL MEAN BIOMASS DISTRIBUTION
STATION=C16 SEASON=6
MEAN OF BIOMASS GROUPED BY DIVISION

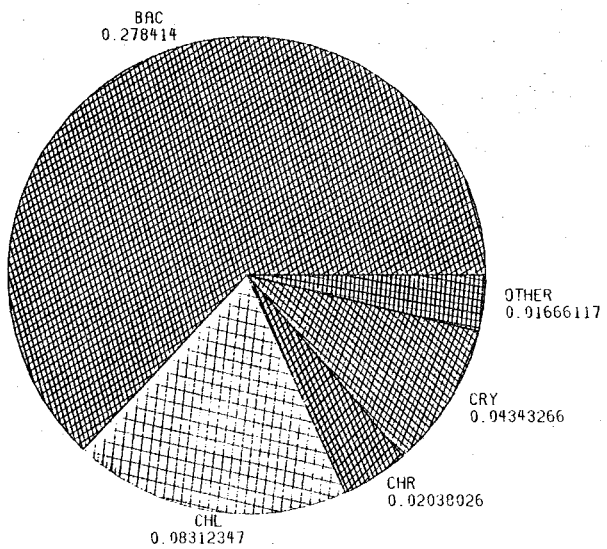


Figure 38: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-16, Season = Winter, 1980.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

SEASONAL MEAN BIOMASS DISTRIBUTION
STATION=C16 SEASON=7
MEAN OF BIOMASS GROUPED BY DIVISION

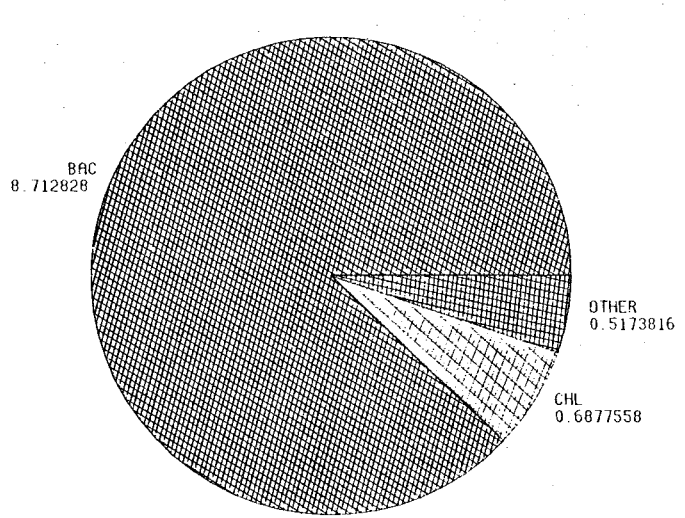


Figure 39: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-16, Season = Spring, 1980.

ALGAL DIVISIONS
BAC = BACILLARIOPHYTA (DIATOMS)
CHL = CHLOROPHYTA (GREENS)
CHR = CHRYSOPHYTA
CRY = CRYPTOPHYTA
CYA = CYANOPHYTA (BLUE-GREENS)
EUG = EUGLENOPHYTA
PYR = PYRROPHYTA
XAN = XANTHOPHYTA

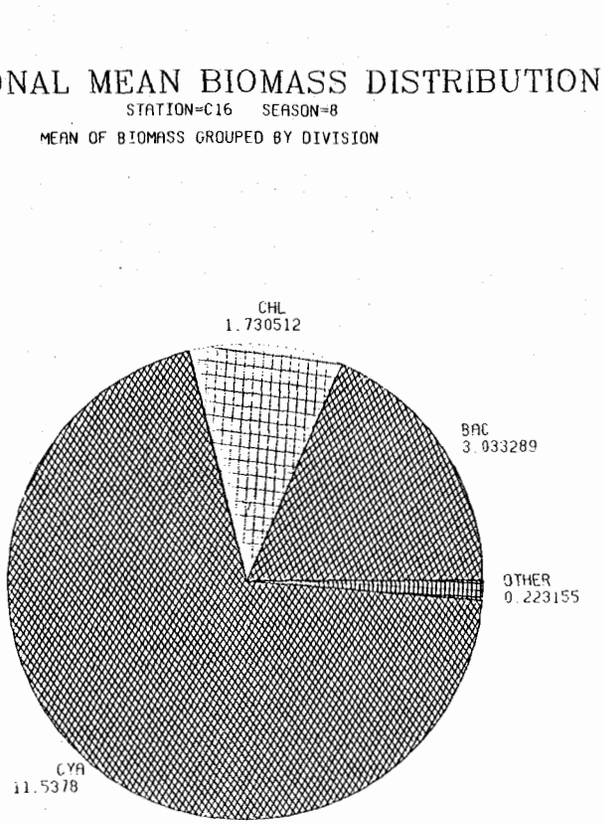


Figure 40: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-16, Season = Summer, 1980.

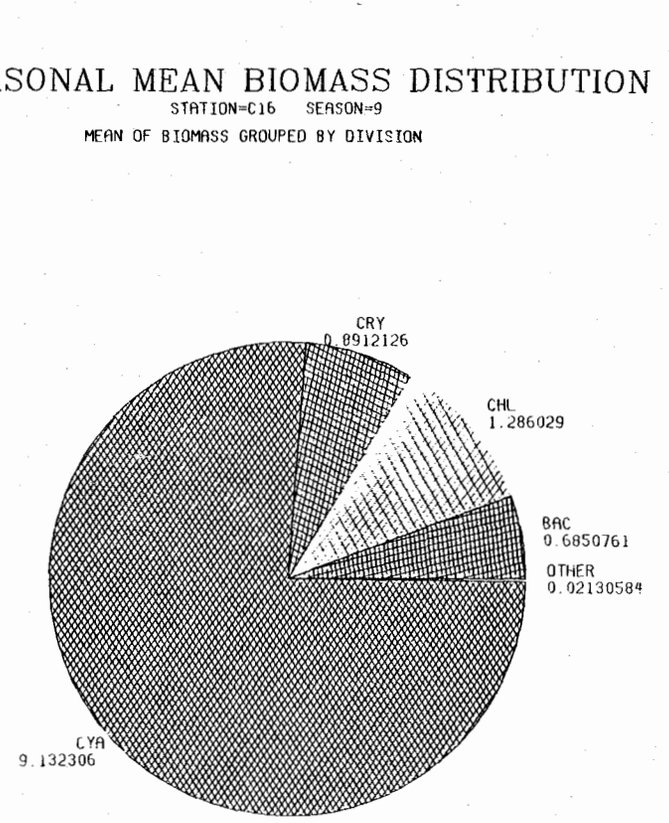


Figure 41: Seasonal Mean Biomass Distribution, Mean of Biomass Grouped by Division. Station C-16, Season = Fall, 1980.

any management scheme that aids the restoration of these two stations will, if correctly done, probably succeed in the restoration of other stations of the lower Chowan. However, if these two stations are not the major focus, then it is likely that any management potential will fall short of its objective.

Figure 24 has a blue-green algal biomass of 18+ mg/l, which make up about 60% of the biomass. This was during September, October and November 1978. Anabaena circinalis had a mean biomass of 12 mg/l and Aphanizomenon flos-aquae had a mean biomass of 4 mg/l. The remaining WWB was accounted for with other genera of blue-green algae (Appendix III).

It should be noted that an excess of 10 mg/l WWB, including a dominance by blue-green algae (5 Chowan River species) as a group, will constitute a bloom of visual proportion. Likewise an excess of 1 mg/l WWB by an individual of the five bloom species will constitute a visual bloom (51, 52). (These findings are discussed later in this report). Thus, station C13 during the fall, 1978, was at bloom proportions. Again, during the summer of 1980 and the fall of 1980, station C13 experienced a bloom. However, the WWB was 15 and 11 mg/l, respectively. Even though at station C13 during fall, 1980 (season 9) blue-green algae was 70% plus of the biomass present, it only constituted a WWB of 11.4 mg/l. This was only slightly above the bloom concentration (Figure 32).

A different pattern was seen at station C16 when algal class or division WWB was measured. Figure 33 indicates that blue-green algae during the fall 1978, only constituted approximately 15% of the total biomass (0.39 mg/l). Mean chlorophyll-a also indicated a reduction in algal growth during this fall (Figures 15 and 21). However, mean chlorophyll-a was up to 19 µg/l (Figure 11). This was indicative of the increased green algae (0.70 mg/l; 25%) found at this station. No group constituted a visual bloom. However, diatoms were 60% of the biomass, but only 1.43 mg/l WWB (Figure 33). A note of caution should be taken

here because one sampling run in September and two in October were aborted at this station. Seemingly, the winds were too high for the sampling boat.

During the summer season of 1980, C16 had a slight blue-green algal bloom, 11.5 mg/l WWB (Figure 40). However, the fall 1980, blue-green algal WWB was a bit under the 10 mg/l that we have established (Figure 41). The summer of 1979 (Figure 36) was almost co-dominated by blue-greens (45%) and diatoms (32%) with the greens very close (18%). Figure 15 shows a chlorophyll-a biomass of 40 µg/l but had only a 4.08 mg/l blue-green algal WWB, clearly not a bloom concentration.

These findings suggest caution when a chlorophyll-a standard is to be used. However, it is an excellent warning or indication that further observations are necessary.

Nutrient Growth Ratios

When algal growth (chlorophyll-a as the dependent variable) was regressed linear with total phosphorus (TP), nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_4-N), ortho-phosphorus (OP), and total nitrogen (TN) as the independent variables, only TP and TN were not significant at the 0.05 level (see Statistical Analysis section). The R-square for each measured parameter (NH_4-N, NO_3-N, OP) was quite low. However, since there was a negative significant correlation of the three nutrients with chlorophyll-a, the assumption was made that the negative relationship was a function of phytoplankton growth (increased biomass resulting in a decrease in nutrients). Therefore, the biological manifestation of nutrients (not the ambient concentrations of nutrients) as measured by chlorophyll-a or WWB should be the criterion for water quality determination in the Chowan River Complex (CRC).

The effort made here was to determine the algal manifestation in growth as a function of the three nutrients (NH_4-N, NO_3-N, OP) through the development

of a growth Response Ratio (RR), i.e., the amount of chlorophyll-a (or of WWB) per unit of nutrient (NO_3, OP, NH_3). Such a determination would allow the assessment of the critical level of the nutrient of concern that will result in unacceptable levels of chlorophyll-a or WWB; 40 µg/l chlorophyll-a and 10 mg/l WWB, respectively (8, 21, 22, 51, 52).

The calculations were as follows:

$$RR_i = \frac{CHLORO}{N_i} \text{ or } \frac{WWB}{N_i},$$

where RR_i = the response ratio of chlorophyll-a (CHLORO) or WWB to nutrient i (N_i = NO_3, NH_4, or OP).

It must be kept in mind that this equation does not account for the unique characteristics of the river that affect the amount of chlorophyll-a or WWB produced per unit of nutrient. However, those unique characteristics are all inclusive.

Factors which may prevent phytoplankton from achieving maximum theoretical concentrations (TC) or may promote growth toward TC based upon ambient nutrient levels in the river include:

1. Availability of light (species specificity)
2. Temperature (species specificity)
3. Short or long hydraulic retention time
4. Presence of toxic substances
5. Limitation of nutrients not under consideration
6. Species community structure
7. Biological availability of TP and TN components (OP, ON, etc.).

The concept of the RR, when properly used, can:

1. change the trophic classification based on ambient nutrient levels to one based on the biological manifestation of nutrients as measured by chlorophyll-a or WWB,

2. determine the "critical" levels of nutrients (OP, NO_3-N, NH_4-N, TP, TN) which will result in an unacceptable level of chlorophyll-a concentration so that the level of the influencing nutrient can be manipulated to achieve the desired use of this given water body, and
3. account for the unique characteristics of the river which affect the RR.

Figures 42, 43, 47, 48, 49 and 50 depict RR_is for station C13 in the lower Chowan. They were determined with both chlorophyll-a and WWB as estimates of algal concentrations.

A high value for a given RR_i indicated a high utilization efficiency for nutrient i and vice versa (21). Figures 42 and 43 present the RR_{op} (chlorophyll-a and WWB) for station C13 with PO_4 as the nutrient of concern. The range of values, from 0.01 to 5.1 (Figure 42) and 0.01 to 18,000 (Figure 43), indicated that RR_{op} varied widely over the duration of the study. It was expected that the efficiency of utilization was greater during the summer and drastically less during the winter. The RR_{op} dropped in early and mid-fall; however, the efficiency of utilization is still high enough (>1) such that the addition of nutrients to the system could cause an unwanted algal increase. This would caution against the release of water containing PO_4-P or NH_4 + NO_3-N at any time in early to mid-fall. Growth data clearly indicated the close relationship between nutrients and algal growth during the fall of 1978, 79 and 80 (Figures 12 and 18). Algal growth (station C13) as measured by chlorophyll-a during the fall, 1978 (61 µg); fall, 1979 (10 µg); fall, 1980 (12 µg) and WWB, fall, 1978 (29mg/l); fall, 1979 (12 mg/l) and fall, 1980 (12 mg/l) decreased with decreased PO_4-P (Figure 44) and increased with decreased NO_3-N and NH_4-N (Figures 12, 18, 45, and 46). The RR_is for station C13 indicated that the

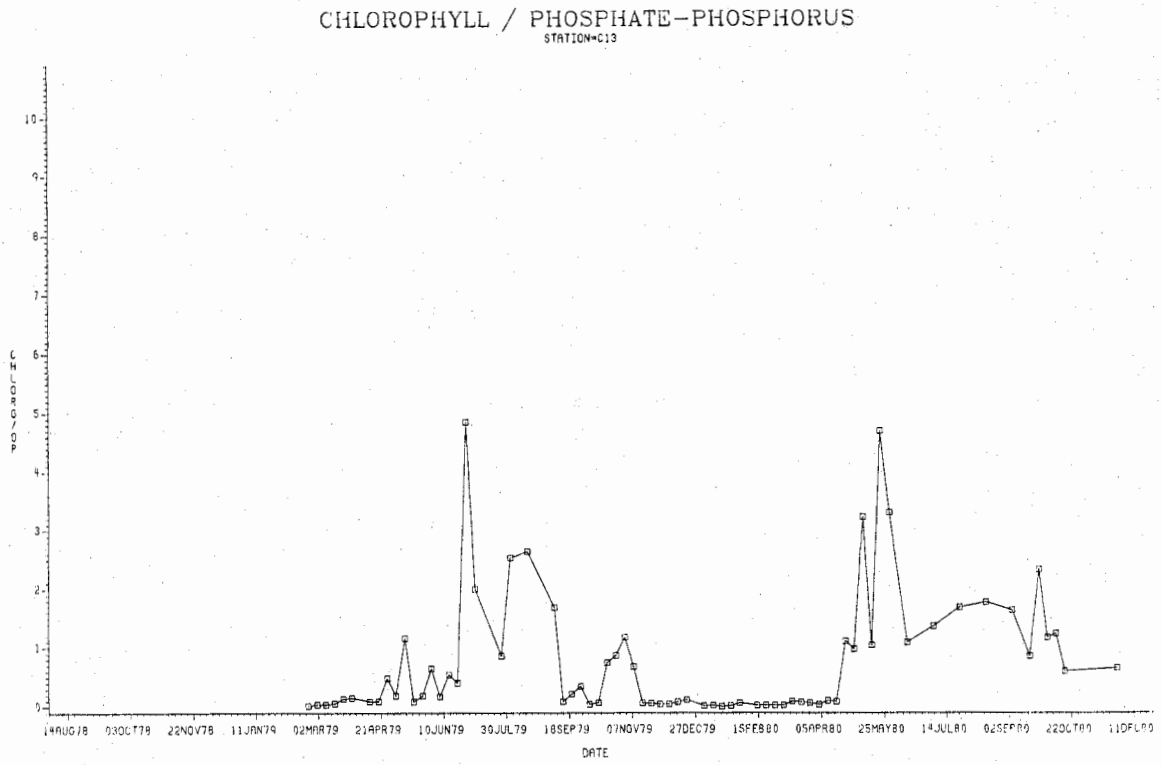


Figure 42: Weekly chlorophyll-a to PO_4 ratios at Station C-13 during the sampling period October 1978-December 1980

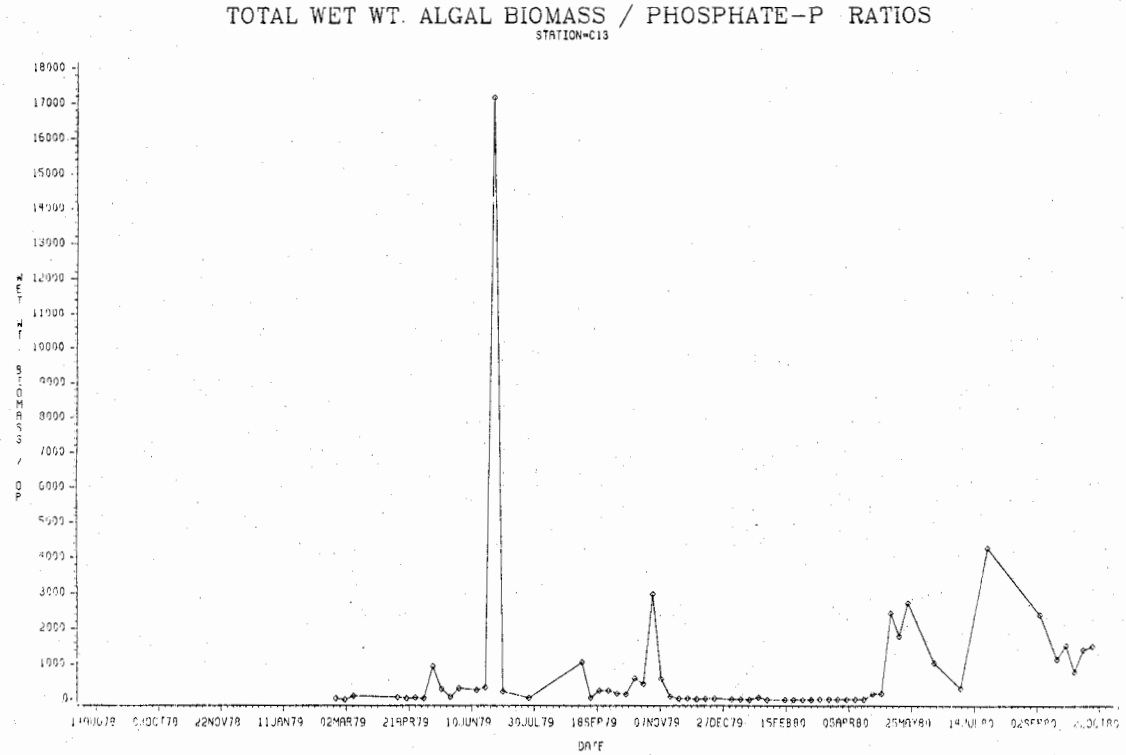


Figure 43 : Weekly wet weight algal biomass to PO_4 ratios at Station C-13 during the sampling period October 1978-December 1980

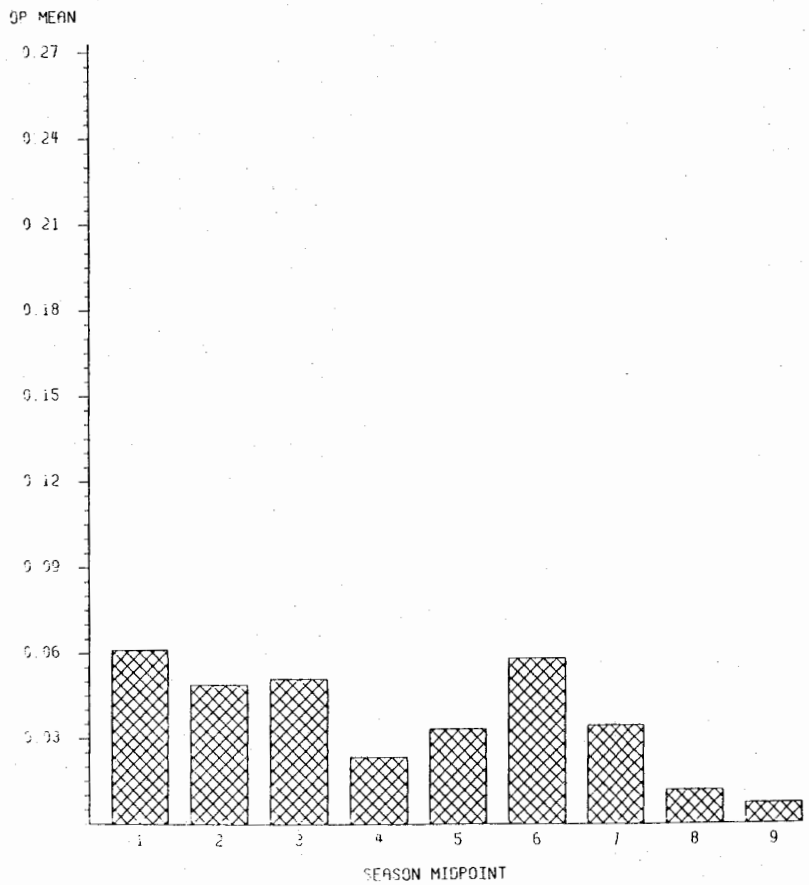


Figure 44: Seasonal PO_4-phosphorus averages, mg/1, Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

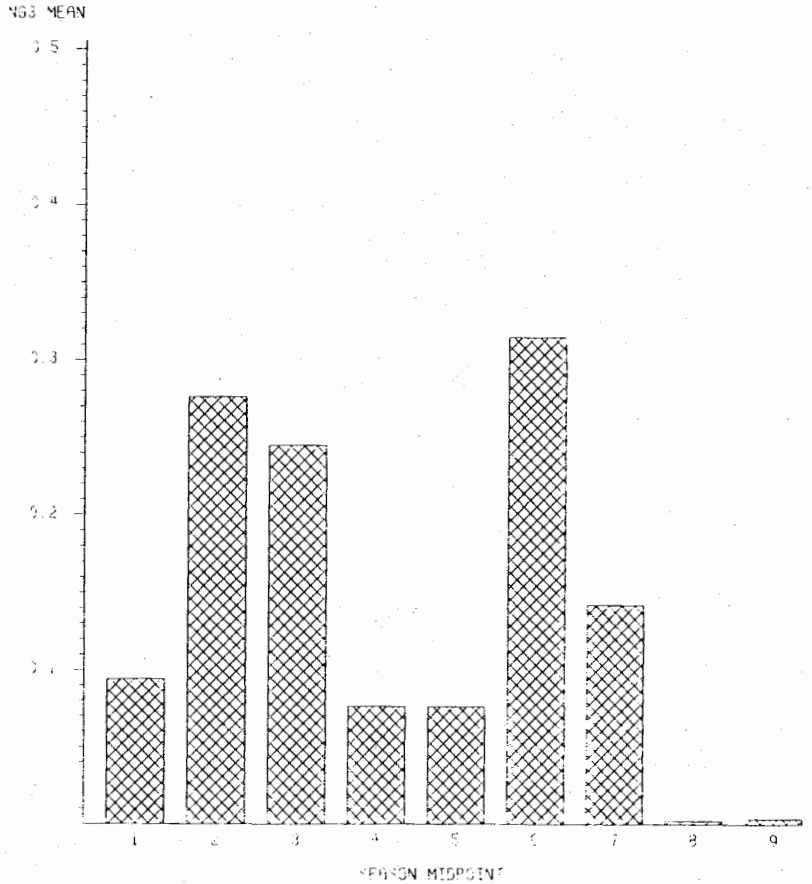


Figure 45: Seasonal nitrite-nitrate nitrogen averages, mg/1. Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

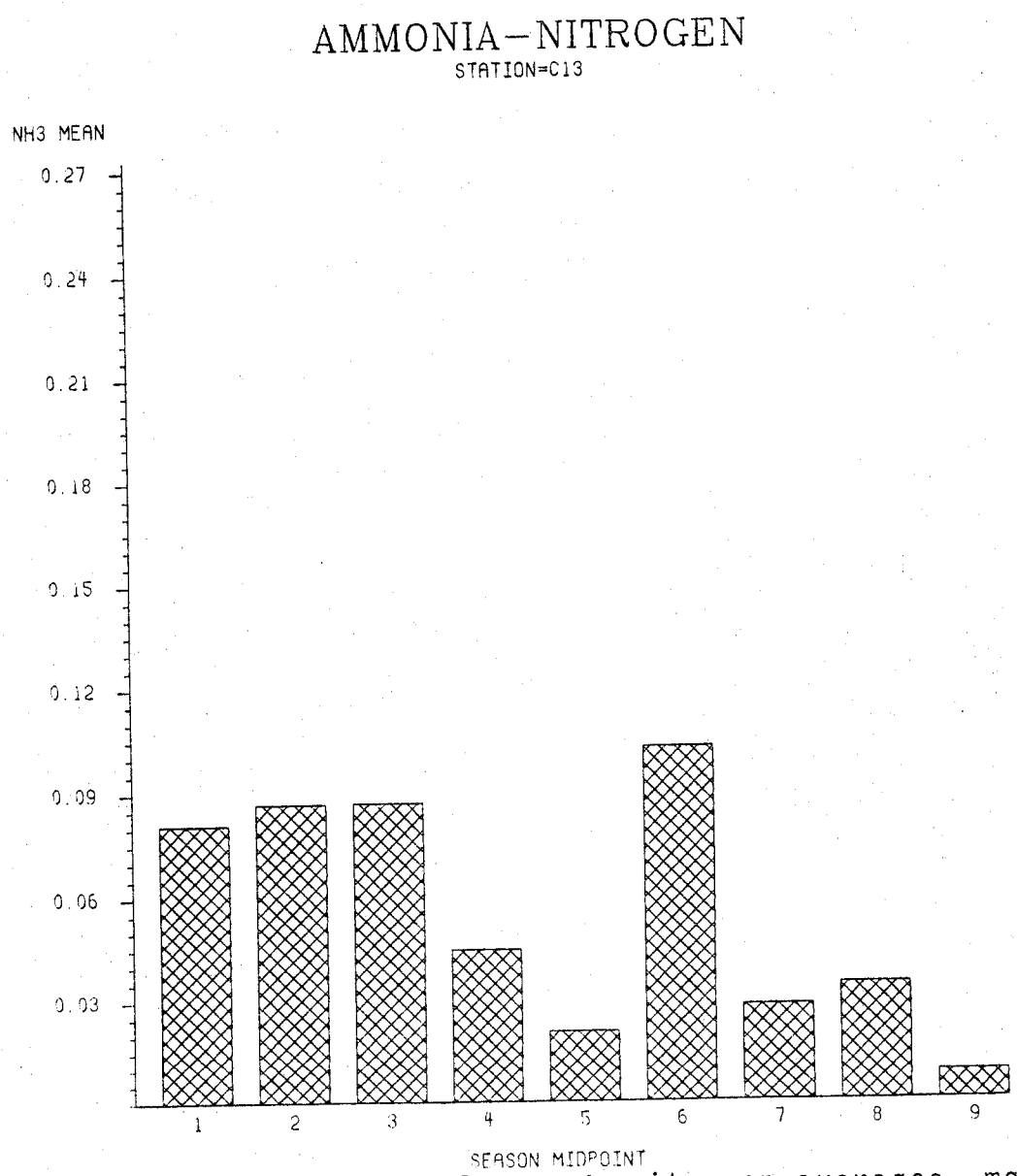


Figure 46 : Seasonal ammonia nitrogen averages, mg/1. Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

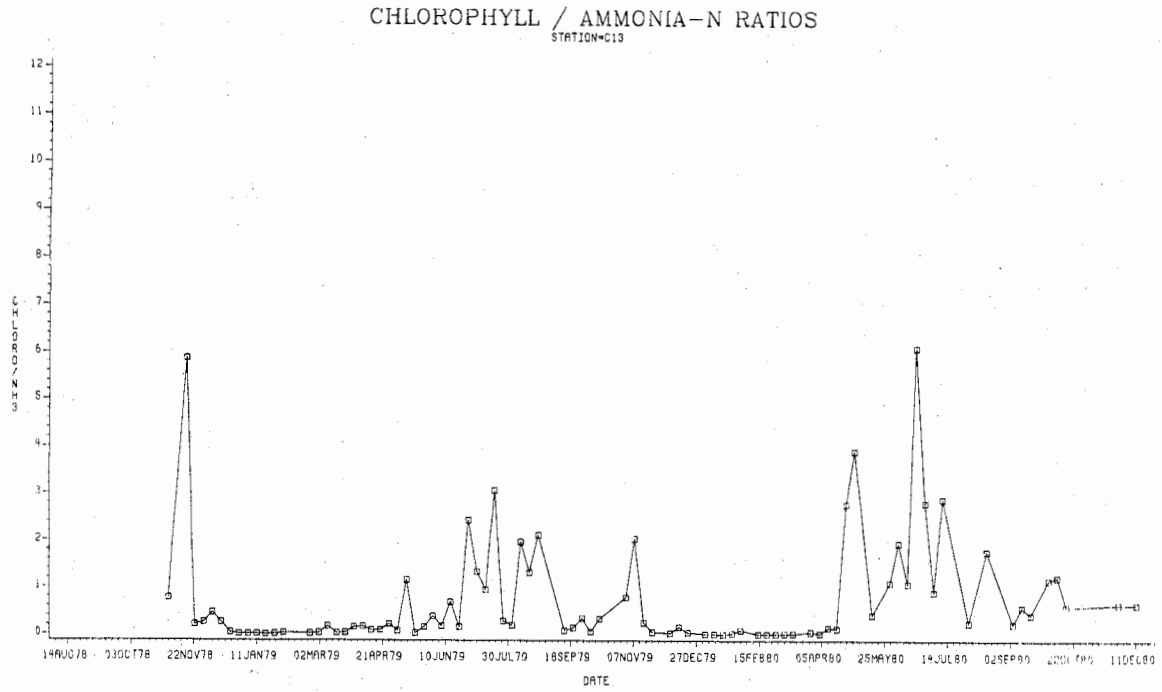


Figure 47: Weekly chlorophyll-a to ammonia-N ratios at Station C-13 during the sampling period October 1978-December 1980

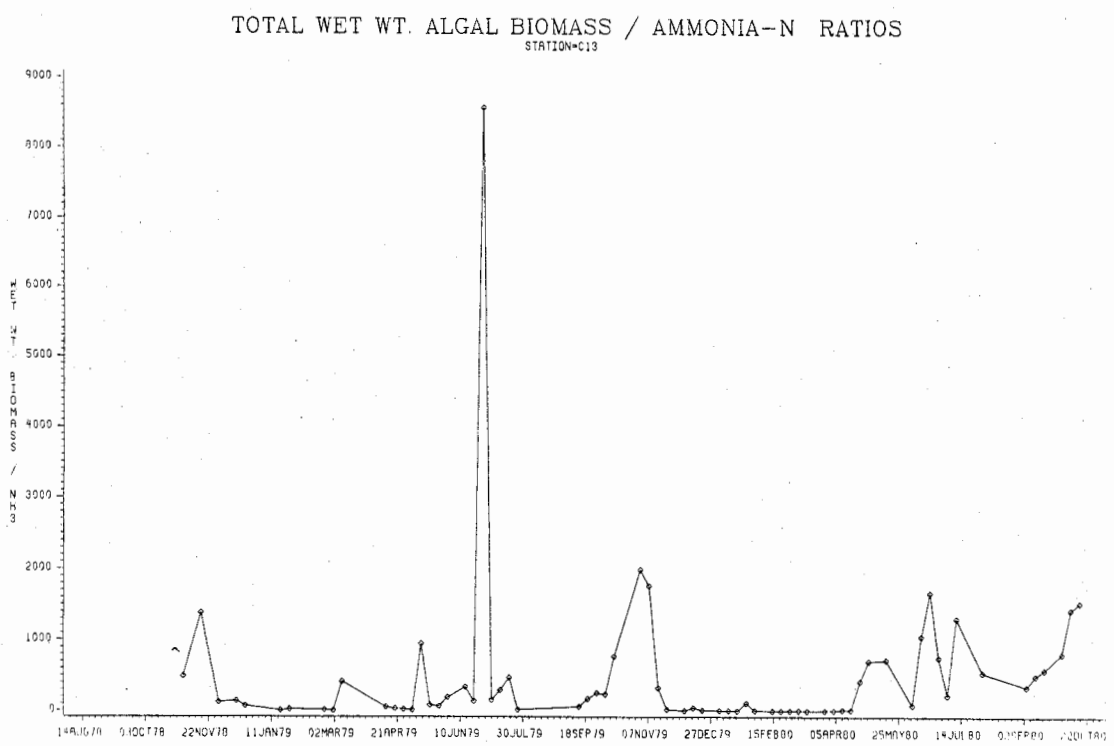


Figure 48: Weekly wet weight algal biomass to ammonia-N ratios at Station C-13 during the sampling period October 1978-December 1980

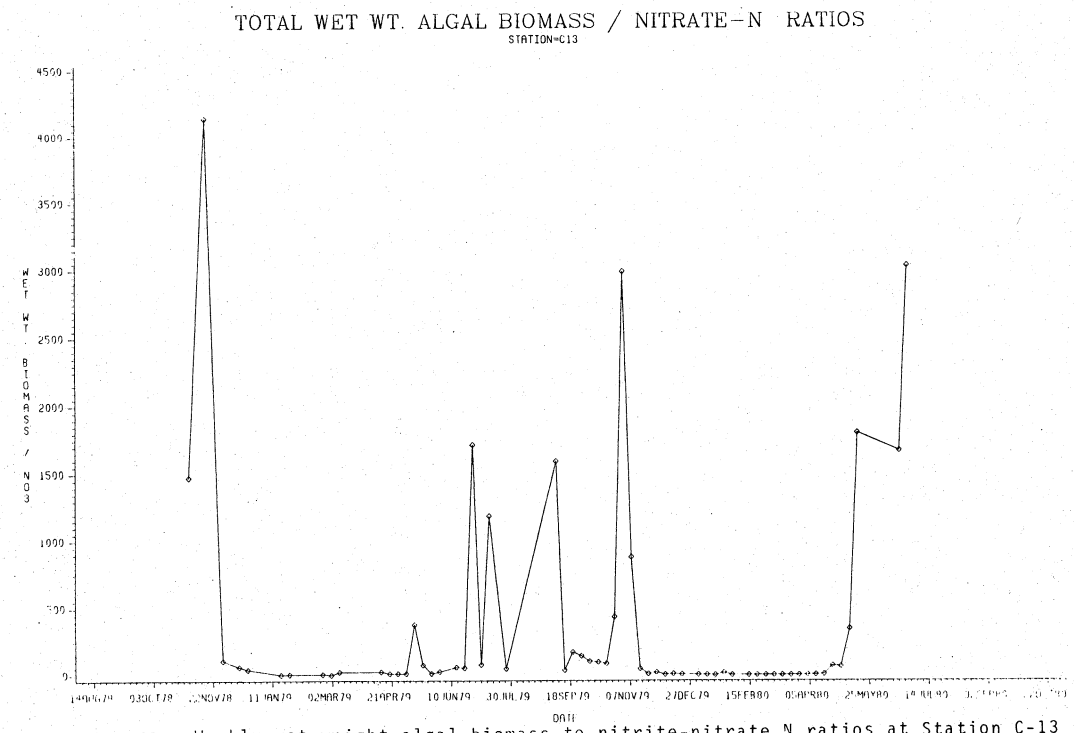


Figure 49: Weekly wet weight algal biomass to nitrite-nitrate N ratios at Station C-13 during the sampling period October 1978-December 1980

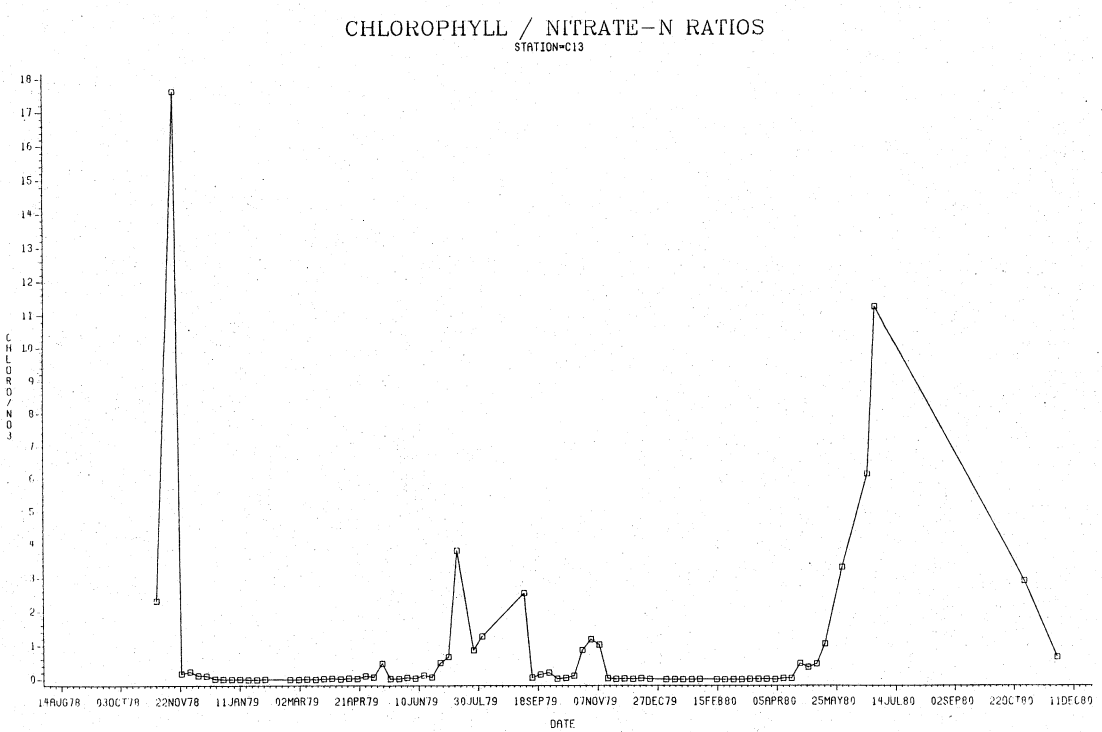


Figure 50: Weekly chlorophyll-a to nitrite-nitrate N ratios at Station C-13 during the sampling period October 1978-December 1980

efficiency of utilization for PO_4-P was poor during the mid-fall seasons of 1979 and 1980 (Figures 42 and 43). However, during these same periods, the efficiency of NO_3-N and NH_4-N utilization was high (Figures 47, 48, 49, and 50). Ammonia nitrogen had a slightly higher RR during these periods than NO_3-N, thus a greater efficiency of utilization. Therefore, because of the high ammonia-nitrogen content of UC effluent (Figure 51, Station C2) and because this effluent can rapidly reach station C13, decisions concerning an October/November UC release should be made with caution.

It was interesting to note that the species dominance during the fall 1978 at station C13 was Melosira, Anabaena, Oscillatoria and Aphanizomenon; during the fall 1979 Melosira, and during the fall 1980 Microcystis. The water temperature ranged from 11.1°C to 20.5°C during these fall seasons. At no time during the 1978, 1979 or 1980 fall seasons (station C13), did PO_4-P drop to a substantially lower level (Figure 44). However, both NO_3-N and NH_4-N reached lower to moderately lower levels during the fall 1980 season, respectively (Figures 45, 46 and 51).

Physiological Observations

The physiological observations reported here represent an initial effort to assess the phytoplankton nutrient interaction of the five bloom species in the lower Chowan River. Greater detail of the interaction is currently under preparation from a companion study supported by the Water Resources Research Institute of The University of North Carolina.

Isolation and Storage of Species

Five species of blue-green algae were isolated from sediment collected in the lower reach of the Chowan River. The five species were the known dominant species that constituted the surface blooms of 1973, 76, 78, 79 and 80 (53). The isolates were purified according to the method of Fehnder et al. (15, 56).

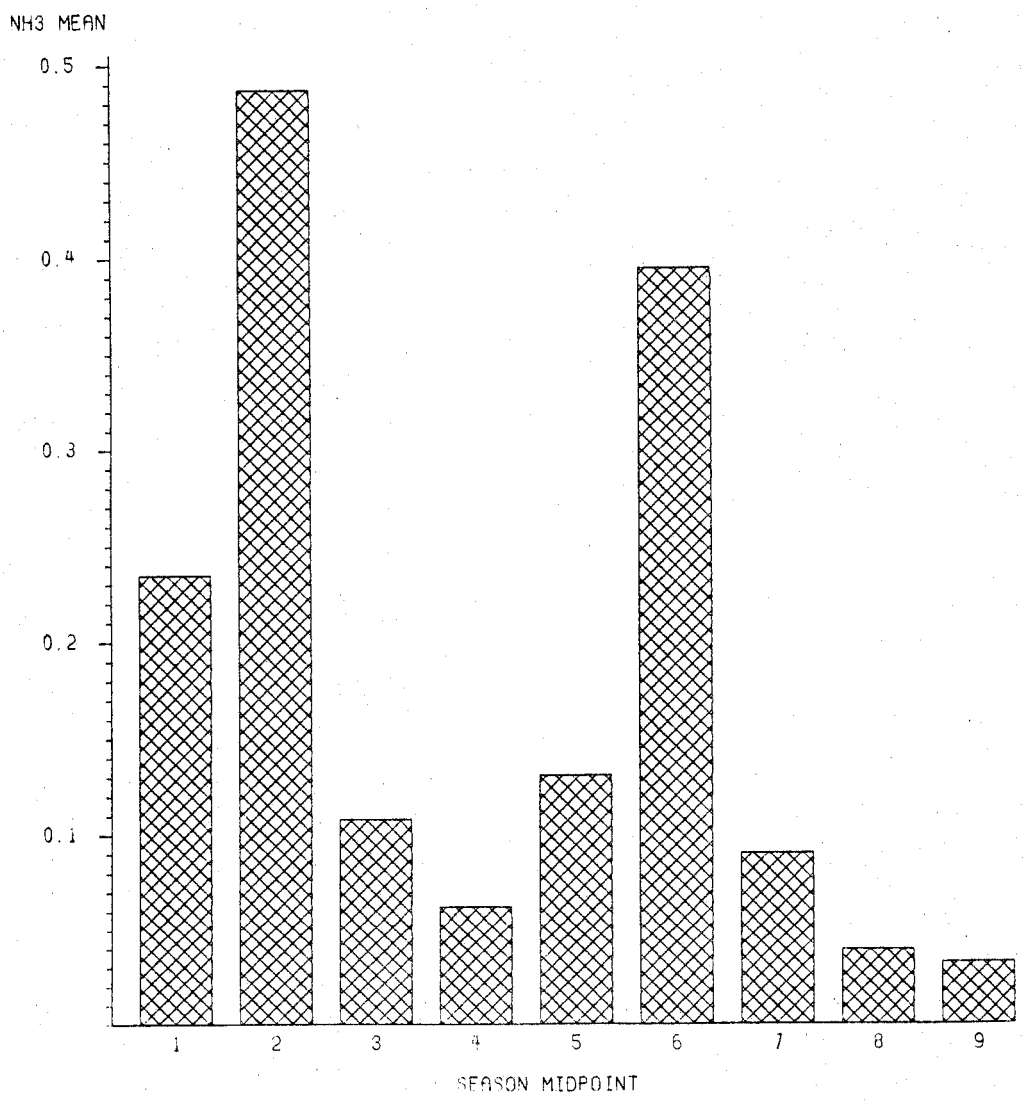


Figure 51: Seasonal ammonia nitrogen averages, mg/1. Station C-2

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

Individual trichomes were stored in agar fortified with sterile river water. These species remain in the cultural collection in the phycological growth room, N.C. State University, under the taxonomy listing as follows:

1. Anabaena circinalis
2. Anabaena aequalis
3. Anabaena flos-aquae
4. Aphanizomenon flos-aquae
5. Microcystis marina

It should be noted that lower Chowan River species of Anabaena and Microcystis have changed quantitatively in dominance over time (1973-1978). Anabaena spiroides and Microcystis aeruginosa were replaced by Aphanizomenon flos-aquae and Microcystis marina, respectively.

Algal Utilization of Nitrogen and Phosphorus

Anabaena, Aphanizomenon, Microcystis

The blue-green algal Anabaena, Microcystis and Aphanizomenon were grown under controlled laboratory conditions to assess the nitrogen levels that would promote a maximum growth of 1 mg/l wet weight biomass.

It was determined that a temperature of 27°C and 300 ft. c. light was adequate for the growth of all three genera (five species): Anabaena circinalis, A. flos-aquae, A. aequalis, Aphanizomenon flos-aquae, and Microcystis marina. However, due to a lack of WWB dominance by other Anabaena species and the similar growth needs of all CRC species of Anabaena, only A. circinalis was assayed.

The effect of nutrient concentration on the growth of the five species is technically difficult to study. The species seemingly have an assimilatory mechanism that allows for saturation at extremely low concentration of mineral ions. This is particularly true in the case of phosphorus. The effect of

supplying a low concentration of phosphorus in a culture of limited volume is to increase the lag phase of growth but does not reduce the relative growth rate and thus the ultimate growth. While it was not our intention to determine the species growth rate but the nutrient concentration that would produce a given WWB, we nevertheless observed a relationship between the two. The Droop (9) and the Hinshelwood (22) expression:

$$K = K_{00}\ C\ /\ C + K_S$$

where K_S is a constant having the dimensions of a concentration numerically equal to the concentration giving half the maximum growth rate, K_{00}; indicating the relationships between the relative growth constant, K, and the limiting nutrient (LN) concentration, C. When C is not large as compared with K, the nutrient of consideration is limiting; thus, cell numbers must remain small throughout the incubation period so as not to appreciably alter the concentration of the nutrient, K.

However, the relationship of growth rate to nutrient concentration is more complicated than the Monod equation suggests (20, 25, 31). Nutrient uptake can be expressed by Michaelis-Menton kinetics (as shown in the Monod equation) but relative growth rate is dependent upon intracellular concentration, not the rate of cellular entry of the nutrient. Likewise, changes in the nutrient concentration outside the cell is dependent upon the intracellular concentration of the nutrient. Thus, adding nutrients to cells and observing their response without considering the intracellular concentration will not give an accurate expression of nutrient limitation. Neither will it allow the assessment of changes in biomass over time as a function of nutrient concentration.

As previously stated, phosphorus is a good example (21, 23, 26, 29, 30). Either of the five species, if given a supply of phosphate, will accumulate internal excesses. These excess concentrations are stored in the cell as

polyphosphate granules. When these reserves reach a critical concentration, growth of the cell may initiate or continue without the need for any external PO_4-P supply. Thus, with these five species, phosphorus may be at undetectable levels in the river and still their growth is promoted. It all depends upon the degree of luxury consumption, the physiological state of the cell.

Critical Nutrient Levels

Figure 52 shows the variation in growth of two species of the three genera cultured for 14 days in ASM-1 medium to which NO_3 and OP were added as follows:

NO_3 = 0.030 mg/l

OP = 0.010 mg/l

These were the total nitrogen and phosphorus concentrations in the medium. The medium was inoculated from a 7 day old culture where the cells were in the logarithmic growth phase.

It is clear from Figure 52B that Anabaena circinalis reached 0.035 mg/l dry weight (DW) on day 12. Analysis of the medium indicated a nutrient presence of 0.0085 mg/l NO_3-N and 0.003 mg/l OP, suggesting that neither NO_3 or PO_4-P was limiting on the 14th day of incubation.

We determined, as stated before, that a single blue-green alga WWB of 1 mg/l was equal to a dry weight maximum of 0.035 mg/l. Further, a 1 mg/l WWB of a single blue-green alga species (of the bloom group) would constitute a visual surface bloom. We, therefore, believe that the nitrogen concentrations of 0.030 to 0.038 mg/l was the critical level of NO_3 for A. circinalis in this experiment.

This experiment was repeated several times with the same appreciable results. However, when the A. circinalis cells were nutrient starved for

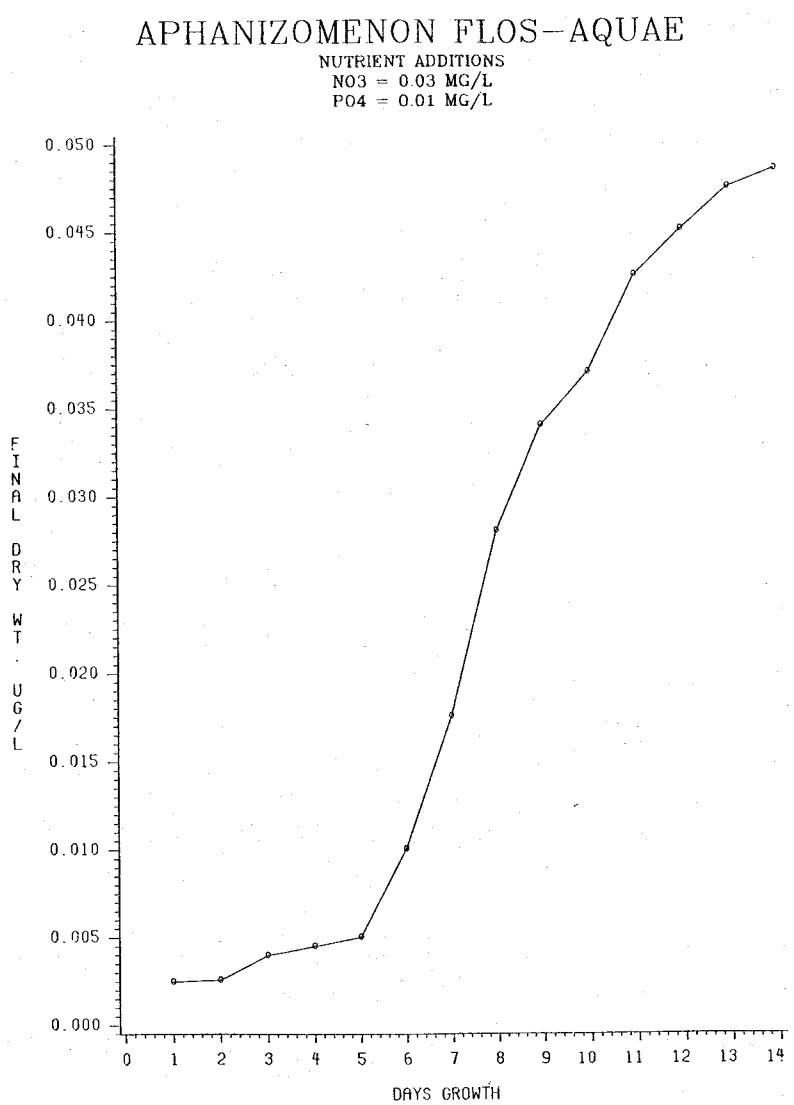


Figure 52A: Growth of Aphanizomenon

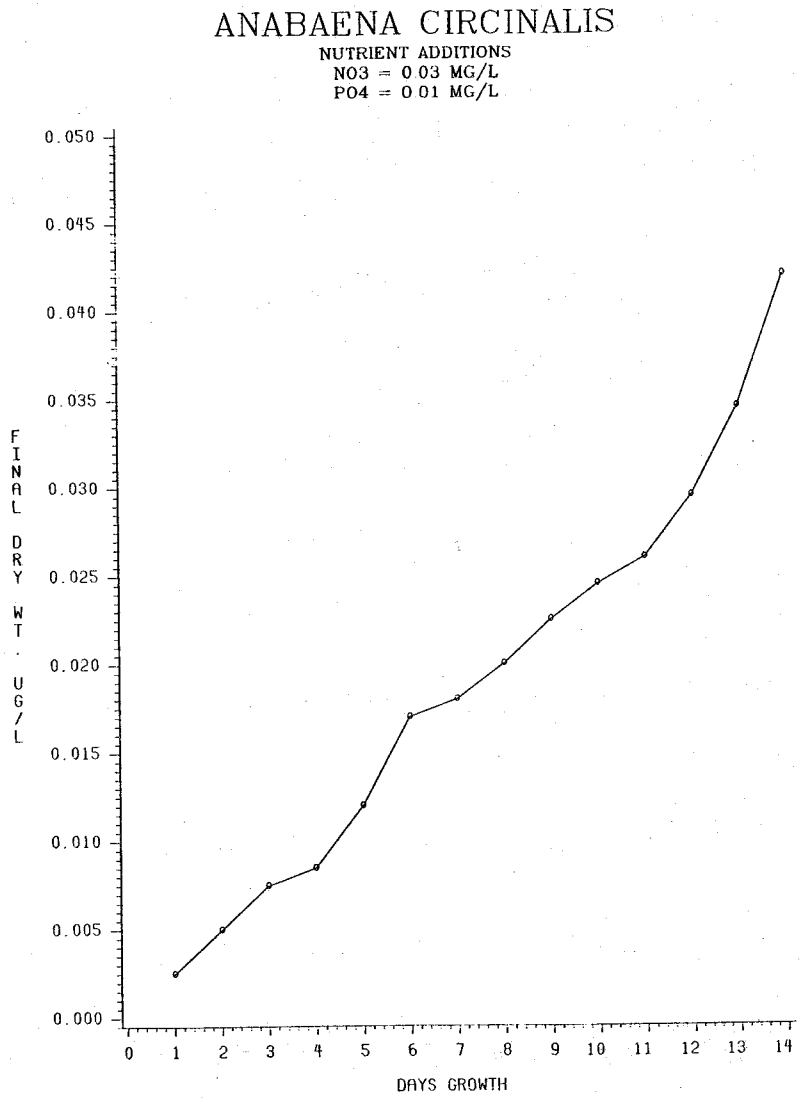


Figure 52B: Growth of Anabaena

three days under continuous light, a different growth pattern developed (Figure 53B) when incubated as above.

The 0.035 mg/l dry weight was reached in nine days. Analysis of the growth medium indicated that both NO_3 and PO_4 were non-detectable.

Thus, the physiological state of the cell was very important when these type experiments were undertaken (36, 37, 38). Even so, we feel that a cell in the Chowan River is constantly under saturated nutrient conditions (except during massive bloom conditions when most nutrients may have been consumed). Therefore, the physiological state of the species is not important as long as the algae are not nutrient starved. This would suggest, however, that under bloom conditions of blue-greens, or heavy growth conditions of other algae, an influx of nutrients could increase the growth rate (assuming the algal community is in a nutrient-starved conditions) and thus the ultimate growth of the community.

Aphanizomenon flos-aquae presented a different growth pattern (Figure 52A) than that of Anabaena circinalis. The 0.03 mg dry weight (DW) was reached after 8-days of incubation. Growth continued to increase until the last day of incubation. This suggests that Aphanizomenon flos-aquae has a faster growth response than Anabaena circinalis. This could account for its presence in the river as the first sign of the summer bloom.

Analysis of the medium for nutrients on the 14th day indicated non-detectable levels of NO_3 and PO_4 levels of 0.005 mg/l (34). The rapid growth of Aphanizomenon flos-aquae would suggest a greater utilization of nutrients. However, only slightly so. The RR (relative efficiency of nutrient utilization to algal growth) for this culture was close to one. This would suggest a high efficiency of nutrient utilization. Therefore, the internal levels of nutrients were perhaps close to optimum, or at least at the growth-promoting critical level.

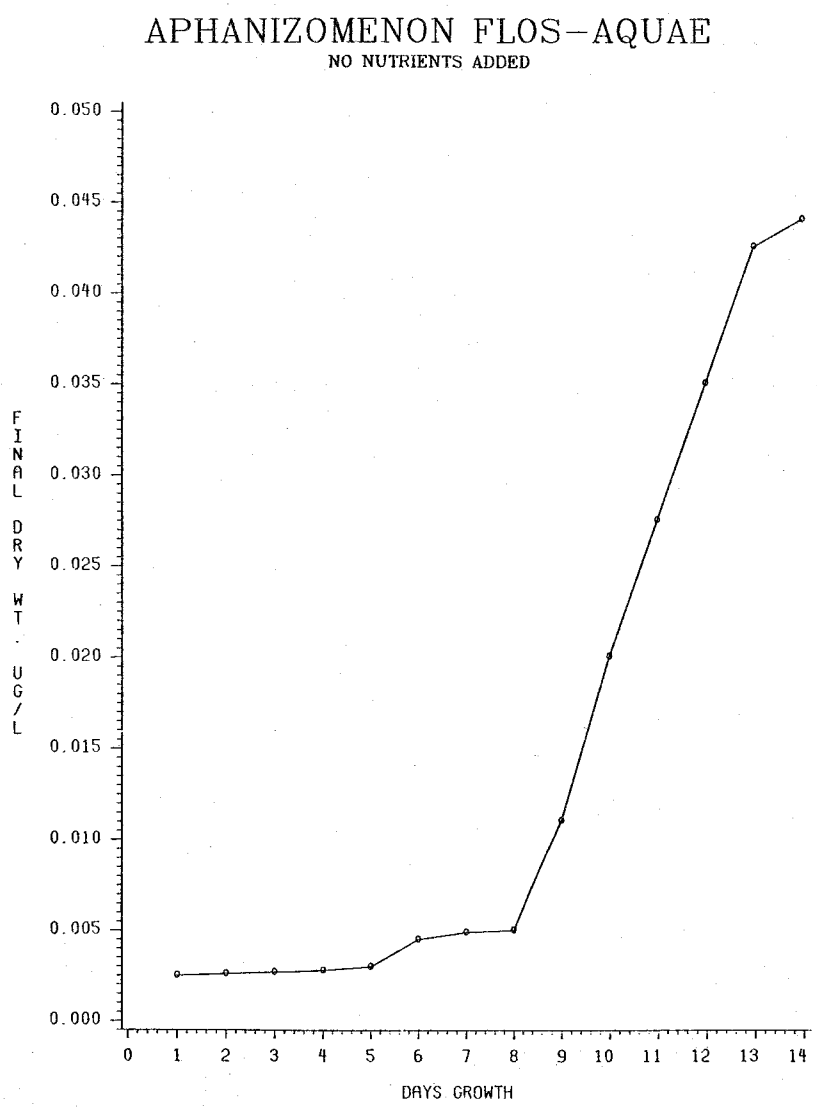


Figure 53A: Growth of Aphanizomenon, starved cells.

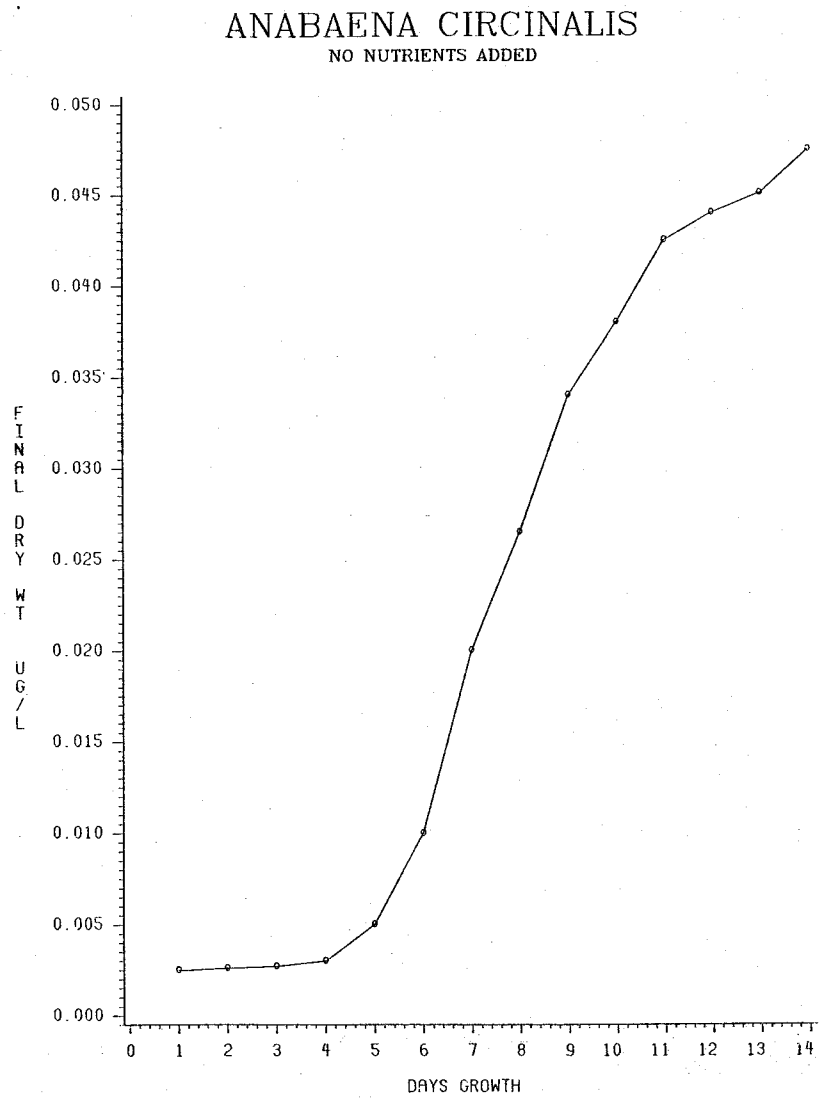


Figure 53B: Growth of Anabaena circinalis, starved cells.

Figure 53A illustrates the growth of Aphanizomenon flos-aquae after three days of nutrient starvation, as with Anabaena circinalis. As can be seen the lag-growth phase was eight days. However, growth was exponential between 8-13 days. The subsequent analysis of the medium revealed no detectable levels of NO_3 or PO_4.

It is apparent that these cells have a critical internal level of required nutrients before growth can take place. However, each species has its own growth rate. Each will reach, in time, the 1 mg/l WWB (0.035 mg/l dry weight) under the same nutrient regime, even though the temporal factor will be different.

Several experiments indicated that an adjustment of either light or temperature would be reflected in the growth of these two species. This growth response was primarily in growth rate. The nitrogen level was nearly the same for the 1 mg/l WWB to be reached.

When cells of Microcystis marina were incubated in increasing concentrations of NO_3 and PO_4, beginning at zero concentration over a 28-day growth period, WWB increased as is shown in Figure 54 A & B. Increasing concentrations in NO_3 at 10 µg/day were added to the culture. After the 10th day of incubation increase in growth was clearly detectable. From the 1st through the 9th day, it was difficult to measure the DW of three replicate cultures.

Following the 18th day, growth increased rapidly until the last three cultures, on the 28th day, were harvested. Analysis of medium for nutrients indicated no measured level of NO_3 present.

This suggests that this species of Microcystis exploits its environment and utilizes nutrients (NO_3) rapidly. The Chowan River nutrient loading is far in excess of the nutrients utilized in this experiment. The degree of that excess changes with the river reach. However, it appears that from 40 to 60% of the

river discharge must be reduced if any hope of algal growth reduction is to come (see section on Regression Analysis-Chlorophyll, etc.).

When Microcystis marina was cultured as was Anabaena circinalis and Aphanizomenon flos-aquae, the 1 mg/l WWB was not reached until the 12th day of incubation. This suggests that the nitrogen requirement for this species, when compared with the other two, was slightly higher. Indeed, its location in the Chowan River around C.F. Industries would support a need for a habitat that is high in nitrogen.

On all three genera, Anabaena, Microcystis and Aphanizomenon, temperature increase caused an increase in growth. However, increased light did not appreciably affect growth. It should be remembered that these three genera, like most of Cyanophycaea, have the capacity to increase or decrease their thylakoids (the membrane-like material where photosynthesis takes place) as radiant energy is increased or decreased. The stronger the light the less thylakoid material developed or vice versa.

Figure 55 indicates the impact of adding nitrogen to Aphanizomenon cells cultured in ASM medium but with 0.03 mg/l NO_3-N as the only nitrogen source. The culture was allowed to grow until the dry weight exceeded the dry weight of 0.03 µg/l (1 mg WWB/l) and no further increase in growth could be determined. At this time 50 ml of each 3-liter culture were taken for nutrient analysis. Then 0.03 mg/l NO_3-N was added to two of the eight 3-liter cultures; filtered (0.45 µm) Union Camp effluent was added to 2 of the 6 remaining 3-liter cultures; PO_4-P as OP was added to two of the four remaining 3-liter cultures; and the control (fortified ASM-1 medium) were allowed to continue to grow to the 50th day completion of the experiment. The 50 ml samples that were collected from each culture were analyzed for NO_3 and OP (day 24, Figure 55). The results were as follows: (1) NO_3-N in 5 of the non-control cultures was below

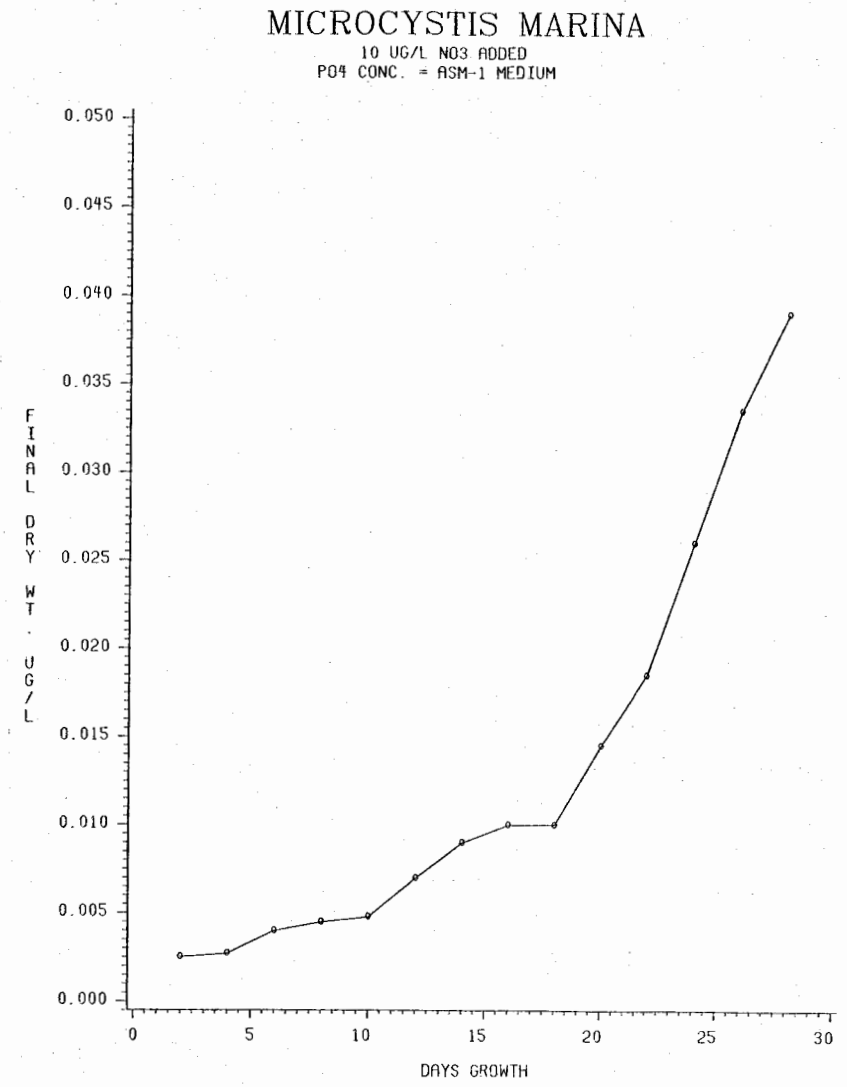


Figure 54A: Growth of Microcystis marina after 10µg NO_3/l was added to ASM-1 medium.

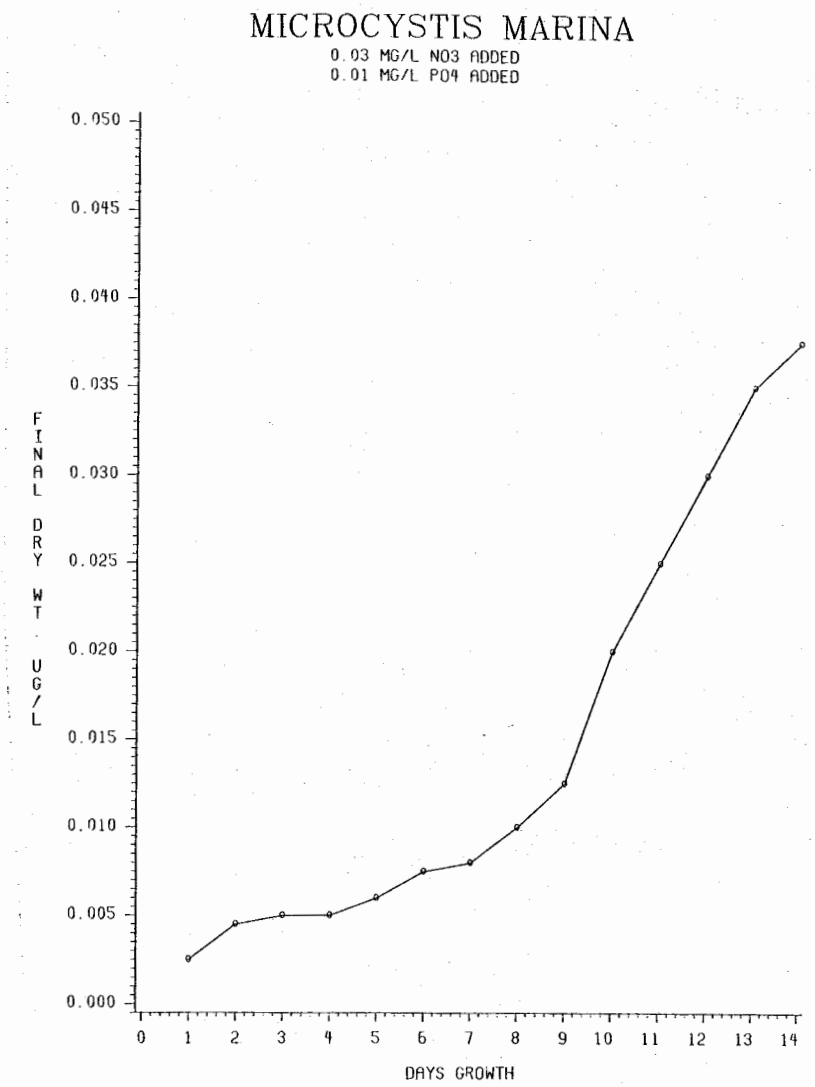


Figure 54B : Growth of Microcystis marina in 0.03 mg NO_3/l and 0.01 mg PO_4/l.

the level of analytical detection; the six non-control cultures had possible traces of NO_3-N but the concentration did not meet the confidence level established by the lab (0.001 mg/l). As a result, all non-control cultures were considered NO_3-N-free, except for the unknown intracellular levels. (2) Of the original 4.200 mg/l, the two control cultures had a nitrogen concentration on the 24th incubation day of 4.161 mg/l. This indicated that 0.039 mg/l nitrogen had been either utilized or was located within the cell cytoplasm. One could surmise that, since other cultures utilized 0.03 mg/l of NO_3-N before growth leveled off on the 24th day and control cells continued to grow, that the 0.009 mg of NO_3-N (0.039-0.03 = 0.009) was the approximate concentration in the intracellular structure of the cells in the other six cultures. However, the variance in the pattern of growth after day 12 would suggest caution, even in gross analysis as stated above (Figure 55). (3) Of the original OP (0.186) both control cultures and the six special NO_3-N-treated cultures had a remaining OP concentration on day 24 of <0.07 mg/l. It was clear that OP concentrations were adequate to sustain growth over the experimental period. As indicated in Figure 55, OP additions of 0.096 mg/l did not appreciably increase growth over the next 26 days. This again illustrates the luxury consumption capacity and importance of OP by the blue-green algae.

When UC effluent was added to the 24-day-old cultures (Figure 55) growth (dry wt.) increased over the next 22 days. It should be remembered that UC effluent was extremely high in usable-nitrogen (NH_4 or NO_3) with respect to phytoplankton need. Clearly there was no inhibition of growth of Aphanizomenon by UC effluent at any time. In fact, Figure 56 shows the result of using UC effluent in serial dilution with water taken from the Nottoway River around station C1. A dry weight of 0.005 g of cells was incubated for 14 days in the dilutions as indicated in Figure 56. It is interesting to note that the highest

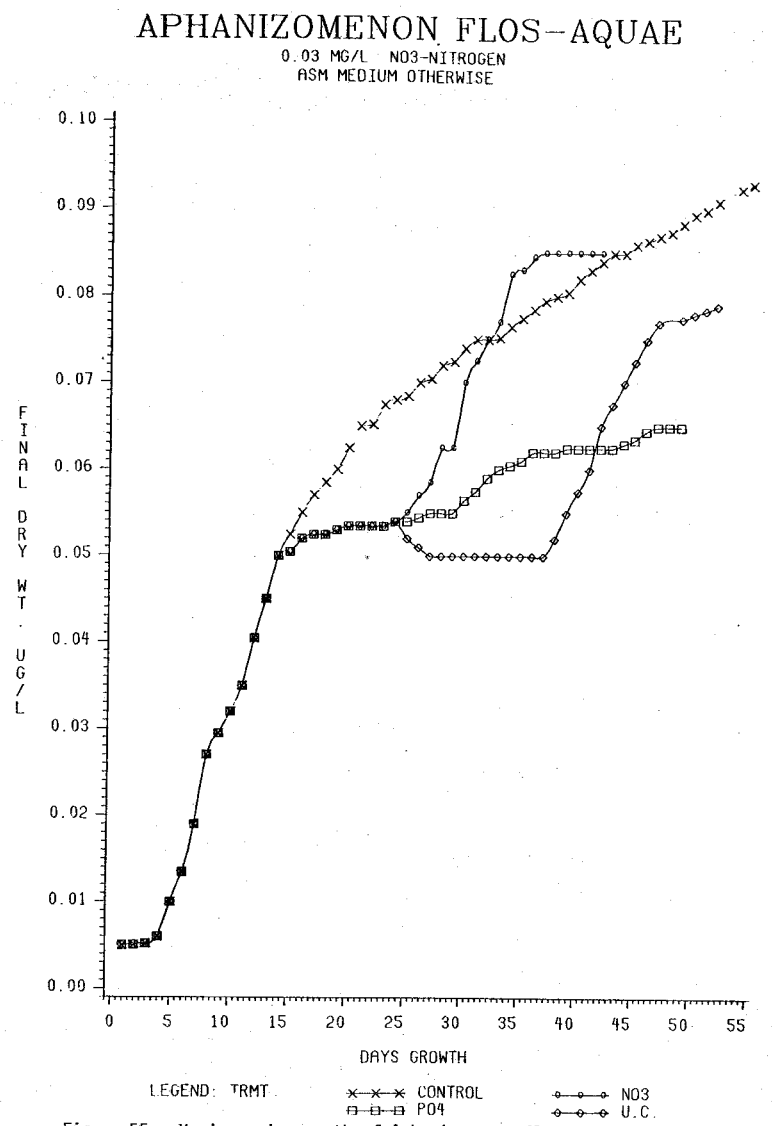


Figure 55: Variance in growth of Aphanizomenon flos-aquae after nutrient addition following 12-day growth.

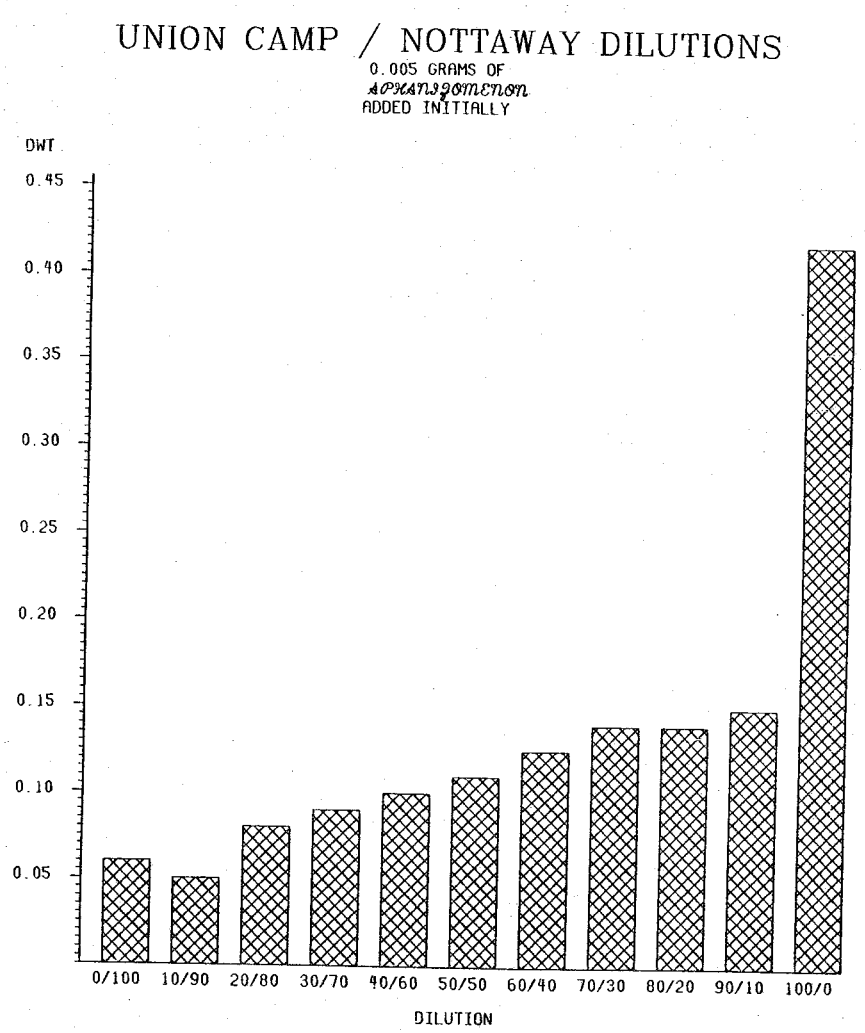


Figure 56: Growth of Aphanizomenon flos-aquae in increasing Union Camp discharge/ Nottaway water mixtures.

DW was seen in the 100% filtered UC effluent. This further demonstrated that UC effluent is capable of supporting blue-green algal growth alone.

Another example of the nitrogen/phosphorus growth-promoting potential is illustrated in Figure 57. On July 12, 1979, phosphorus levels were too low (TL) for detection at station C13, nitrogen in mg/l was NH_4-N = 0.04 and NO_3-N = 0.01; TP was 0.06; station C16, NO_3-N = 0.05, NH_4-N = 0.05, OP was TL, TP = 0.06; station C7A, NO_3-N = 0.13, NH_4-N= 0.06, OP = 0.01, TP = 0.08 (54).

To these stations (as examples) 0.225 mg/l NO_3-N was added to the 100 ml cultures and incubation took place with 0.001 g comparative DW of Anabaena added to each culture. The Anabaena cells were taken in log phase and washed before preparation for incubation. All river water was filtered. Again it is interesting that the TL OP cultures had a phosphorus capacity to grow to the extent observed in Figure 57. It should be kept in mind that these were monocultures of the Chowan River bloom species Anabaena circinalis, not an unfiltered culture of mixed phytoplankton from the river.

It is not unlikely that a mixed natural phytoplankton population would contain taxa with a range of optimal growth requirements and predisposing nutritional status. Addition of either nitrogen or phosphorus could potentially evoke a net increase in phytoplankton growth, especially in those cases in which the ambient nitrogen/phosphorus ratio is intermediate between the optimal growth requirements of the various phytoplankton elements (36).

Nitrogen to Phosphorus Ratios

Nitrogen and phosphorus have been highly acclaimed as the growth nutrients most likely to limit growth of algae. Liebig's Law of the Minimum, the source from which the concept of a limiting nutrient is derived, suggests that some nutrient, least available relative to the growth requirements of a given organism, imposes primary limitation on the growth of that organism.

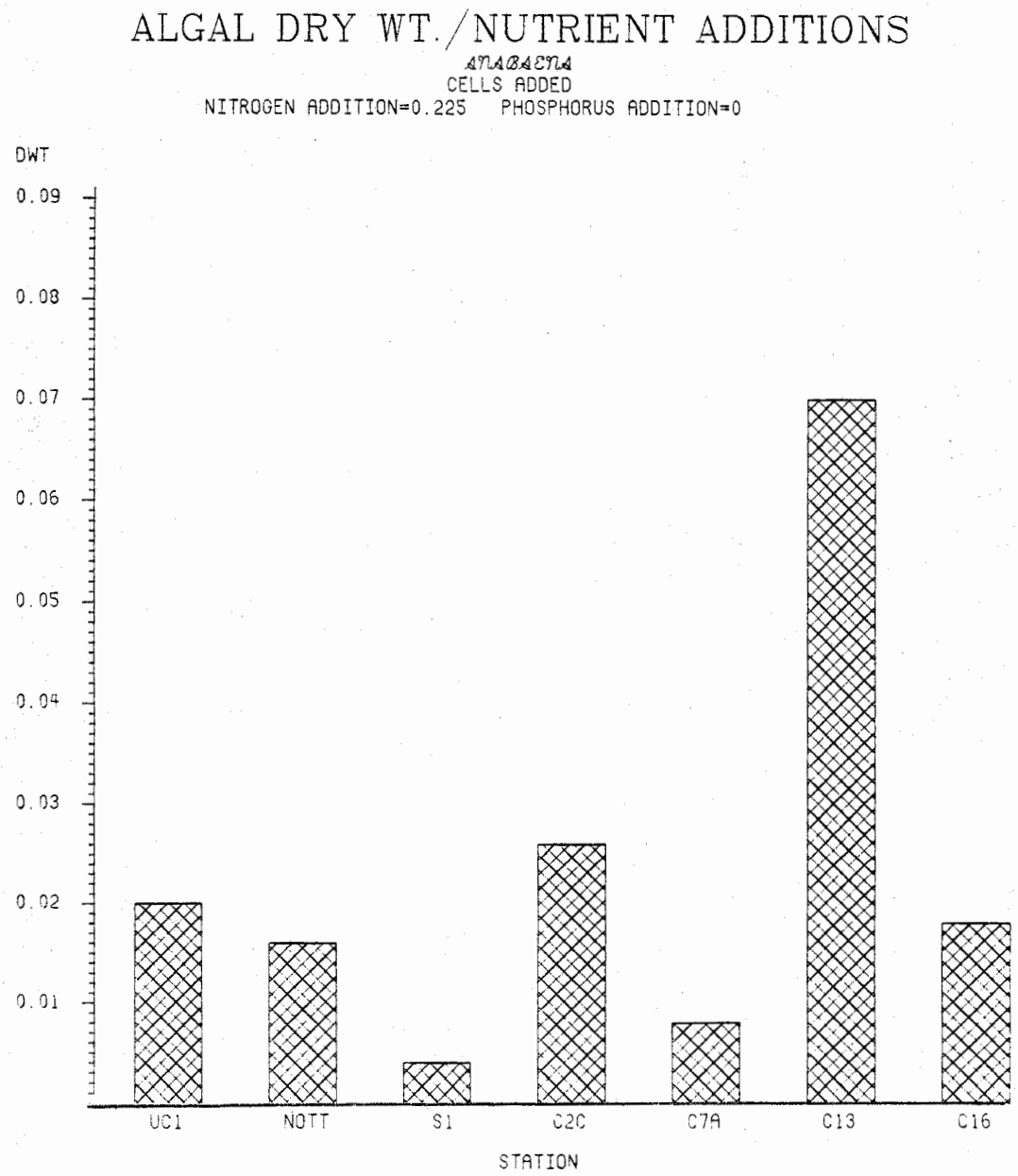


Figure 57 : Growth of Anabaena at select river stations after a 0.225 mg NO_3/1 addition

While no absolutes have been determined, there is reasonable agreement that estimates of ratios (N:P) are justly (20, 31, 29, 45, 46):

1. Nitrogen/phosphorus > 14 = phosphorus-limited
2. $\leq$ 10 nitrogen/phosphorus > 14 = transitional
3. Nitrogen/phosphorus < 10 = nitrogen-limited
4. 14:1, N:P, respectively, is considered the ratio at which the addition of either results in the limitation of the other (20). However, ratios as low as 5:1 and as high as 30:1 have also been estimated to be optimum.

There, too, is evidence that indicates that the effects of phosphorus and nitrogen are interdependent (1, 3, 7, 12, 14, 17, 19, 25, 27, 36, 38).

We have determined the annual (1978-1981) N:P ratios for each station sampled weekly in the Chowan River. Unlike some studies (4, 5, 6, 7, 20, 21) which were forced to use TP and TN for lack of a better data set, or the data set was limited in sampling frequency, total years sampling or both, we have OP and NH_4-N + NO_3-N = nitrogen as our N:P species. In addition we utilized the TP procedure as used by Hern et al. (20, 21). We present here the results of only three stations, C1, C2B1 and C13, as they are representative of the other stations in the upper and lower Chowan and the CRC in general. It should be understood that the N:P ratios presented in Figures 58, 59 and 60 are those of NH_4 + NO_3 = Nitrogen:OP. Due primarily to the high TP in the CRC, the OP ratios presented here were the most conservative.

The line across the middle (Figures 58, 59, 60) divides phosphorus-limited periods (upper) from nitrogen-limited (lower) periods. The P-limited, though very seldom, is most interesting as they were in the spring (primarily March-early June 1979, 1980). This implies that early spring pulses of phosphorus are most detrimental. This is the very opposite of the scenario recently mentioned by informational sources relative to the Chowan River.

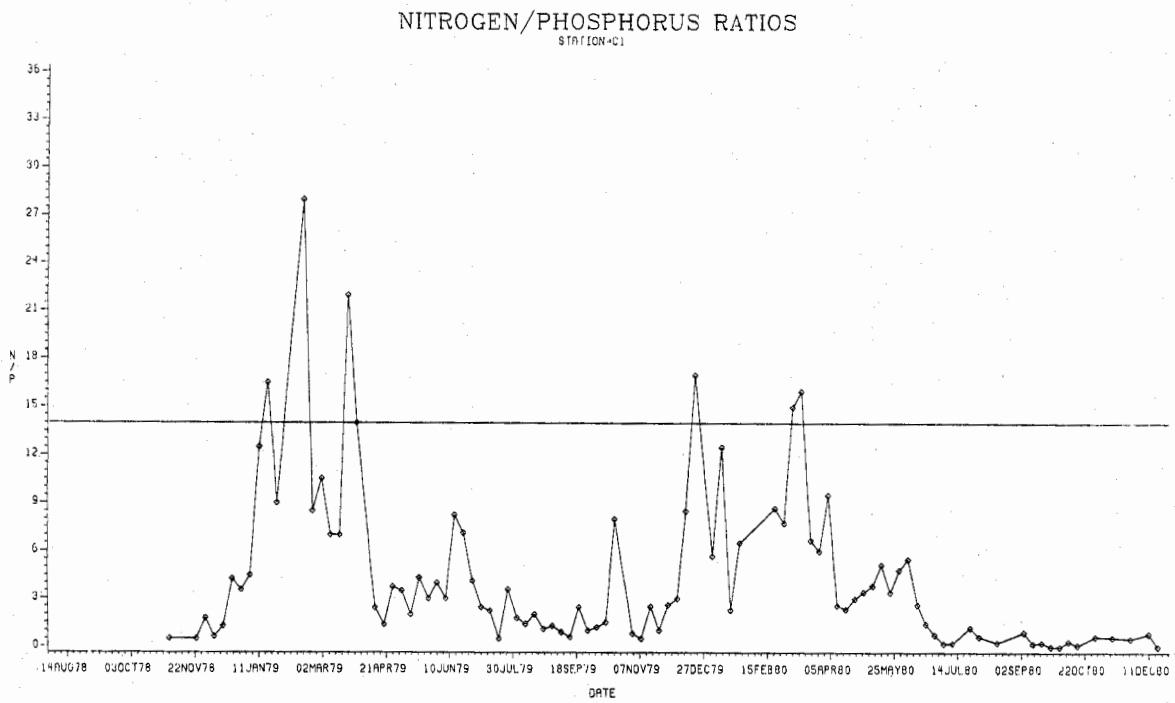


Figure 58 : Weekly available nitrogen to available phosphorus ratios at Station C-1 during the sampling period October 1978 to December 1980

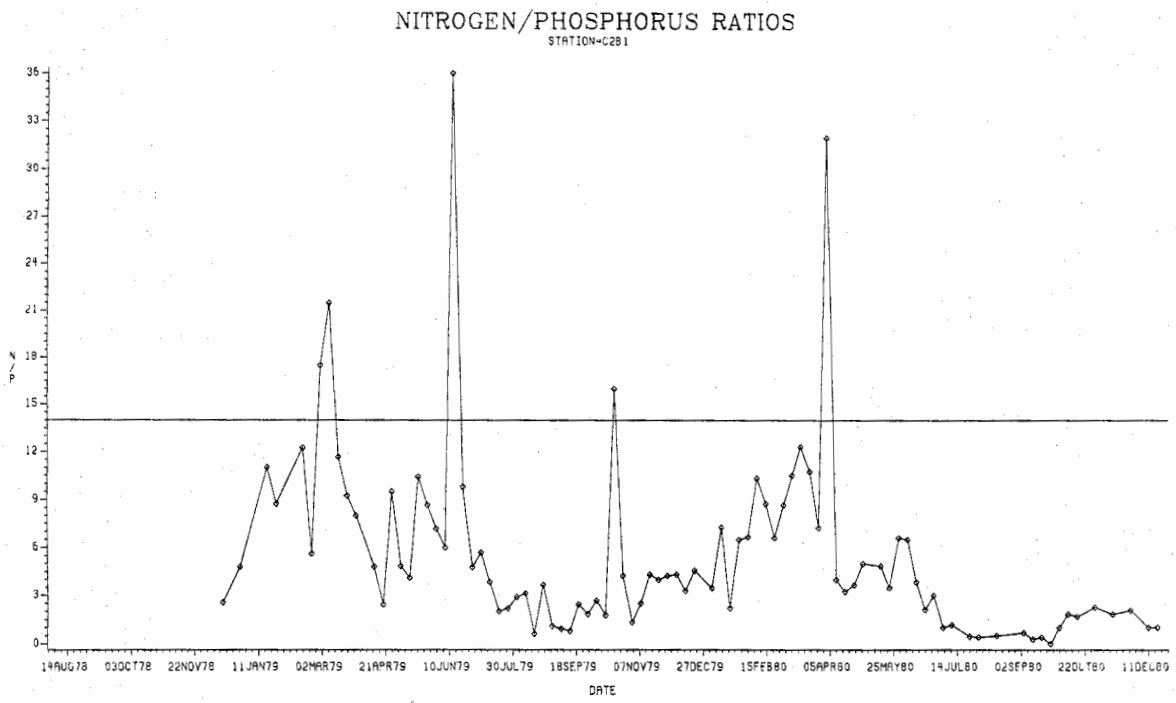


Figure 59: Weekly available nitrogen to available phosphorus ratios at Station C2B1 during the sampling period October 1978 to December 1980

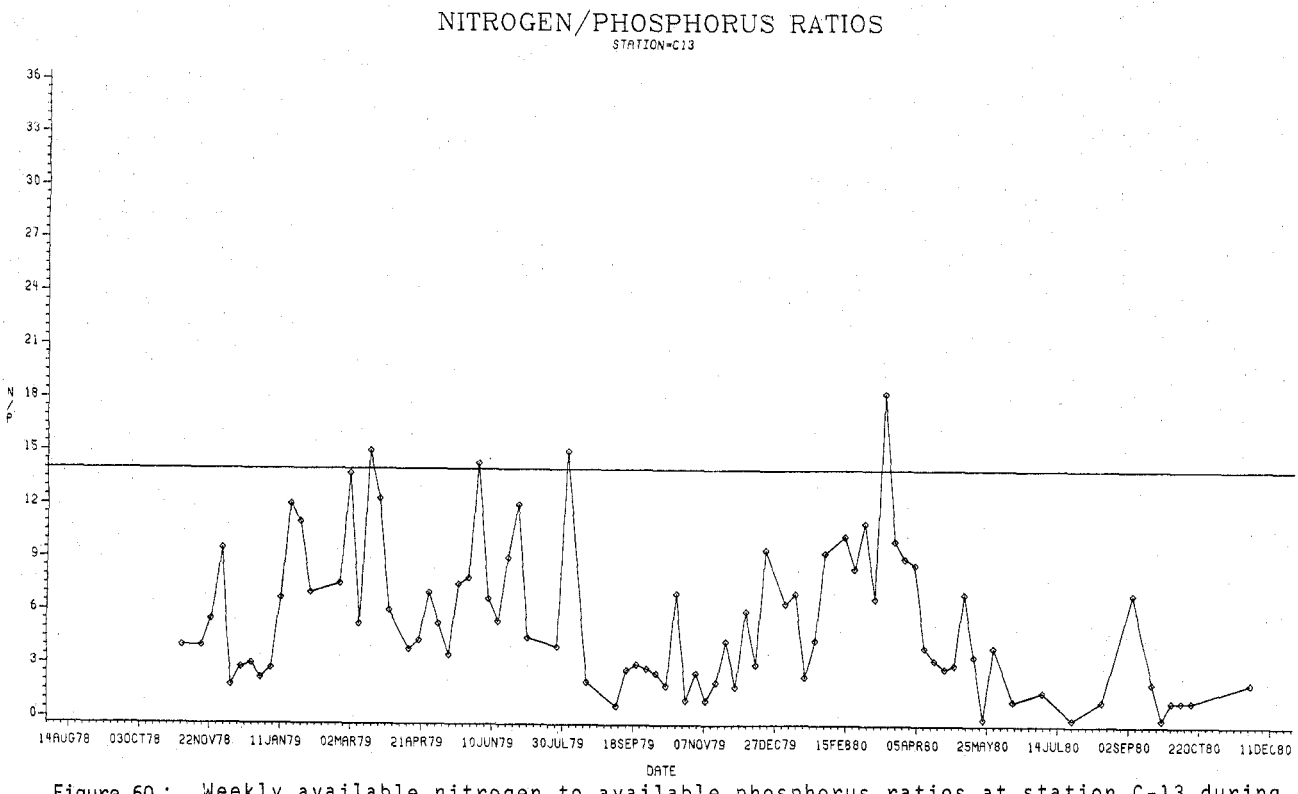


Figure 60 : Weekly available nitrogen to available phosphorus ratios at station C-13 during the sampling period October 1978 to December 1980

However, our data is the only full river reliable nutrient data set on the CRC and the data suggest otherwise (Figure 59, C2B1, upper river; Figure 60, C13, lower river).

Even if we use the most conservative N:P ratio from the literature for P-limitation, our data would not indicate other than as previously discussed; PO_4-P is seldom limiting.

This suggests a note of caution to management. Considering the best of the potential worsening situation, the periodic appearance of Microcystis at particular locations in the river. Microcystis does not fix nitrogen (though no blue-green algae has been shown to bloom with N_2-fixation as their only source of nitrogen). Yet, Microcystis can reach maximum growth in an N:P ratio as high as 75:1 (16). Thus, as far as mineral nutrition is concerned, nitrogen supply is most likely to limit its growth. Microcystis has shown in both the upper and lower Chowan River in visual proportions. If management plans are not carefully scrutinized, it is possible that they could create a natural selection for this very dangerous species, dangerous because of its apparent disregard for water (32, 40) flow and its capacity to fix the "fast-kill" toxin (16, 17, 18).

Microcystis, like many of the other CRC blue-green algae, is sensitive to pH. Usually pH toward the alkaline condition is necessary for maximum growth. The yearly (1979-1980) average mean pH for the CRC was more toward the natural condition, even though there were many individual times and stations in which the pH was 8 to 9.

It is still a puzzle to the researchers in the Great Lakes region as to why, even though their PO_4 reductions have reduced algal biomass, blue-green algae seem to continue to return to the lakes: Baybutt and Makarewicz, 1981: "A response to decreased PO_4 loading to the nearshore region of Lake Michigan appears to be a decrease in community phytoplankton biomass. The increase in

abundance of blue-green algae since the 1940's is possibly a response to some factor other than PO_4 (e.g., other nutrients, allelopathic effects)."

Could it possibly be a reverse effect between the diatoms and blue-green algae in the Chowan River? The data (Figures 24-30) does not support the concept. Diatoms are prevalent throughout the summer, fall, winter and spring, often in larger percentages than blue-green algae (Figure 27, summer 1979).

It suggests that a wrong management decision now could prove to be more devastating than the current Chowan River situation. It is only upon factual information derived through pin-pointed research that proper decisions can be made.

The algal community structure can and has supplied many answers to the cause/effect in the CRC (53). The companion project (results currently under preparation) to this one will consider the specificity of the phytoplankton in greater detail. It is hoped that the emphasis in the Chowan River system water quality management will shift from the nutrient loading concept to the biological manifestation concept and to specific biological responses, in particular.

Available CRC Nitrogen:Phosphorus Ratios

Several factors including nutrients are probably simultaneously limiting to any natural algal population because each member has varying growth requirements. In fact, as shown previously, increases in either NH_4, NO_3 or OP may lead to increased algal growth in the Chowan. Nevertheless, the concept of a limiting nutrient does have some management utility. It is used here to judge the relative importance of nitrogen and phosphorus by their simple ratio. Chief among the assumptions required here is that N or P is limiting, not both or neither.

The ratio of biologically available nitrogen (NH_4 + NO_3) to available

phosphorus (OP) is generally considered optimum for algal growth at about 14:1, though estimates vary (1). This means that, at a nitrogen-phosphorus ratio (NP) of 14, an addition of one nutrient will induce a limitation in the other nutrient. From this, as indicated above, calculated NP's are often used to characterize a system in the following way (20, 21, 25, 45, 46):

Nitrogen limitation	NP < 10
Phosphorus limitation	NP > 14
Transitional	10 $\leq$ NP $\leq$ 14

The NP summer average (1979 & 1980) for the lower reach was 7.26, characterizing the Chowan as nitrogen limited. The summer lower reach NP averages were 9.22 in 1979 and 4.66 in 1980. P-limitation conditions occurred 13% of the time in 1979 and only 4% of the time in 1980, never occurring for more than 2 consecutive samples. Again then, nitrogen reductions would have been most effective in lowering overall algal biomass in the Chowan.

Because many blue-green algae can biologically fix atmospheric N_2-nitrogen, they are often considered to have a competitive advantage in N-limited systems such as the Chowan. Field estimates of blue-green biomass (BGBMASS) and calculated NP ratios support this idea in that the summer Chowan is mostly N-limited and blue-green algae often dominate the summer biomasses. Such dominance is not, however, a functon of N_2-fixation but due to the high levels of nitrogen already present in the system. Furthermore, for the lower reaches, the 1979 summer NP average of 9.66 (slightly N-limited) resulted in 2.52 mg/l (27%) average BGBMASS while the 1980 summer NP average of 4.66 (N-limited) yielded 11.48 mg/l (67%) BGBMASS.

The NP averages associated with the dominant occurrence (> 10% of WWB) for three important blue-green genera are:

Aphanizomenon	6.24,

Anabaena, and 6.02,

Microcystis 6.39.

The N_2-fixing species frequently occurring as dominants, Anabaena flos-aquae, A. aequalis, A. circinalis and Aphanizomenon flos-aquae, had NP averages of 5.05, 5.10, 5.82 and 6.24, respectively.

These low NP averages concurrent with high BGBMASS averages clearly suggest that OP was closely associated with BGBMASS. Therefore, OP reductions seem most likely to decrease BGBMASS and its attendant problems. This is in fact the usual conclusion (literature) for most fresh-water systems and it is also supported by the previous response ratio development. One must ask, however, at what level and at what price to other algal species that compete for NO_3-N.

On the other hand, laboratory studies (earlier) show that nitrogen additions also stimulate BGBMASS growth. Correlation coefficients on summer field data, given in Tables IX through XI, give similar results. That is, while TKN (largely organic nitrogen) correlates positively with NH_4 and NO_3 overall, the relationship is negative (inverse) at station C13, the site of frequent BGBMASS problems. Apparently then, blue-green algae also consume, and thereby require, substantial amounts of nitrogen.

The PO_4-P needs of these species can be met regardless of the concentration levels of phosphorus in the system so long as there exist amounts above a critical level, or low concentrations over extended periods of time (across seasons).

In summary, the limiting nutrient concept developed here with NP ratios fully supports previous statements on the nutrient-algal biomass relationship. To wit:

1. Algal biomass in the Chowan in mostly nitrogen limited. Improved

Table IX

Product moment correlation coefficients for nitrogen and phosphorus species, using all summer data.

Summer Overall

	TKN-N	NH_4-N	NO_3-N	OP	TP	Total Nitrogen
TKN-N	-	-	-	-	-	-
NH_4-N	0.84*	-	-	-	-	-
NO_3-N	0.70*	0.94*	-	-	-	-
OP	0.08*	0.02	0.04	-	-	-
TP	0.77*	0.41*	0.24*	0.51	-	-
Total Nitrogen	0.91*	0.98*	0.93*	0.53	0.53*	-

Table X

Product moment correlation coefficients for nitrogen and phosphorus using Station C1 summer data.

Summer C1

	TKN-N	NH_4-N	NO_3-N	OP	TP	Total Nitrogen
TKN-N	-	-	-	-	-	-
NH_4-N	0.48*	-	-	-	-	-
NO_3-N	0.06	0.58*	-	-	-	-
OP	-0.13	-0.09	-0.12	-	-	-
TP	0.42*	0.49*	0.55*	0.05	-	-
Total Nitrogen	0.96	0.61	0.33	-0.16	0.55*	-

Table XI

Product moment correlation coefficients for nitrogen and phosphorus using Station C13 summer data.

Summer C13

	TKN-N	NH_4-N	NO_3-N	OP	TP	Total Nitrogen
TKN-N	-	-	-	-	-	-
NH_4-N	0.07	-	-	-	-	-
NO_3-N	-0.41*	0.31	-	-	-	-
OP	-0.28	0.40*	0.62*	-	-	-
TP	0.30	0.14	0.09	-0.02	-	-
Total Nitrogen	0.99	0.13	-0.26	0.33	0.33	-

overall water quality will therefore most likely be achieved through nitrogen reductions.

2. Reductions in phosphorus are also necessary to eventually create phosphate limited conditions (high NP's), not favorable to Chowan BGBMASS. This goal is necessarily long term because of the Chowan's excessive TP, the precursor to OP.

Further implications derived here from NP ratios are:

1. Substantial ambient inorganic nitrogen levels are required for BGBMASS to flourish, probably because direct nitrogen uptake is preferred to energy expensive N_2-fixation.
2. Phosphate reductions without concurrent nitrogen reductions in 1980 would have actually favored BGBMASS during the growth period (summer). For example, a simple 25% OP reduction during the summer of 1980 would have raised the NP average of 4.66 to 6.23, creating NP conditions more favorable to Aphanizomenon.

REGRESSION ANALYSES OF CHLOROPHYLL-a ON ALGAL NUTRIENTS

Among the more important questions asked about excessive algal growth in the Chowan River, from a management viewpoint, are:

1. Is there a need for algal nutrient reduction?
2. Which algal nutrient(s), NH_4, NO_3, OP and/or TP, is most closely associated with increasing algal growths?, and
3. To what extent are reductions in these nutrients necessary to limit excessive algal growth?

Unfortunately, the overall averages with ranked station groupings (Tables 1-3) and the seasonal averages for certain stations (Figures 10-15 and 65-67) show no precise trends or hard relationships. Therefore, answers to the above questions are sought here by using routine and widely recognized statistical procedures on the 1978-1980 nutrient data. Temperature is also evaluated in this way because of its direct and indirect effects on the algal-nutrient relationship (Figures 61 to 65).

Nutrient effects are first evaluated using simple multiple-regression analyses, constrained to a 0.0 intercept, with algal biomass as chlorophyll-a (CHLORO) for the dependent variable, that is;

(1) $CHLORO = \beta_{NH4}NH_4 + \beta_{NO3}NO_3 + \beta_{OP}Op + \beta_{TP}TP + \varepsilon.$

The magnitude of each nutrient's partial regression coefficient (NH_4...TP) indicates the extent of the nutrient's effect, its sign (+/-) gives the effect's direction and fiducial probabilities (F) estimate the reliability of the coefficient itself (within the overall model). Pearson product-moment correlation coefficients (R) between actual and predicted CHLORO judge the overall model's "goodness of fit."

Regression analyses of this form (1) were performed on:

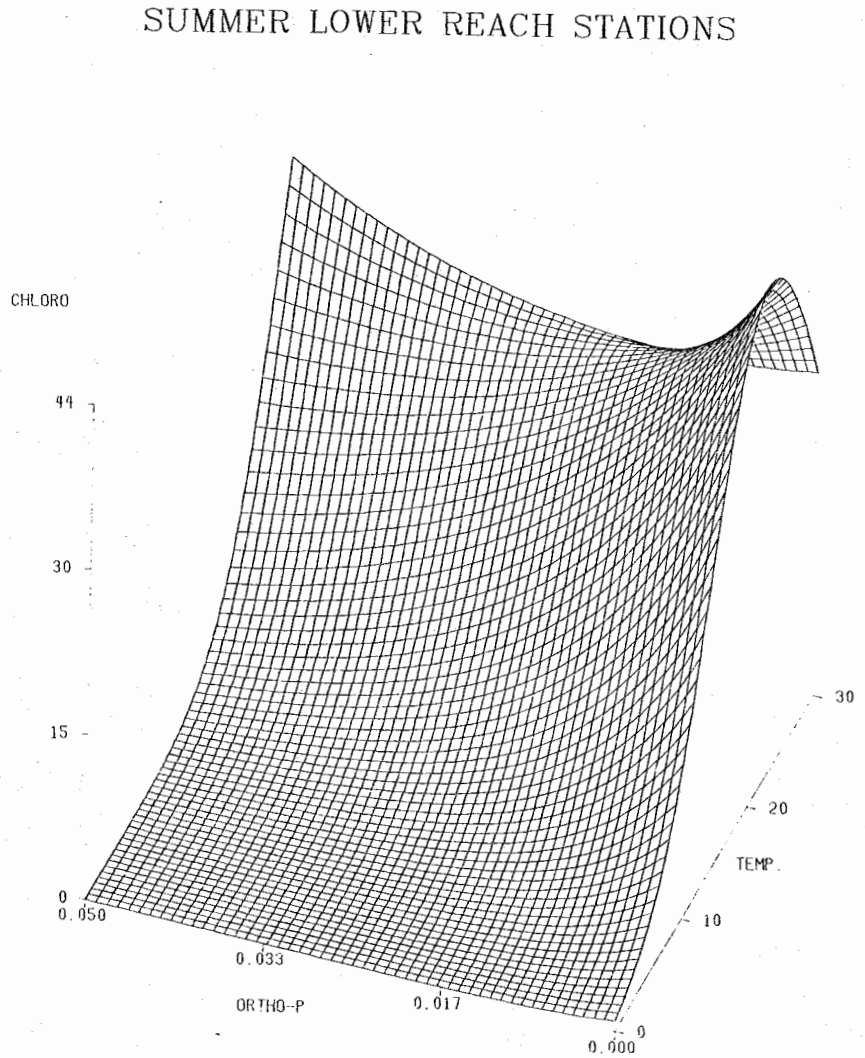


Figure 61: The response surface of chlorophyll-a on PO_4 X temperature variables, derived from a regression using Summer lower reach Chowan Data CORR. COEF. = 0.98
MEAN SUMMER ORTHO-P = 0.025 MG/L

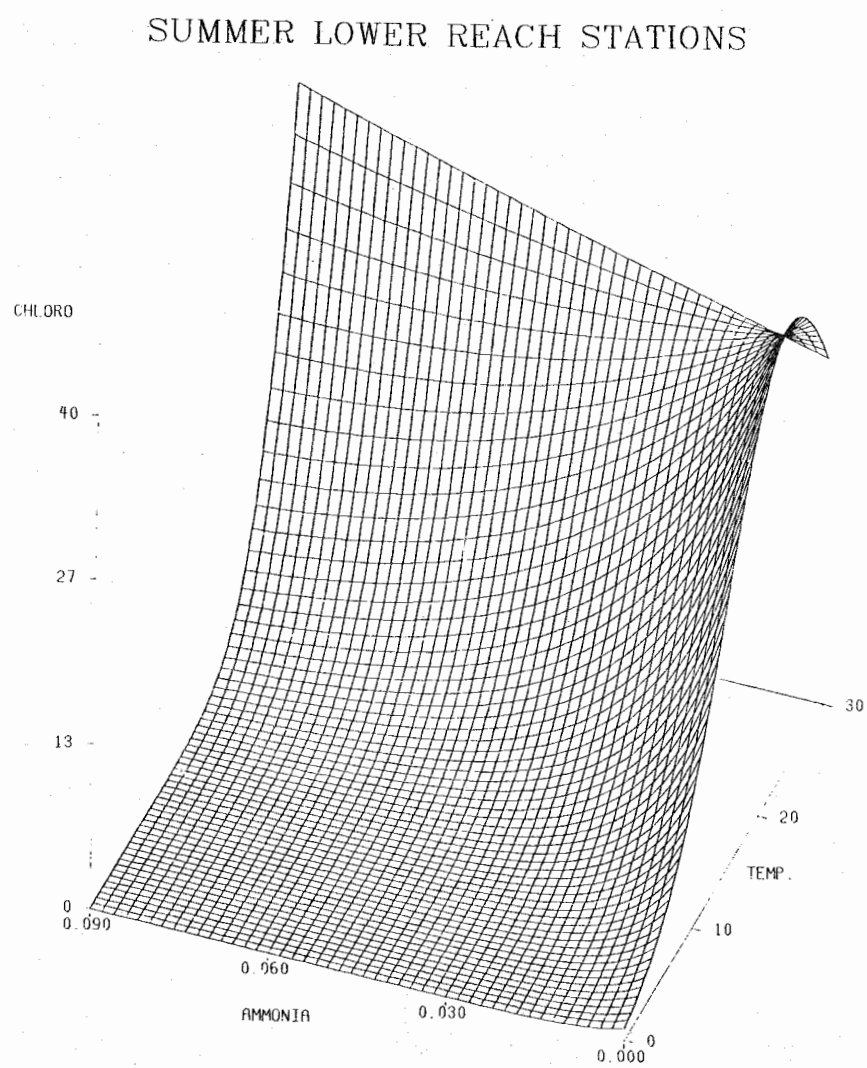


Figure 62: The response surface of chlorophyll-a on PO_4 X temperature variables, derived from a regression using summer lower reach Chowan Data CORR. COEF. = 0.98
MEAN SUMMER AMMONIA-N = 0.045 MG/L

SUMMER LOWER REACH STATIONS

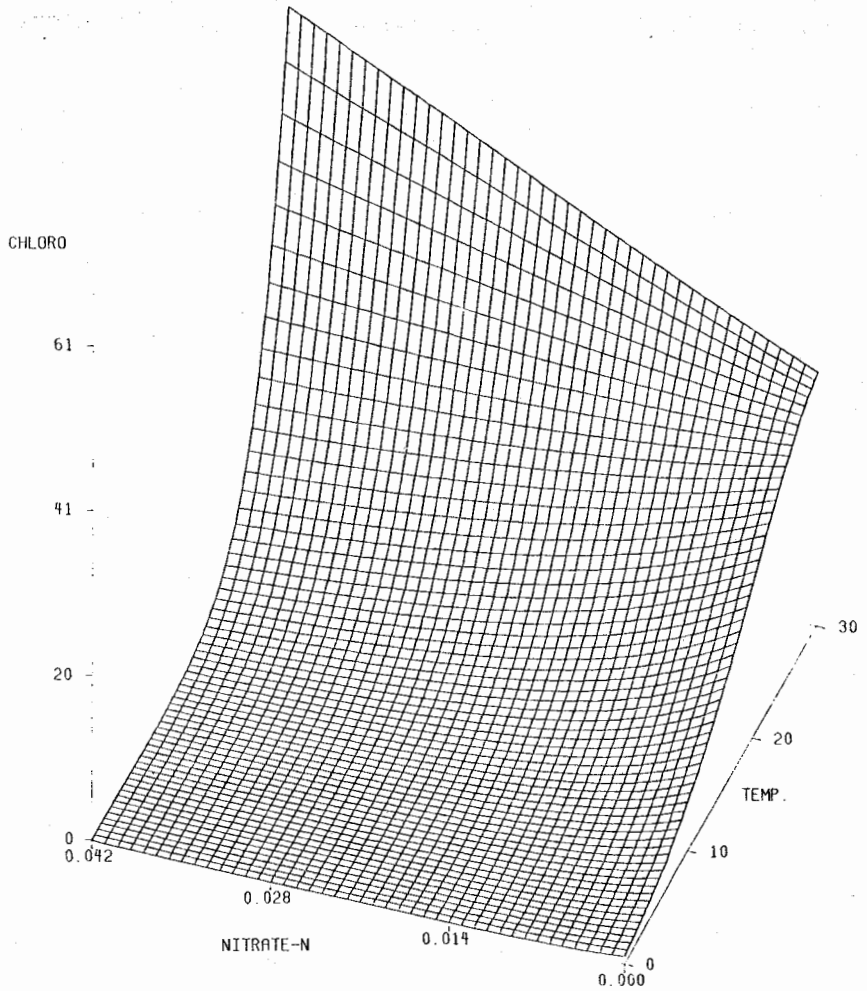


Figure 63: The response surface of chlorophyll-a on NO_3 X temperature variables, derived from a regression using summer lower reach Chowan Data CORR. COEF. = 0.98
MEAN SUMMER NITRATE-N = 0.021 MG/L

SUMMER LOWER REACH STATIONS

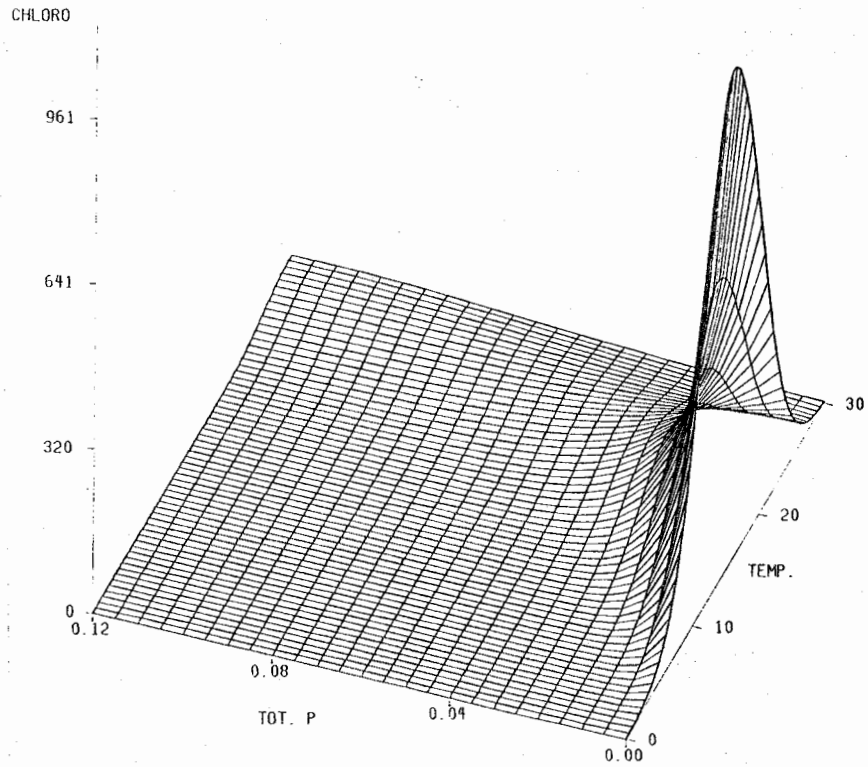


Figure 64: The response surface of chlorophyll-a on total phosphorus X temperature variables, derived from a regression using summer lower reach CORR. COEF. = 0.98 Chowan Data
MEAN SUMMER TOT. P = 0.106 MG/L

STATION C13 CHLOROPHYLL

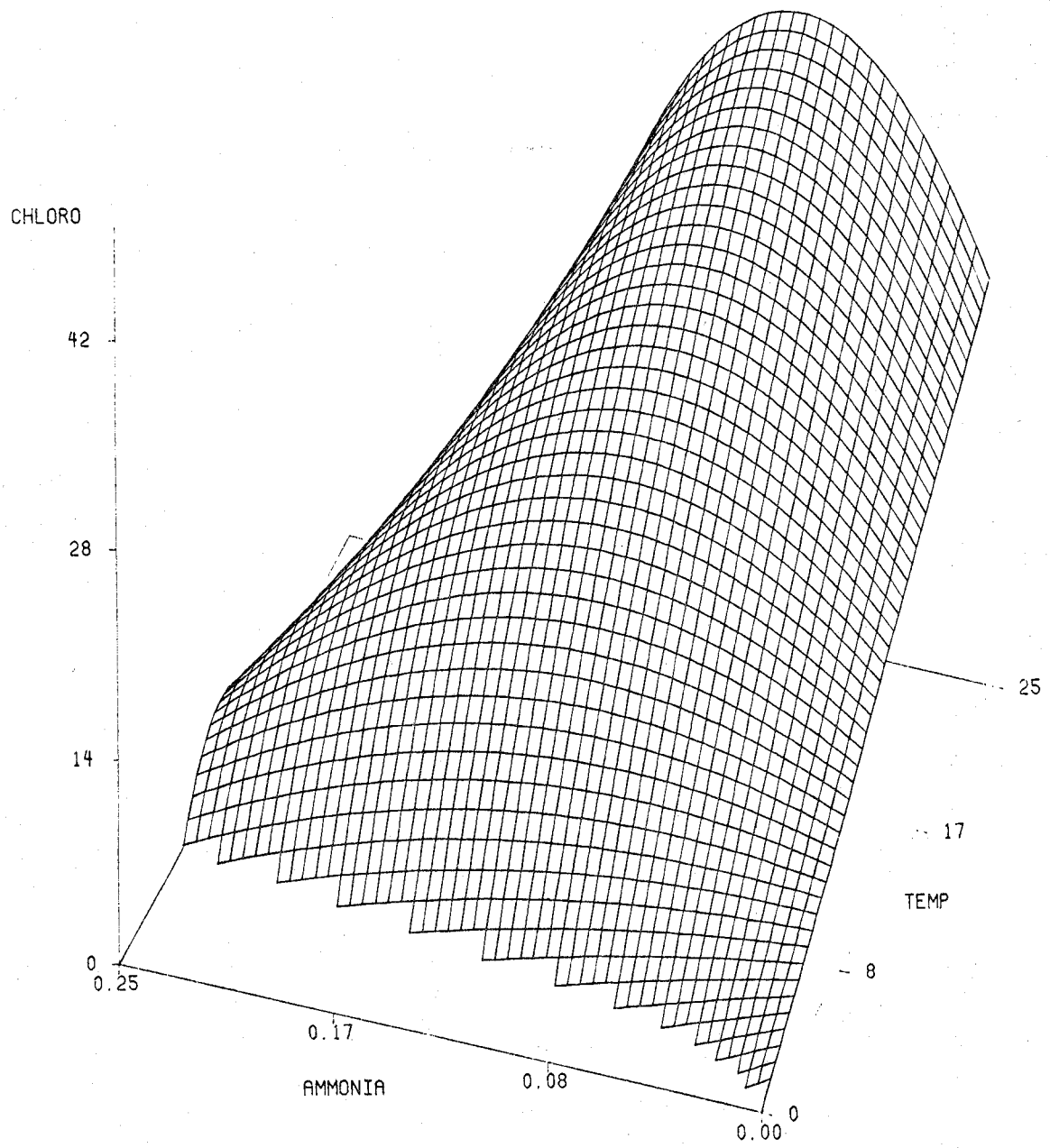


Figure 65: The response surface of Chlorophyll-a on ammonia-N X temperature variables, derived from a regression using Station C-13 Summer data

1. the overall Chowan data base,
2. each Chowan station separately, where chlorophyll-a measurements were taken,
3. seasonal subsets,
4. station groups, and
5. station-seasonal subsets.

Furthermore, each of these analyses was repeated using the logarithmic transformation of chlorophyll-a (CHLORO) as the dependent variable. The results from all of these analyses were important in that they all had poor R's, ambiguous partial regression coefficients and high (i.e., random) F probabilities. This can only be explained by there having been excessive levels of algal nutrients in the Chowan River. Other factors have, therefore, been largely in control of algal growth in the Chowan River, a point made with little doubt. For example, a non-linear least-squares regression of CHLORO on temperature (T, ° Celsius) and date (as days since Jan. 1 = D) alone, resulted in the expression:

(2) CHLORO = 0.798 (T) - 5.229 Cos [(D-70.070) / 49.480],

which can explain 84-88% of the temporal CHLORO change (1978-1980 data).

In spite of these difficulties however, the chlorophyll-a-nutrient relationship is intuitively sound and of management importance. Therefore, expressions for this relationship are further sought here by analyzing subsets of the overall data, with temperature included. The subset of the most interest is the lower reaches summer data (stations C9, C11, C12, C13, C15, and C16; June-Sept. inclusive). It is best suited to the approach used here because:

1. it is the area of excessive algal growths,
2. occasional nutrient depletions here suggest that they were not always excessive, and

3. chlorophyll-a tends to increase with nutrient depletions, most likely due to algal uptake (relationship).

With this data subset, response surface regression analyses of chlorophyll-a (ln transformed) on temperature (T) and each nutrient (N_i) individually, is the first approach. The general form of these models is:

(3) $CHLORO = \beta_1 T + \beta_2 T^2 + \beta_3 N_i + \beta_4 N_i^2 + \beta_5 T N_i + \beta_6 T^2 N_i + \beta_7 T^2 N_i^2 + \varepsilon$.

In spite of the generally good R's found with this model, the results for the lower reach summer (Figures 61-65) and for station C13 alone (Figures 66-67) mainly illustrate the large temperature effect.

The second approach then, was to use a full multiple curvilinear (polynomial) regression analysis on these same data and variables. This time, however, weekly lower reach averages for chlorophyll-a (CHLORO) temperature (T) and nutrients ($N_{i-\ell}$) were used as data. The 2-, 3- and 4-factor interaction components, the cubic main effects and the ln transformation of chlorophyll-a were derived from these averages. This very large model was reduced to a manageable set of components (14) by iterative deletions of those components that had F probabilities greater than 0.20.

In its final form, the model:

(4) $\ln CHLORO = \beta_1 T + \beta_2 T^2 + \beta_3 (T x NH_4) + \beta_4 (T x NO_3) + \beta_5 (T x TP) + \beta_6 (T x OP^2) + \beta_7 (T x NO_3^2) + \beta_8 OP + \beta_9 OP^2 + \beta_{10} (OP x NH_4) + \beta_{11} (OP x NO_3) + \beta_{12} TP + \beta_{13} TP^2 + \beta_{14} NO_3^2 + \varepsilon$, resulted in an R^2 of 0.92.

The partial regression coefficients of the TP components had only positive

STATION C13 CHLOROPHYLL

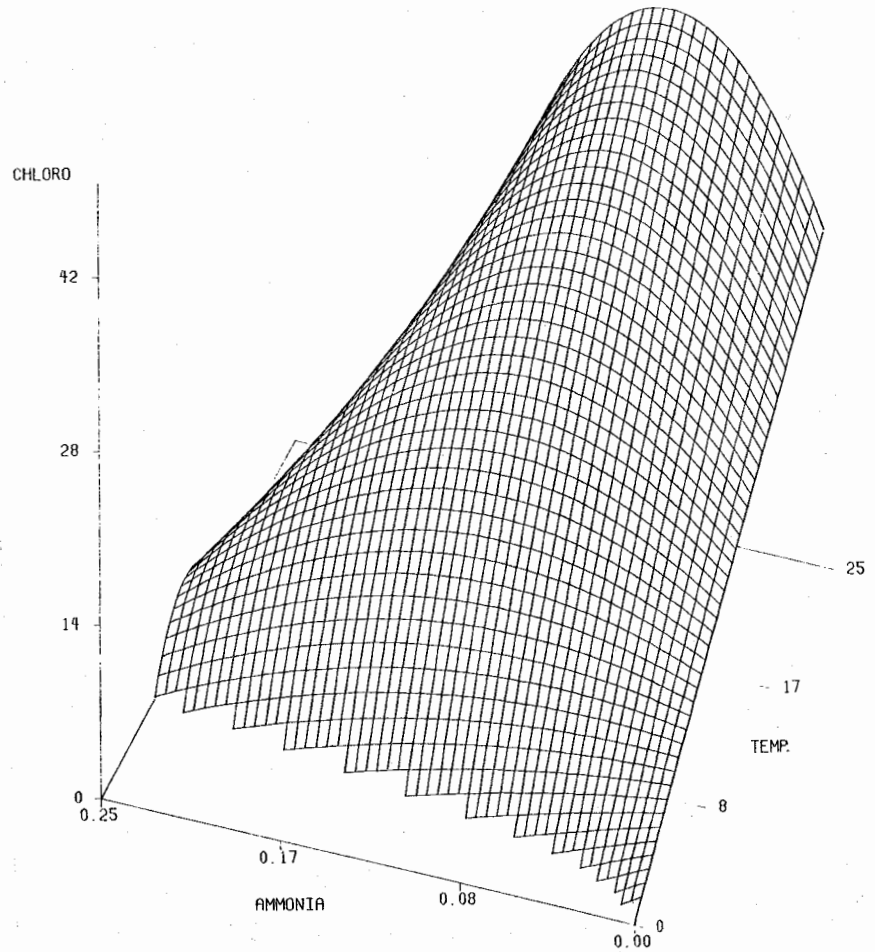


Figure 66: The response surface of chlorophyll-a on ammonia-N X temperature variables, derived from a regression using Station C-13 Summer data

STATION C13 CHLOROPHYLL

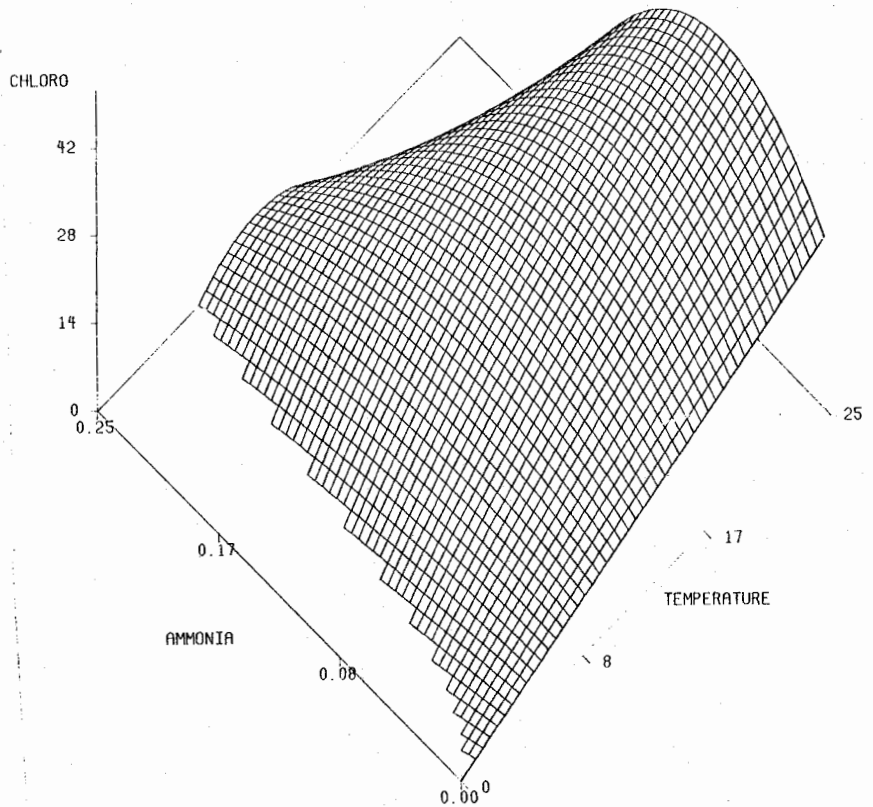


Figure 67: The response surface of chlorophyll-a on ammonia-N X temperature variables, derived from a regression using Station C-13 Summer data

values while those of NH_4 were only slightly negative. However, the NO_3 and OP components each yielded negative coefficients. This reciprocal relationship of the NO_3 and OP effects implies that, as nutrients, they were most closely associated with chlorophyll-a changes.

In order to quantify the nutrient effects, overall averages (1978-1980 summers) were first calculated as:

$\overline{\overline{CHLORO}}$, 39.87 mg/l,

$\overline{\overline{NH_4}}$, 0.0455 mg/l,

$\overline{\overline{NO_3}}$, 0.0496 mg/l,

$\overline{\overline{OP}}$, 0.0254 mg/l,

$\overline{\overline{TP}}$, 0.1094 mg/l.

Simulations were then performed to test the effect of various nutrient reductions on $\overline{\overline{CHLORO}}$. The amount of reduction for a given nutrient was as a percentage of its overall average. For example, a simulation to test the effect of a 10% reduction of NH_4 involved subtracting $0.10 \times \overline{\overline{NH_4}} = 0.00455$ mg/l from each weekly $\overline{NH_4}$. The average weekly temperature (T) was unaltered.

Simulations using various percentage reductions of NO_3 and OP have also been performed in this way. These simulations were more meaningful here because of the established close and inverse NO_3 + OP -- CHLORO relationship. The results of one such simulation show that 5% $\overline{NO_3}$ and 10% $\overline{OP}$ reductions will reduce $\overline{\overline{CHLORO}}$ from 39.87 to 36.88 µg/l with fewer extreme values. The standard error (σ) of this prediction, however, is $\pm$ 7.00 g/l (α=0.05, d.f.=5) as estimated from reasonably consistent weekly coefficients of variation (C.V.):

$$C.V. = 100\ \sigma / \overline{CHLORO}\ \mu g/l,$$

which averaged to 47.00.

The last step here is to extrapolate these simulation results to give

Table XII

1978-1980 Fall nutrient and response ratio averages over chlorophyll-a product moment correlation coefficient. * significance at α = 0.05. Units are: nutrients, mg/l; chlorophyll a, μg/l; ratios, unit-less.

Fall Chlorophyll
Avg./Correlation Coefficient (R)

	Overall	C1	C4	C13	C16
TKN	1.56/0	0.62/-.22	0.73/-.26	0.82/0.09	0.77/0.14
NH_3	0.75/-.05	0.03/-.05	0.08/-.11	0.04/0.14	0.03/0.04
NO_3	2.51/-.10*	0.05/-.55*	0.13/-.11	0.06/-.17	0.08/-.51
OP	0.10/-.10*	0.11/.29	0.03/-.32	0.02/-.14	0.02/-.20
TP	0.16/-.05	0.06/.28	0.10/0.08	0.10/-.03	0.08/0.03
TN	4.08/-.03	0.68/.28	0.86/-.22	0.88/-.05	0.85/0.04
Chloro	9.30/--	2.84/--	4.75/--	25.63/--	16.74/--
Chloro/TKN	0.01/0.88	0.01/0.92*	0.01/0.97*	0.03/0.98*	0.03/.66*
Chloro/NH_3	0.27/0.77	0.11/0.64*	0.18/0.83*	0.72/0.95*	0.76/.61*
Chloro/NO_3	0.30/0.86	0.03/0.94*	0.05/0.85*	1.25/0.99*	0.30/.78*
Chloro/OP	0.37/0.91	0.04/0.97*	0.17/0.88*	0.48/0.63*	0.74/.76*
Chloro/TP	0.14/0.66	0.02/0.96*	0.05/0.99*	0.34/0.97*	0.27/.65*
Chloro/TN	0.01/0.91	0.01/0.93*	0.01/0.97*	0.03/0.98*	0.02/.70*

Table XIII

1978-1980 Winter nutrient and response ratio averages over chlorophyll-a product moment correlation coefficient. * significance at $\alpha = 0.05$.

Winter Chlorophyll
Avg./Correlation Coefficient (R)

	Overall	C1	C4	C13	C16
TKN	2.51/0.11*	0.60/0.45*	0.74/0.20	0.82/0.18	0.71/0.08
NH_3	1.42/-.01	0.04/0.10	0.10/-.28	0.10/-.16	0.10/0.51*
NO_3	3.10/.05	0.21/0.07	0.29/0.04	0.30/0.20	0.26/-.32
OP	0.20/-.03	0.02/0.22	0.05/-.34	0.05/-.03	0.05/0.54
TP	0.27/.07	0.07/0.59*	0.10/-.15	0.11/-.57*	0.10/0.41
TN	5.62/.10*	0.82/0.45*	1/03/0.18	1.12/0.23	0.97/-0.09
Chloro	1.52/--	1.00/--	1.04/--	1.16/--	2.11/--
Chloro/TKN	0 /0.91*	0 /0.84*	0 /0.68*	0 /0.58*	0 /0.97*
Chloro/NH_3	0.03/0.58*	0.03/0.58*	0.02/0.67*	0.02/0.45	0.03/0.41
Chloro/NO_3	0.01/0.87*	0 /0.93*	0 /0.80*	0 /0.67*	0.01/0.95*
Chloro/OP	0.06/0.81*	0.05/0.83*	0.03/0.79*	0.03/0.88*	0.05/0.66*
Chloro/TP	0.02/0.79*	0.01/0.62*	0.01/0.89*	0.01/0.76*	0.02/0.56*
Chloro/TN	0 /0.91*	0 /0.90*	0 /0.79*	0 /0.69*	0 /0.98*

Table XIV

1978-1980 Spring nutrient and response ratio averages over chlorophyll-a product moment correlation coefficient. * significance at $\alpha = 0.05$. Units are: nutrients, mg/l; chlorophyll a, µg/l; ratios, unit-less.

Spring Chlorophyll
Avg./Correlation Coefficient (R)

	Overall	C1	C4	C13	C16
TKN	4.08/0.01	0.89/0.07	0.79/0.21	0.86/0.34	0.93/0.67*
NH_3	2.76/-0.08*	0.06/0.26	0.08/0.08	0.06/-0.40	0.06/0.14
NO_3	5.81/-0.04	0.17/-0.22	0.22/-0.31	0.19/-.61*	0.17/-.44*
OP	0.14/-0.02	0.06/-0.29	0.05/0.07	0.04/-0.41	0.03/-.03
TP	0.23/-0.02	0.12/-0.28	0.10/0.09	0.11/-0.06	0.10/0.18
TN	9.91/0	1.06/0.03	1/02/0.15	1.06/0.10	1.11/0.59*
Chloro	9.08/--	1.84/--	2.63/--	17.68/--	21.36/--
Chloro/TKN	0.01/0.82*	0 /0.71*	0 /0.79*	0.02/0.90*	0.02/0.55*
Chloro/NH_3	0.23/0.78*	0.04/0.41	0.04/0.61*	0.58/0.81*	1.02/0.71*
Chloro/NO_3	0.12/0.54*	0.01/0.82*	0.01/0.90*	0.31/0.45*	0.61/0.39
Chloro/OP	0.31/0.80*	0.06/0.68*	0.06/0.76*	0.85 0.71*	0.93/0.63*
Chloro/TP	0.10/0.91*	0.02/0.79*	0.03/0.63*	0.19/0.95*	0.23/0.88*
Chloro/TN	0.01/0.87*	0 /0.77*	0 /0.89*	0.02/0.93*	0.02/0.67*

Table XV

1978-1980 Summer nutrient and response ratio averages over chlorophyll-a product moment correlation coefficient. * significance at α = 0.05. Units are: nutrients, mg/l; chlorophyll a, μ g/l; ratios, unit-less.

Summer Chlorophyll
Avg./Correlation Coefficient (R)

	Overall	C1	C4	C13	C16
TKN	3.11/0.13*	.8497/-.32	1.0047/-.07	1.2518/0.28	1.1585/0.14
NH_3	1.52/0.83	.0391/-.29	.0556/0.18	.0394/-.04	.0365/-.10
NO_3	3.23/-.11*	.1003/-.06	.1288/0.04	.0391/-.33	.0306/0.08
OP	0.10/-.09*	.0897/.37*	.0562/0.26	.0176/-.32	.0191/0.17
TP	0.24/-.01	.1262/-.27	.1065/-.27	.1085/-.05	.0915/0.19
TN	6.24/0.05	.9500/-.31	1.1335/-.05	1.2909/0.24	1.1891/0.15
Chloro	24.96/--	8.07/--	14.88/--	40.39/--	37.27/--
Chloro/TKN	.0266/.85*	.0148/.90*	0.172/0.86*	.0348/0.82*	.0359/0.85*
Chloro/NH_3	.7505/.73*	.2915/.92*	.3710/0.60*	1.3170/0.58*	1.4521/0.71*
Chloro/NO_3	.6862/.64*	.1574/.25	.2524/0.40*	1.9661/0.91*	1.3390/-.09
Chloro/OP	.8931/.82*	.0857/.97*	.2795/0.74*	1.4250/0.90*	2.3145/0.59*
Chloro/TP	.2420/.86*	.0687/.98*	.1719/0.79*	.4119/0.47*	.4227/0.88*
Chloro/TN	.0239/.86*	.0117/.94*	0.0149/.84*	.0338/0.83*	.0343/0.88*

desired nutrient reductions, again from a management viewpoint. So doing, it is seen that to reduce $\overline{CHLORO}$ to 33.60 $\pm$ 6.4 µg/l (i.e., < 40 µg/l average), 10.5% NO_3 and 21% OP reductions are necessary. Further, to reduce the $\overline{CHLORO}$ to a more reasonable 20 µg/l average, 33.2% NO_3 and 66.5% OP reductions are necessary.

In brief summary, three main results have been derived here using routine statistical analyses on 1978-1980 Chowan River data. These results, based on nearly 3,000 observations, serve to answer the three originally posed questions.

The first result shows that nutrients are generally far in excess of algal requirements and that reductions are unquestionably necessary.

The second result shows that NO_3, and to a lesser extent OP, are the nutrients most closely associated with algal growth. Reductions mainly in NO_3 but also OP levels are therefore most necessary.

The third result suggests that to achieve meaningful reductions in algal biomass, NO_3 and OP levels should be reduced, by at least 10.5% and 21% respectively, and preferably by 33.2% and 66.5%, respectively. These reduction levels are quite conservative for they are based on river conditions (CRC included) following the major nutrient and biomass loads of 1978, not the conditions that gave rise to the bloom. They may or may not have been in greater magnitude.

Response Ratios

Another way to quantify the algal-nutrient relationship is by the simple algal:nutrient ratio. This ratio of response (RR_i) is essentially a measure of the Chowan system's utilization efficiency for nutrient$_i$. However, since it is also a measure of the per unit nutrient$_i$ effect, RR_i's are used here to estimate, for the Chowan:

1. chlorophyll-*a*, total wet wt. algal biomass (WWB) and total wet wt.

blue-green algal biomass (BGBMASS) responses to varying nutrient$_i$ concentrations, and

2. which nutrient(s) is most critical to each of the three biomass estimates, chlorophyll-a, WWB and BGBMASS.

While this approach is mainly designed to modify nutrient loading models (Hern et al., 1981), it is used here for two reasons:

1. growth controlling factors other than nutrient$_i$ (e.g. temperature) are implicit to RR$_i$ and may therefore be ignored, and
2. more than 757 lake systems have been analyzed in this manner forming a comparison base (Ibid.).

From Tables XII through XV it appears that the seasonal averages for NH_4, NO_3 and OP are highest in the winter and spring, high in the fall and relatively lower during the summer. But chlorophyll-a averages seem to follow nearly a reverse trend.

The overall pattern of increasing chlorophyll-a with declining levels of NH_4, NO_3 and OP is important to the RR concept. This is because algal uptake with subsequent growth is probably responsible for the lower nutrient levels. It follows from this, that changes in the level of nutrient$_i$ result in chlorophyll-a changes proportional to RR$_i$. The confidence in this estimated proportional change is given by its correlation to chlorophyll-a. The calculated values of each RR$_i$ for stations C1, C4, C13, C16 are illustrated in figures 68 through 97.

Hern et al. (1981) (21) state that an RR value of 1.0 or greater is indicative of a "high efficiency" algal population (i.e. nutrient sensitive). They further state that RR values lower than 1.0 occur when some other nutrient or environmental factor is limiting to algal growth. An RR value of 1.0 will therefore be used here to judge the strength of a given nutrient's effect on chlorophyll-a.

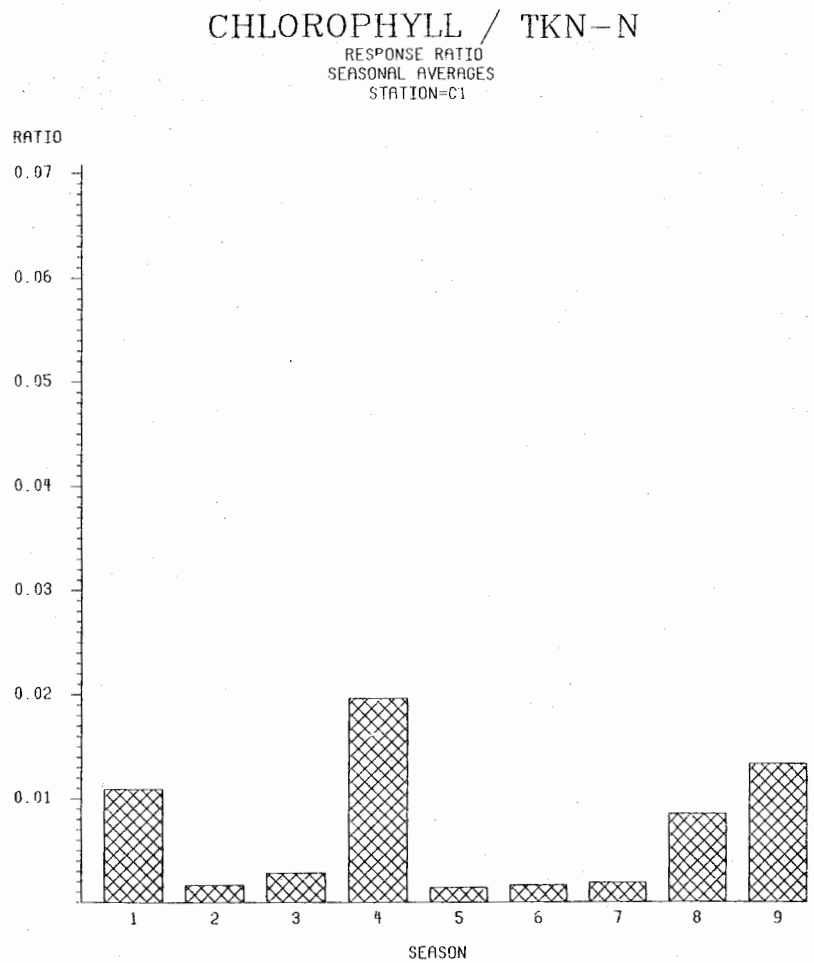


Figure 68 : Seasonal chlorophyll-a to total Kjeldahl nitrogen response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

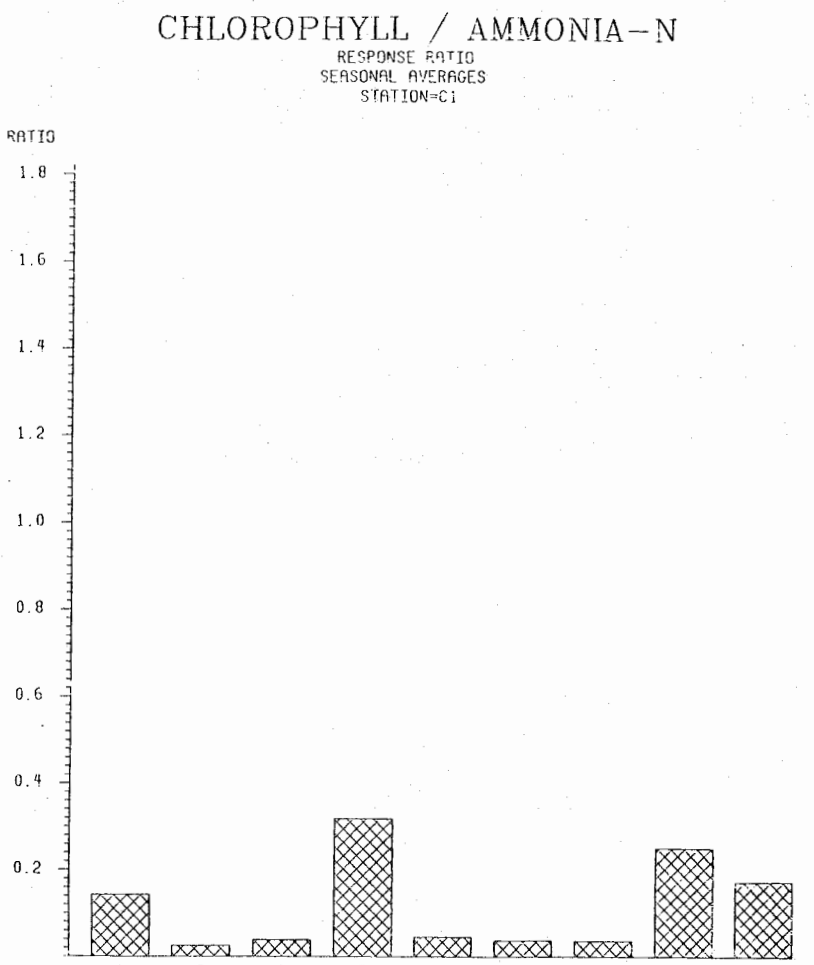


Figure 69: Seasonal chlorophyll-a to ammonia nitrogen response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

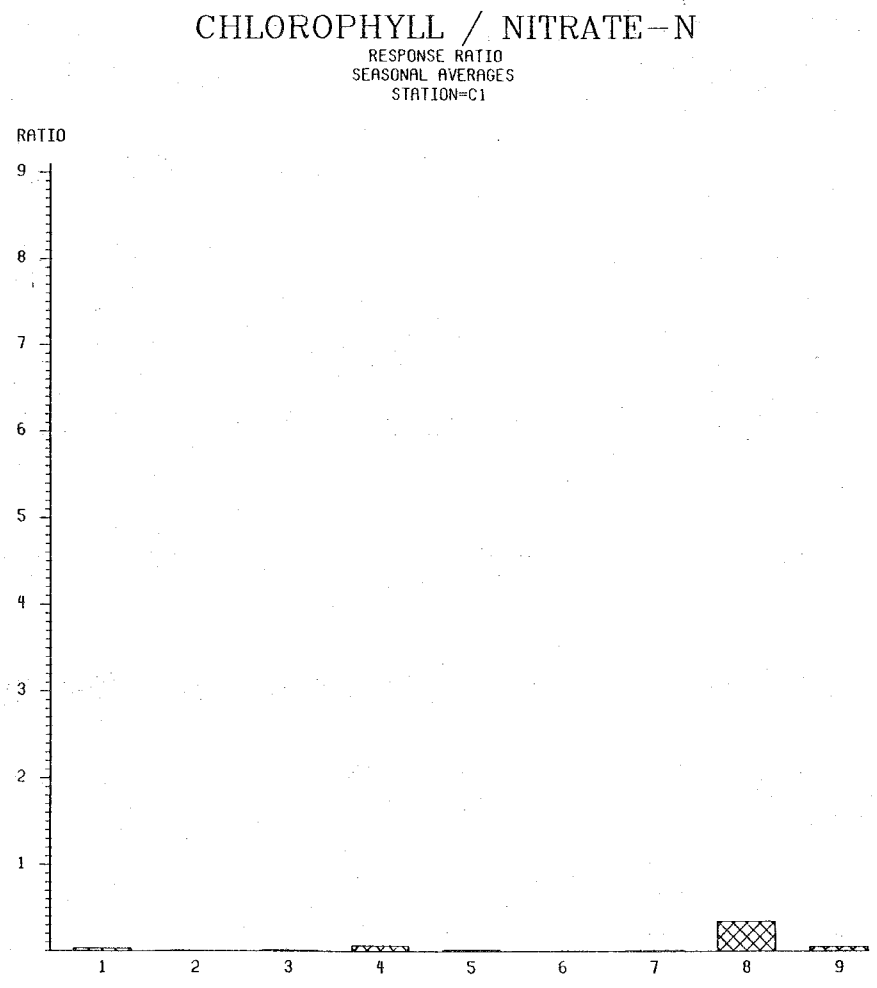


Figure 70 : Seasonal chlorophyll-a to nitrite-nitrate nitrogen response ratio averages for Station C-1

SEASON 1 = FALL , 1978 SEASON 6 = WINTER , 1980
SEASON 2 = WINTER , 1979 SEASON 7 = SPRING , 1980
SEASON 3 = SPRING , 1979 SEASON 8 = SUMMER , 1980
SEASON 4 = SUMMER , 1979 SEASON 9 = FALL , 1980
SEASON 5 = FALL , 1979

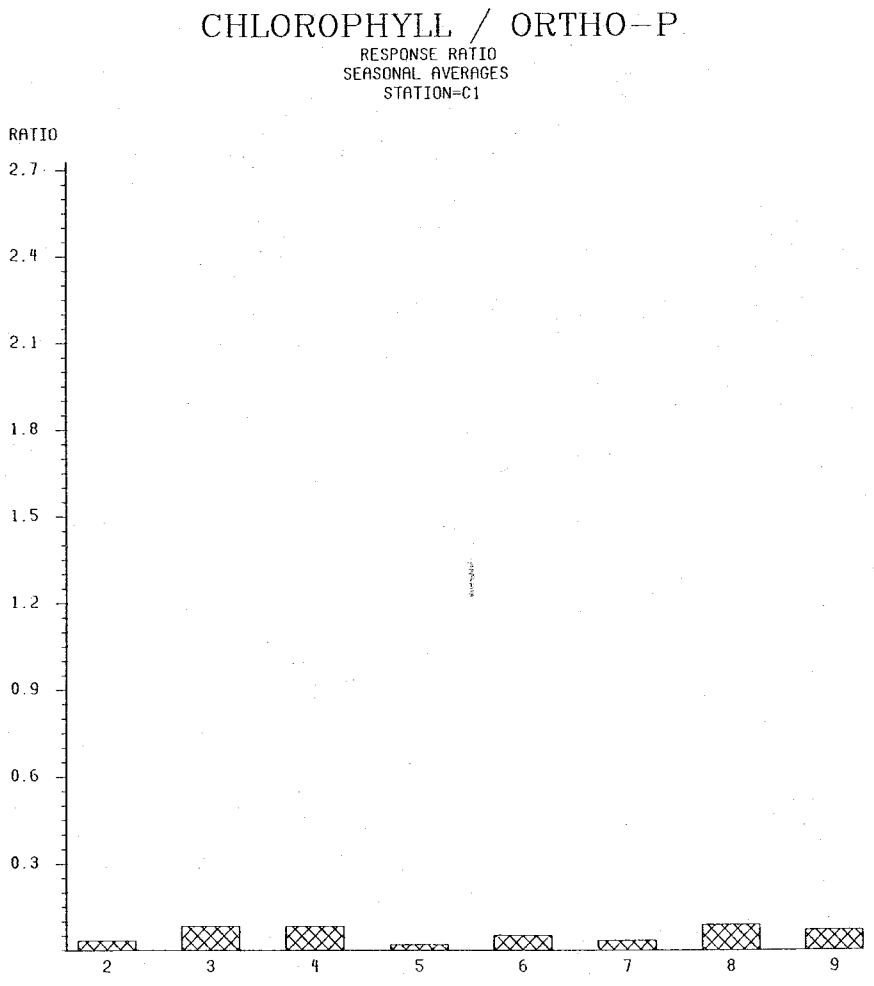


Figure 71: Seasonal chlorophyll-a to Ortho-PO_4 phosphorus response ratio averages for Station C-1

SEASON 1 = FALL , 1978 SEASON 6 = WINTER , 1980
SEASON 2 = WINTER , 1979 SEASON 7 = SPRING , 1980
SEASON 3 = SPRING , 1979 SEASON 8 = SUMMER , 1980
SEASON 4 = SUMMER , 1979 SEASON 9 = FALL , 1980
SEASON 5 = FALL , 1979

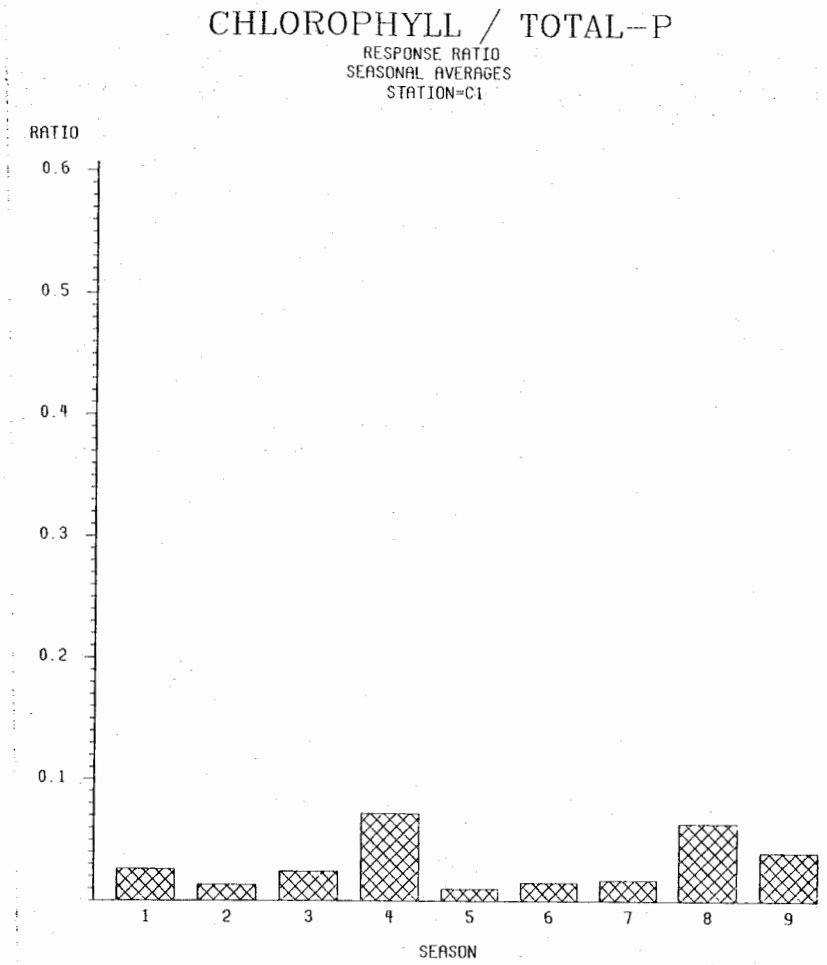


Figure 72 : Seasonal chlorophyll-a to total phosphorus response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

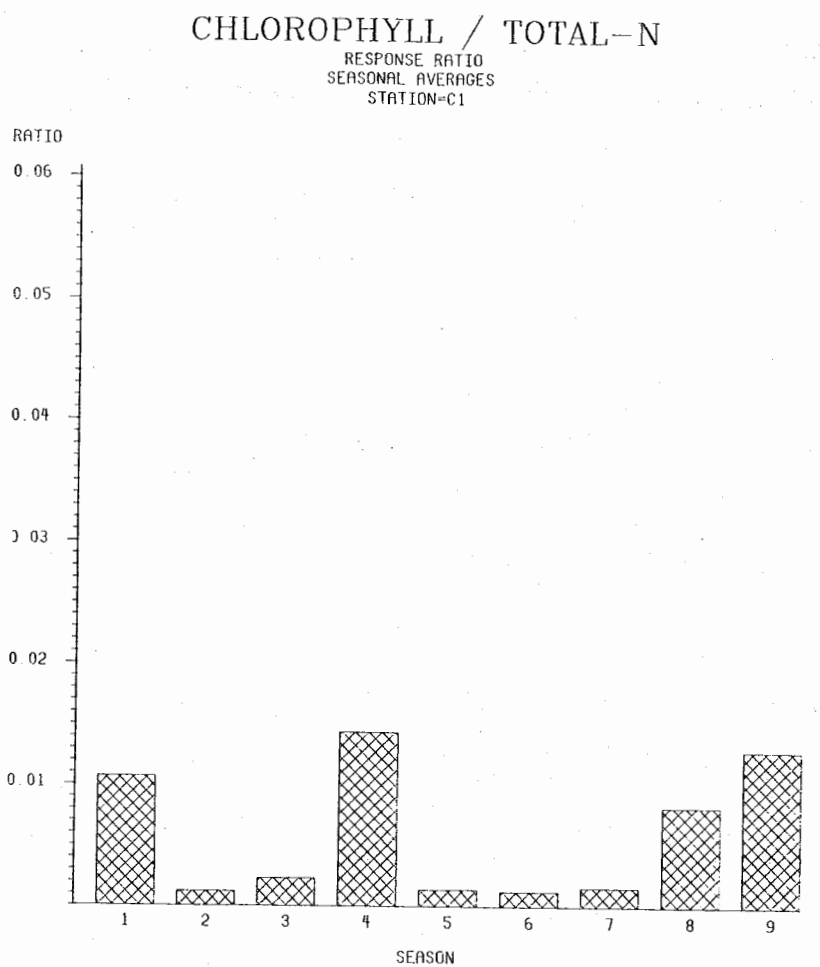


Figure 73 : Seasonal chlorophyll-a to total nitrogen response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

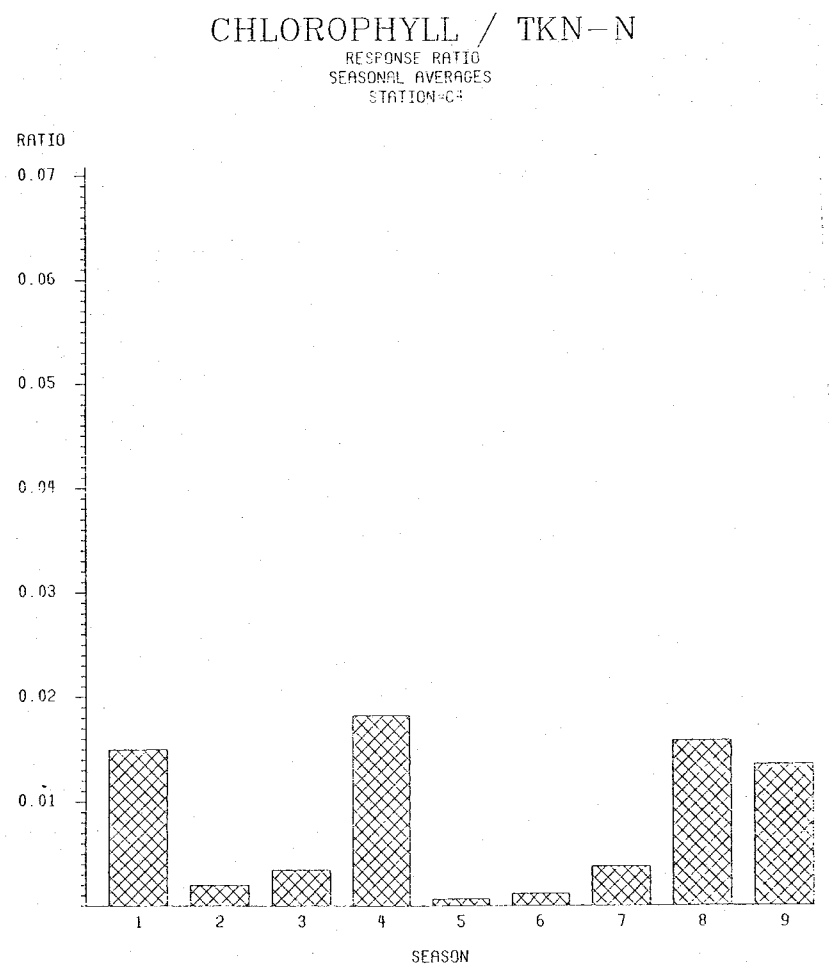


Figure 74: Seasonal chlorophyll-a to total Kjeldahl nitrogen response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

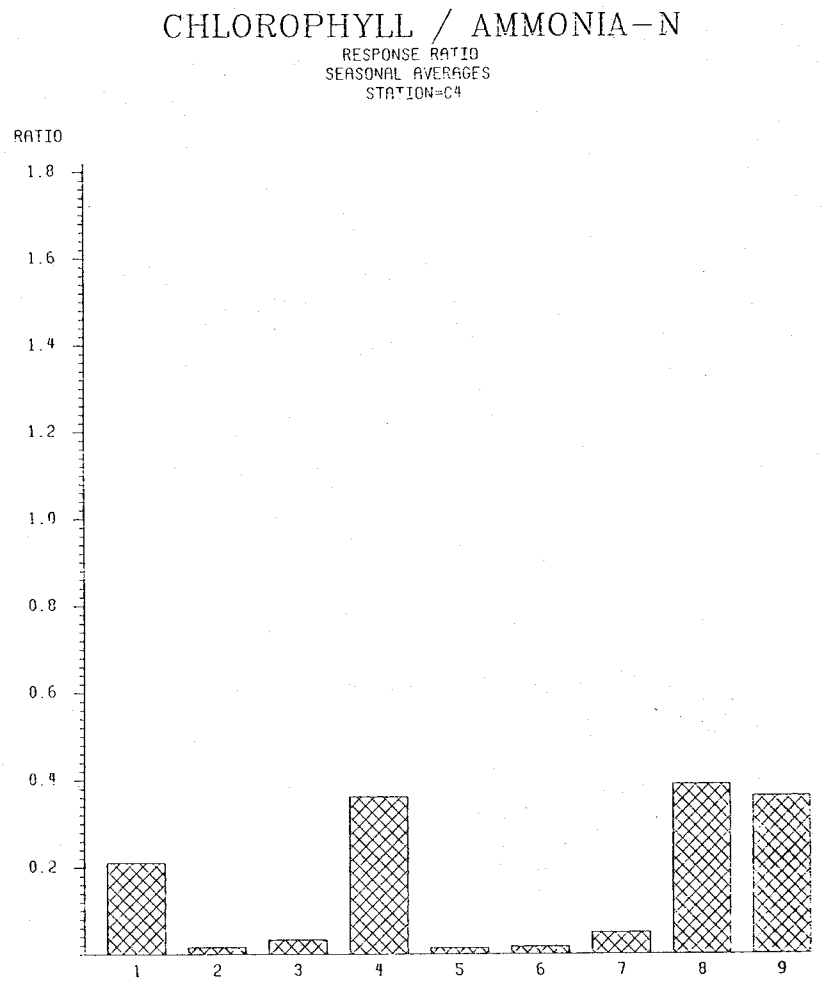


Figure 75: Seasonal chlorophyll-a to ammonia nitrogen response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

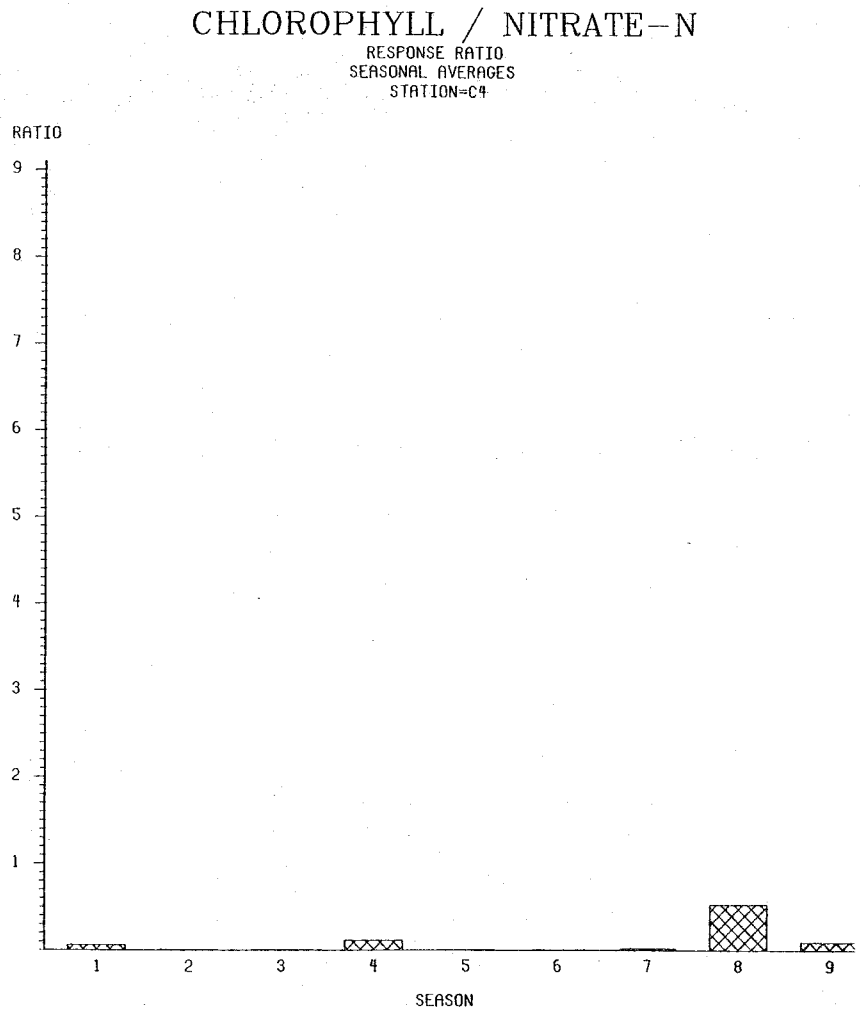


Figure 76 : Seasonal chlorophyll-a to nitrite-nitrate nitrogen response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

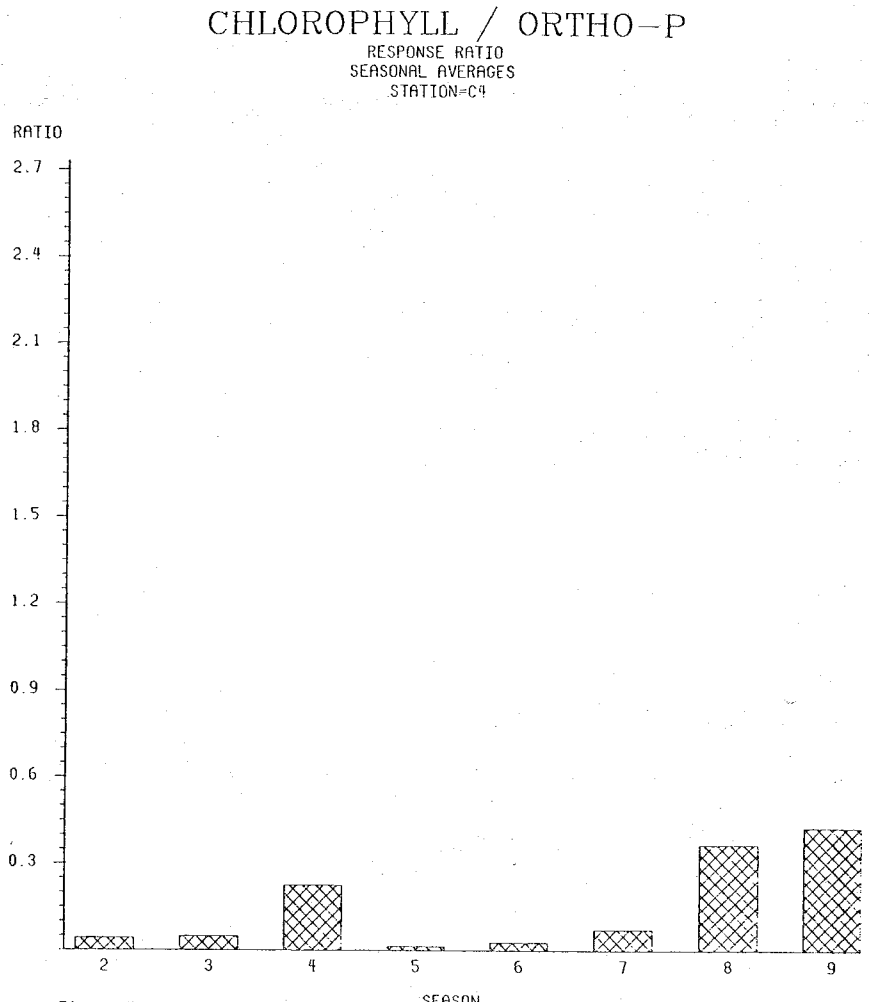


Figure 77: Seasonal chlorophyll-a to ortho-PO_4 phosphorus response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

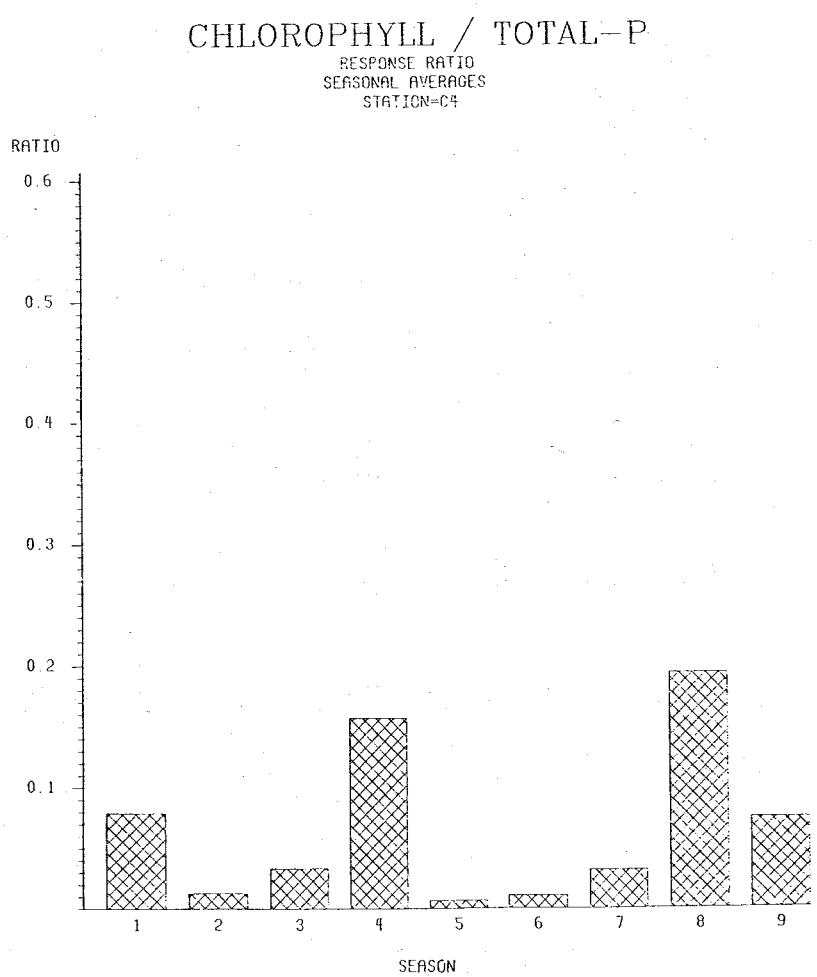


Figure 78: Seasonal chlorophyll-a to total phosphorus response ratio averages for Station C-4

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

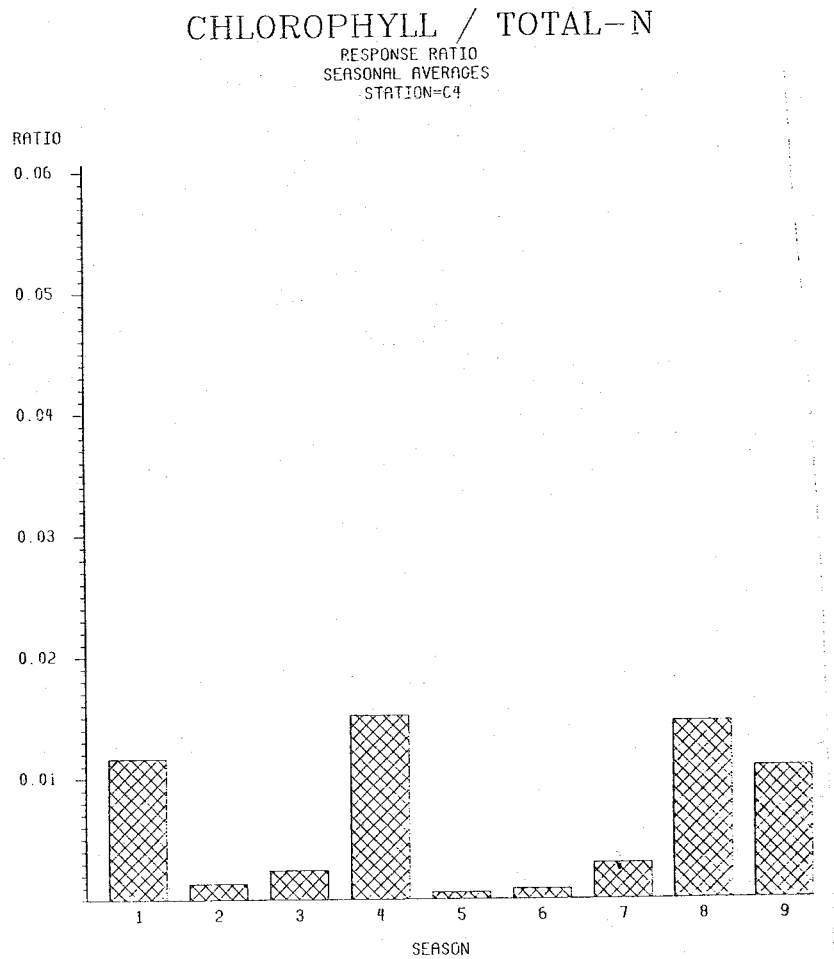


Figure 79: Seasonal chlorophyll-a to total nitrogen response ratio averages for Station C-4

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

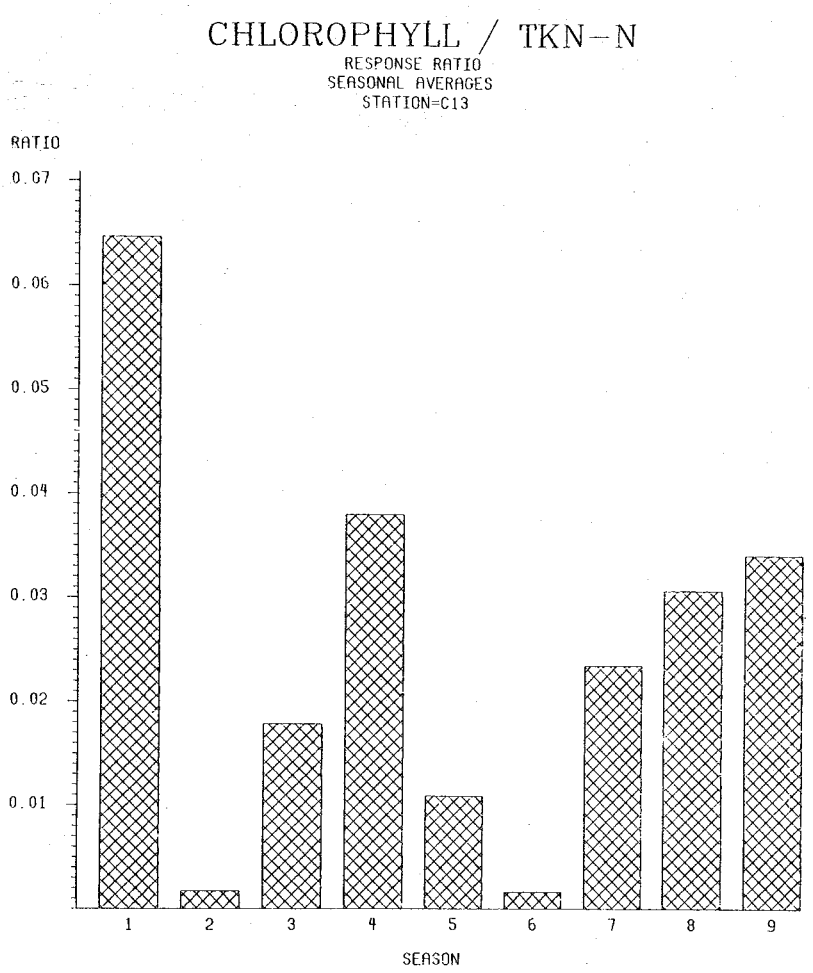


Figure 80: Seasonal chlorophyll-a to total Kjeldahl nitrogen response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

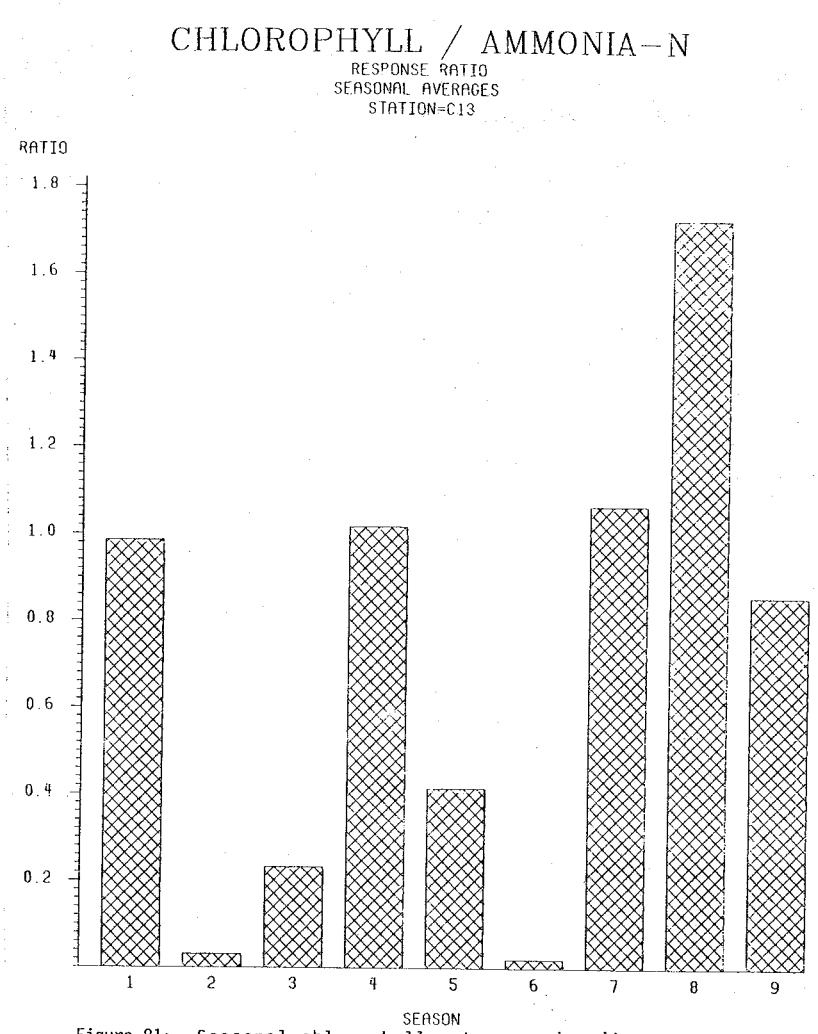


Figure 81: Seasonal chlorophyll-a to ammonia nitrogen response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

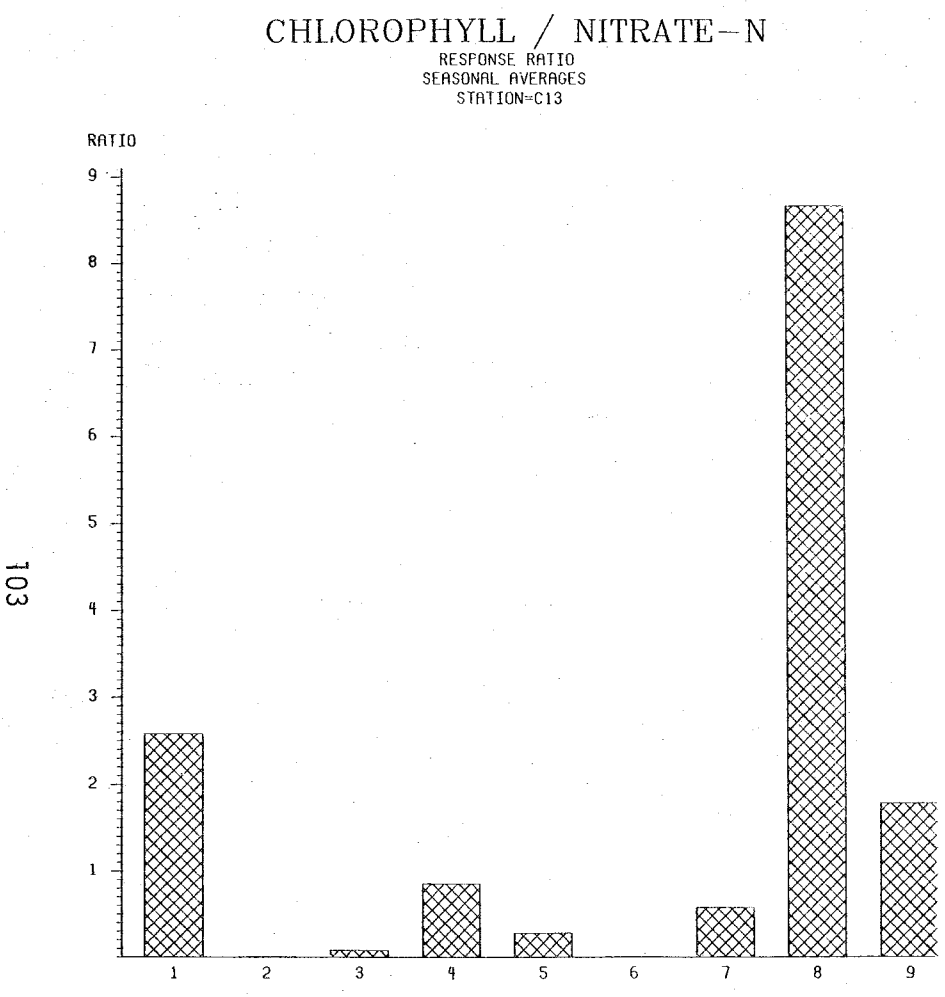


Figure 82: Seasonal chlorophyll-a to nitrite-nitrate response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

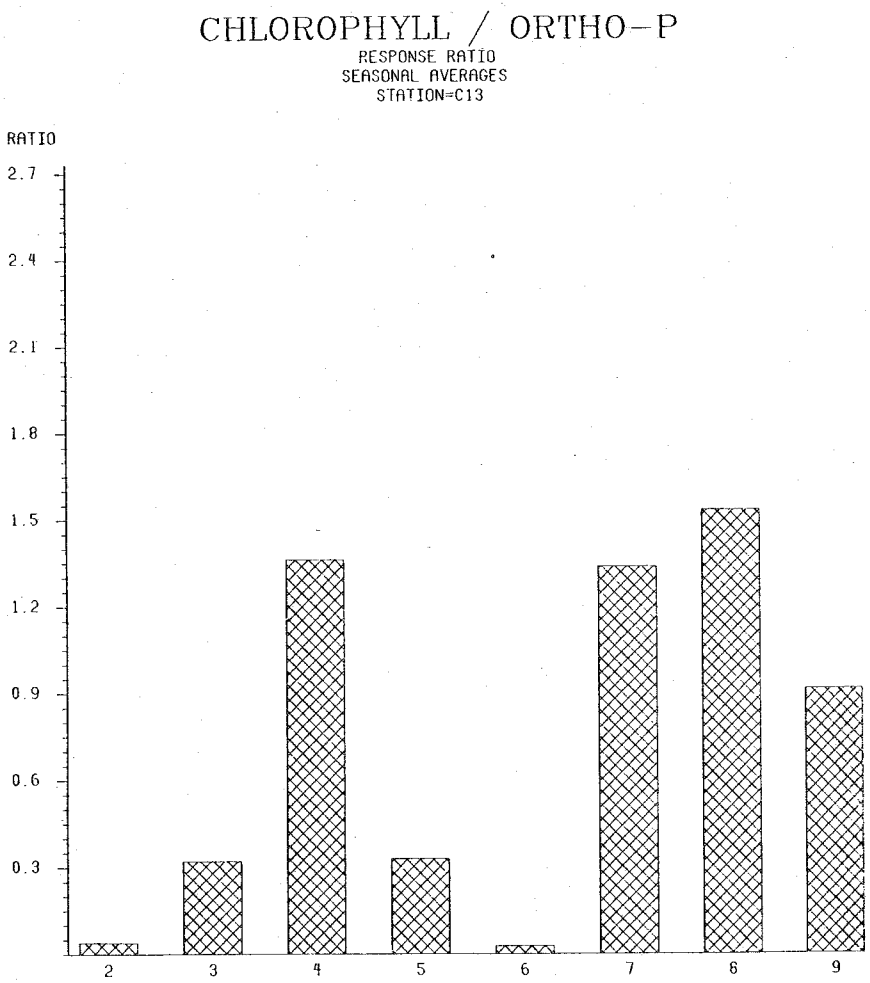


Figure 83: Seasonal chlorophyll-a to Ortho-PO_4 phosphorus response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

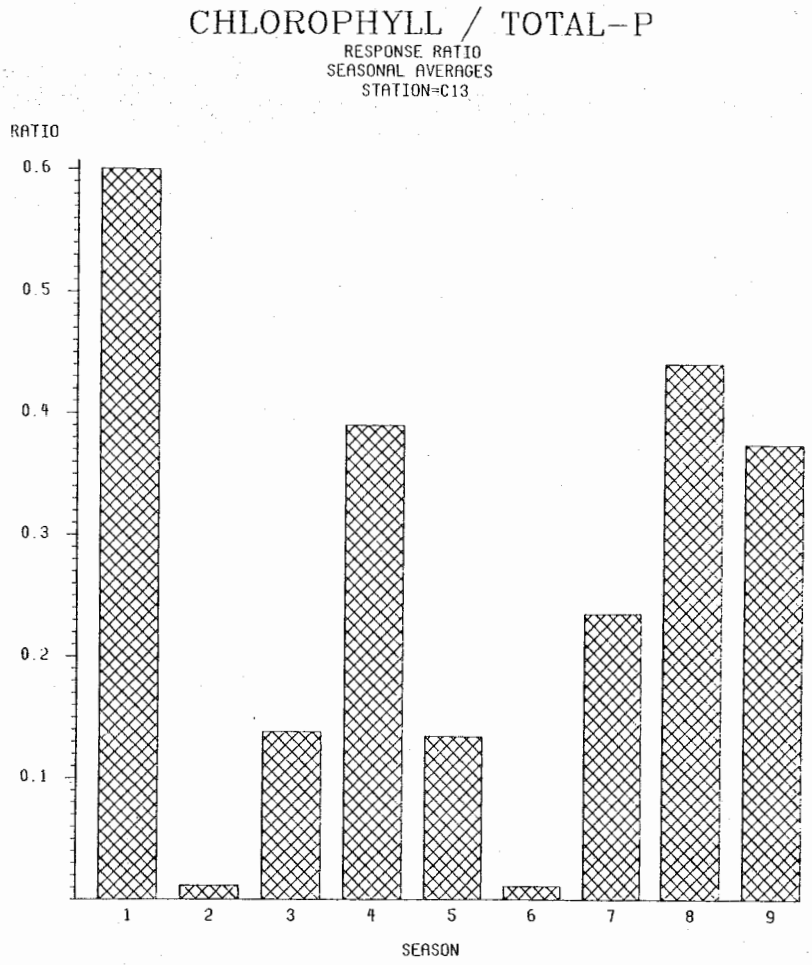


Figure 84 : Seasonal chlorophyll-a to total phosphorus response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

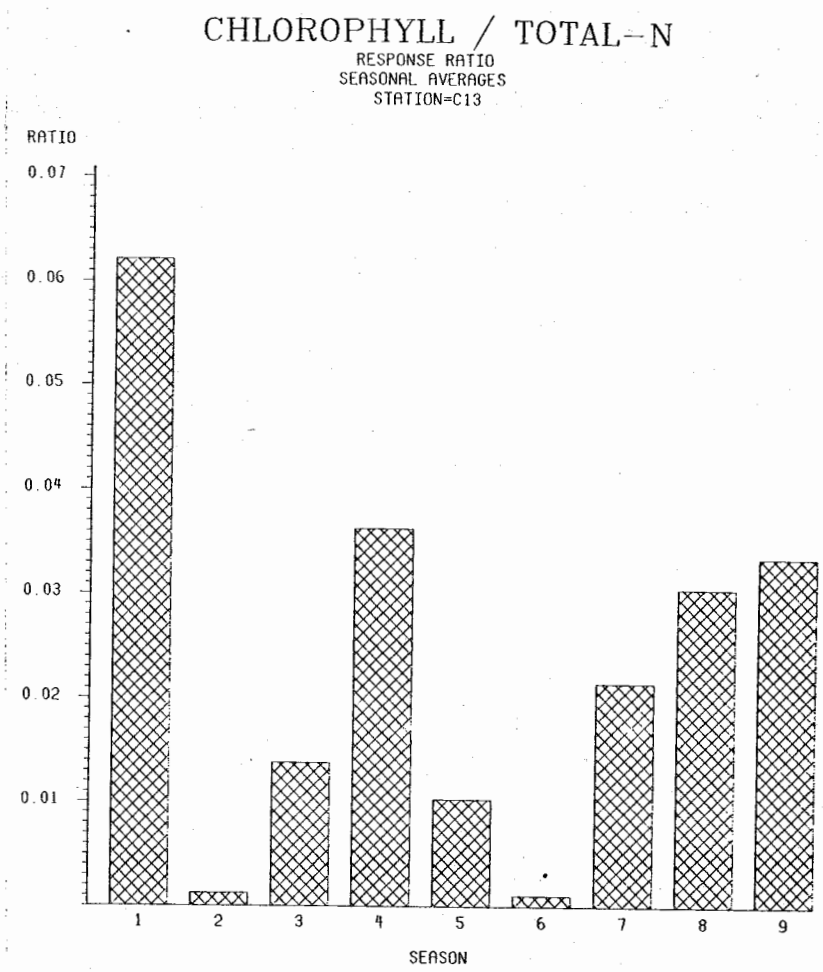


Figure 85: Seasonal chlorophyll-a to total nitrogen response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

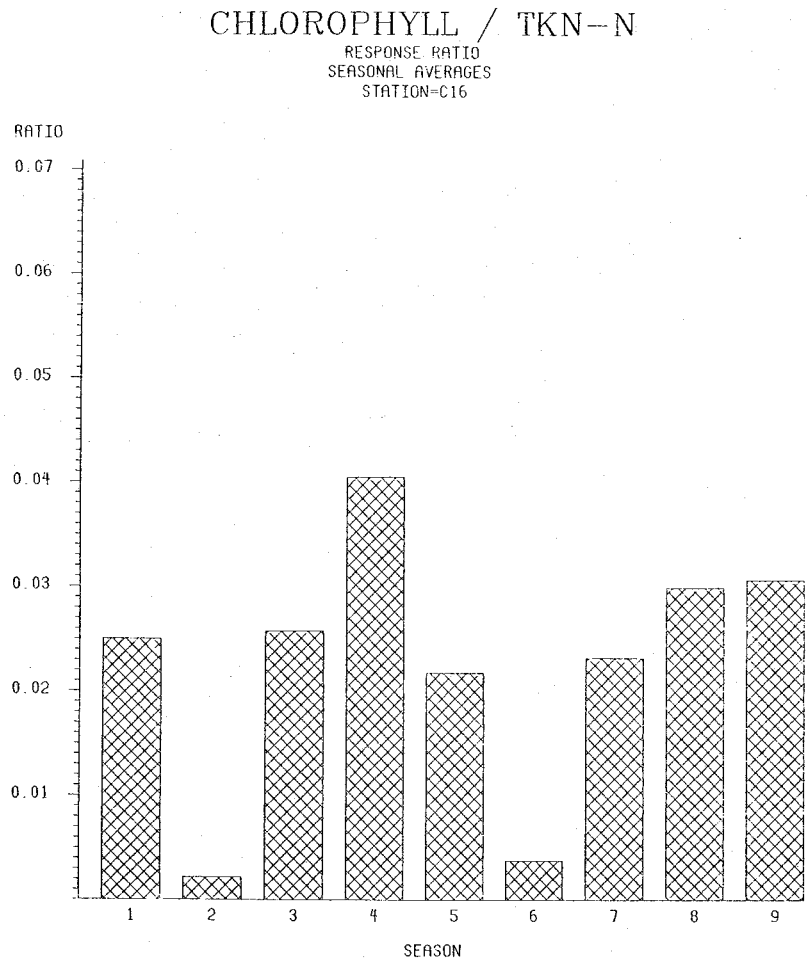


Figure 86 : Seasonal chlorophyll-a to total Kjeldahl nitrogen response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

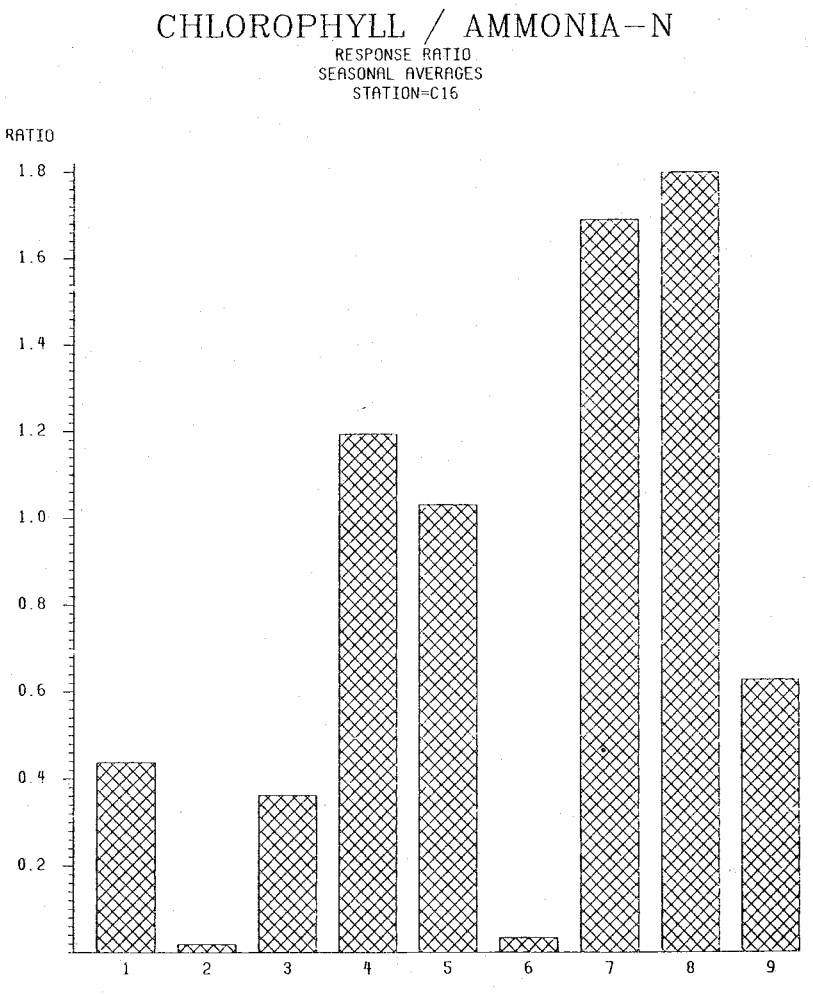


Figure 87: Seasonal chlorophyll-a to ammonia nitrogen response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

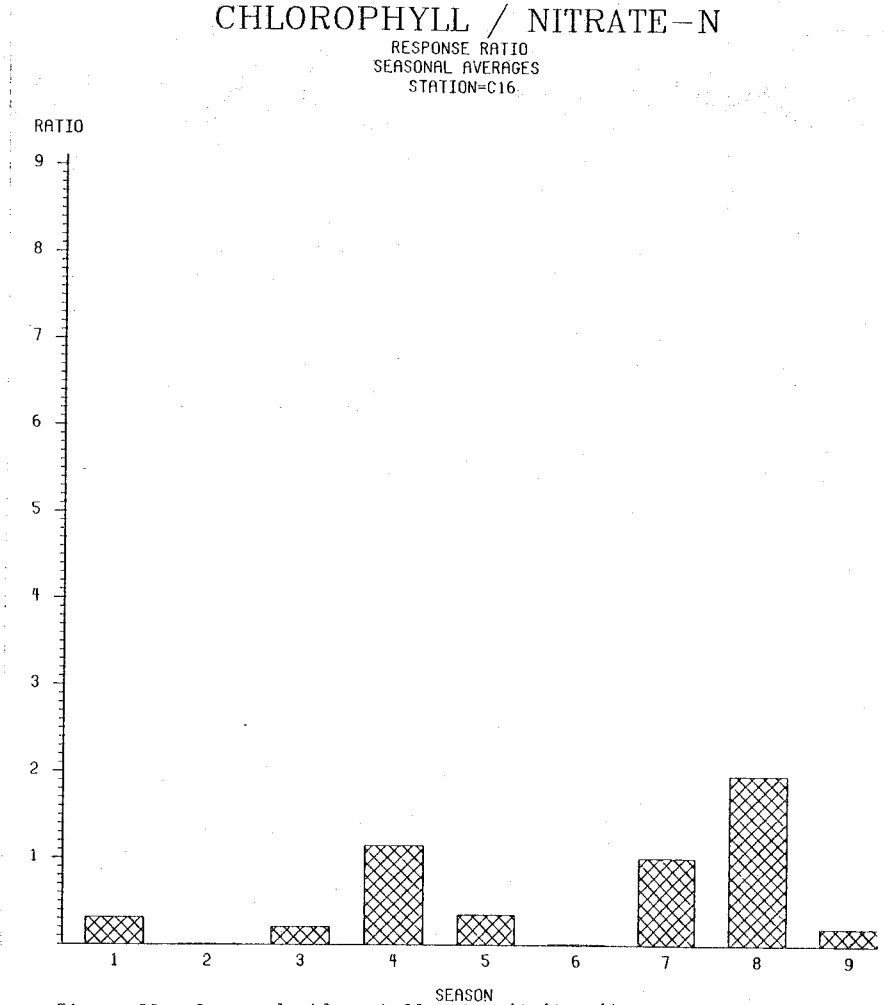


Figure 88: Seasonal chlorophyll-a to nitrite-nitrate response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

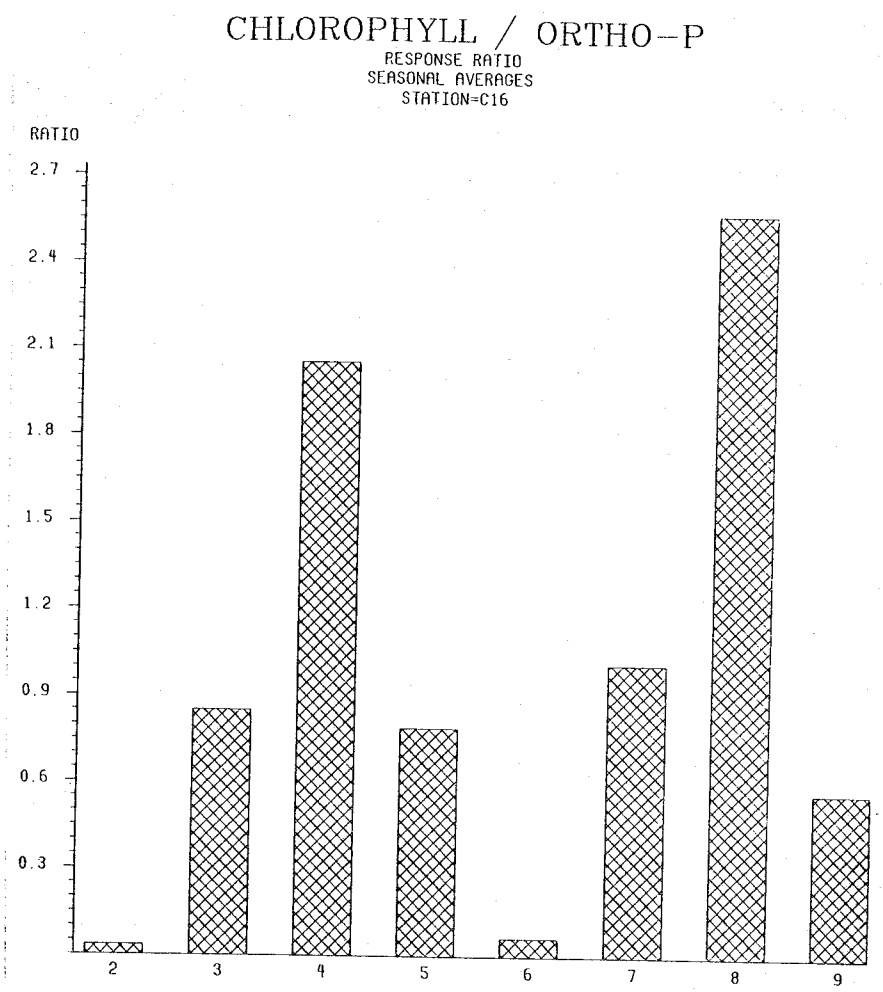


Figure 89 : Seasonal chlorophyll-a to Ortho-PO_4 phosphorus response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

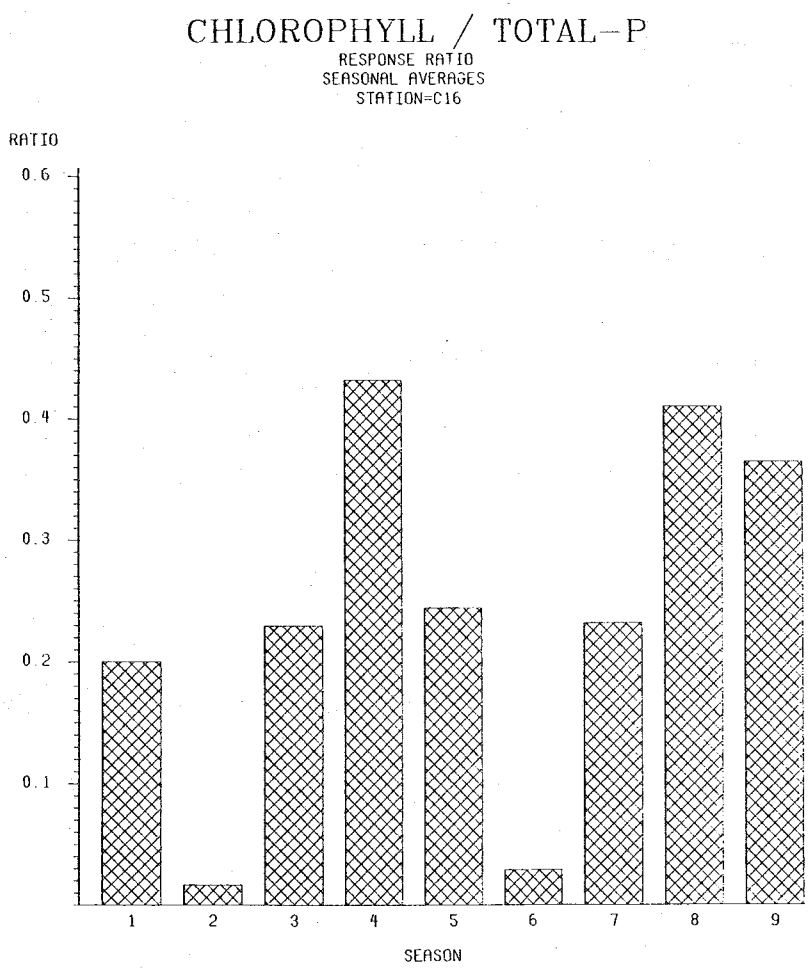


Figure 90: Seasonal chlorophyll-a to total nitrogen response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

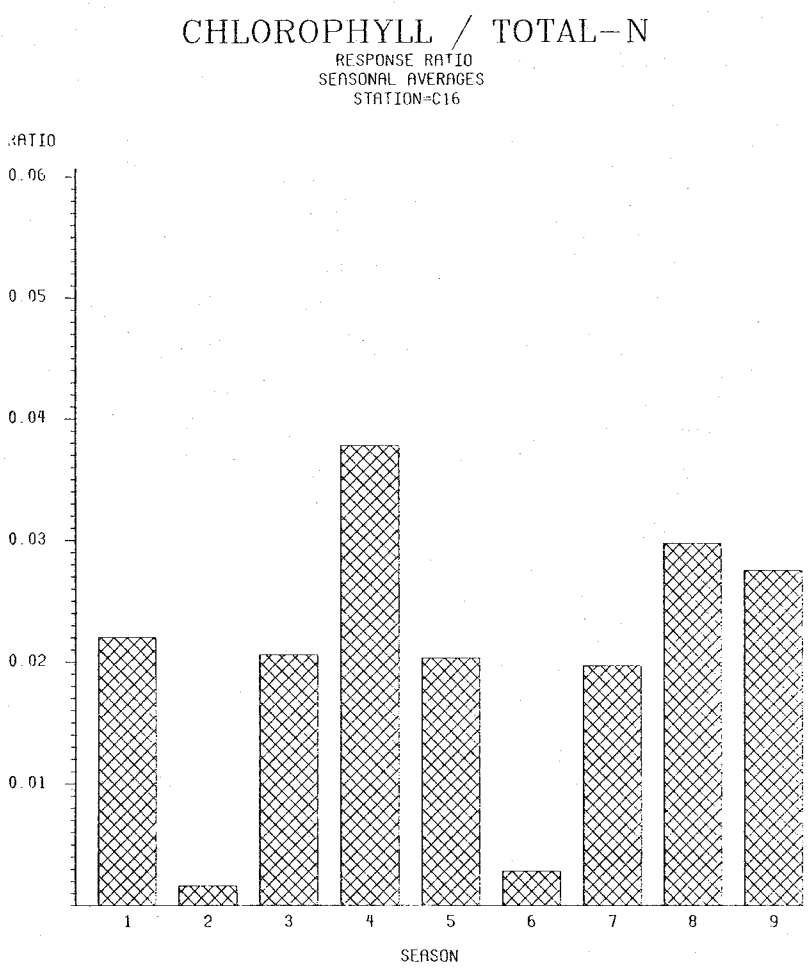


Figure 91: Seasonal chlorophyll-a to total nitrogen response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

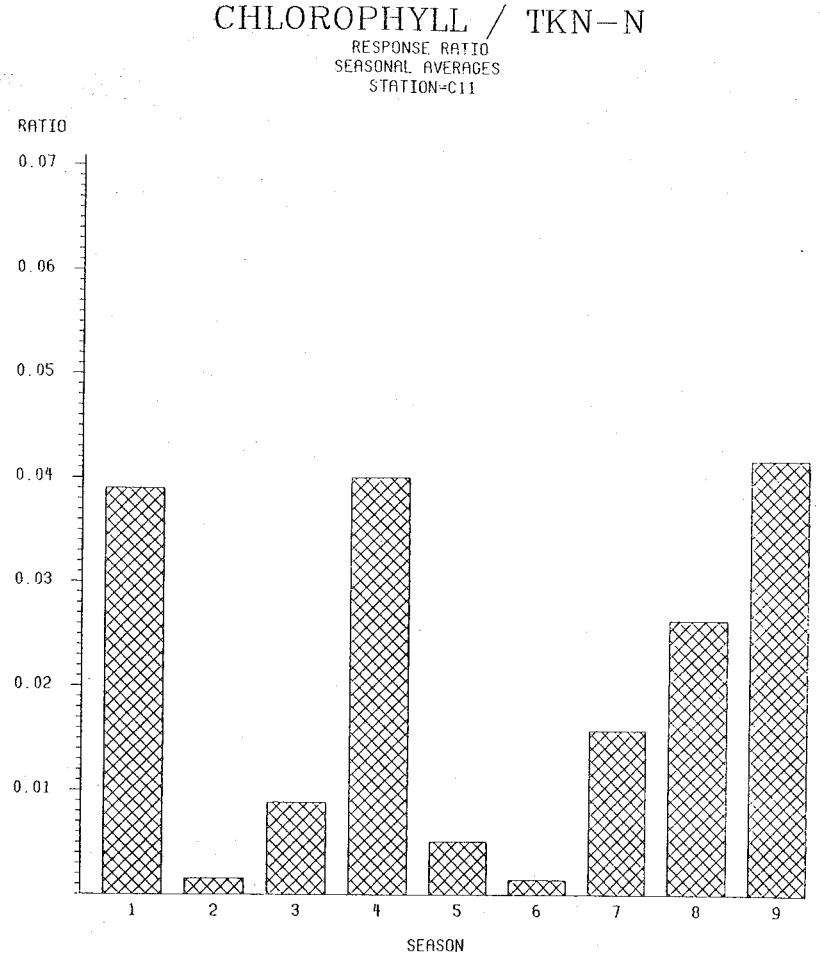


Figure 92: Seasonal chlorophyll-a to total Kjeldahl nitrogen response ratio averages for Station C-11

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

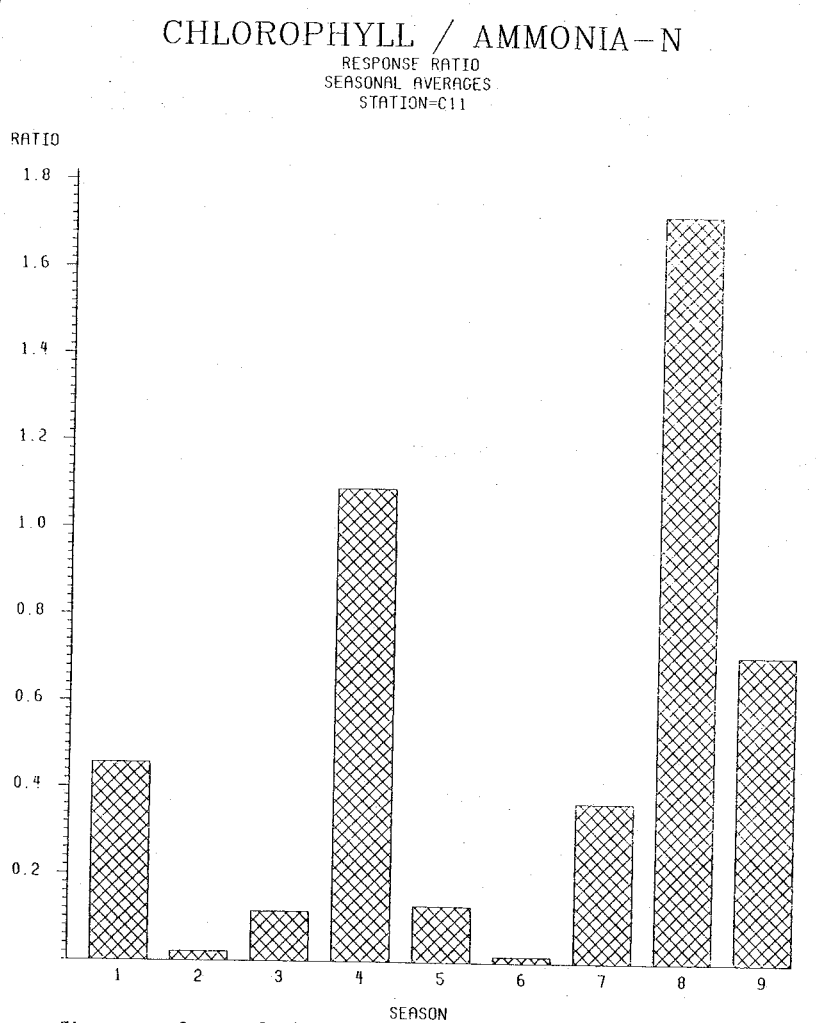


Figure 93: Seasonal chlorophyll-a to ammonia nitrogen response ratio averages for Station C-11

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

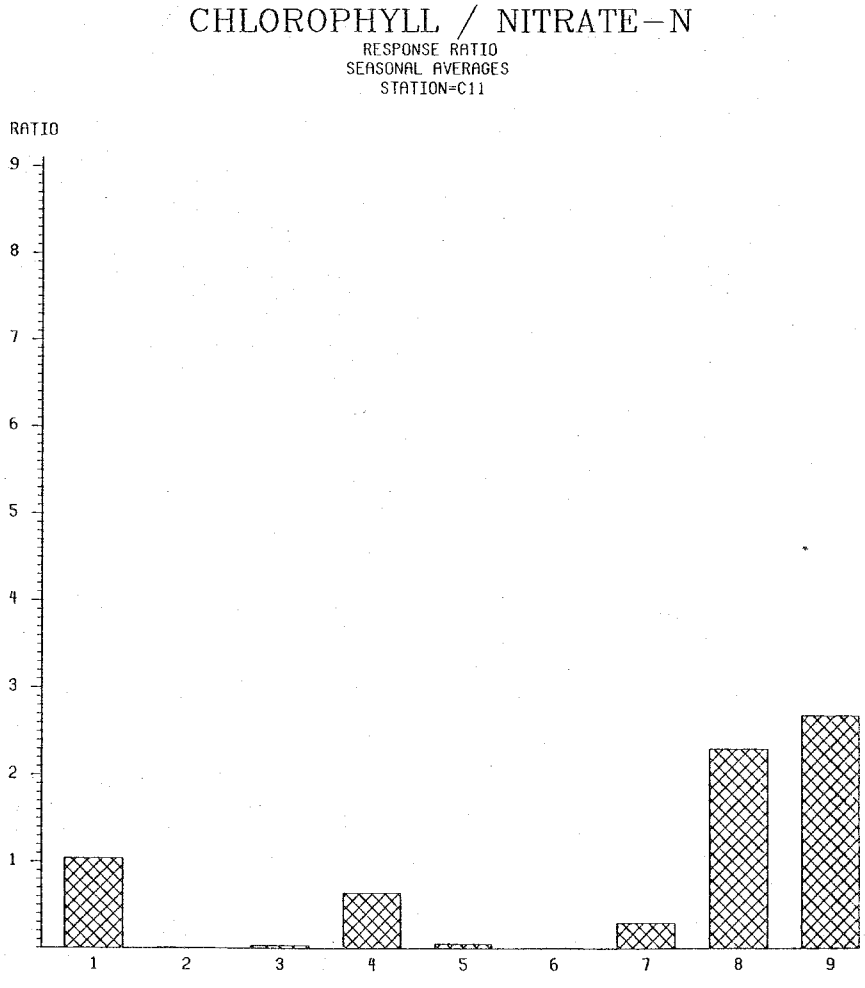


Figure 94: Seasonal chlorophyll-a to nitrite-nitrate response ratio averages for Station C-11

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

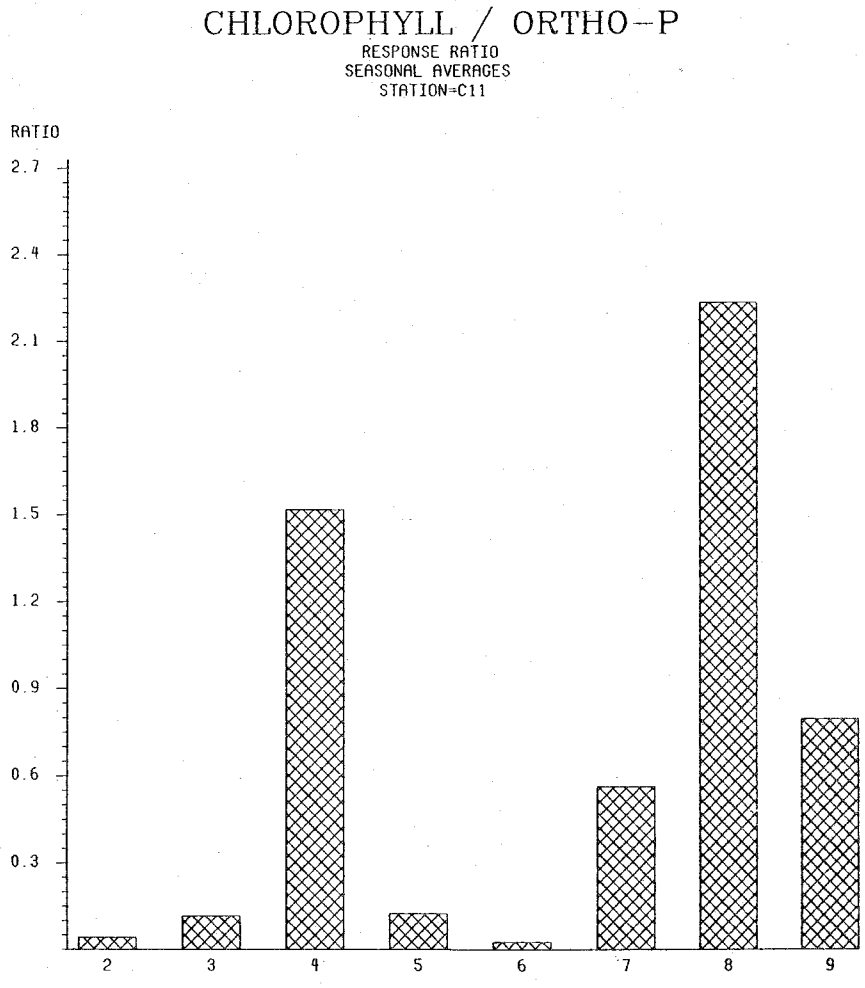


Figure 95: Seasonal chlorophyll-a to Ortho-PO_4 phosphorus response ratio averages for Station C-11

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

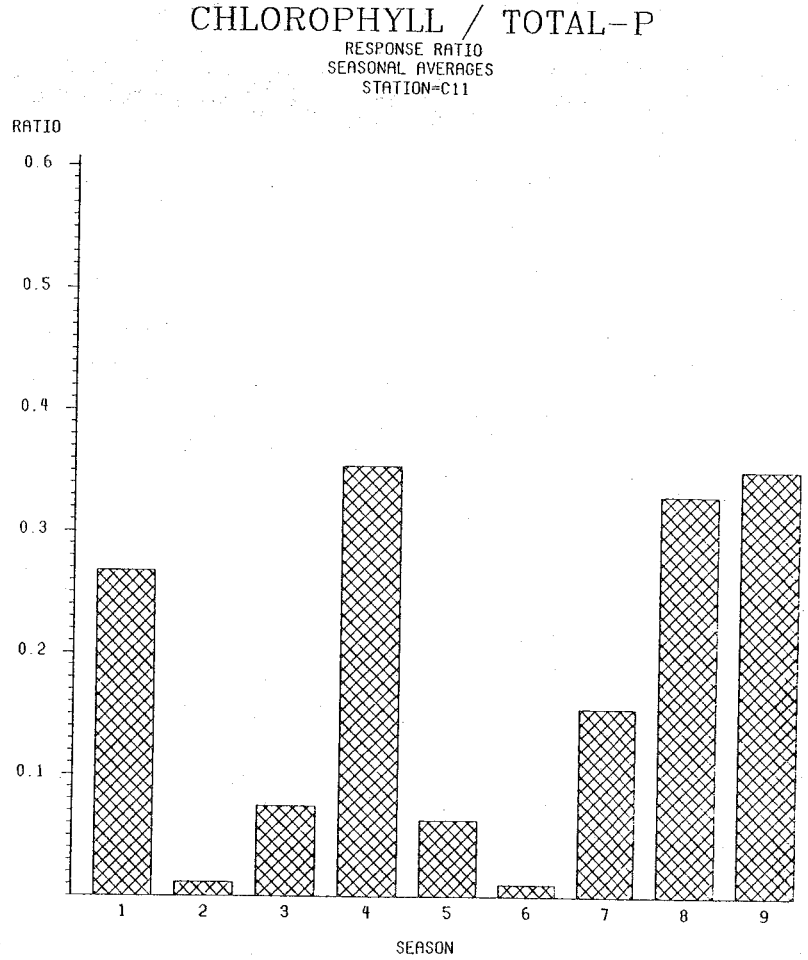


Figure 96: Seasonal chlorophyll-a to total phosphorus response ratio averages for Station C-11

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

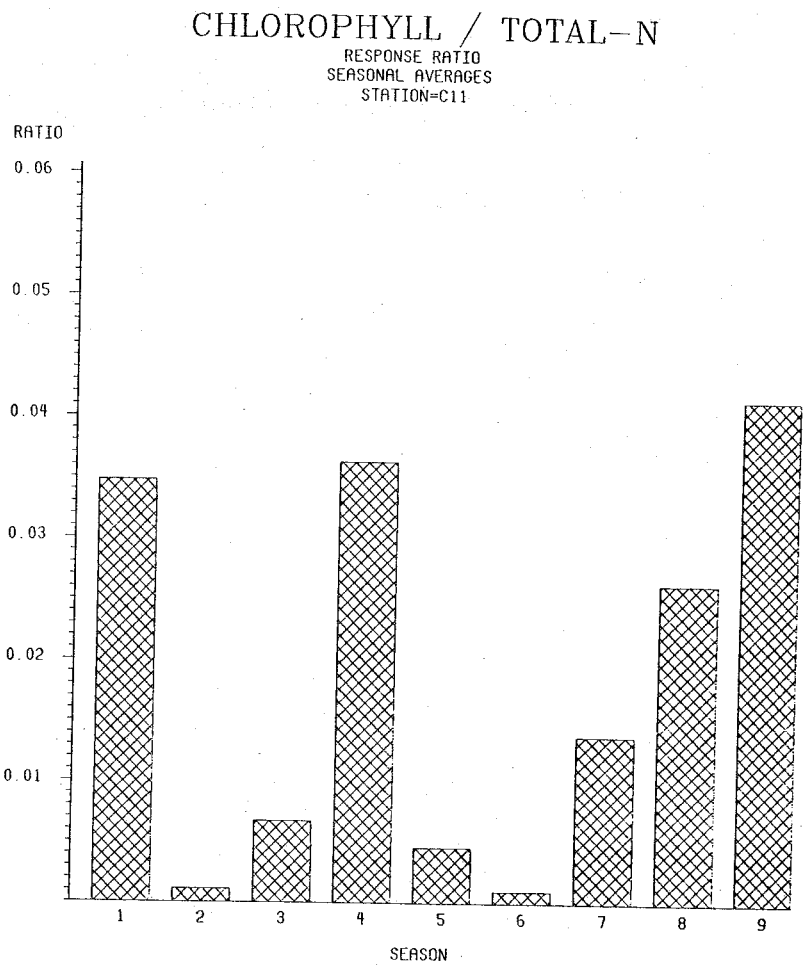


Figure 97: Seasonal chlorophyll-a to total nitrogen response ratio averages for Station C-11

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

Tables XII through XV show that with few exceptions, RR_{NH_4}, RR_{NO_3} and RR_{OP} are low during fall, winter and spring. However, these same RR's go above 1.0 for the lower reach summer averages, with high and significant correlation coefficients. This again implies that the Chowan system is nutrient sensitive.

Because the summer lower reach RR_{NO_3} is highest followed by RR_{NH_4}, the Chowan system is most sensitive to nitrogen levels, especially NO_3-nitrogen. To estimate the reductions of NO_3 and NH_4 necessary to achieve a given chlorophyll-a level, respective RR_is are used with the following formulae:

$$\frac{\text{desired chloro}}{RR_i} = \text{desired nutrient}_i$$

and

$$\%\ \text{reduction of nutrient}_i = \frac{\text{desired nutrient}_i}{\text{nutrient}_i\ \text{average}}$$

From these, it appears that reductions of 48% NO_3 and 23% NH_4 would still result in 40 µg/l summer average chlorophyll-a at station C13. Likewise, 61% NO_3 and 42% NH_4 reductions will result in 30 µg/l summer average chlorophyll-a. Furthermore, since RR_{OP} also exceeds 1.0, an increase in OP levels would likely result in higher chlorophyll-a levels. [Reductions in OP, however, show no effect since its level is so low, apparently explained by rapid and efficient phosphate recycling.]

A similar set of response ratios based on total wet weight algal biomass (WWB) is given in Tables XVI through XIX. Figures 98 through 121 show per station seasonal average trends. The RR's here show the same overall seasonal pattern as with chlorophyll-a. That is, spring, winter and all upper reach averages are low, fall lower reach averages are moderate and summer lower reach averages are high.

Table XVI

1978-1980 Fall total wet weight algal biomass averages with response ratio/adjusted response ratio averages. Adjusted RR's are comparable to chlorophyll-a RR's.

Fall Biomass
Nutrient Response Ratios

	C1	C4	C13	C16
Total biomass mg/l / chlorophyll-a µg/l	0.47/2.84	0.56/4.75	15.72/25.63	4.29/16.74
RR_{TKN}/RR_{TKN} ADJ	0.73/0	0.75/0.01	18.27/0.03	5.27/0.02
RR_{NH_4}/RR_{NH_4} ADJ	41.46/0.25	9.64/0.08	656.27/1.07	236.31/0.90
RR_{NO_3}/RR_{NO_3} ADJ	1.29/0.01	7.25/0.06	618.26/1.01	79.71/0.30
RR_{OP}/RR_{OP} ADJ	7.14/0.04	14.89/0.13	595.95/0.97	225.66/0.86
RR_{TP}/RR_{TP} ADJ	4.48/0.03	5.23/0.04	198.43/0.32	52.93/0.20
RR_{TN}/RR_{TN} ADJ	0.77/0	0.64/0.01	17.51/0.03	5.02/0.02

Table XVII

1978-1980 Winter total wet weight algal biomass averages with response ratio/adjusted response ratio averages. Adjusted RR's are comparable to chlorophyll-a RR's.

Winter Biomass
Nutrient Response Ratios

	C1	C4	C13	C16
Total biomass mg/l / chlorophyll-a µg/l	0.35/1.00	0.19/1.04	1.01/1.16	0.39/2.11
RR_{TKN}/RR_{TKN} ADJ	0.65/0	0.28/0	1.60/0	0.56/0
RR_{NH_4}/RR_{NH_4} ADJ	15.39/0.04	2.36/0.01	40.44/0.05	5.31/0.03
RR_{NO_3}/RR_{NO_3} ADJ	1.19/0	0.73/0	4.16/0	1.79/0.01
RR_{OP}/RR_{OP} ADJ	10.14/0.03	5.13/0.03	20.10/0.02	10.37/0.06
RR_{TP}/RR_{TP} ADJ	3.32/0.01	1.97/0.01	12.18/0.01	4.52/0.02
RR_{TN}/RR_{TN} ADJ	0.41/0	0.19/0	1.13/0	0.41/0

Table XVIII

1978-1980 Spring total wet weight algal biomass averages with response ratio/ adjusted response ratio averages. Adjusted RR's are comparable to chlorophyll-a RR's.

Spring Biomass
Nutrient Response Ratios

	C1	C4	C13	C16
Total biomass mg/l / chlorophyll-a µg/l	0.11/1.84	0.38/2.63	10.41/17.68	7.27/21.36
RR_{TKN}/RR_{TKN} ADJ	0.12/0	0.58/0	12.74/0.02	7.01/0.02
RR_{NH_4}/RR_{NH_4} ADJ	2.64/0.04	6.55/0.05	221.45/0.38	492.06/1.45
RR_{NO_3}/RR_{NO_3} ADJ	0.71/0.01	1.90/0.01	167.68/0.28	376.60/1.11
RR_{OP}/RR_{OP} ADJ	2.71/0.05	7.65/0.05	513.14/0.87	326.71/0.96
RR_{TP}/RR_{TP} ADJ	1.10/0.02	4.26/0.03	109.32/0.19	76.95/0.23
RR_{TN}/RR_{TN} ADJ	0.10/0	0.43/0	10.80/0.02	6.38/0.02

Table XIX

1978-1980 Summer total wet weight algal biomass averages with response ratio/ adjusted response ratio averages. Adjusted RR's are comparable to chlorophyll-a RR's.

Summer Biomass
Nutrient Response Ratios

	C1	C4	C13	C16
Total biomass mg/l / chlorophyll-a µg/l	1.60/8.07	3.53/14.88	24.69/40.39	12.83/37.27
RR_{TKN}/RR_{TKN} ADJ	2.37/0.01	3.66/0.02	20.71/0.03	11.27/0.03
RR_{NH_4}/RR_{NH_4} ADJ	58.51/0.30	88.47/0.37	878.09/1.44	463.96/1.34
RR_{NO_3}/RR_{NO_3} ADJ	21.01/0.11	64.47/0.27	815.89/1.33	488.77/1.42
RR_{OP}/RR_{OP} ADJ	18.67/0.09	71.10/0.30	2131.22/3.32	893.68/2.59
RR_{TP}/RR_{TP} ADJ	13.65/0.07	46.64/0.20	235.67/0.39	142.46/0.41
RR_{TN}/RR_{TN} ADJ	2.04/0.01	3.27/0.01	19.68/0.03	10.98/0.03

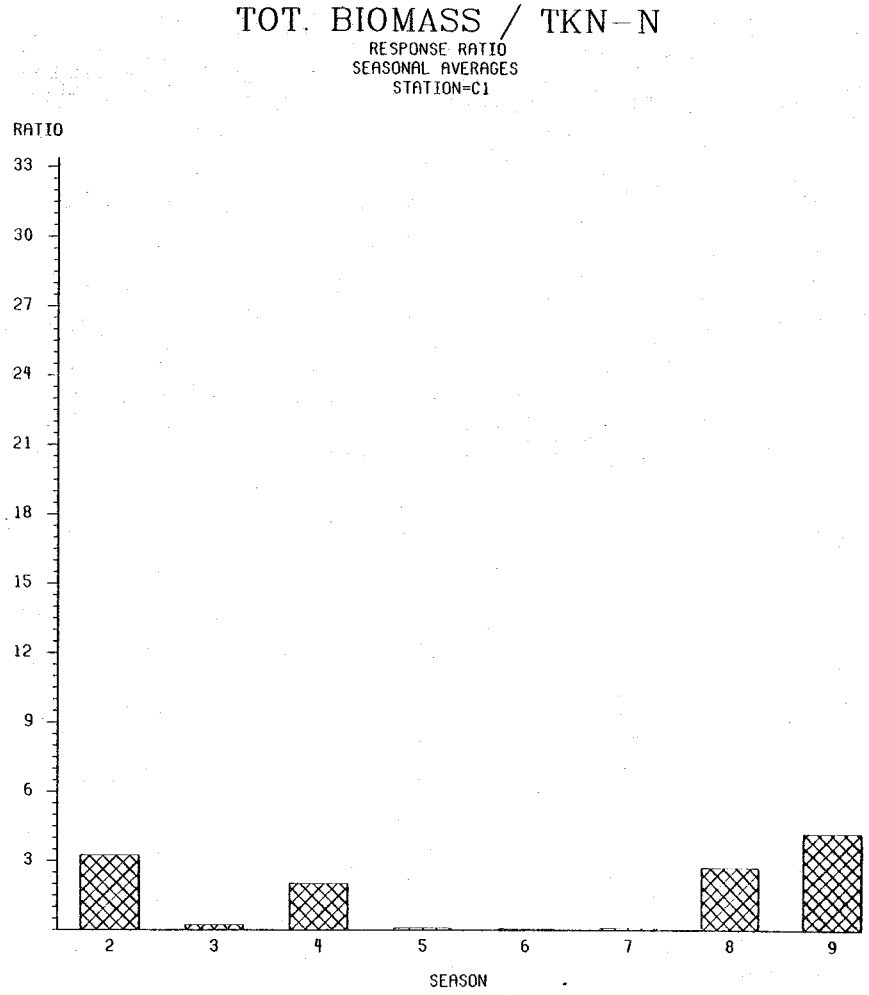


Figure 98: Seasonal wet weight algal biomass to total Kjeldahl nitrogen response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

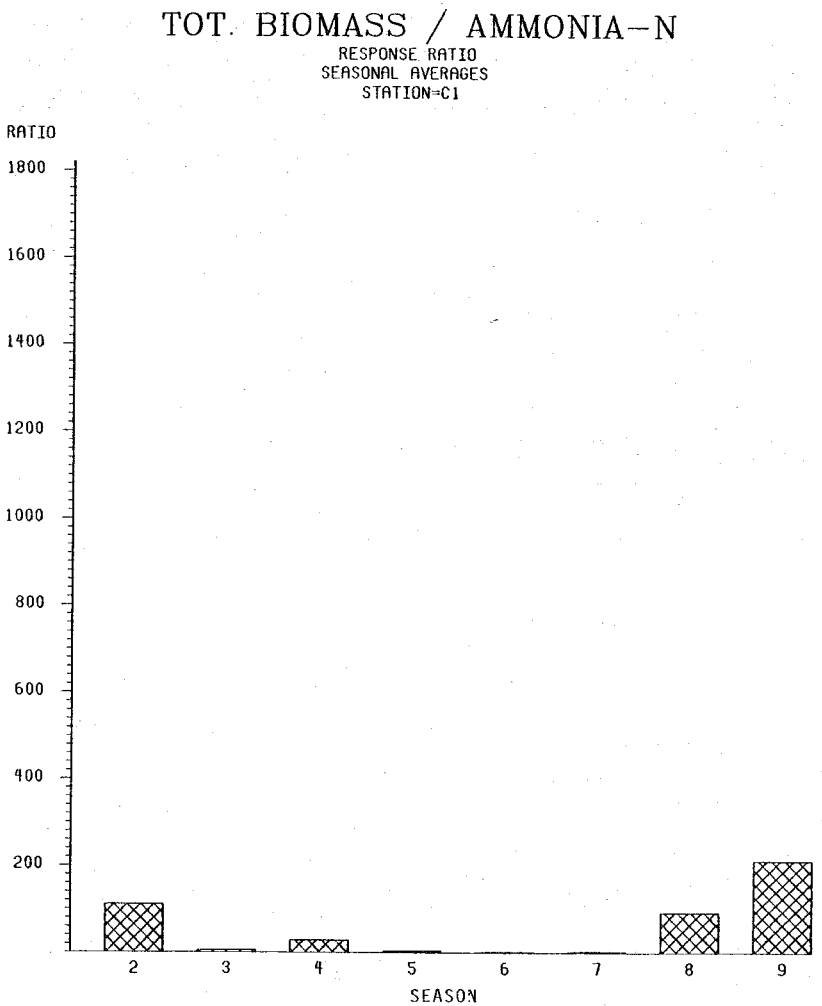


Figure 99: Seasonal wet weight algal biomass to ammonia-nitrogen response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

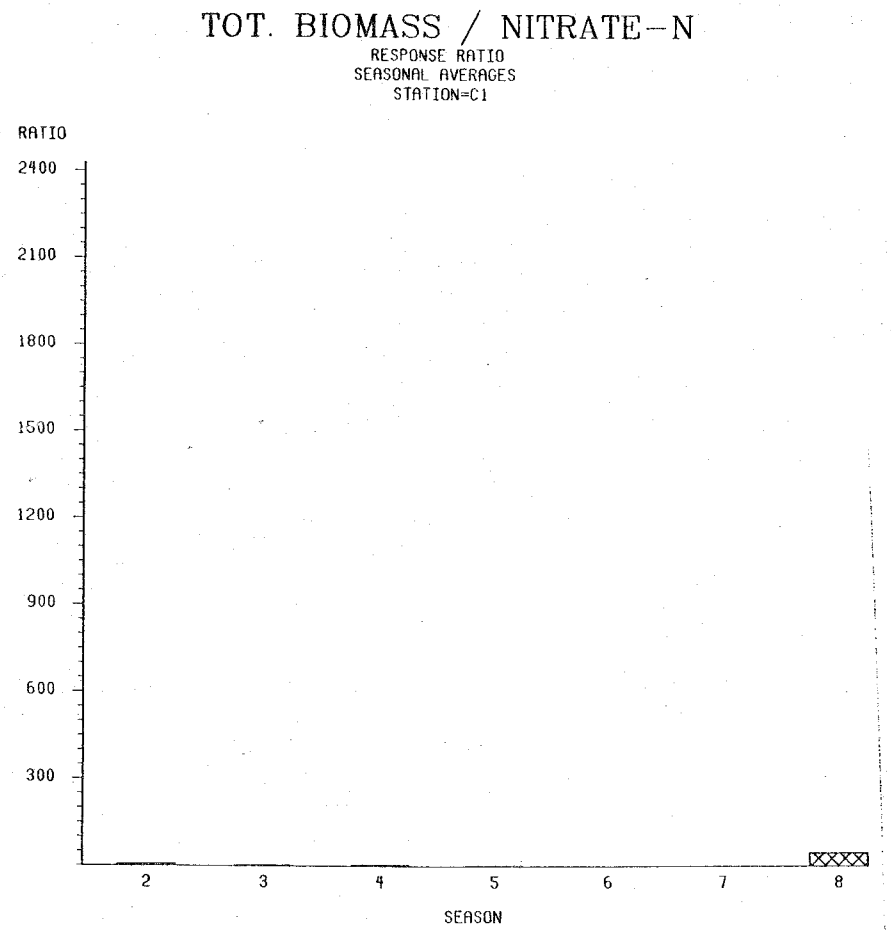


Figure 100: Seasonal wet weight algal biomass to nitrite-nitrate nitrogen response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

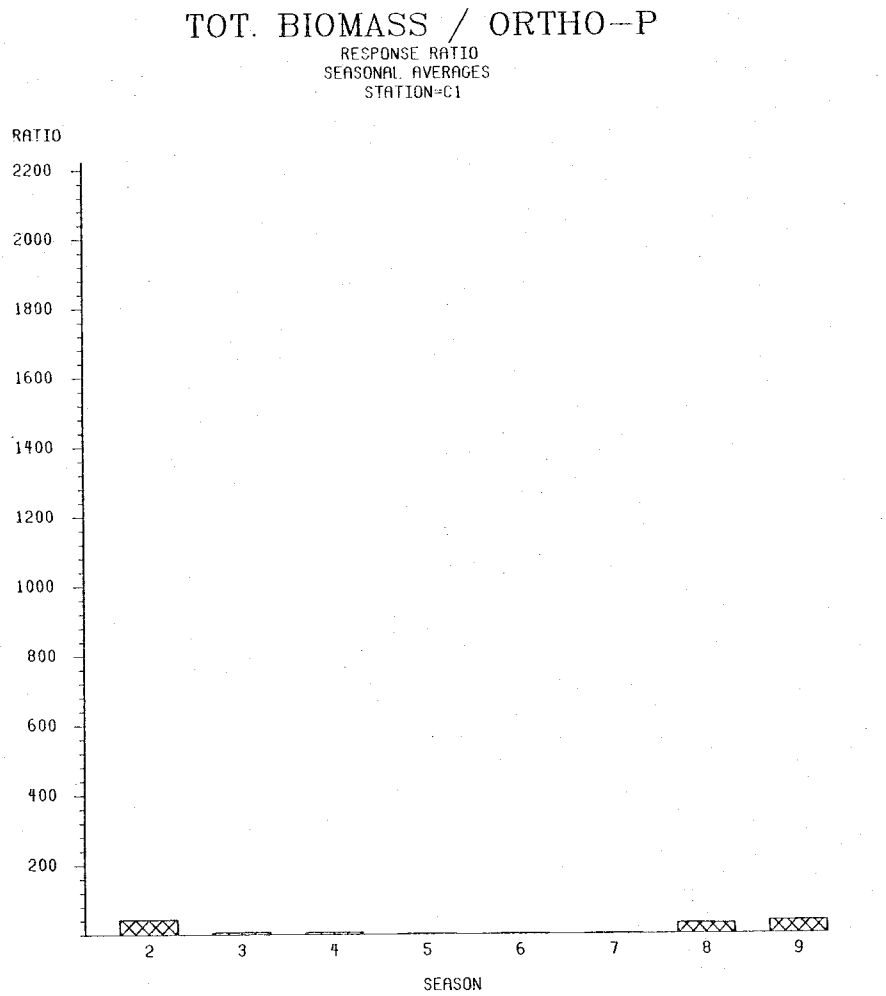


Figure 101: Seasonal wet weight algal biomass to Ortho-PO_4 phosphorus response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

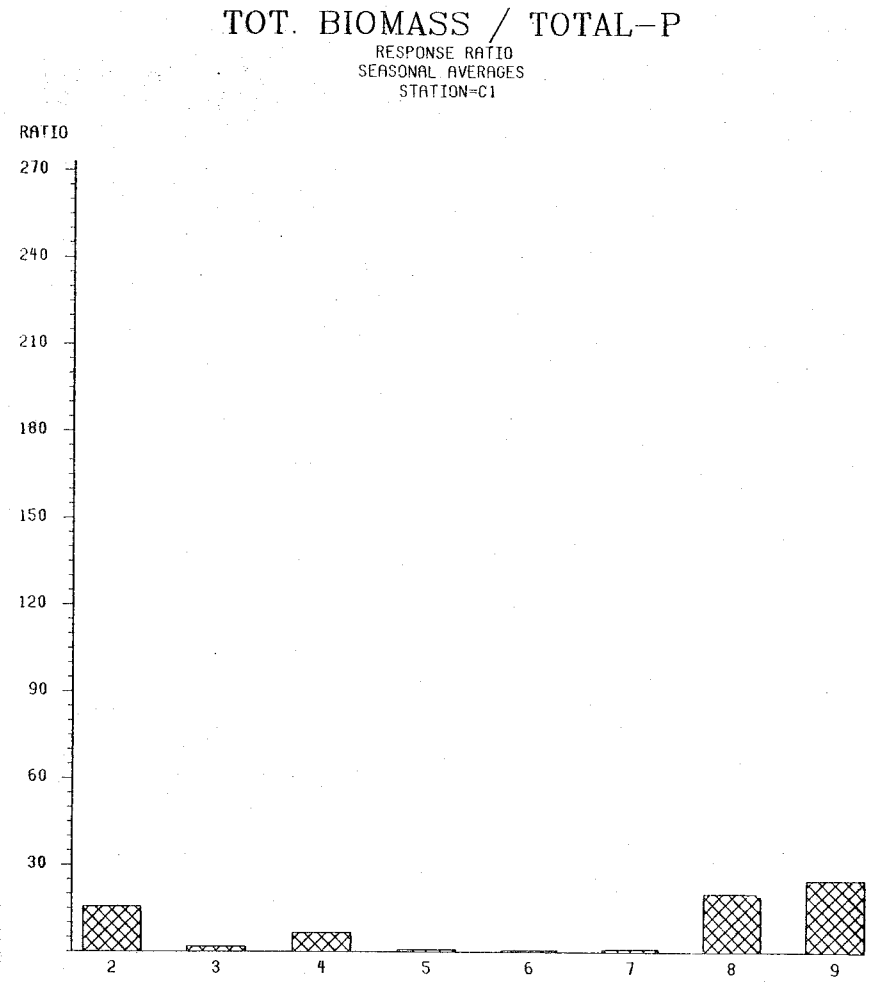


Figure 102: Seasonal wet weight algal biomass to total phosphorus response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

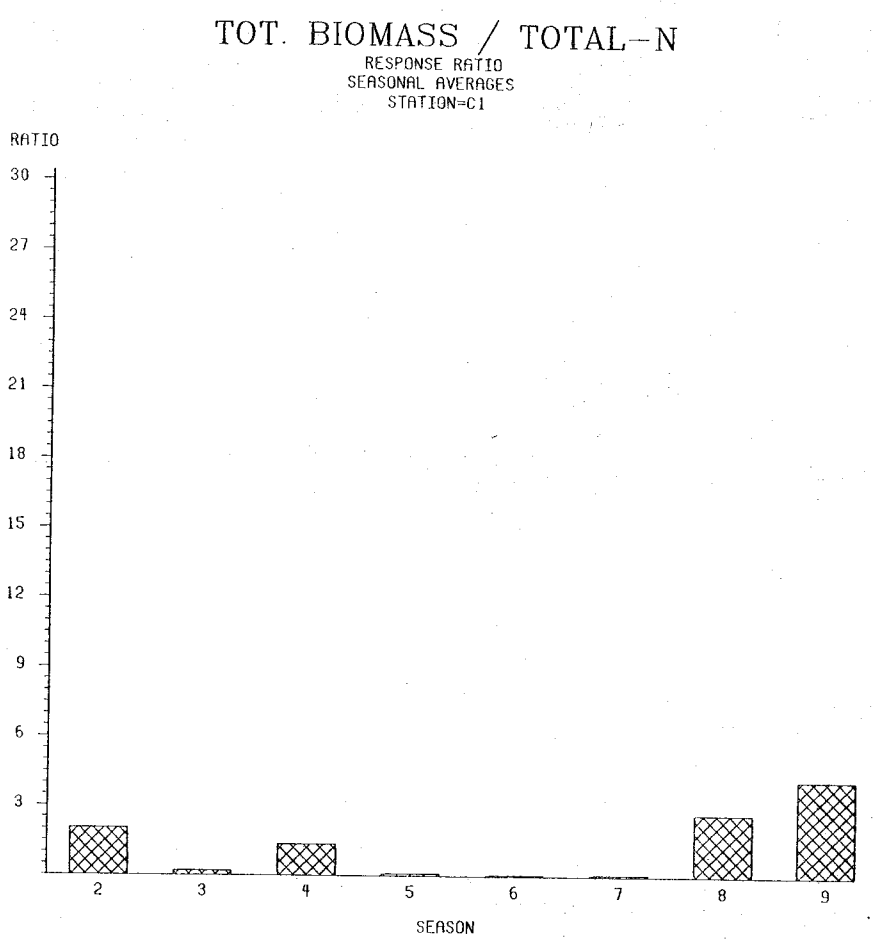


Figure 103: Seasonal wet weight algal biomass to total nitrogen response ratio averages for Station C-1

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

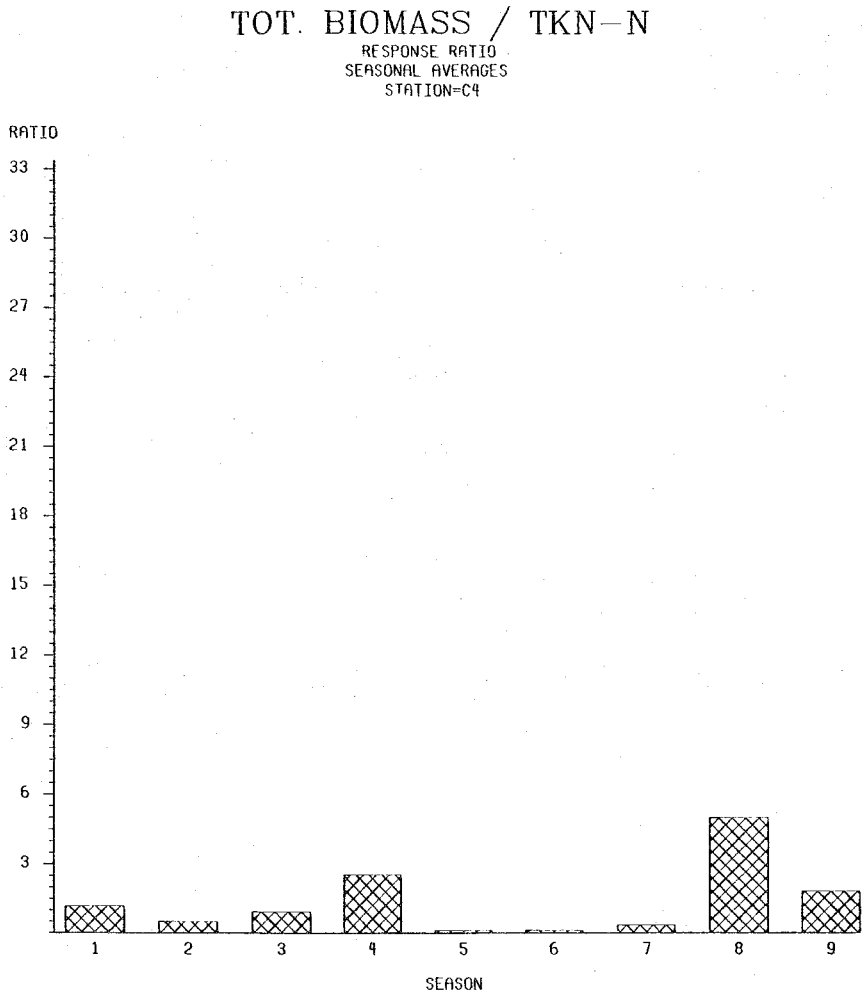


Figure 104: Seasonal wet weight algal biomass to total Kjeldahl nitrogen response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

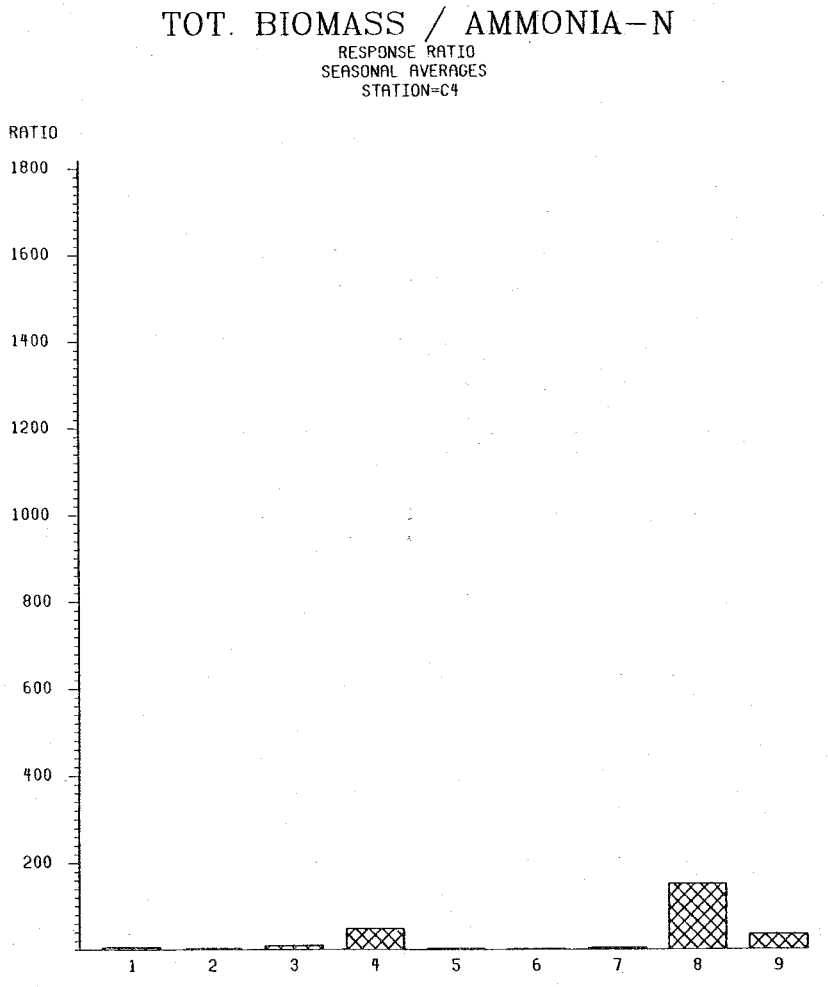


Figure 105: Seasonal wet weight algal biomass to ammonia-nitrogen response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

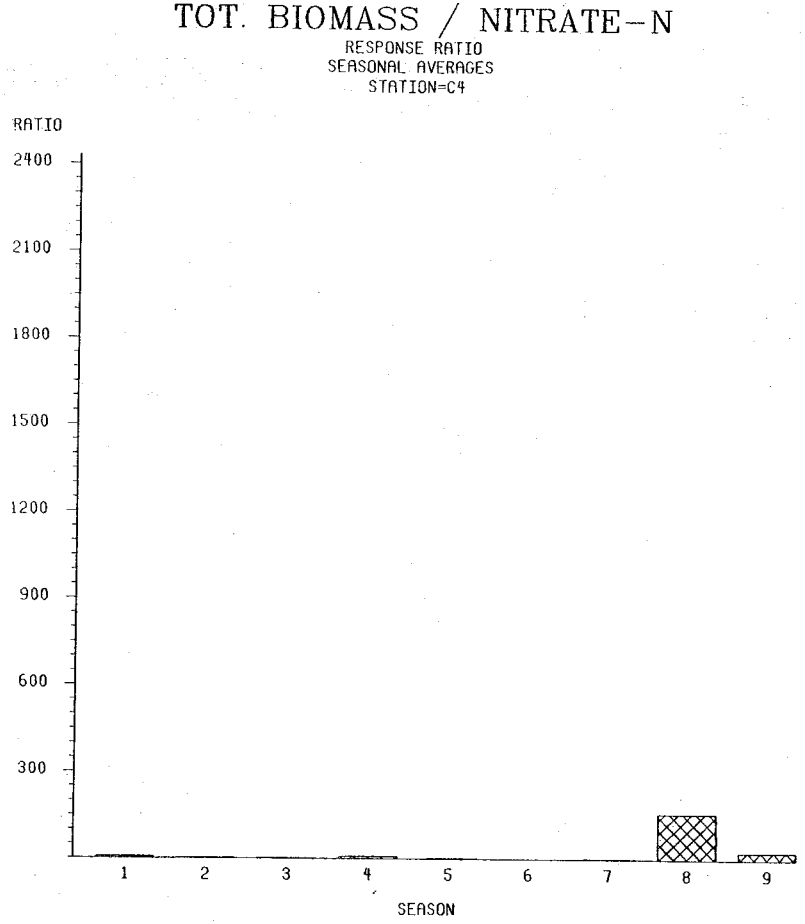


Figure 106: Seasonal wet weight algal biomass to nitrite-nitrate nitrogen response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

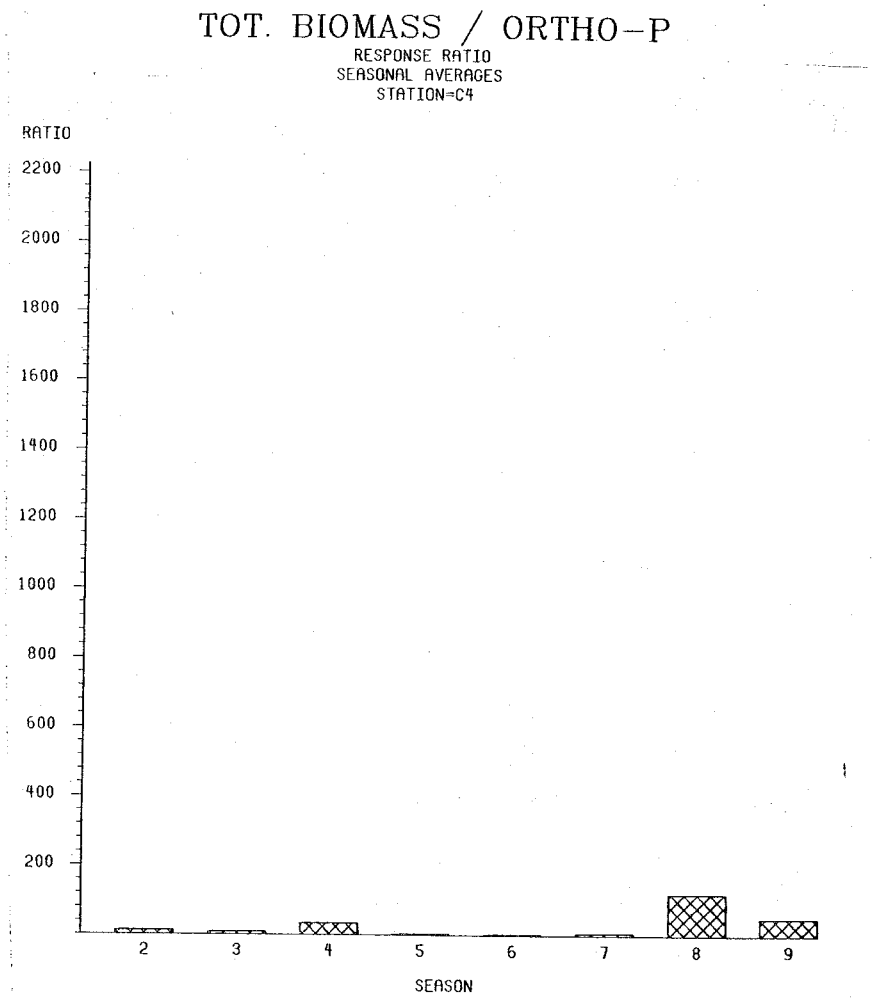


Figure 107: Seasonal wet weight algal biomass to Ortho-PO_4 phosphorus response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

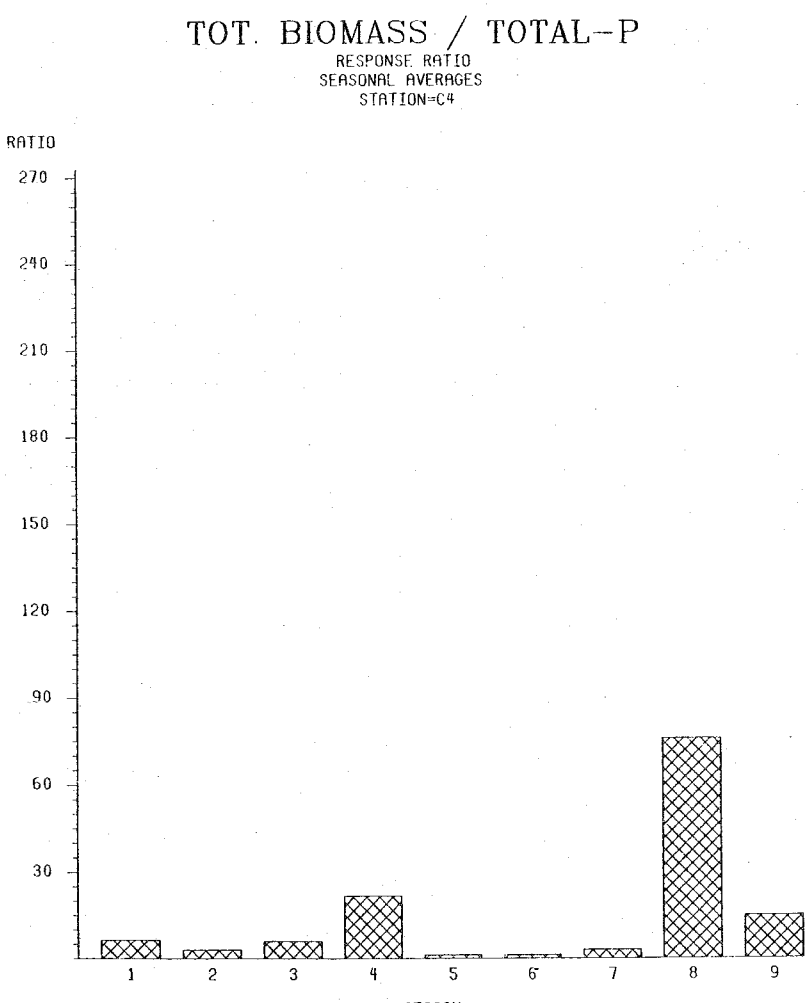


Figure 108: Seasonal wet weight algal biomass to total phosphorus response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

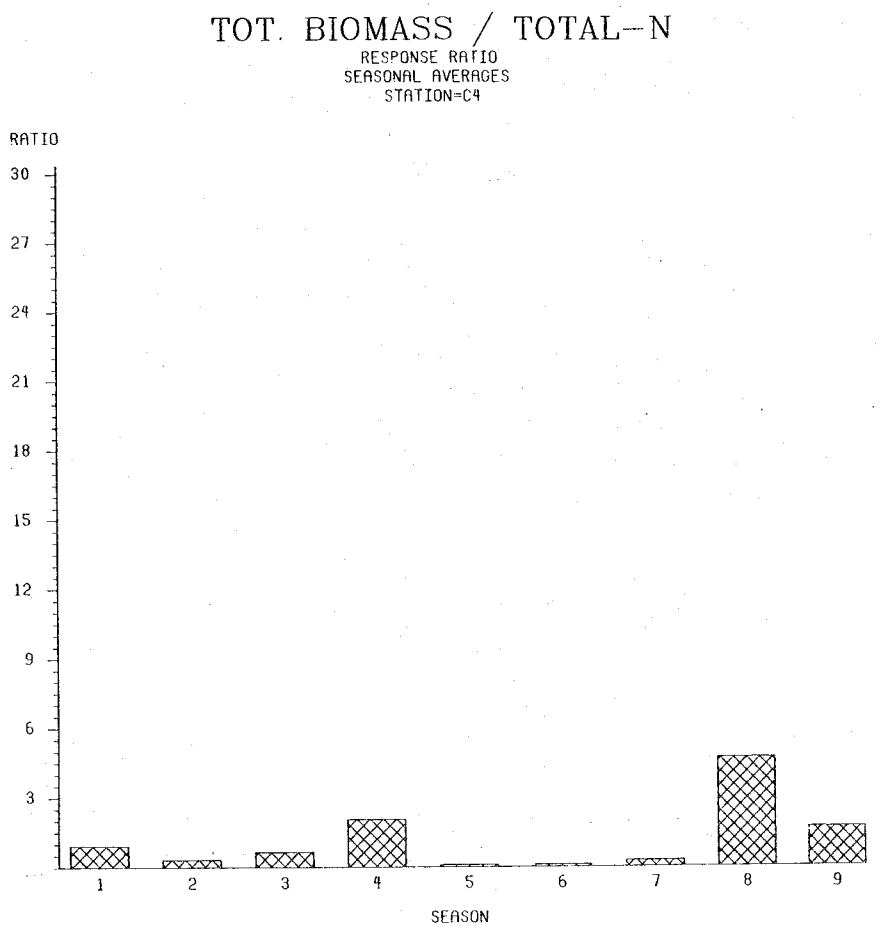


Figure 109: Seasonal wet weight algal biomass to total nitrogen response ratio averages for Station C-4

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

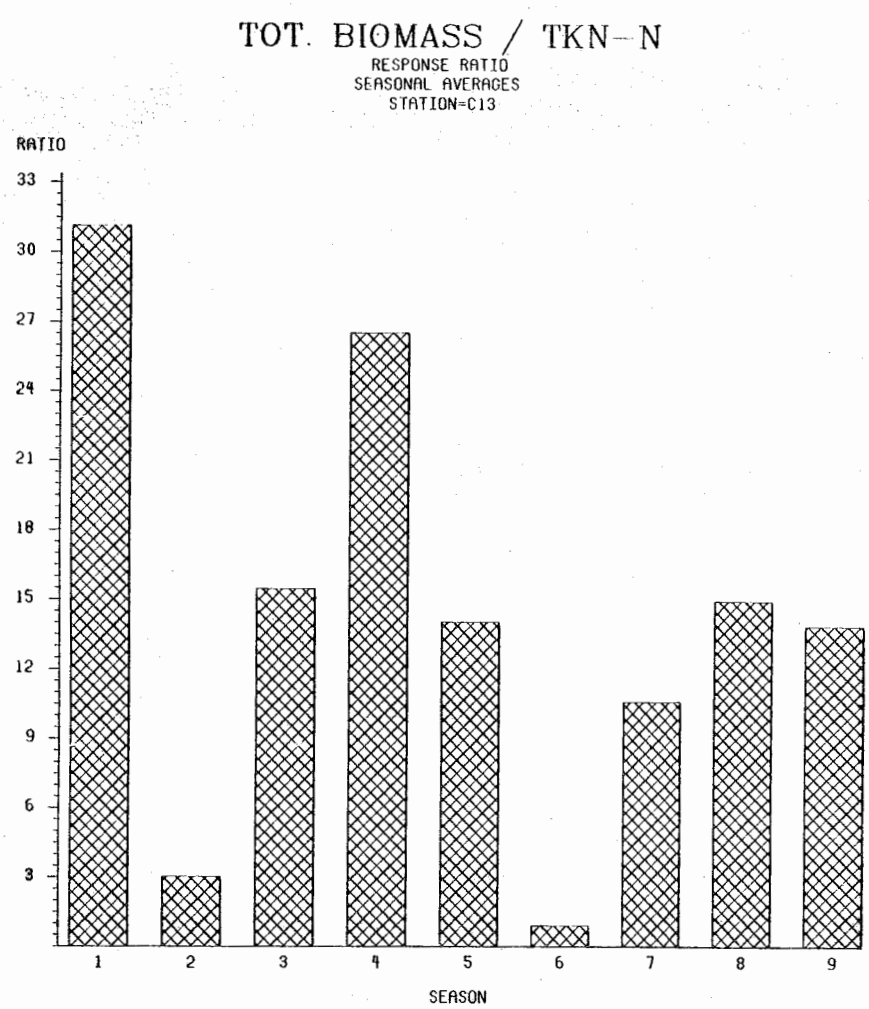


Figure 110: Seasonal wet weight algal biomass to total Kjeldahl nitrogen response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

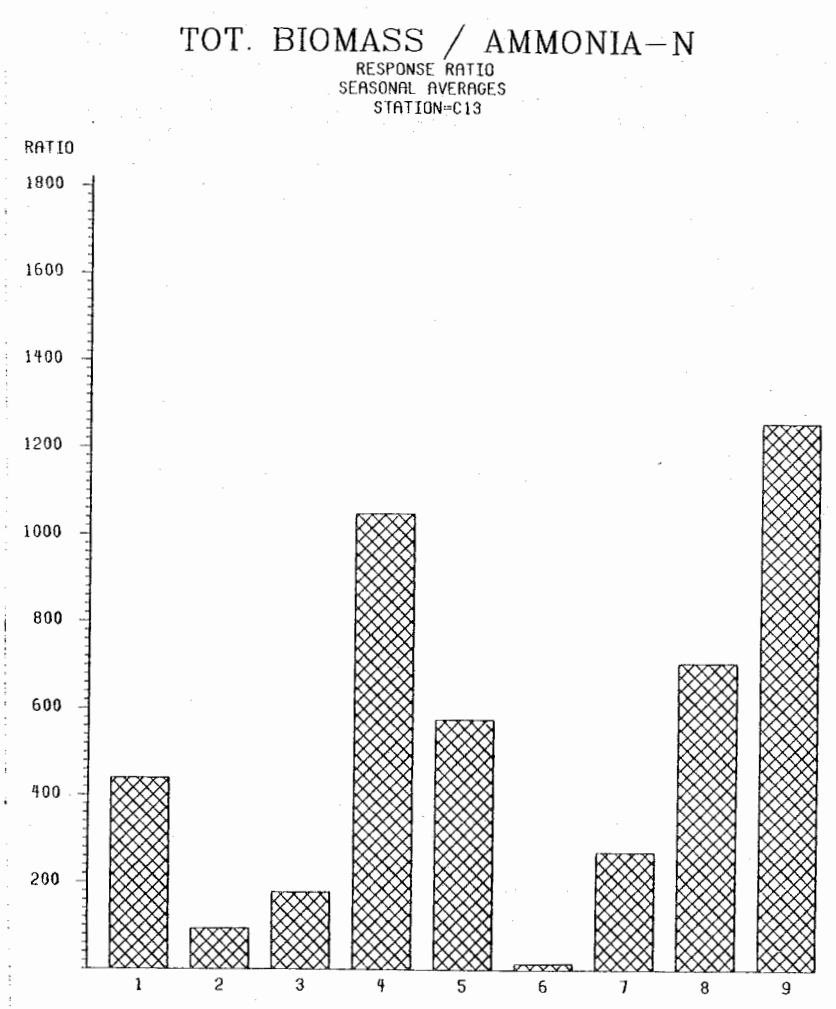


Figure 111: Seasonal wet weight algal biomass to ammonia-nitrogen response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

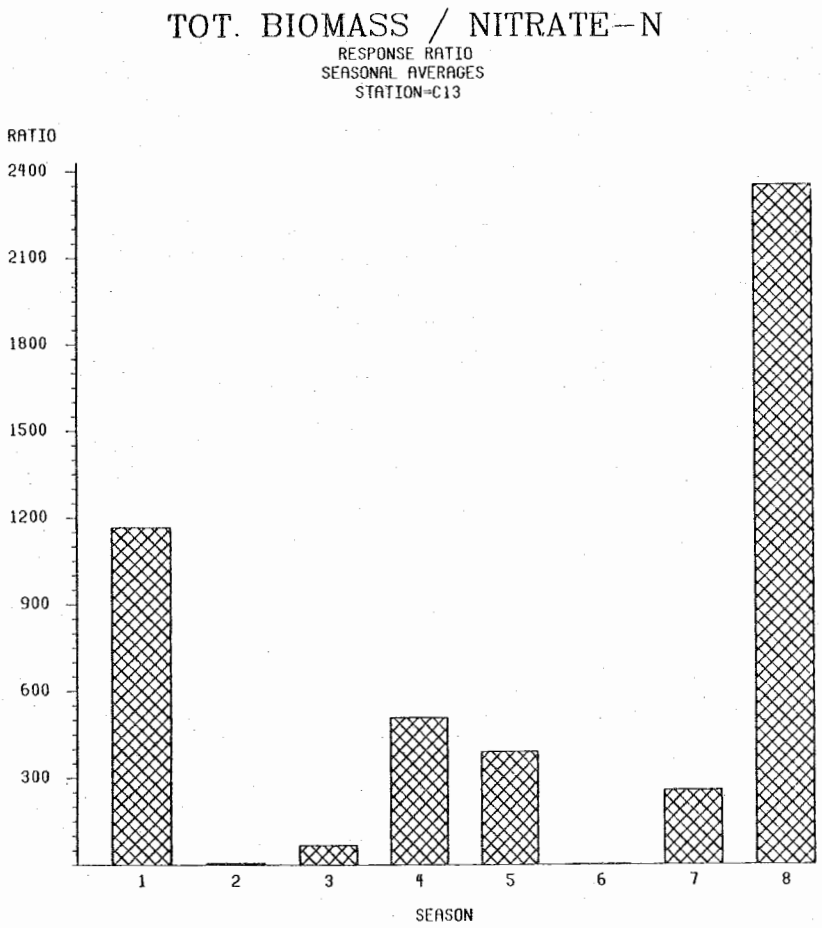


Figure 112 : Seasonal wet weight algal biomass to nitrite-nitrate nitrogen response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

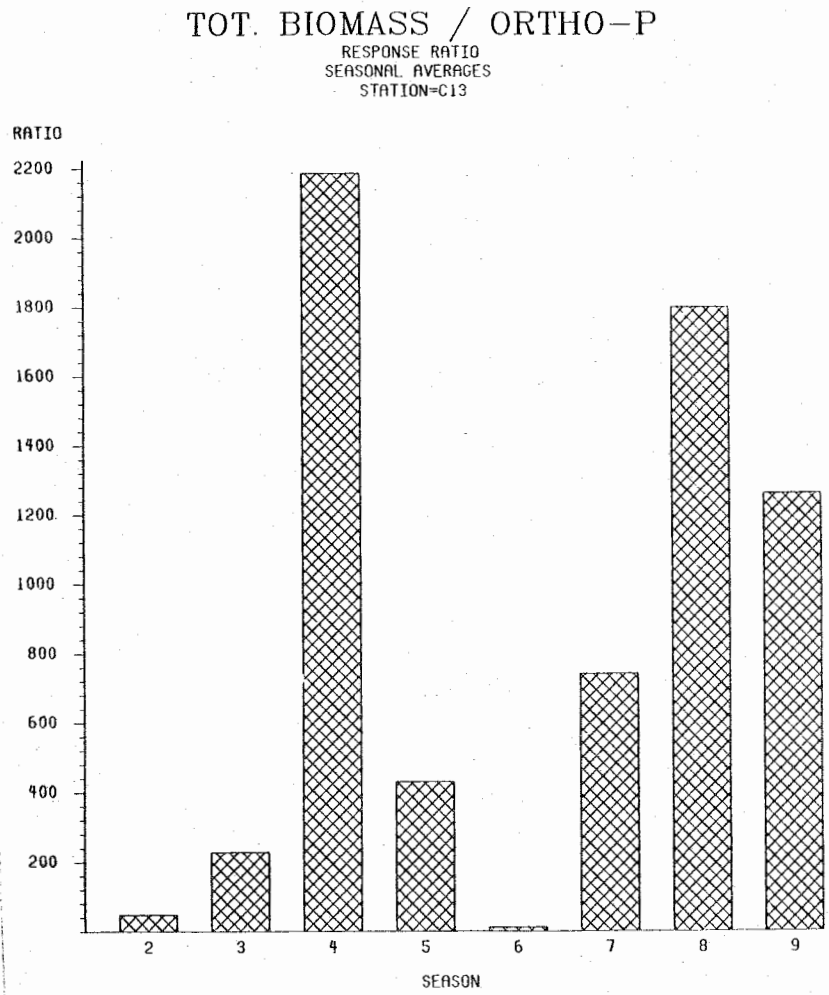


Figure 113 : Seasonal wet weight algal biomass to Ortho-PO_4 phosphorus response ratio averages for Station C-13

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

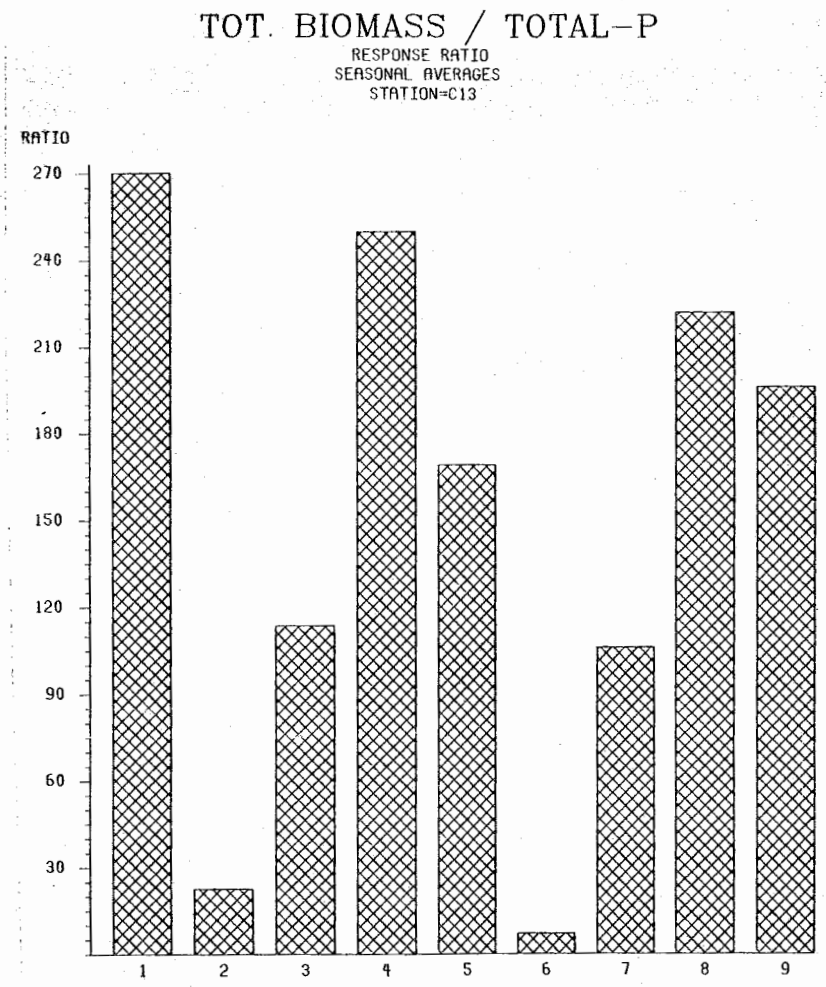


Figure 114: Seasonal wet weight algal biomass to total phosphorus response ratio averages for Station C-13

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

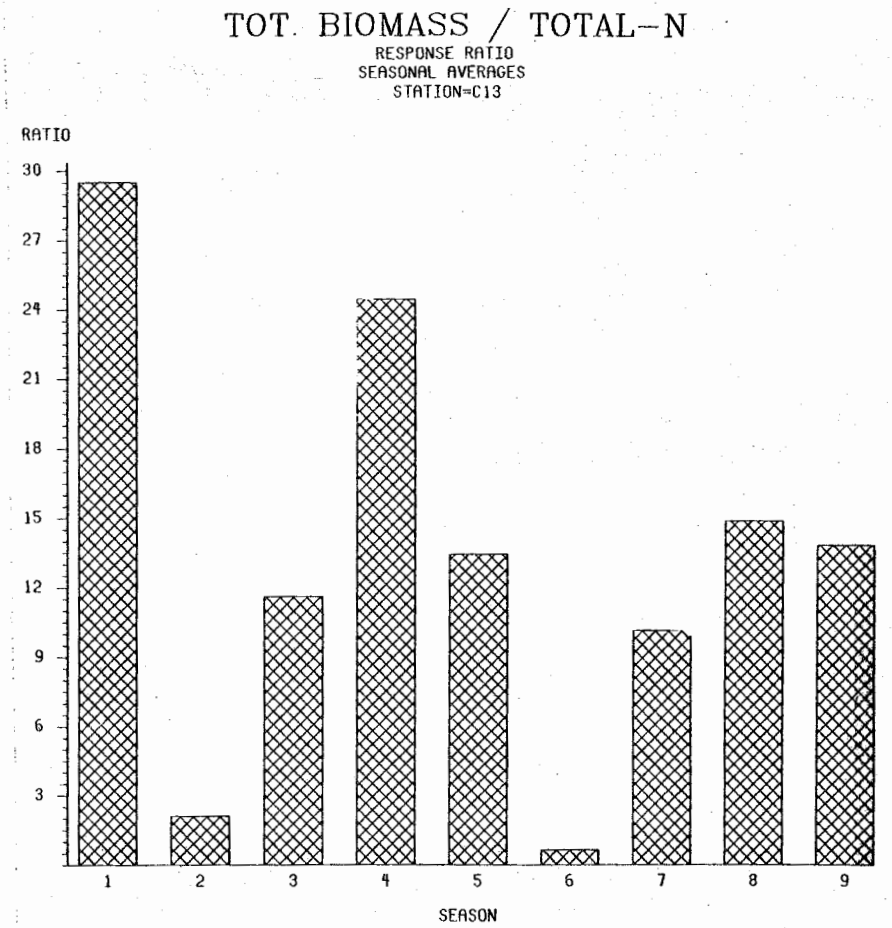


Figure 115: Seasonal wet weight algal biomass to total nitrogen response ratio averages for Station C-13

SEASON 1 = FALL . 1978
SEASON 2 = WINTER . 1979
SEASON 3 = SPRING . 1979
SEASON 4 = SUMMER . 1979
SEASON 5 = FALL . 1979
SEASON 6 = WINTER . 1980
SEASON 7 = SPRING . 1980
SEASON 8 = SUMMER . 1980
SEASON 9 = FALL . 1980

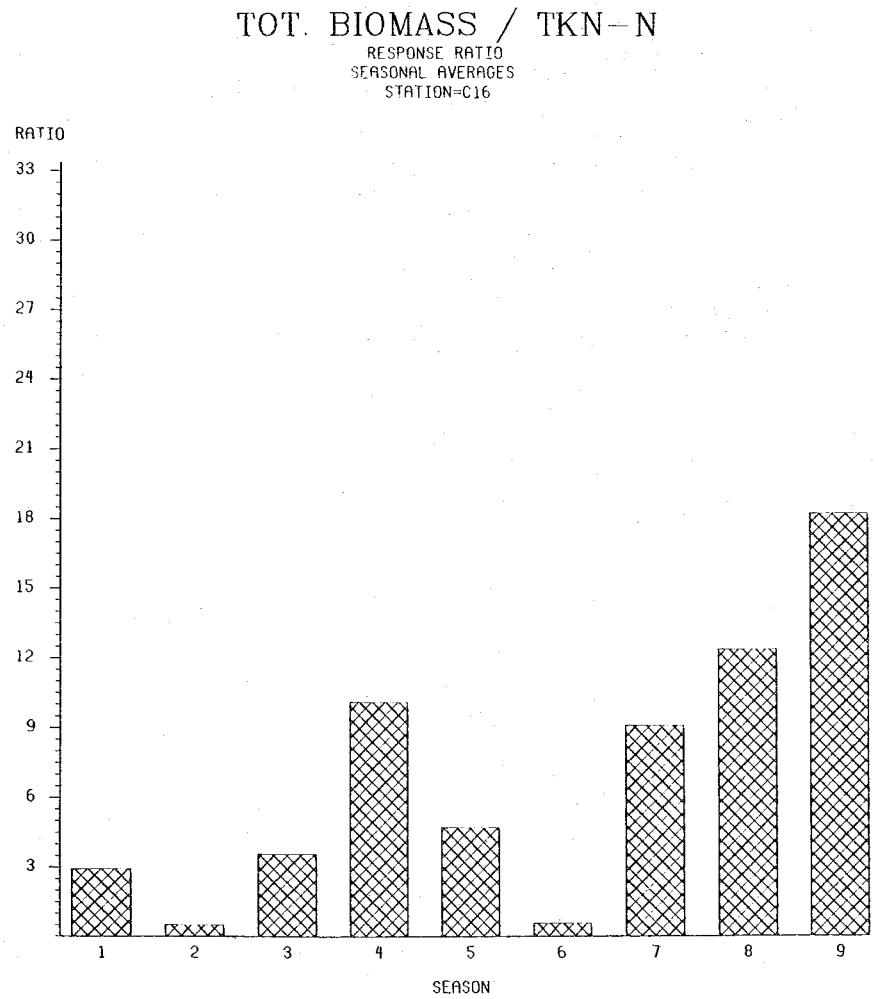


Figure 116: Seasonal wet weight algal biomass to total Kjeldahl nitrogen response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

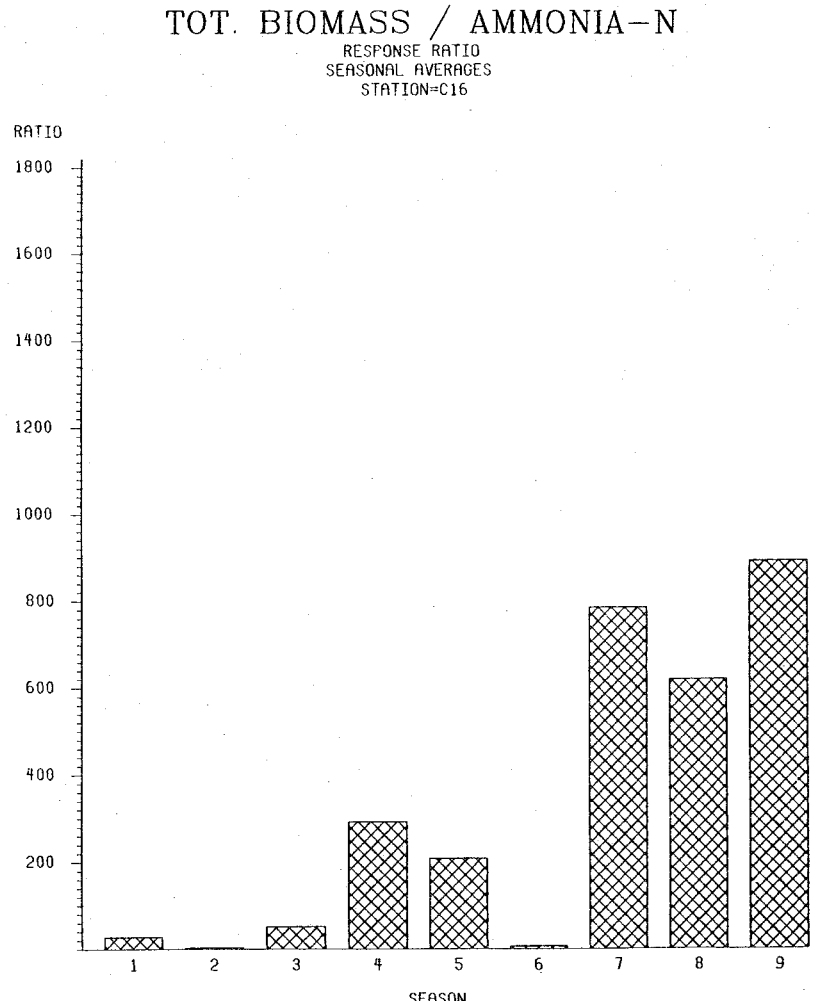


Figure 117: Seasonal wet weight algal biomass to ammonia-nitrogen response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

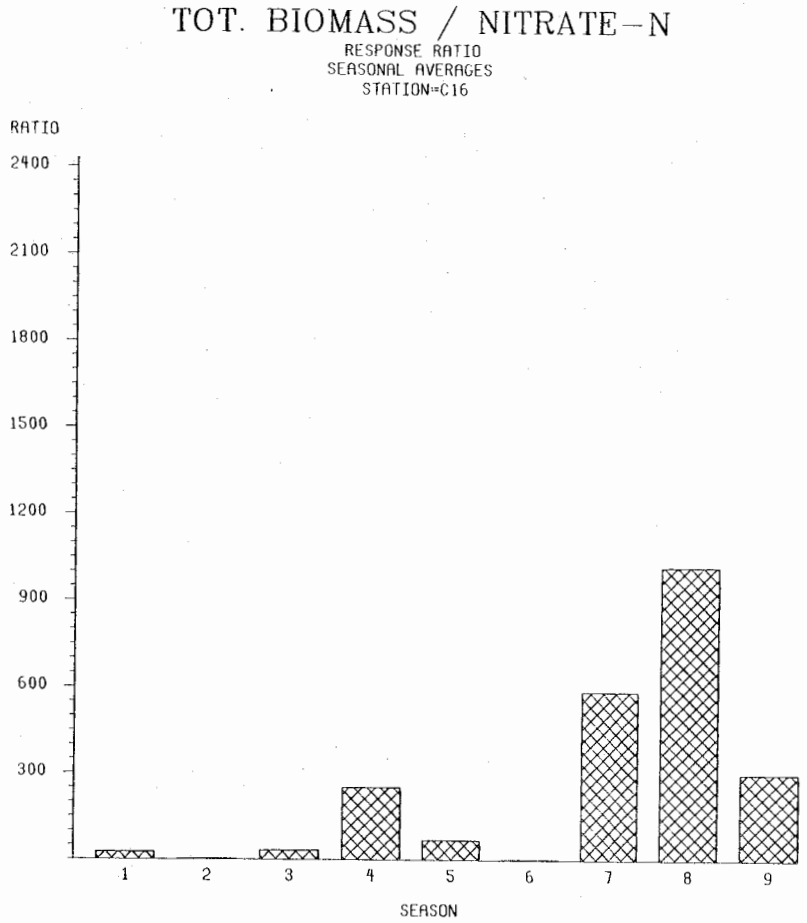


Figure 118: Seasonal wet weight algal biomass to nitrite-nitrate nitrogen response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

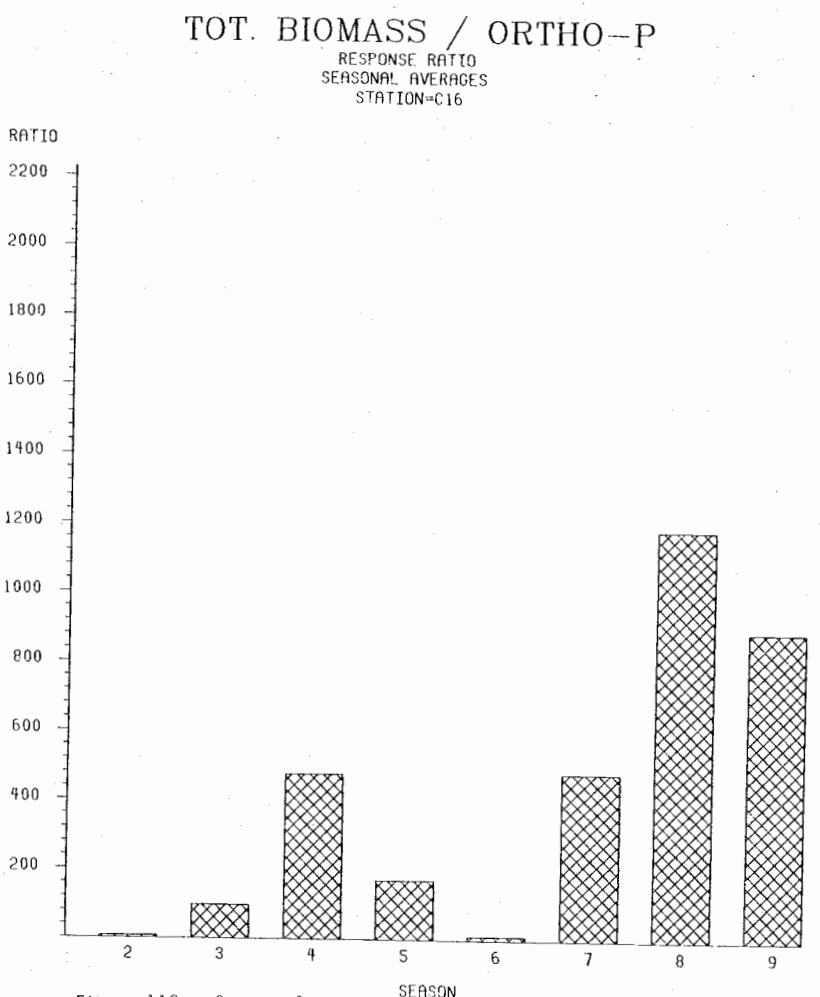


Figure 119: Seasonal wet weight algal biomass to Ortho-PO_4 nitrogen response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

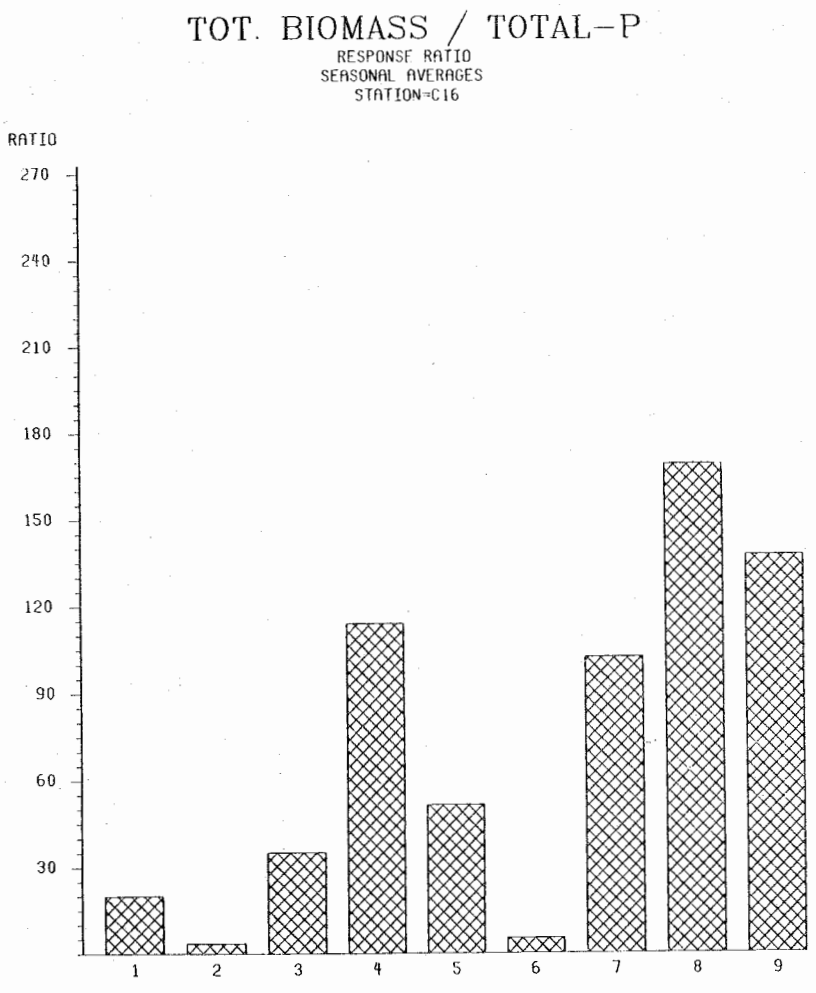


Figure 120: Seasonal wet weight algal biomass to total phosphorus response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

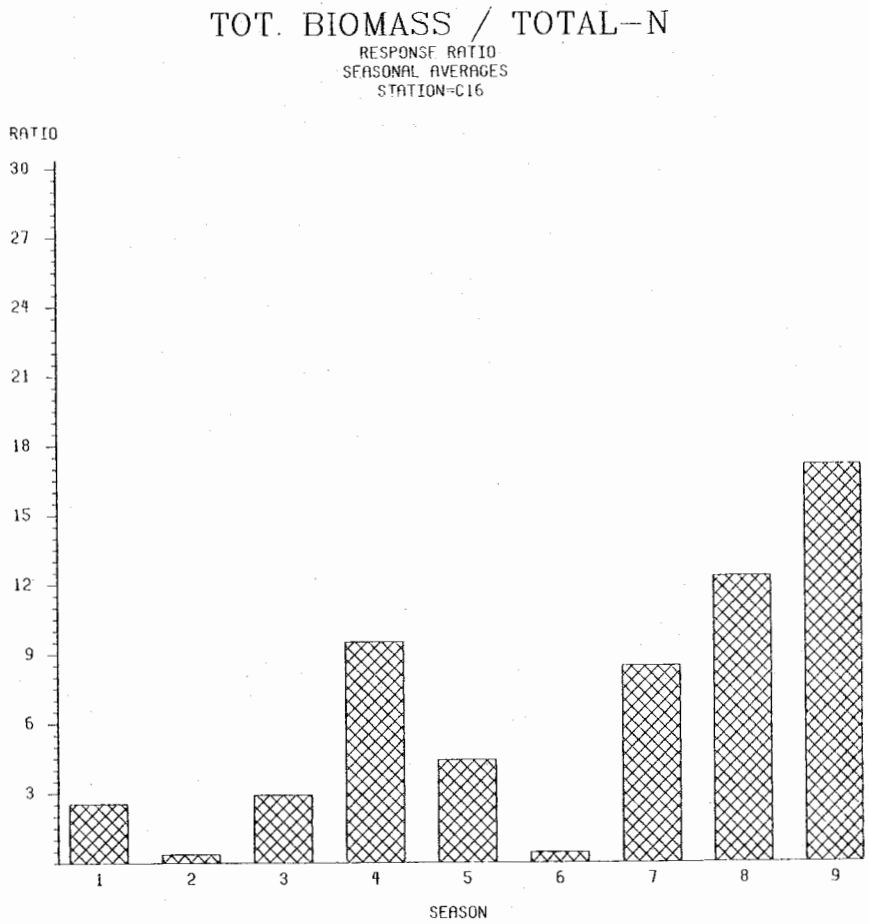


Figure 121: Seasonal wet weight algal biomass to total nitrogen response ratio averages for Station C-16

SEASON 1 = FALL , 1978
SEASON 2 = WINTER , 1979
SEASON 3 = SPRING , 1979
SEASON 4 = SUMMER , 1979
SEASON 5 = FALL , 1979
SEASON 6 = WINTER , 1980
SEASON 7 = SPRING , 1980
SEASON 8 = SUMMER , 1980
SEASON 9 = FALL , 1980

Each WWB RR_i is adjusted according to:

$$RR_{i\ ADJ} = RR_i \left(\frac{\text{chlorophyll-}\underline{a}\ \mu g/l}{\text{WWB}\ \mu g/l}\right),$$

so that it is comparable to chlorophyll-a RR_i's.

From these adjusted RR_i's, it is again seen that the Chowan is nutrient sensitive. However, based on WWB, the Chowan is most sensitive to levels of OP, NH_4 and NO_3, in that order of importance. Using average summer lower reach nutrient levels and their average RR_i's, it is seen that OP, NH_4, and NO_3 levels are in excess by 27.8%, 26.5% and 18.5%, respectively. That is ambient levels of OP, NH_4 and NO_3 could have resulted in these percentage biomass increases, had not some other factor become limiting. To achieve a 10 mg/l WWB average, a "laboratory/river" determined acceptable level, the necessary reductions are 72.0% OP, 71.1% NH_4, and 68.7% NO_3.

While chlorophyll-a and total biomass are important parameters, most of the so-called "nuisance" algal conditions in the Chowan are associated with blue-green algal biomass (BGBMASS). Therefore, nutrient response ratios for BGBMASS are calculated the same as with chlorophyll-a and listed in Tables XX through XXIII. Again for comparison to chlorophyll-a RR's, each BGBMASS RR_i is adjusted by the expression:

$$RR_{i\ ADJ} = RR_i \left(\frac{\text{CHLORO}\ \mu g/l}{\text{BGBMASS}\ \mu g/l}\right).$$

The RR_i seasonal averages for BGBMASS seem to follow nearly the same pattern as those of WWB, with the same implications. However, an additional implication here is that, whenever an $RR_{i\ ADJ}$ exceeds 1.0, the system may be characterized as prone to nuisance algal growth.

Four points concerning the BGBMASS-nutrient relationship, as developed here, deserve mention.

Table XX

1978-1980 Fall blue-green algal biomass averages with associated nutrient response ratios over adjusted response ratio averages. Adjusted response ratios are comparable to chlorophyll-a ratios.

Fall Blue-Green Biomass
Nutrient Response Ratios

	C1	C4	C13	C16
Blue-green algal biomass mg/l over chlorophyll-a average µg/l	0.0232/2.84	0.09/4.75	6.71/25.63	1.48/16.74
RR_{TKN}/RR_{TKN} ADJ	0.03/0	0.12/0.01	7.31/0.03	1.62/0.02
RR_{NH_4}/RR_{NH_4} ADJ	2.02/0.25	1.94/0.10	264.42/1.01	82.94/0.94
RR_{NO_3}/RR_{NO_3} ADJ	0.03/0	1.35/0.07	309.67/1.18	28.98/0.33
RR_{OP}/RR_{OP} ADJ	0.40/0.05	3.15/0.17	194.67/0.74	81.08/0.92
RR_{TP}/RR_{TP} ADJ	0.22/0.03	0.80/0.04	79.61/0.30	14.36/0.16
RR_{TN}/RR_{TN} ADJ	0.04/0	0.10/0.01	7.17/0.03	1.52/0.02

Table XXI

1978-1980 Winter blue-green algal biomass averages with associated nutrient response ratios over adjusted response ratio averages. Adjusted response ratios are comparable to chlorophyll-a ratios.

Winter Blue-Green Biomass
Nutrient Response Ratios

	C1	C4	C13	C16
Blue-green algal biomass mg/l over chlorophyll-a average µg/l	0.04/1.00	0.02/1.04	0.01/1.16	0.01/2.11
RR_{TKN}/RR_{TKN} ADJ	0.07/0	0.03/0	0.01/0	0.01/0
RR_{NH_4}/RR_{NH_4} ADJ	1.75/0.04	0.21/0.01	0.13/0.02	0.05/0.01
RR_{NO_3}/RR_{NO_3} ADJ	0.12/0	0.07/0	0.02/0	0.03/0.01
RR_{OP}/RR_{OP} ADJ	1.06/0.03	0.66/0.03	0.07/0.01	0.12/0.03
RR_{TP}/RR_{TP} ADJ	0.35/0.01	0.24/0.01	0.10/0.01	0.05/0.01
RR_{TN}/RR_{TN} ADJ	0.05/0	0.02/0	0.01/0	0.01/0

Table XXII

1978-1980 Spring blue-green algal biomass averages with associated nutrient response ratios over adjusted response ratio averages. Adjusted response ratios are comparable to chlorophyll-a ratios.

Spring Blue-Green Biomass
Nutrient Response Ratios

	C1	C4	C13	C14
Blue-green algal biomass mg/l over chlorophyll-a average µg/l	0/1.84	0.01/2.63	0.71/17.68	0.23/21.36
RR_{TKN}/RR_{TKN} ADJ	0/0	0.01/0	0.66/0.02	0.26/0.02
RR_{NH_4}/RR_{NH_4} ADJ	0.05/0	0.13/0.03	11.72/0.29	8.11/0.75
RR_{NO_3}/RR_{NO_3} ADJ	0/0	0.05/0.01	24.31/0.6d1	9.94/0.92
RR_{OP}/RR_{OP} ADJ	0.03/0	0.20/0.05	46.52/1.16	8.04/0.75
RR_{TP}/RR_{TP} ADJ	0.01/0	0.10/0.03	7.23/0.18	2.81/0.26
RR_{TN}/RR_{TN} ADJ	0.0	0.01/0	0.65/0.02	0.23/0.02

Table XXIII

1978-1980 Summer blue-green algal biomass averages with associated nutrient response ratios over adjusted response ratio averages. Adjusted response ratios are comparable to chlorophyll-a ratios.

Summer Blue-Green Biomass
Nutrient Response Ratios

	C1	C4	C13	C16
Blue-green algal biomass mg/l over chlorophyll-a average µg/l	0.15/8.07	0.48/14.88	10.19/40.39	7.75/37.27
RR_{TKN}/RR_{TKN} ADJ	0.31/0.02	0.52/0.02	7.16/0.03	6.54/0.03
RR_{NH_4}/RR_{NH_4} ADJ	5.61/0.30	11.88/0.37	271.48/1.08	290.05/1.39
RR_{NO_3}/RR_{NO_3} ADJ	3.95/0.21	9.02/0.28	279.90/1.11	291.40/1.40
RR_{OP}/RR_{OP} ADJ	1.66/0.09	8.37/0.26	549.12/2.18	558.54/2.69
RR_{TP}/RR_{TP} ADJ	1.36/0.07	5.71/0.18	97.77/0.39	84.40/0.41
RR_{TN}/RR_{TN} ADJ	2.24/0.01	0.49/0.02	7.11/0.03	6.43/0.03

(1) The $RR_{NH_4\ ADJ}$, $RR_{NO_3\ ADJ}$ and $RR_{OP\ ADJ}$ averages all exceed 1.0 for the summer lower reach. Therefore, the Chowan might be metaphorically described as nutrient allergic instead of nutrient sensitive.

(2) For station C13, the frequent site of algal blooms, only summer average OP was in limiting supply, 5.1% below that level judged necessary for optimal response with respect to BGBMASS. This points to the critical need for OP reductions. Even at apparent limiting OP conditions algal growth continued. This is indicative of the very low levels of OP that can promote BGBMASS. This gives blue-green algae a highly competitive advantage over other algae at these low levels of OP.

(3) The C13 summer average BGBMASS of 10.19 mg/l far exceeds the laboratory determined 1.0 mg/l acceptable level. Actually, therefore, each nutrient was also far in excess.

(4) Reductions of 90.7% NH_4, 90.9% NO_3 and 89.7% OP appear necessary to achieve a 1.0 µg BGBMASS/l summer average at C13. Again, these reductions ignore organic nitrogen and total phosphorus, which are precursors to NH_4, NO_3 and OP and are at high levels in the Chowan.

Using RR_j averages based on BGBMASS alone neglects the effect of other algal types on nutrient utilization. Some caution is therefore necessary here.

A brief summary of the response ratio results follows.

(1) The RR concept was found to be most applicable to the summer lower reach data.

(2) NO_3-N and NH_4-N were found most closely associated with chlorophyll-a levels. Their summer averages should be reduced by 61% and 42%, respectively, for a chlorophyll average of 30 µg/l.

(3) Average summer levels of OP, NH_4 and NO_3 are most closely associated to WWB, in that order of importance. Reductions of 72.0% OP, 71.1% NH_4 and 68.7% NO_3 appear necessary for a recommended 10 mg WWB/l summer average.

(4) The summer average OP was most closely associated with BGBMASS at station C13 where frequent algal blooms have occurred. This indicates the need for OP reductions. Still, OP, NH_4 and NO_3 should all be reduced by 89.7%, 90.7% and 90.9%, respectively, for a summer recommended average of 1.0 mg BGBMASS/l blue-green algae/species. However, other algal competition for nutrients with blue-green algae would substantially reduce nutrients, thus reducing the needed precent reduction in order to reach the 1 mg/l/species blue-green biomass.

Another implication arises from these results. Namely, since chlorophyll-a is mainly N-limited, BGBMASS seems P-limited and WWB is intermediate. It appears that BGBMASS contributes relatively more to WWB than to chlorophyll-a. That is, its cubic displacement per unit chlorophyll-a is relatively low. This in turn suggests that a 40 µg/l chlorophyll-a standard may not adequately describe water quality, depending upon the algal composition.

Light

Light availability in the Chowan River is a potentially limiting factor for both total and blue-green algal biomasses (3, 12, 13, 19, 25, 27, 32, 39, 50). It is considered here because of recent interest in the Union Camp, Co. discharge, which is highly colored.

In order to judge the quality of light penetration in the Chowan, Carlson's (1977) formula was used to estimate residual secchi values (RS):

$$\ln \text{PREDICTED SECCHI (m)} = 2.04 - [0.68 \ln \text{Chlorophyll-a } (\mu g/l)]$$

and then,

$$RS = \text{PREDICTED SECCHI} - \text{OBSERVED SECCHI (m)}.$$

According to NES study estimates (21, 22), an RS of 0.46 or more is indicative of high non-chlorophyll light interference. RS values from 0.46 down to -2.00 suggest that most light attenuation is due to chlorophyll-a.

Using summer lower reach Chowan data again, average RS's were found to be 0.53 for 1979 and -0.01 for 1980. These averages characterize 1979 and 1980 as low and high response growth periods based on light availability. Supporting this is the increase of biomass and BGBMASS percentage during 1980.

Of the 63 genera dominating more than 10 times during both summers, the blue-green Anabaena and Aphanizomenon ranked nearly the lowest in average associated RS values. Blue-green species of interest also show low average RS values:

Anabaena flos-aquae	-0.153
A. aequalis	-0.030
A. circinalis	0.050
Aphanizomenon flos-aquae	-0.011.

The clear implication is that the blue-greens of the Chowan are not favored by highly colored waters. Instead, the important blue-green species seem to flourish with high light penetration. Therefore, the idea that Chowan colored water (U.C. effluent) tends to effectively increase BGBMASS cannot be supported here. Lab studies (earlier) show that U.C. effluent supports a proliferation of blue-green algae, given adequate lighting. It then is not the color of the U.C. effluent that favors BGBMASS but the nutrient content therein.

One very important physiological factor concerning the blue-green algal species found in abundance in the Chowan River is noteworthy. These species have the capacity to increase or decrease the amount of thylakoids (membrane-like structures upon which respiration and photosynthesis occur) as the radiant energy increases or decreases. In strong light the species will decrease the concentration of thylakoids and in low or weak light they will increase the cell content. This increases or decreases the surface area upon which the photosynthetic process takes place. Thus, the critical level of light for these

species is quite low while the perferred light level is quite high (1A, 41A, 41B).

If nitrogen is reduced alone the results will probably be an overgrowth of flagellates, in particular of the dinoflagellate types as seen in the PO_4-P loaded Pamlico River Estuary (23).

It is clear that the first order of business to restoring the Chowan River is a reduction of nutrients in the CRC. We have suggested a minimum for both nitrogen and phosphorus. It is clear that the N:P ratio is more important than either PO_4-P or nitrogen. If the N:P ratio is too high, Microcystis will be dangerous; if the N:P ratio is too low, Anabaena and Aphanizomenon will be dangerous.

We have studied the N:P ratio as a growth factor of the five bloom species in a companion project funded by WRRI. These data will be reported very soon in a WRRI publication.

NUTRIENT-SEDIMENT ANALYSIS

Even though sediment samples were not assayed with the same weekly intensity as nutrients, nevertheless, enough samples were analyzed to allow for a statement concerning their nutrient concentration.

Figures 122 through 130, encompassing stations C3, C13 and C16, show no specific trends. However, it is clear that the bottom sediment at these stations is high in both nitrogen and phosphorus.

It is interesting that C3, the uppermost river station, showed a temporal decline in ammonia nitrogen while an increase in PO_4-P (1978-1980, Figures 122 and 124). This same pattern was seen at station C13 with the exception of Fall, 1978 when PO_4-P was very low (Figure 128 and 130); likewise was station C16 (Figure 125 and 127). Seemingly, PO_4-P was reduced at C13 also during early springs 1979 and 1980 (Figure 130). To some extent this pattern existed with ammonia at C16 (Figure 125).

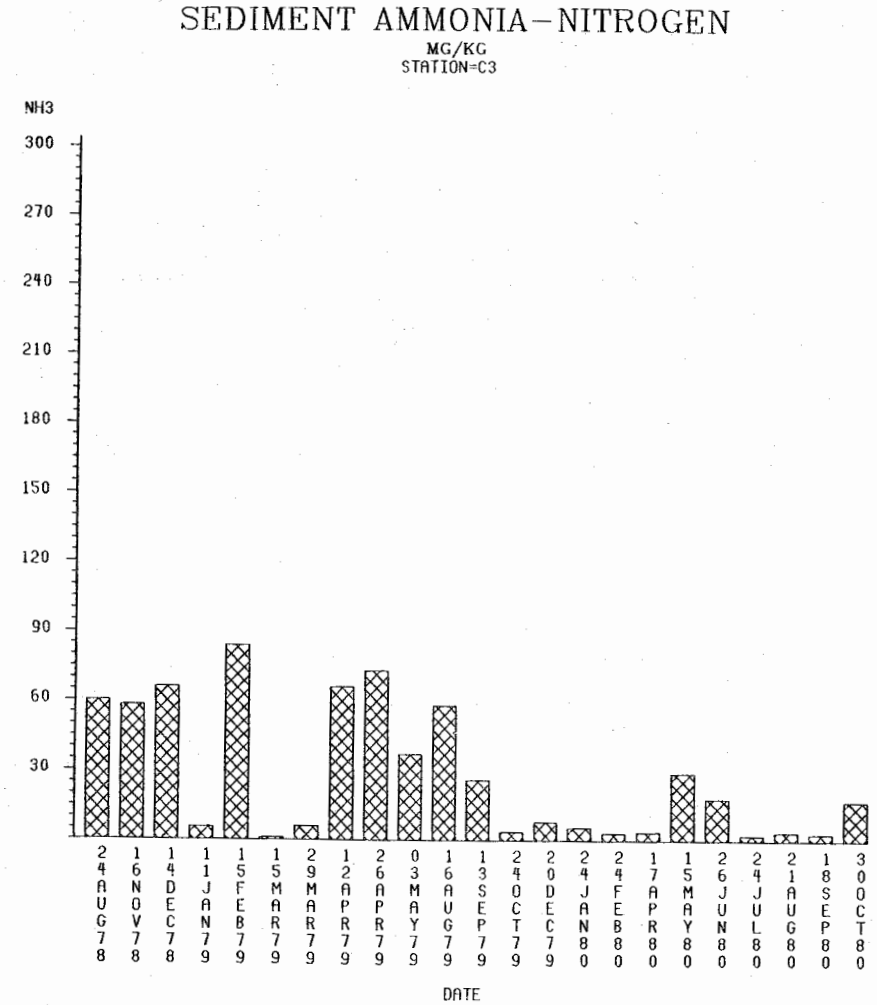


Figure 122: Ammonia nitrogen from the sediments at Station C-3 during the sampling period August 1978-December 1980, mg/kg

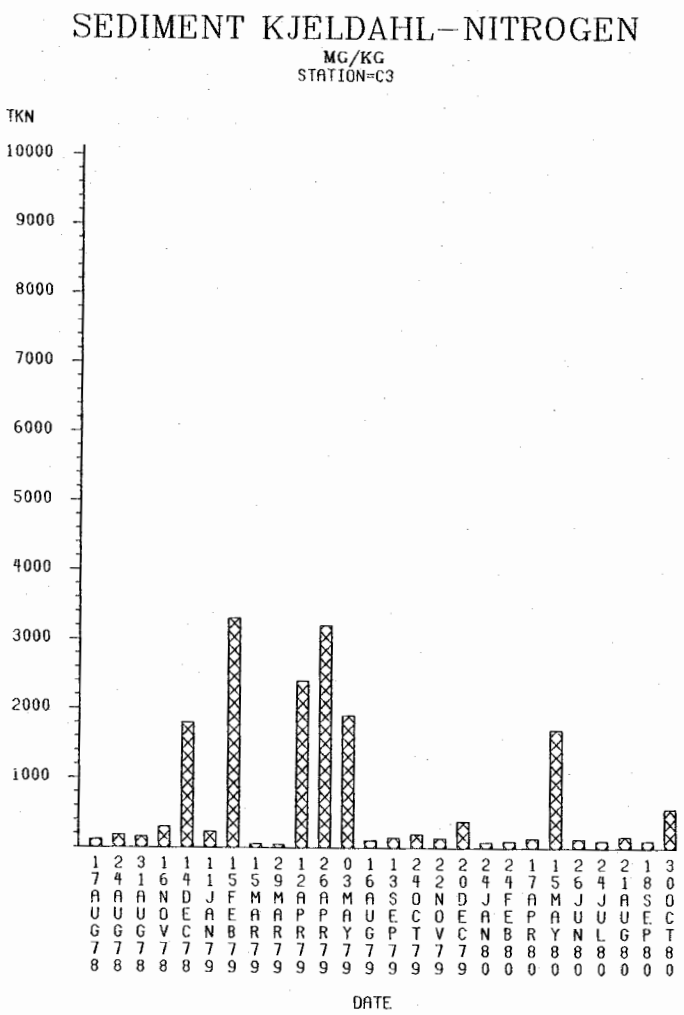


Figure 123: Total Kjeldahl nitrogen from the sediments at Station C-3 during the sampling period August 1978-December 1980, mg/kg

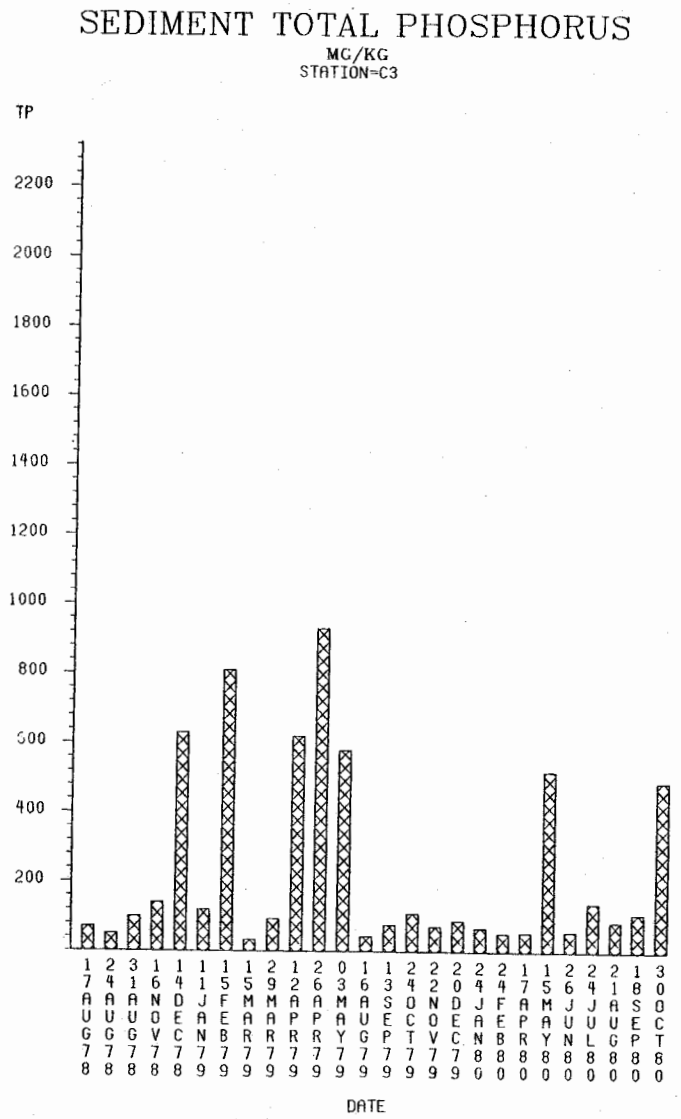


Figure 124 : Total phosphorus from the sediments at Station C-3 during the sampling period August 1978-December 1980, mg/kg

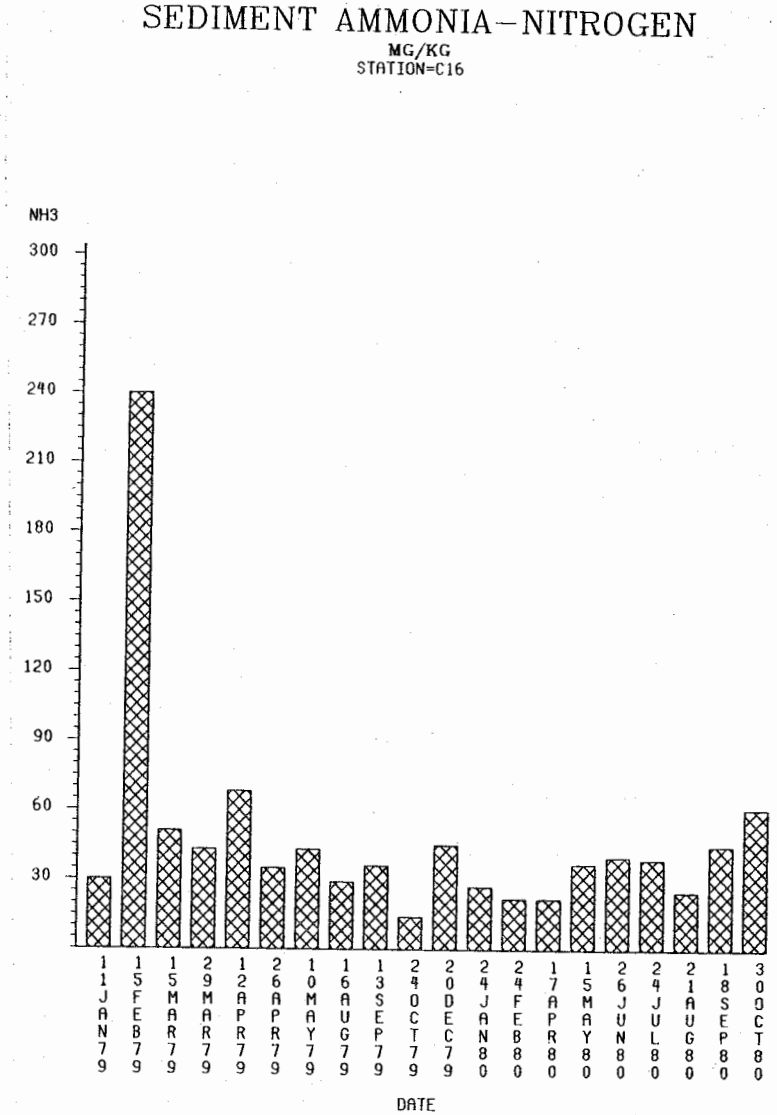


Figure 125 : Ammonia nitrogen from the sediments at Station C-16 during the sampling period August 1978-December 1980, mg/kg

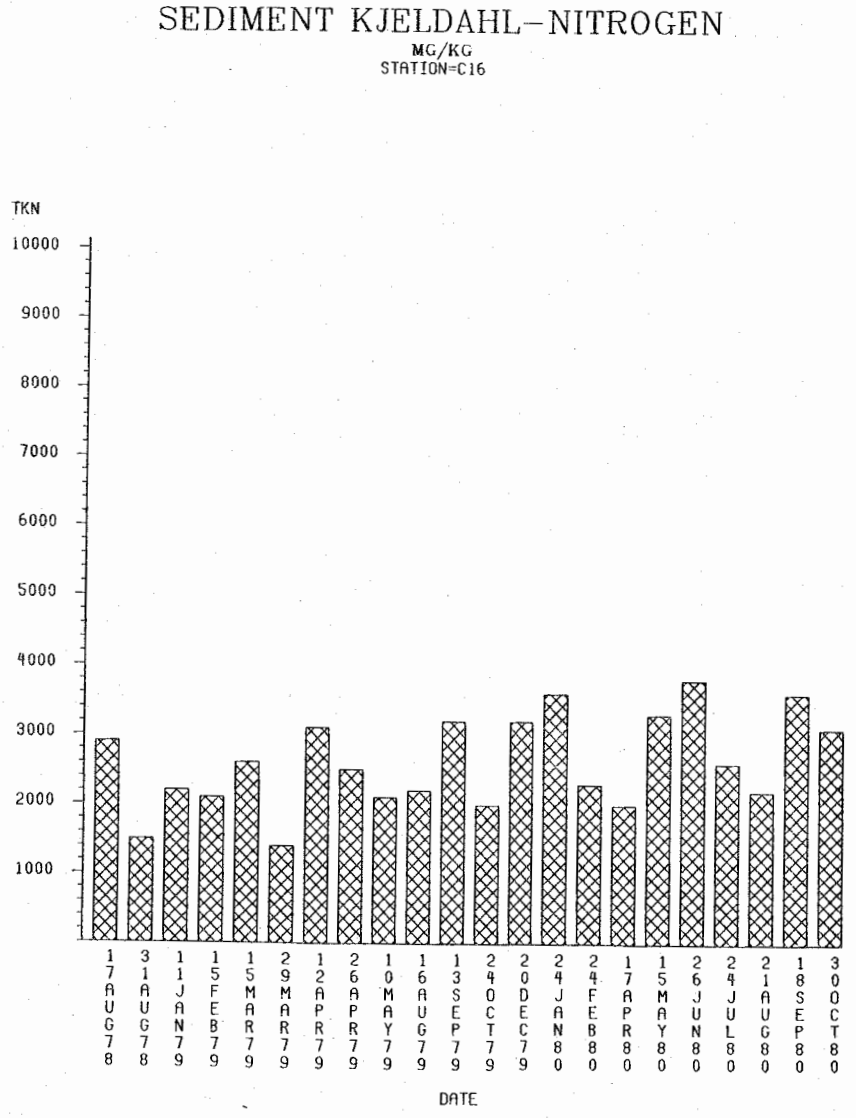


Figure 126: Total Kjeldahl nitrogen from the sediments at Station C-3 during the sampling period August 1978-December 1980, mg/kg

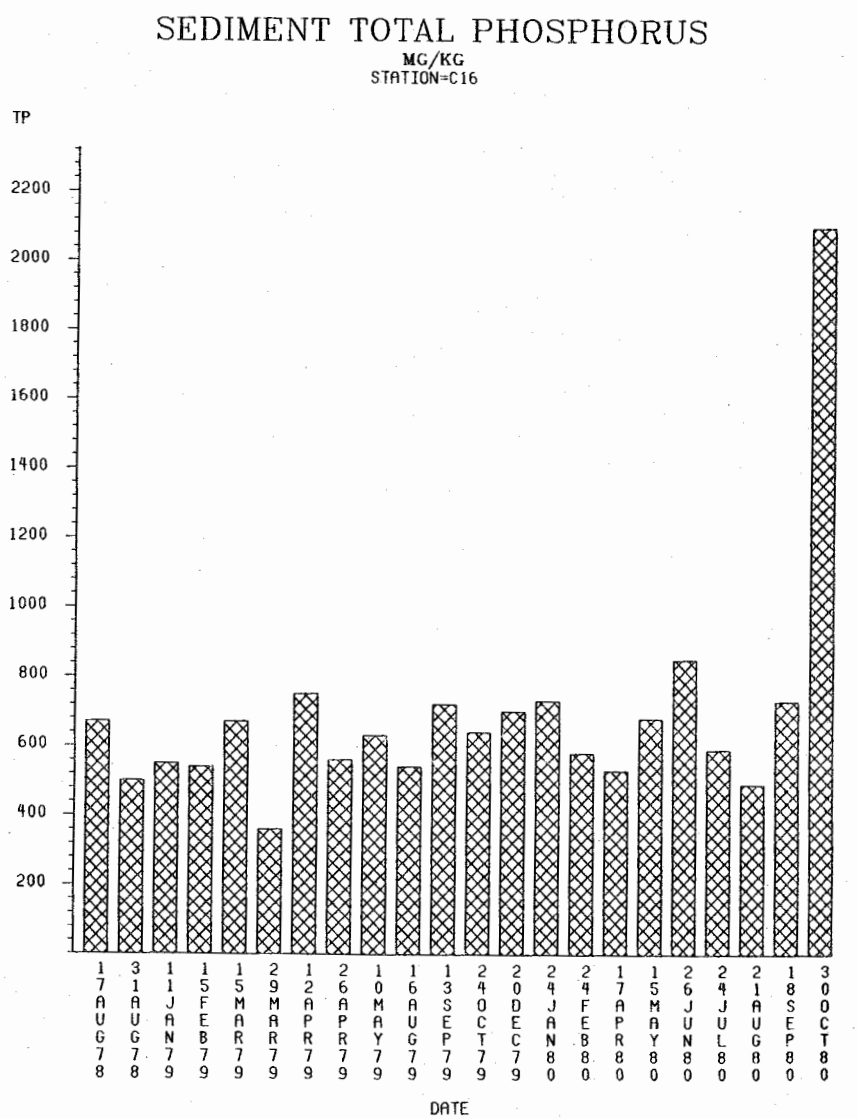


Figure 127: Total phosphorus from the sediments at Station C-3 during the sampling period August 1978-December 1980, mg/kg

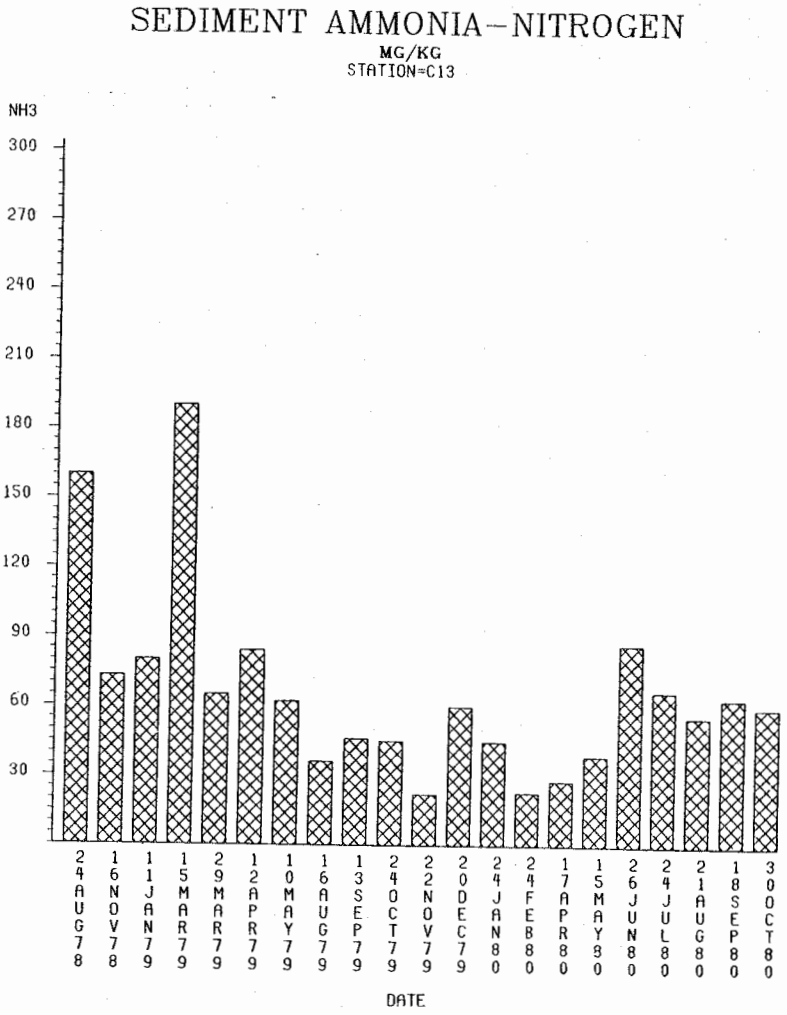


Figure 128: Ammonia nitrogen from the sediments at Station C-13 during the sampling period August 1978-December 1980, mg/kg

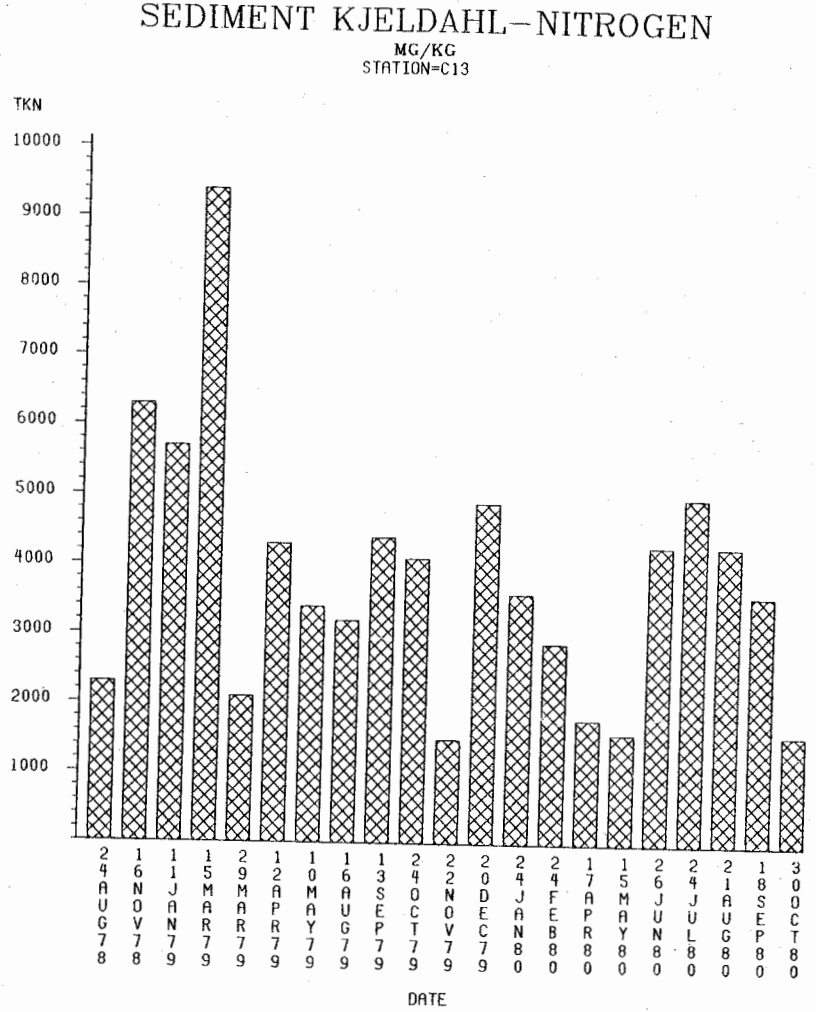


Figure 129: Total Kjeldahl nitrogen from the sediments at Station C-13 during the sampling period August 1978-December 1980, mg/kg

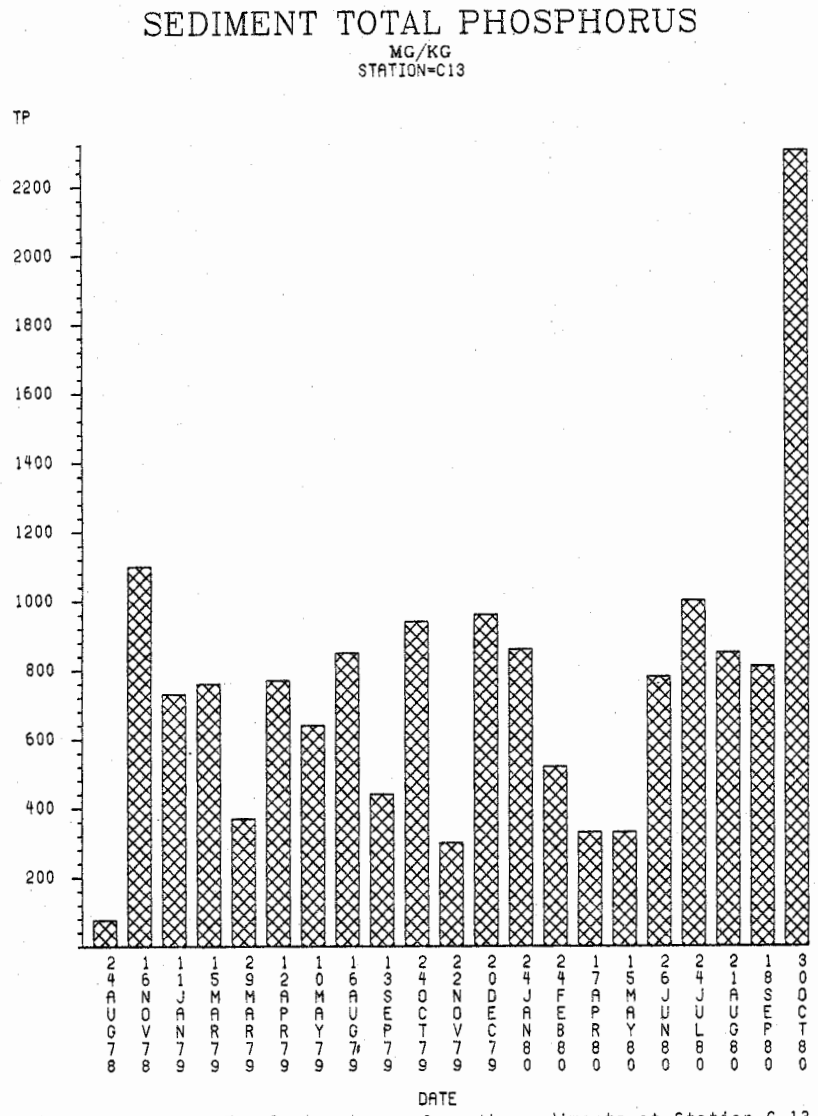


Figure 130: Total phosphorus from the sediments at Station C-13 during the sampling period August 1978-December 1980, mg/kg

The fact that blue-green algae overwinter as akinetes (spores) in the sediment, germinating when the water temperature is above 11-14°C suggests an interesting concept. As we have seen in laboratory cultures, these species can germinate out of the sediment without any addition of nutrients in the water column. Once germinated, NO_3 and PO_4-P could be absorbed from the sediment. As luxury consumption enhances the cellular content of the cells, growth could continue. Air pockets form and the species rise to the water surface. With the millions of spores in the sediment bed this type nutrient uptake would reduce the nutrients at the sediment level. This process could continue into the late summer to early fall. By mid to late fall, however, all algal cells would have sunk to the sediment; thus nutrients therein would increase again.

If the sediment surface is high in heavy metals (Zn, Cu, etc.) as our 1975 work indicated (reported 1979 (53)), this could prevent the germination of akinetes and thus no algal bloom. As water flow increases during subsequent seasons, sediment is moved further out from the river, or the metals may be chelated as suggested by Pearl (35).

That nutrients move temporally and spatially in the CRC was clearly indicated at upper river stations (C2 (Figure 131), UC1 (Figure 132) and C1B (Figure 133)). The trend of increased nutrients was clear.

The question is, why did the 1978 heavy blue-green algal bloom occur suddenly with lesser blooms in 1979 and 1980? It is certain that some kind of suppression, inhibition, or stimulation has been operative between the 1972 year and 1979 year blooms. As it was, factors such as light, temperature nutrient levels, retention times, water turbidity, hydrology, flow, etc., were not appreciably different in 1974, 75, 76, 77 (even though we had pulse blooms in all those years except 1975). Do we know the total content of UC effluent? CF Industry's? Other point sources along the river? Speculation and quick

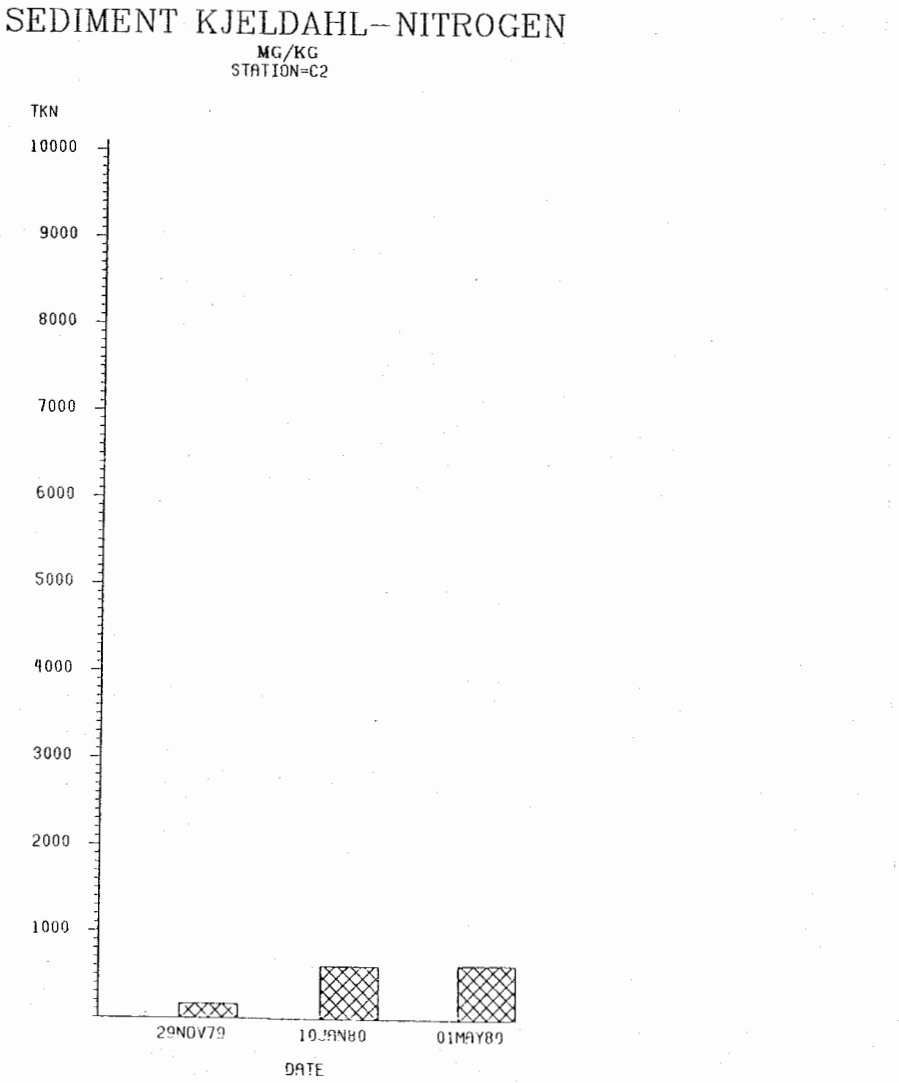


Figure 131: Total Kjeldahl nitrogen from the sediments at Station C-2 during the sampling period August 1978-December 1980, mg/kg

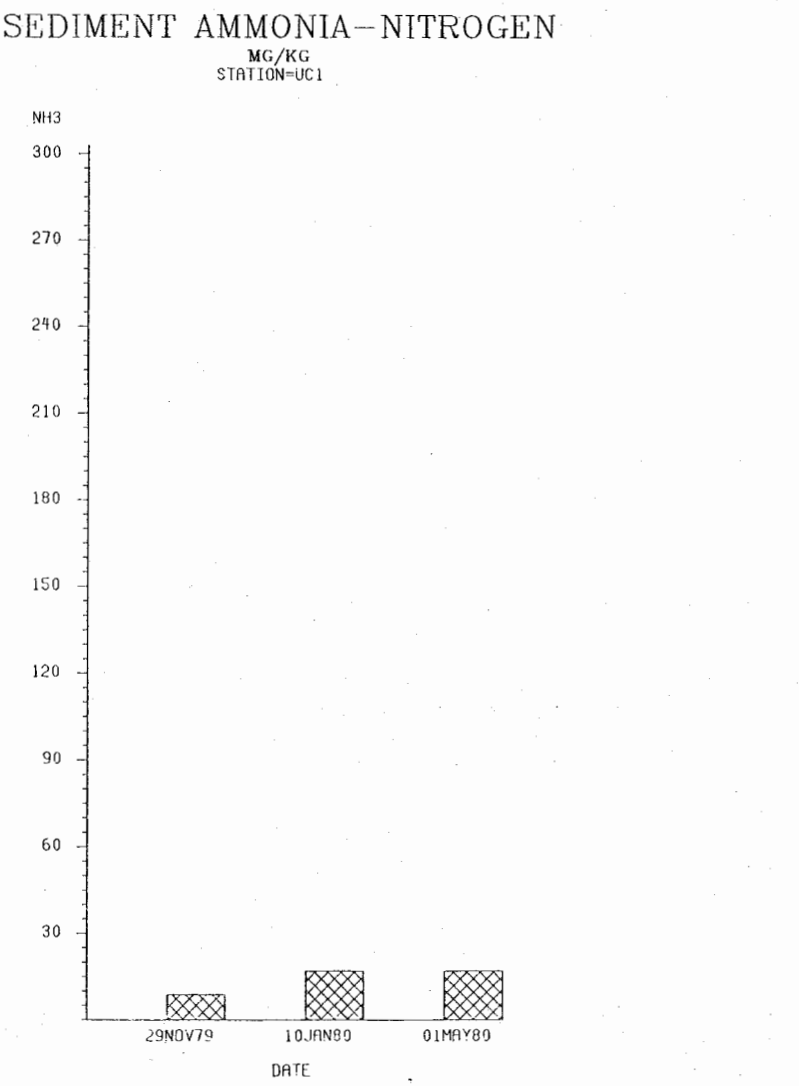


Figure 132: Ammonia nitrogen from the sediments at Station UC1 during the sampling period August 1978-December 1980, mg/kg

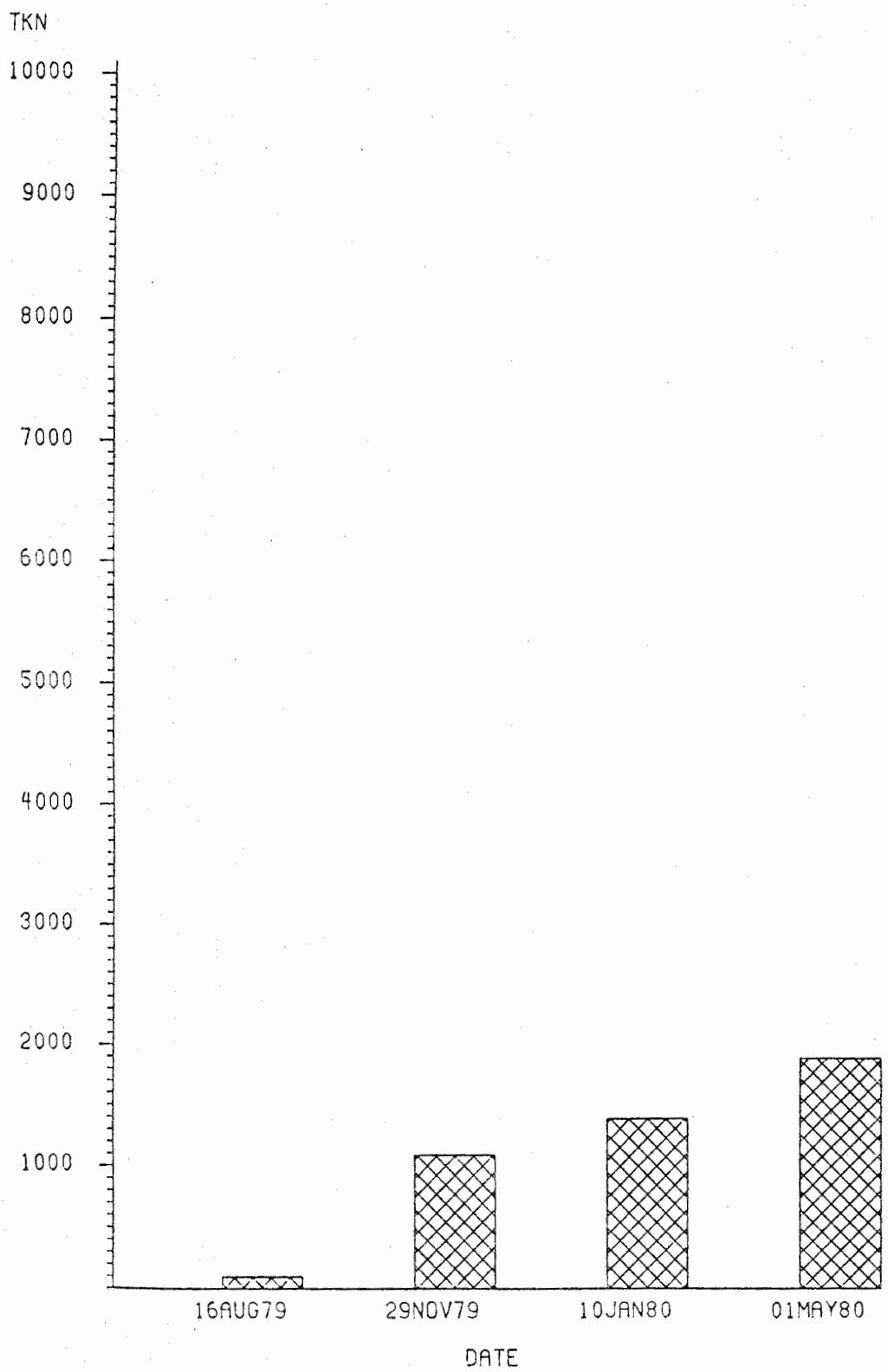


Figure 133: Total Kjeldahl nitrogen from the sediments at Station C 1B during the sampling period August 1978-December 1980, mg/kg

political answers will not negate the fact that we do not know very much about the complicated CRC. Until we do, caution is suggested.

Different factors affect different species of algae differently. It is naive to talk in terms of algal biomass or algal chlorophyll-a until we know qualitatively to what we are referring. Proper management of this system is critical. If PO_4-P is reduced, even drastically as a management ploy, it will lead to a competitive advantage for Microcystis. This species is a high nitrogen user, a low PO_4-P user and a luxury consumer of PO_4-P. A reduction in PO_4-P alone will negate competition by other algal types, greens, diatoms, etc. This will most assuredly reduce uptake of all growth nutrients as general WWB will be reduced. A lack of reduction in nitrogen either by management practices or at least by other useful algae will promote unwanted phytoplankton.

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