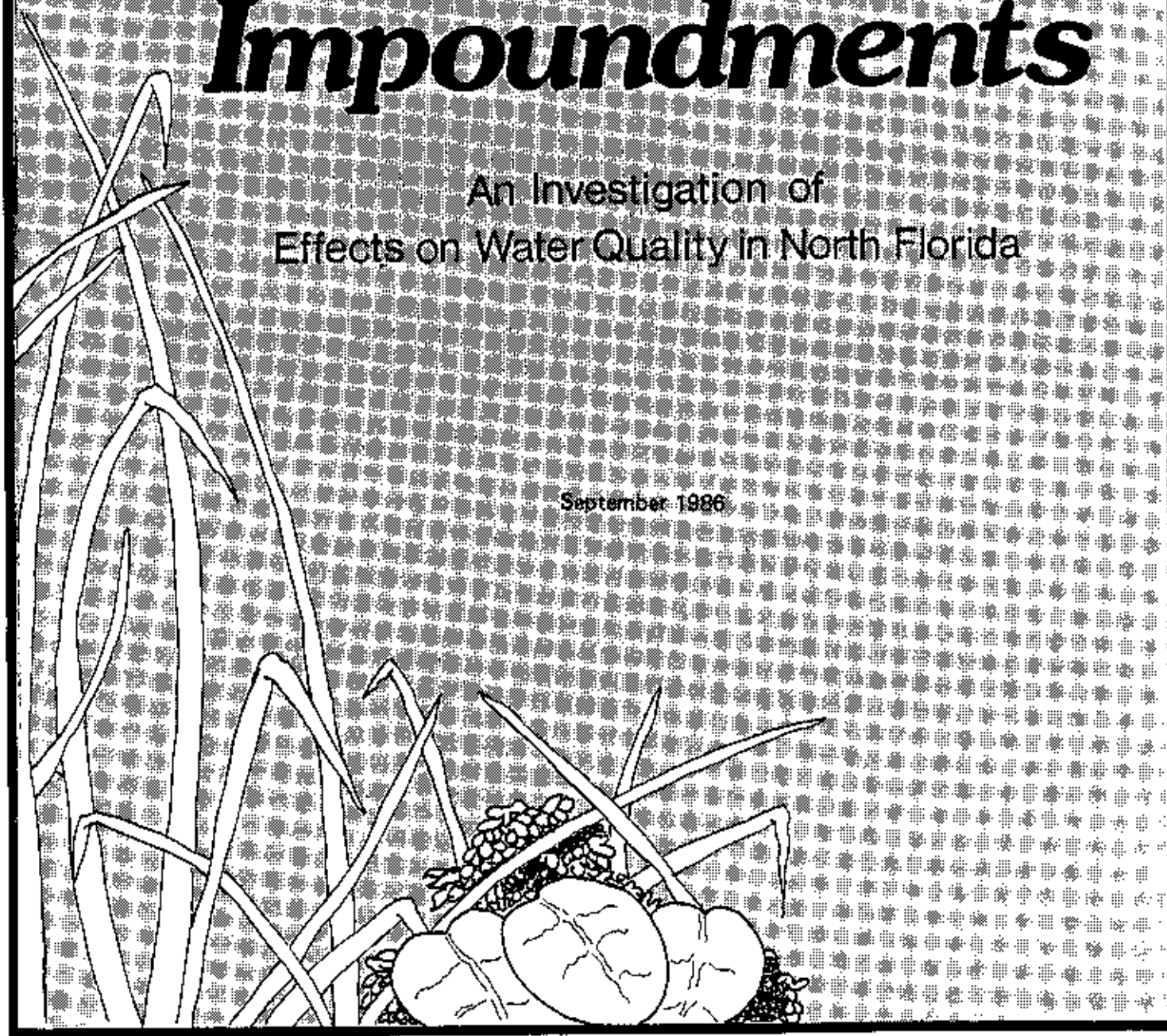
Stream Impoundments

An Investigation of Effects on Water Quality in North Florida

September 1986



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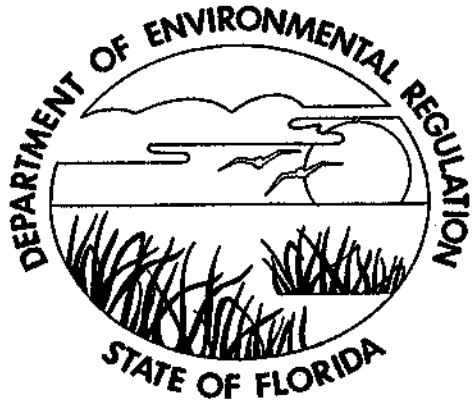

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Biology Section
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EXECUTIVE SUMMARY

INTRODUCTION

This report documents the results of a limnological study of impoundments in the Florida panhandle made from November, 1984, to August, 1985. The goals of this study were to examine the physical, chemical, and biological changes that occur when a stream or spring is dammed or impounded. A knowledge of the consequences of these radical alterations in the upstream ecosystem which is dammed to form the pond, as well as the changes in the areas downstream of the pond, is vitally important in that many impoundments in Florida will require construction permits based on the impact they are likely to have on water quality.

The ponds chosen for this study represented a wide variety of geological, topographical, land use, and age types, and are typical of the impoundments most frequently constructed in this state. These ponds were divided into two groups. Four sites, which had fairly constantly flowing streams into and out of the impoundments, were sampled intensively on a monthly basis. The second group, made up of 13 sites, was highly variable with respect to size, depth, capacity, and area drained. This set was chosen to be sampled only during "worst case conditions", and analytical frequency of some of the more intensive biological parameters was somewhat reduced.

WATER CHEMISTRY

The physical and chemical conditions of the environment influence the well-being and distribution of plants and animals, and are generally a reflection of local geography and climate. In all cases, water in the impoundments and effluent streams possessed water quality characterisitics which differed from upstream conditions. In the majority of impoundments, inputs from agricultural sources and drowned vegetation resulted in increased nutrient concentrations. Total Kjeldahl nitrogen (TKN) levels in the ponds and effluent streams were found to be especially elevated. Hypolimnetic oxygen depletion was observed in all ponds throughout the summer and, in some cases (deeper ponds in particular), during spring and winter, indicating large quantities of decomposing organic matter on the bottom. A general pH increase from upstream to outfall was observed, which is probably the result of increased plankton productivity, which effectively decreases CO_2 concentrations and boosts pH. Temperature ranges generally reflected seasonal variations during the study, although mean temperatures downstream of the ponds were slightly elevated. The severity of effects within the impoundment and downstream areas appears to be largely dependent upon the type of anthropogenic activities in proximity to the site.

PERIPHYTON AND PHYTOPLANKTON

The algal community inhabiting surfaces of underwater vegetation, rocks, and other submerged substrate is called periphyton. Due to the sedentary nature of periphyton, its community composition, structure, and biomass are sensitive to changes in water quality. A number of differences in periphyton community characteristics were noted at the pond stations relative to upstream stations. Algal abundance, as well as chlorophyll a were increased, probably in response to elevated nutrient concentrations. Diversity was reduced in the ponds, as evidenced by the lower total and mean numbers of taxa, and the reduced Shannon-Weaver diversity ($\bar{d}$). While these changes are characteristic of eutrophic conditions, a detrimental effect on this algal community is not surprising, since periphyton is more characteristic of flowing water habitats. Below the pond discharges, however, most of the changes noted in the impoundments persisted. At stations downstream of the impoundment, the periphyton community did not regain the characteristics of the upstream community: Substantial diversity strongly dominated by diatoms.

Algae which float in the water column are called phytoplankton, and are usually more important in ponds and lakes. At impoundment and downstream stations, phytoplankton biomass was dramatically increased, both in terms of abundance and chlorophyll a. These biomass measurements were extremely variable, and were probably related to time of pond-fill, and nutrient inputs based on the impoundment usage at each particular site. Diversity measurements, however, indicated either an increase or no appreciable change from upstream to pond and outfall.

BACTERIA

Bacteria are ubiquitious in nature. Selected groups have been used historically to assess environmental water quality and public health. Among these are total aerobic bacteria (often referred to as standard plate count bacteria (SPC)), total coliform bacteria, fecal coliform bacteria, and fecal streptococci. Total aerobic bacteria indicate the bacterial burden to a system. Each of the three remaining groups are sub-populations of this larger group. Total coliform bacteria, comprising the four genera Enterobacter, Citrobacter, Escherichia, and Klebsiella, are used to indicate waterborne pollution from soils. Fecal coliform bacteria, specifically Escherichia and Klebsiella, are used to determine the fecal pollution associated with warm blooded animals, including man. Fecal streptococci are bacteria also commonly found in the intestines of warm blooded animals but in varying densities. The use of a fecal coliform to fecal streptococci ratio allows the investigator to differentiate between human and other warm-blooded animal sources.

During this study, each of these four major groups of bacteria was identified at upstream, impoundment, and downstream stations at each location. To investigate the effect of the impoundments on bacterial densities, data were compared on the basis of station means to reduce the influence of sampling frequency. Major findings were:

(1) Impoundments substantially reduce densities of fecal coliform bacteria and fecal streptococci below upstream values. Total coliform and SPC bacteria are also reduced, but not substantially.

(2) The impoundments appear to discharge a considerable increase in fecal streptococci to downstream waters. The other three groups of bacteria showed similar, but smaller, increases.

(3) Comparisons between upstream and downstream stations show that all four groups become reduced below upstream values - fecal coliform bacteria and fecal streptococci substantially so.

Total coliform and fecal coliform data were also reviewed for water quality violations. No substantial variation was observed, however, among upstream, impoundment, and downstream stations in this regard. Based upon the overall results of this study, water quality violations are twice as likely to occur for the total coliform parameter than for the fecal coliform parameter for the impoundment.

ZOOPLANKTON

Zooplankton are microscopic animals such as water fleas that inhabit the water columns of streams and ponds. They typically feed on the phytoplankton and periphyton of aquatic systems and are, in turn, eaten by large animals such as fish and aquatic insects. Thus zooplankton are an important intermediate step in the transfer of energy through the food web from primary producers (phytoplankton) to higher consumers (fish) and, therefore, are an important community in any aquatic system. The data from our study suggested that the number of zooplankton taxa may increase in an impoundment when compared with the upstream community. However, the diversity ($\bar{d}$) may not show a concurrent increase since one or two organisms may be dominant. The mean number of taxa, the mean number of organisms, and pooled diversity ($\bar{d}$) generally increased from the influent stream to the pond. However, these measurements showed a decrease in the effluent streams. Community composition data indicated that, of the three major groups of zooplankton, the Cladocera were more dominant in the influent streams, while the Rotifera and Copepoda remained relatively constant from upstream to the ponds. A weakly developed trend was observed in which an increase in diversity and abundance from upstream to ponds paralleled a similar increase in nutrient and chlorophyll *a* concentrations.

ALGAL GROWTH POTENTIAL AND LIMITING NUTRIENTS

The algal growth potential (AGP) test measures the maximum amount of growth that could be expected to occur in a sample of water in which the only growth-limiting characteristics are those involving the natural chemical constituents of the water. The sample is first sterilized and then inoculated with a test organism, the alga Selenastrum capricornutum. The algal culture is then allowed to grow for a fixed length of time and the resultant growth is measured. AGP was generally less than 1 mg/l dry weight in most samples except for a few from stations associated with livestock and recreational use. This low AGP was probably the result of low phosphorus concentrations or inhibition by low pH ($\leq$ 5.0); 68% of samples adjusted to a more optimum pH (7.5) displayed significant increases in algal growth. In most cases, AGP measured at impoundments was substantially greater than that measured at the respective upstream stations. Generally, results of AGP tests indicated that productivity increases when a stream is dammed due to the impoundment acting as a nutrient sink.

The nutrients which are limiting to algal growth are determined in much the same way as algal growth potential. Concentrations of various nutrient substances are, however, increased in different subsamples to determine which nutrient (or combination of nutrients) is responsible for limiting algal growth. Generally, tests showed phosphorus to be the primary limiting nutrient, although nitrogen was the substance predicted most often based upon nitrogen to phosphorus ratios. This could be due to the greater bioavailability of nitrogen to the test algae than phosphorus, which was usually less than 2% available. Additionally, it was noted that Selenastrum may have sometimes utilized nitrogen sources other than total soluble inorganic nitrogen.

BENTHIC MACROINVERTEBRATES

The benthic macroinvertebrates, organisms such as worms, snails, and insect larvae, are quite important to the functioning of aquatic ecosystems and are sensitive indicators of environmental quality. Analyses performed on both artificial substrate and ponar grab sampled macroinvertebrate data clearly indicated that impoundments have a profound and deleterious effect on benthic communities. Significant declines in abundance, species richness, and diversity generally occurred between the upstream and pond stations. Biological integrity criterion violations were numerous in the ponds. Sensitive groups of organisms were repeatedly found to be eliminated as a result of impoundment. Species level data and data on frequently occurring species also indicated dramatic changes in the biota due to impoundment. Multivariate cluster analysis results supported these findings.

Physical-chemical factors responsible for changes in the benthos were drastically lowered dissolved oxygen levels and increases in both temperature and pH. Qualitative benthic sampling in the littoral zone of selected ponds indicated the presence of many organisms there which were not found in the rest of the pond. Most of these organisms preferred aquatic macrophytes as habitat. However, despite the ability of the littoral zone to support benthic organisms, the far greater benthic area below the littoral zone was inhospitable to life.

GENERAL CONCLUSIONS

In conclusion, the results of this study indicate that impoundment of streams or springs can affect water quality in a number of ways. The water in the pond tends to become enriched with nutrients from run-off and drowned vegetation, leading to increased algal productivity and, possibly, to extensive blooms. Hypolimnetic oxygen depletion regularly occurs in the impoundments, and is often intensified by decomposing organic matter on the bottom and by lack of reaeration in deep water. This oxygen depletion renders the environment inhospitable to many sensitive benthic macroinvertebrates. Although most of these changes could be predicted based on the differences in pond and stream habitats and their respective physical, chemical, and biological characteristics, the impacts downstream are related more to the nature of the impoundment than to the local habitat.

INTRODUCTION

When a stream or river is dammed and impounded to form a reservoir or artifical lake/pond numerous changes occur in the physical, chemical and biological properties of the resulting water body. The physical shape of an impoundment, for example, is quite different from that of a natural lake. Whereas natural lakes tend to be deepest at their center, impoundments reach their maximum depth just upstream from the dam (Hutchinson 1966, Neel 1966). This physical property can lead to unusual circulation patterns within the impoundment, particularly since the retention time of most impoundments is relatively short. Another impediment to normal circulation patterns can be caused when a wooded area is flooded to form an impoundment. The trees left standing in such a reservoir can significantly reduce or halt normal wind driven turbulent mixing of the water column (Leentvar 1966, Baxter 1977). Such abnormal circulation patterns frequently result in profound changes in the normal dissolved oxygen and temperature patterns as well.

However, the most fundamental change that occurs after impounding a stream is the transformation of a lotic, highly oxygenated and heterotrophically based system to a lentic, less well oxygenated photoautotrophic system (Baxter 1977). This fundamental change results in large differences in the plant and animal populations; not only the type of organisms but also their diversity and biomass. Whether the changes that result from impounding streams are salutary or not is often a value judgement that is, in large measure, based on the intended use.

Farm impoundments are a large subclass of artificial reservoirs that can range in size from 0.4 ha. to more than 400 ha. (Dendy 1966). These small impoundments are used for a variety of purposes including: Irrigation, livestock water, household and barn water, fire protection, fish production, attraction of wild fowl, swimming and boating and aesthetic values as well as erosion control (Dendy 1966, Boyd 1979). The bulk of scientific literature on the subject of farm ponds, however, indicates that fish production is the dominant function of these impoundments, particularly in the southeast U.S.

Construction techniques for this type of impoundment are designed to reduce the littoral area of ponds to maximize phytoplankton production and minimize the growth of submergent and/or emergent aquatic macrophytes (Swingle and Smith 1947, Dendy 1966). In addition to these construction requirements pond owners are also advised to apply fertilizers to their ponds to increase fish yield and control aquatic weeds (Swingle and Smith 1942, Dendy 1966). Taken together, these practices result in a radical alteration of the previous stream ecosystem that was impounded to form the pond. In addition to the changes that occur within the impounded stream course, the discharge from these impoundments may also have unusual or undesirable effects on the biota downstream of the ponds, including increased biomass and reduced diversity of algae and benthic invertebrates (Kujawa 1974, Ward 1974).

Many farm impoundments in Florida will require DER construction permits based on the impact they are likely to have on water quality. Therefore, the Biology Section undertook a limnological study of a number of ponds in the panhandle area of Florida, to determine the ecological effects that result from impounding small streams or springs. The ponds chosen for study represented a wide variety of geological, topographical, land use and age types and are typical of the impoundments that are most frequently constructed in this state.

GENERAL METHODS AND DESCRIPTION OF SAMPLING SITES

To obtain as much data as possible in the time allotted for the study, a two part sampling regime was adopted. First, a small set of ponds was chosen to sample intensively on a monthly basis. These are henceforth referred to as the FREQUENCY group. A second, larger set of ponds was chosen to sample only during "worst case conditions" (i.e., during the summer when dissolved oxygen would likely be depleted). This set is known as the MASS group.

Information on location and ownership of ponds in the panhandle area was obtained primarily from the Soil Conservation Service of Leon, Gadsden, Walton, Jackson, and Escambia Counties. Additional information was obtained from the Northwest Florida Water Management District (NWFWMD) and the Department of Environmental Regulation Northeast District Tallahassee Branch Office.

Of the 32 ponds considered for inclusion in the study, four sites were chosen for FREQUENCY sampling. Three of these sites were streams at different stages of impoundment construction and filling. The fourth site was a series of two well established ponds. All have constantly flowing streams into and out of the pond site. An additional thirteen ponds were chosen for the MASS sampling on the basis of their accessability, drainage pattern and size. Most of the MASS sites are located in Gadsden County.

The impoundments at these sites were highly variable with respect to size, depth, capacity and area drained. Tables 1 and 2 summarize several important characteristics of both pond groups, and geographic locations are shown in Figures 1 to 3. Figures 4 to 7 illustrate the particular station locations and characteristics at each of the FREQUENCY sites.

Usage patterns for these impoundments are less variable, with the majority of ponds primarily used for recreation, fish production, homesite or development. Thus, the classical image of a "farm" pond, with its attendant potential problems associated with agricultural runoff (nutrients, sediment, control chemicals) may not always hold true for this subgroup of ponds.

Site locations for the FREQUENCY group were designated with an abbreviated name, while the MASS sites were designated by single letters (Tables 1 and 2). Stations at the different sites were given numbers. Stations upstream of the ponds, (where they existed) were numbered "1",

TABLE 1. Physical and geographical characteristics of FREQUENCY sampling ponds

	County	Range	Township	Section	Date Const.	Size (Hectares)	Cap'y (m^3)	Max Depth (M)	Discharge	Usage	Watershed (Hectares)
SHOAL RIVER ENTERPRISES (CRES)	O	23W	2,3N	4,5,33	1984/85	2	24,700	3.1	B	D,S	N/A
CRAWFORD (QUIN)	G	4W	3N	27	3/85	1.6	35,800	5.6	B	D	38.5
MOSS 2	J	11W	2N	5	1968	14.2	311,200	5.5	T	R,D	N/A
MOSS 3	J	11W	2N	5	1971	8.1	148,200	4.6	T	R,D	N/A
COBEY (GADS)	G	2W	2N	21	8/85	4.1	69,000	4.3	B	S,I,R	70.4

County: (O) Okaloosa
(J) Jackson
(G) Gadsden

Usage: (S) Stormwater Control
(D) Development
(R) Recreation
(I) Irrigation

TABLE 2. Physical and geographical characteristics of MASS sampling ponds.

	County	Range	Township	Section	Date Const.	Size (Hectares)	Cap'y (m^3)	Max Depth (M)	Discharge	Usage	Watershed (Hectares)
SYFRETT (A)	J	12W	3N	2	1978	1.2	13,200	2.7	B	R	N/A
KEVER (B)	G	5W	2N	31	3/79	.8	7,300	2.4	B	I,H	28.3
HOPPER (C)	G	5W	2N	10	N/A	.6	4,400	1.8	T	L	6.1
CRAWFORD (D)	G	4W	3N	27	N/A	.8	7,300	3.0	T	D	38.5
MCLENDON (E)	G	3W	2N	22	10/75	.4	4,900	3.6	T	H	N/A
SUBER (F)	G	2W	2N	30	6/83	.8	13,400	5.5	B	R	7.3
LETT (G)	G	2W	1N	3	10/76	2.8	20,700	1.8	T	H	38.1
WHITTLE (H)	G	6W	2N	8	9/82	.4	8,300	4.8	B	R,I	20.2
SCOTT (I)	G	5W	4N	31	12/82	.8	8,800	2.7	B	I,R	32.4
THOMPSON (J)	G	5W	3N	8	10/76	.4	4,900	3.0	T	H	16.8
KINGRY (K)	G	6W	3N	24	4/76	.4	4,900	5.2	T	L;R	19.4
MCCORMICK (L)	G	6W	3N	25	2/79	.8	13,400	4.2	B	L,I,R	14.2
FAIRCLOTH (M)	G	5W	3N	18	1/83	.8	7,300	4.2	B	R	30.0

County: (J) Jackson
(G) Gadsden

Discharge: (T) Top
(B) Bottom

Usage: (R) Recreation
(D) Development
(I) Irrigation
(S) Stormwater Control
(L) Livestock
(H) Homesite

FIGURE 1. Locations of the FREQUENCY sites in North Florida.

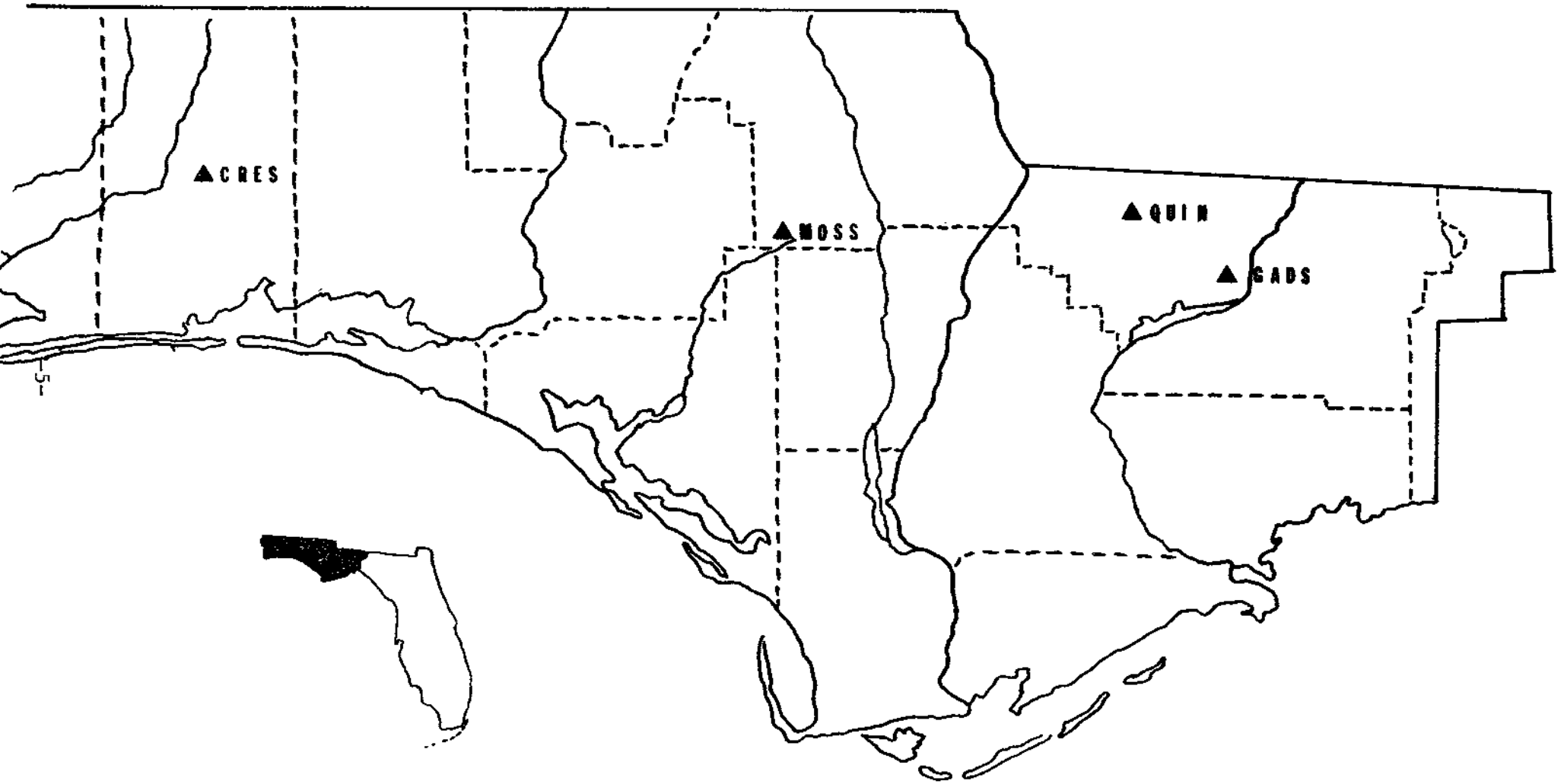


FIGURE 2. Locations of the MASS sites in Gadsden County, Florida.

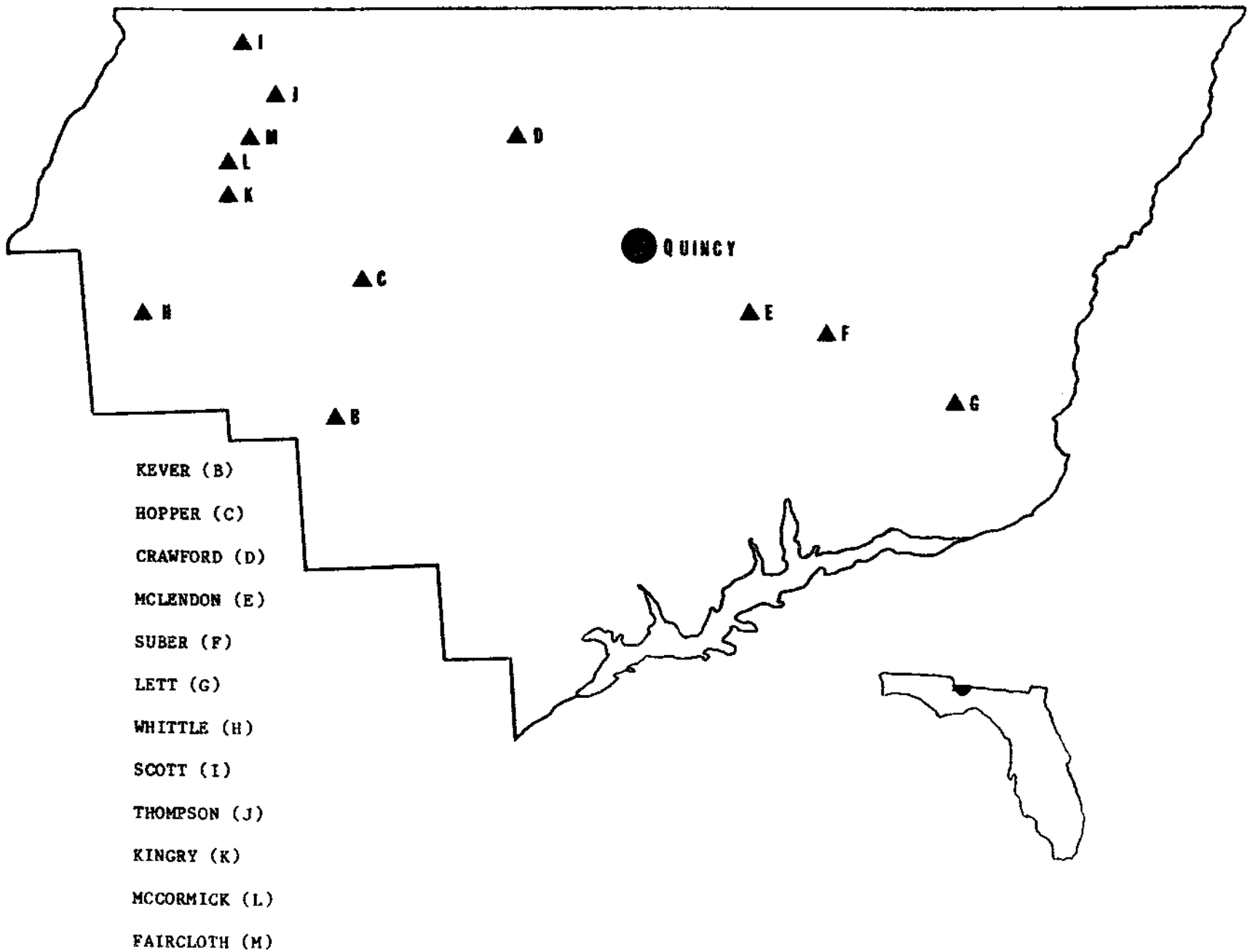


FIGURE 3. Location of the remaining MASS site in Jackson County, Florida.

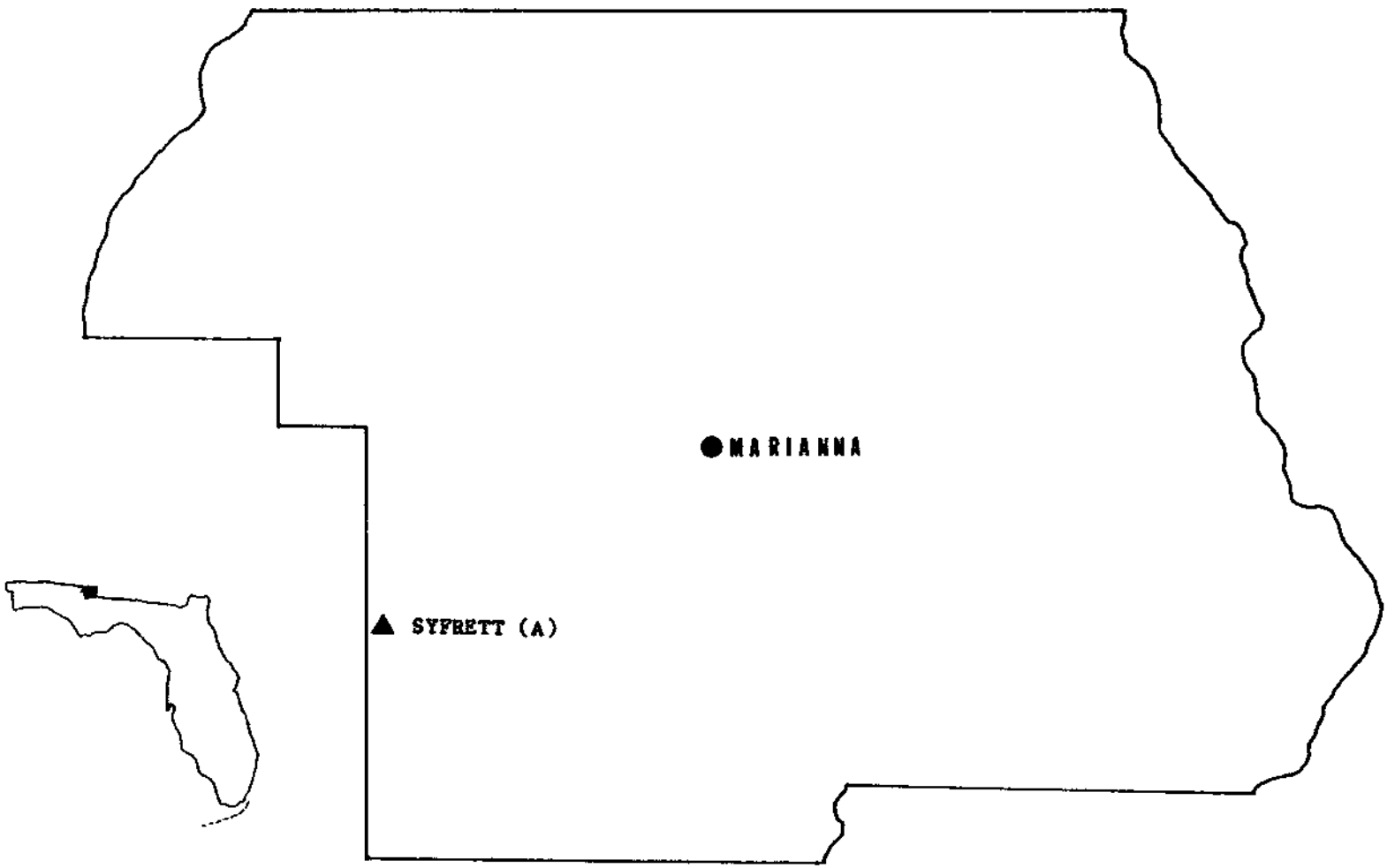


FIGURE 4. Station locations at the QUIN site.

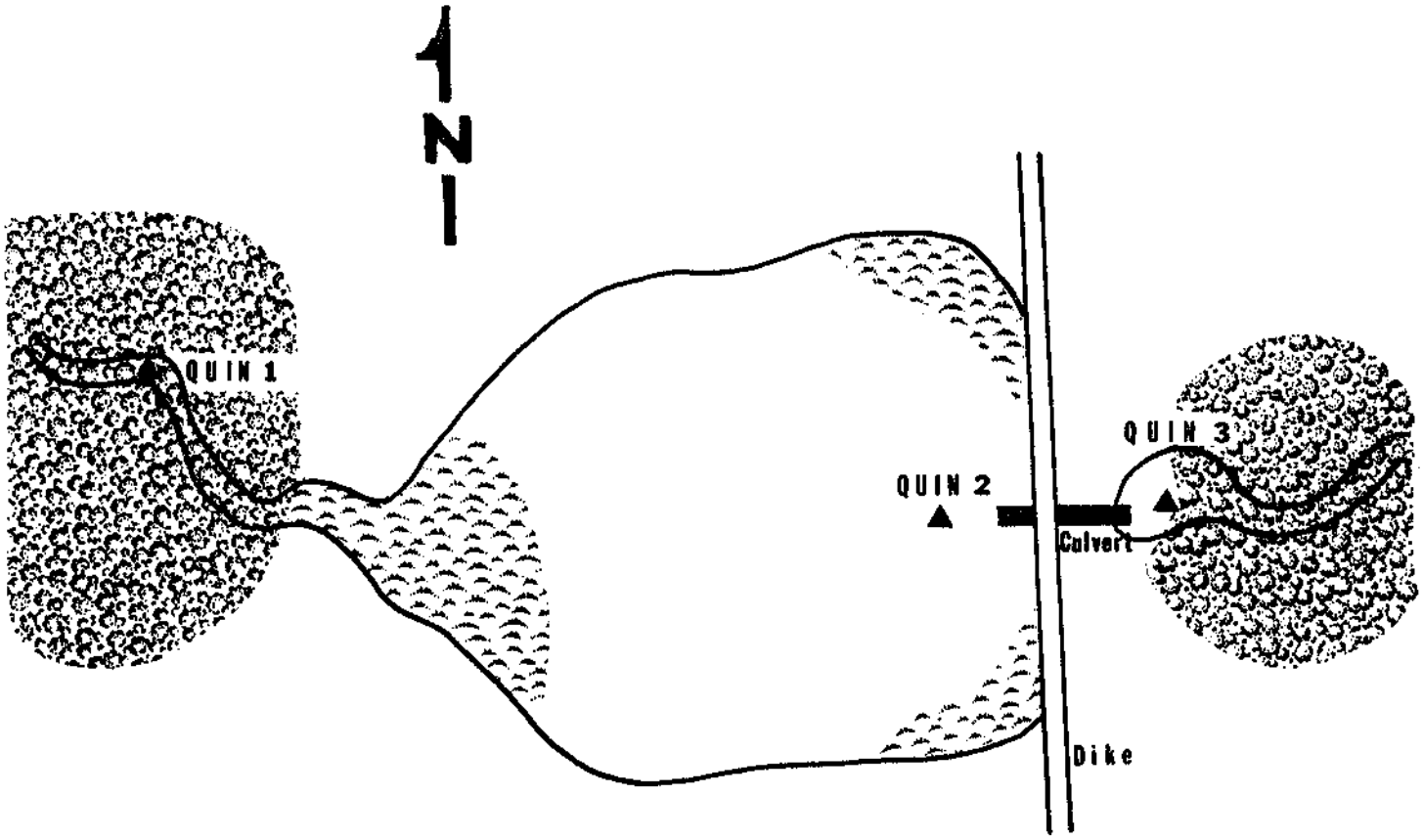


FIGURE 5. Station locations at the MOSS site.

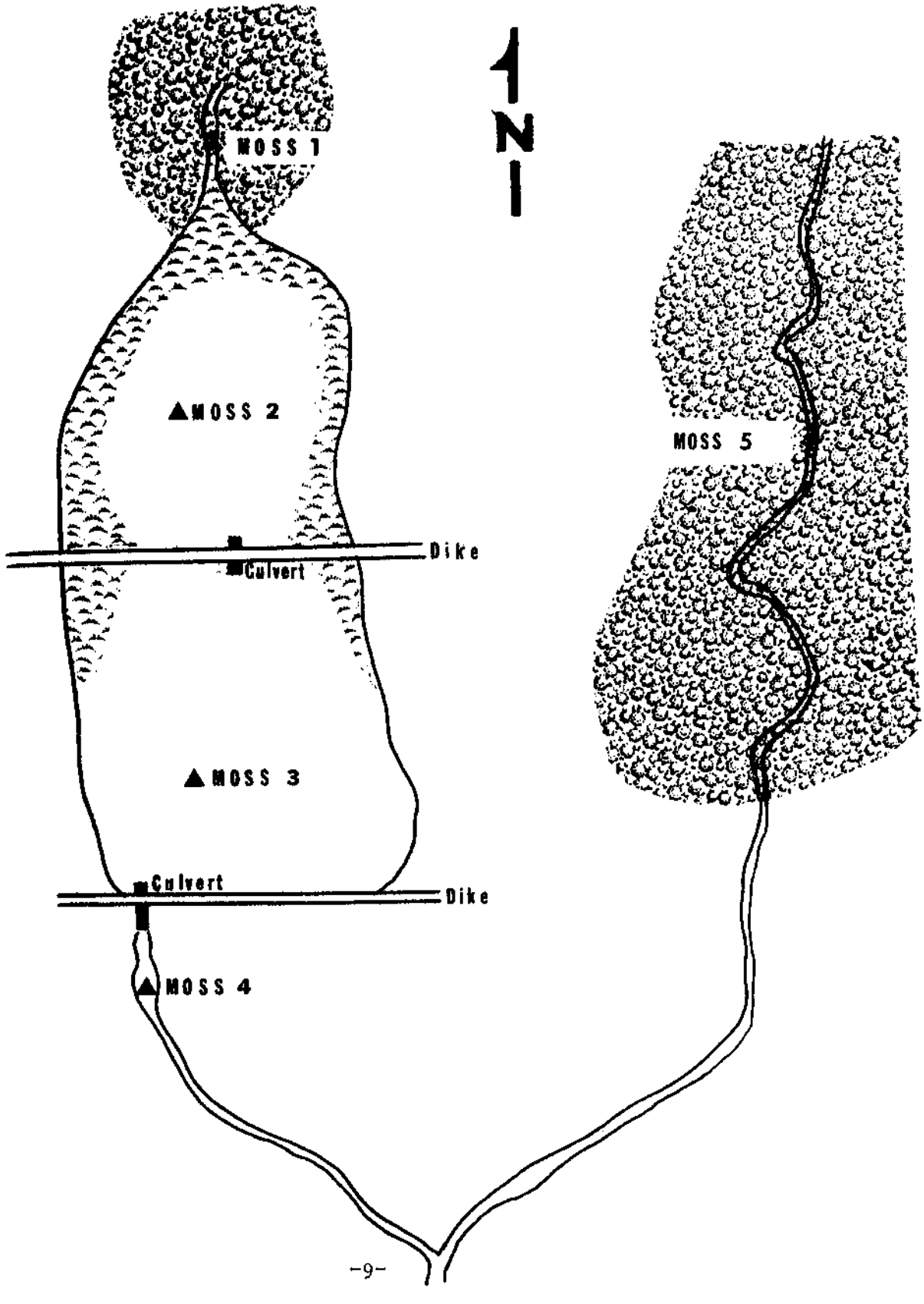


FIGURE 6. Station locations at the CRES site.

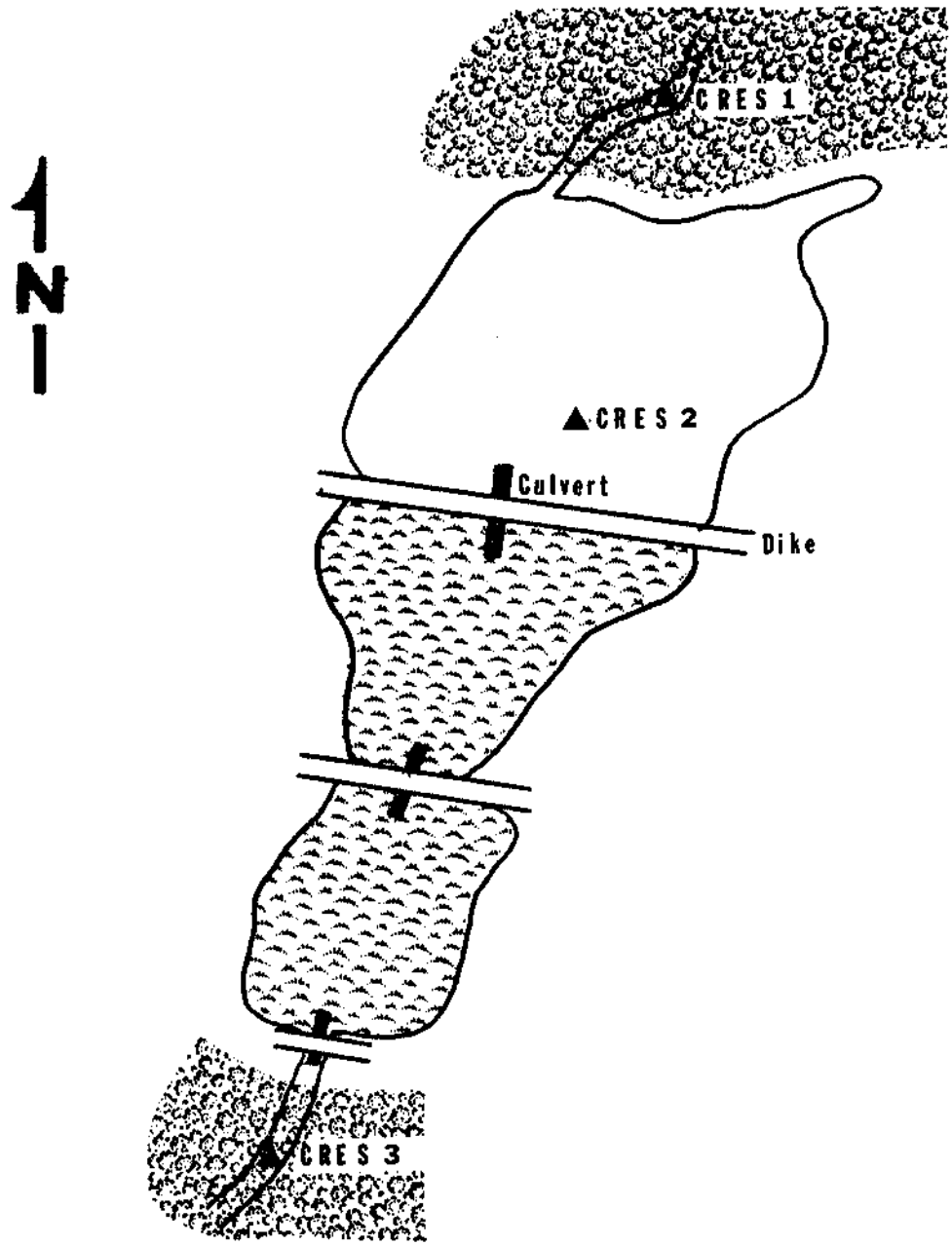
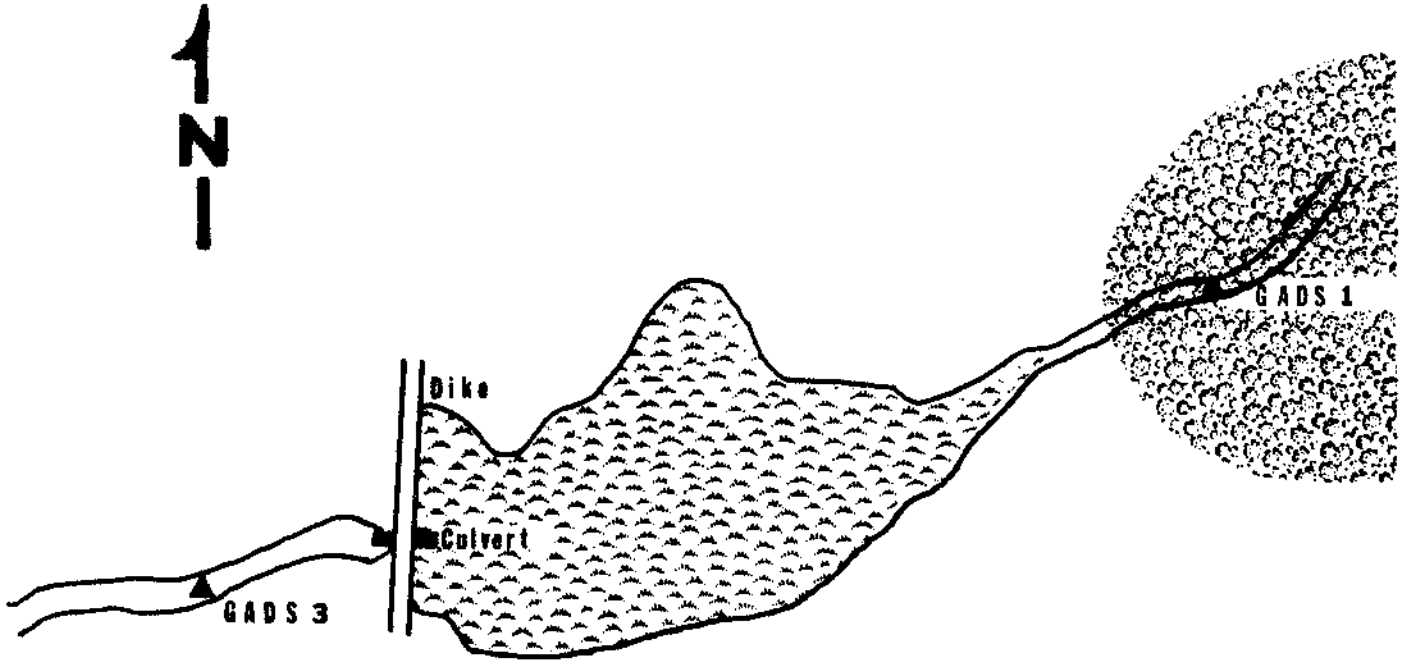


FIGURE 7. Station locations at the GADS site.



pond stations were numbered "2", and downstream stations were numbered "3". The exception to this scheme was at the FREQUENCY MOSS site where the upstream was "1", the first pond was "2", the second pond was "3", its outstream was "4", and a fifth station, established in a nearby unimpounded stream, was "5".

Sampling at FREQUENCY stations began 13 November, 1984, and was repeated every 28 days through 19 August, 1985. Physical, chemical, and biological parameters sampled at each station are listed in Table 3. The winter sampling for the MASS groups began 29 January, 1985, and was repeated on 26 February. Sampling at the MASS sites resumed in April and continued every 28 days through August. The amount of sampling for the MASS stations was somewhat reduced and is summarized in Table 3. A more detailed description of the methodology employed in the analysis of a particular parameter is given in the appropriate section.

TABLE 3. Field and laboratory physical, chemical and biological measurements for the FREQUENCY and MASS pond sites.

FREQUENCY Sites

Field Physical/Chemical Measurements

Temperature	at surface in streams and at
Dissolved oxygen	1 m intervals (depth profile)
Secchi disc	in ponds

Laboratory Physical/Chemical Measurements

pH	
Alkalinity	
Hardness	
Conductivity	
TKN-N	
NH_3-N	surface grabs at stream sites
NO_2+NO_3-N	and depth composite in ponds
Dissolved and total phosphate	(surface, mid-depth, bottom)
Chloride	
Sulfate	
Turbidity	
TSS	
Sediment Analysis (ponds only)	

Biological Measurements

Free Water Chlorophyll *a*	- Surface grabs at stream sites and depth composite in ponds (surface mid-depth, bottom)
Periphyton Chlorophyll *a*	- Glass slides incubated 28 days
Net Plankton (Phytoplankton and Zooplankton)	- 20 liter sample in streams, bottom to surface net tow in ponds
Periphyton	- Glass slides incubated 28 days
Macroinvertebrates	- Hester-Dendy artificial substrates 4 replicates, incubated 28 days
Macroinvertebrates	- Ponar grab samples, 3 replicates MOSS ponds only
Bacteria	- Surface grabs at all sites
Algal assay	- Algal growth potential and limiting nutrients - grab samples in streams, depth composite in ponds

MASS Sites

Field Physical/Chemical Measurements

Same as FREQUENCY sites

Laboratory Physical/Chemical Measurements

Same as FREQUENCY sites except all samples are grabs
Sediment analysis (ponds only)

Biological Measurements

Same as FREQUENCY sites except only 3 replicates of Hester-Dendy samplers, no ponar samples and algal assay measures algal growth potential only

PERSONNEL

The following individuals were involved in this report, with the specified areas of concentration. Unless specified, all are or were associated with the Florida Department of Environmental Regulation, Biology Section.

Robert Cowdery:	zooplankton
Craig W. Dye:	field and laboratory direction, benthic macroinvertebrates, editing
J. Marshall Faircloth:	algal assays
Mark O. Friedemann:	water chemistry, sediments
Russel B. Frydenborg:	benthic macroinvertebrates
Kathleen M. Lurding:	periphyton, phytoplankton, editing
Frances D. Moore:	manuscript preparation
Landon T. Ross:	planning, editing
Victoria K. Tauxe:	periphyton, phytoplankton
Leslee A. Williams:	bacteria
Loretta E. Wolfe:	statistics, programming

We also wish to acknowledge the contributions of:

Jerrell J. Daigle (macroinvertebrate identifications - Florida Department of Environmental Regulation, Tallahassee)

David Staples (chemical data - Florida Department of Environmental Regulation, Pensacola)

Finally, we wish to thank all the pond owners who participated in this study and allowed us access to their property.

WATER CHEMISTRY

INTRODUCTION

The chemical content of natural water varies from region to region and is normally a reflection of local geography and climate. It is also a recognized concept that the interaction of environment and organism is a fundamental mechanism which helps determine the physio-chemical composition of an aquatic system (Hutchinson 1957, Hynes 1970, Wetzel 1975). Thus, even though a stream and lake system may be located in the same geographic area, the chemical nature of the water in each may be quite different.

Stream or lotic ecosystems are generally based on allochthonous input with imported substances of terrestrial origin, such as leaf litter, making up the bulk of nutrition entering the system (Hynes 1970, Cummins 1974, Fisher and Likens 1973). Lotic habitats are typically high in flow, low in nutrients, and lack thermal stratification. The dynamics that govern stream chemical composition are thus subject to a high degree of influence from surrounding terrestrial morphology and land use patterns.

In contrast, lentic ecosystems, such as lakes and ponds, exhibit autochthonous characteristics. Productivity here is a function of nutrient cycling and organism interaction within the system. Photosynthesis exceeds respiration and terrestrial input accounts for only a fraction of the nutritional budget (Bott 1983). They are low flow nutrient sinks which may develop thermal stratification for all or part of the year.

Impoundment of a stream creates an autochthonous hybrid ecosystem which will inevitably generate new physio-chemical conditions. The magnitude of biological and physio-chemical changes elicited in response to impoundment will vary according to local geology, pond morphometry, watershed qualities and land use patterns. Nutrients entering an impoundment undergo energetic and distributional changes and, although a quantity of nutrient material may continue to move downstream, a portion of incoming nutrients will become trapped in the cycles characteristic of lakes and ponds.

An increasing demand for permits to construct impoundments has created the need to determine whether man-made impoundments eventually mimic natural lake conditions and/or precipitate detrimental changes in water quality downstream. In this section a summary of chemical data is presented to ascertain possible trends or impacts as a result of impoundment.

METHODS AND MATERIALS

Chemical samples were taken at all the FREQUENCY and MASS stations throughout the ten month course of the study. Samples taken at stream stations were surface grabs while those collected at pond stations were composite samples. Composites were made by collecting water from the surface, mid-depth and bottom and integrating the sample for analysis. Water samples were collected in opaque, half-gallon polyethylene containers and transported on ice to the Pensacola DER district office for chemical analysis.

Dissolved oxygen and temperature were measured in situ utilizing a YSI Model 51B oxygen meter. Conductivity, alkalinity, hardness, and pH were determined at the DER Biology Laboratory in Tallahassee. A YSI S-C-T meter (Model 33) was used to measure conductivity. Alkalinity and hardness were calculated through titrimetric methods (HACH Method), while a Corning pH meter (Model 10) was used to measure pH.

Parameters measured at the Pensacola laboratory and the Tallahassee laboratory are listed separately in Tables 4 and 5. All chemical methods follow the Methods for Chemical Analysis of Water and Wastes (U.S. EPA 1979), and Standard Methods (APHA 1980).

RESULTS AND DISCUSSION

FREQUENCY Sites

The results for chemical parameters measured at the FREQUENCY stations from November 1984 to August 1985 are summarized in Tables 6 through 9. The tables list means, ranges and standard deviations for all physico-chemical parameters measured over the period of investigation.

pH

The pH of a given body of water is an expression of hydrogen ion activity, based on the negative logarithm of hydrogen ion concentration. The mobility, solubility, degree of dissociation, and potential toxicity of many elements are dependent on pH (Lee and Hoadley 1967, Mason 1952, Fritz 1980). Since acidic water has a variety of inhibitory effects on common lacustrine processes, particularly algal growth (Stewart 1974) and bacterial nitrification (Wetzel 1975), and produces stress and even acute toxic effects in fish populations (Fritz 1980), pH serves as an important diagnostic tool in the assessment of water quality.

All sites in the study receive water from surficial aquifers. This water is characterized by low pH, alkalinity, and specific conductance. Not unexpectedly then, low pH values were found at all sites, ranging from 3.7 at CRES 1 to 6.5 at GADS 1. The results suggest the effect that the low buffering capacity of the water and the impact of organic matter decomposition have in generating acidic conditions (Kaufman 1970).

TABLE 4. Physico-chemcial parameter measured at the Pensacola DER district laboratory.

PARAMETER	METHOD	UNITS	REFERENCE
Total & dissolved phosphate	Colorimetric Automated block digestor	mg/l	U.S. EPA 1979
Ammonia	Colorimetric Automated phenate	mg/l	U.S. EPA 1979
Nitrite-nitrate nitrogen	Colorimetric Cadmium reduction	mg/l	U.S. EPA 1979
Total Kjeldahl nitrogen	Colorimetric Semi-automated block digestor	mg/l	U.S. EPA 1979
Non-Filterable Residue	Total suspended matter, dried	mg/l	APHA 1985
Total Residue	Total suspended matter, dried	mg/l	APHA 1985
Sulfate	Turbidimetric	mg/l	Standard Methods (APHA 1985)
Chloride	Mercuric nitrate	mg/l	Standard Methods (APHA 1985)
Turbidity	Turbidimeter	FTU's	Standard Methods (APHA 1985)

TABLE 5. Physico-chemical parameters measured at the Tallahassee DER biology laboratory.

PARAMETER	METHOD	UNITS	REFERENCE
pH	Electrometric	SU	U.S. EPA 1979
Hardness	Titrimetric	mg/l	HACH Methods Man. 7th Ed.
Alkalinity	Titrimetric	mg/l $CaCO_3$	HACH Methods Man. 7th Ed.
Conductivity	YSI SCT Probe	umhos/cm	APHA 1980
Temperature	YSI Thermistor	°C	APHA 1980
Dissolved oxygen	YSI membrane electrode	mg/l	APHA 1980

TABLE 6. Means, standard deviations, and number of observations for physico-chemical parameters measured at the CRES site.

	CRES 1			CRES 2			CRES 3		
	X (Min-Max)	Standard Deviation	No. Obs.	X (Min-Max)	Standard Deviation	No. Obs.	X (Min-Max)	Standard Deviation	No. Obs.
Conductivity umhos/cm	16.82 (5-60)	17.2	11	9.29 (5-15)	4.50	7	22.27 (10-55)	13.3	11
Alkalinity mg/l $CaCO_3$	2.73 (0-30)	9.05	11	4.29 (0-30)	11.3	7	4.09 (0-20)	6.64	11
Hardness mg/l	1.82 (0-5)	2.52	11	4.29 (0-10)	3.45	7	10.0 (0-25)	6.32	11
pH SU	4.12 (3.7-4.9)	.34	11	4.04 (3.9-4.3)	.14	7	5.27 (4.7-6.2)	.42	11
TKN-T mg/l	.20 (.03-.50)	.14	11	.56 (.23-.82)	.23	7	.50 (.25-1.19)	.27	11
NH_3-T mg/l (as N)	.01 (.01-.03)	.01	11	.05 (.01-.10)	.04	7	.31 (.13-.60)	.15	11
NO_2 + NO_3-T mg/l (as N)	.01 (.01-.02)	.00	11	.10 (.01-.25)	.09	7	.12 (.04-.19)	.04	11
Phos-T mg/l	.02 (.01-.06)	.01	11	.04 (.01-.07)	.02	7	.03 (.01-.06)	.02	11
Chloride-T mg/l	2.86 (2.1-4.4)	.72	11	2.93 (2.3-4.4)	.79	7	3.08 (2.4-4.4)	.61	11
Sulfate-T mg/l	2.11 (2.0-3.0)	.30	11	2.04 (2.0-2.30)	.11	7	2.0 (2.0-2.0)	0.00	11
Turbidity NTU	3.14 (1.0-8.5)	2.11	11	23.29 (11-42)	11.4	7	30.09 (5-82)	25.9	11
TSS mg/l	7.49 (4.6-25)	6.74	11	9.33 (4.6-17)	5.27	7	10.02 (4.6-22)	6.08	11

TABLE 7. Means, standard deviations, and number of observations for physico-chemical parameters measured at the MOSS site.

	MOSS 1			MOSS 2			MOSS 3			MOSS 4			MOSS 5		
	X (Min-Max)	Standard Deviation	No. Obs.	X (Min-Max)	Standard Deviation	No. Obs.	X (Min-Max)	Standard Deviation	No. Obs.	X (Min-Max)	Standard Deviation	No. Obs.	X (Min-Max)	Standard Deviation	No. Obs.
Conductivity umhos/cm	14.09 (5-20)	5.39	11	13.18 (10-20)	3.37	11	12.91 (5-20)	4.01	11	13.75 (10-20)	4.43	8	11.82 (10-15)	2.52	11
Alkalinity mg/l $CaCO_3$	1.82 (0-20)	6.03	11	1.82 (0-10)	3.37	11	1.82 (0-10)	3.37	11	.62 (0-5)	1.77	8	.91 (0-10.0)	3.01	11
Hardness mg/l	4.54 (0-10)	3.50	11	6.36 (0-10)	3.23	11	7.23 (5-15)	3.40	11	6.56 (5-10)	2.29	8	4.36 (0-10.0)	2.73	11
pH SU	4.45 (3.8-5)	.36	11	4.90 (4.4-5.2)	.24	11	5.20 (4.6-6.1)	.42	11	5.44 (5.2-6.0)	.34	8	4.47 (3.9-5.2)	.37	11
TKN-T mg/l	.26 (.07-.49)	.14	11	.48 (.35-.65)	.10	11	.53 (.25-.95)	.18	11	.46 (.29-.61)	.10	8	.23 (.04-.39)	.10	11
NH_3-T mg/l (as N)	.02 (.01-.06)	.02	11	.02 (.01-.05)	.01	11	.01 (.01-.03)	.01	11	.01 (.01-.01)	.00	8	.01 (.01-.01)	0.00	11
NO_2 + NO_3-T mg/l (as N)	.18 (.16-.23)	.02	11	.27 (.01-.09)	.03	11	.02 (.01-.08)	.03	11	.02 (.01-.08)	.02	8	.20 (.17-.24)	.03	11
Phos-T mg/l	.02 (.01-.07)	.02	11	.02 (.01-.07)	.02	11	.02 (.01-.05)	.01	11	.02 (.01-.04)	.01	8	.02 (.01-.03)	.01	11
Chloride-T mg/l	4.34 (3.4-5.8)	.64	11	3.87 (3.1-5.8)	.71	11	3.74 (3.0-5.8)	.77	11	3.77 (3.1-4.1)	.47	8	4.18 (3.5-5.8)	.68	11
Sulfate-T mg/l	2.0 (2.0-2.0)	0.00	11	2.19 (2.0-3.0)	.31	11	2.20 (2.0-3.5)	.46	11	2.31 (2.0-4.5)	.88	8	2.0 (2.0-2.0)	0.00	11
Turbidity NTU	2.71 (1.0-5.0)	1.35	11	5.17 (2.0-10.0)	2.93	11	5.67 (2.0-18)	4.89	11	4.21 (2.0-9.0)	2.21	8	3.52 (1.0-9.0)	2.76	11
TSS mg/l	5.58 (4.6-10.0)	2.14	11	5.63 (4.6-9.0)	1.56	11	5.54 (4.6-10)	1.80	11	6.22 (4.6-15.0)	3.59	8	4.65 (4.6-5.2)	.18	11

TABLE 8. Means, standard deviation and number of observations for physico-chemical parameters measured at the QUIN site.

	QUIN 1			QUIN 2			QUIN 3		
	X (Min-Max)	Standard Deviation	No. Obs.	X (Min-Max)	Standard Deviation	No. Obs.	X (Min-Max)	Standard Deviation	No. Obs.
Conductivity umhos/cm	9.54 (5-10)	1.51	11	16.1 (10-20)	4.86	9	20.91 (10-30)	6.25	11
Alkalinity mg/l$CaCO_3$	2.27 (0-20)	6.07	11	5.56 (0-30)	4.92	9	5.45 (0-20)	6.11	11
Hardness mg/l	3.64 (0-5)	2.34	11	6.67 (0-10)	4.33	9	9.54 (5-20)	4.16	11
pH SU	4.87 (4.3-5.5)	.38	11	5.14 (4.7-6.0)	.38	9	5.14 (4.7-5.8)	.35	11
TKN-T mg/l	.18 (.03-.65)	.18	11	.95 (.44-1.27)	.31	9	.95 (.22-1.76)	.49	11
NH_3-T mg/l (as N)	.01 (.01-.04)	.01	11	.04 (.01-.06)	.03	9	.25 (.04-.64)	.17	11
NO_2 + NO_3-T mg/l (as N)	.30 (.21-.36)	.05	11	.01 (.01-.03)	.01	9	.03 (.01-.13)	.04	11
Phos-T mg/l	.04 (.01-.10)	.03	11	.09 (.01-.18)	.06	9	.15 (.01-.36)	.11	11
Chloride-T mg/l	3.3 (2.5-4.4)	.55	11	3.73 (3.2-4.6)	.50	9	3.60 (.4-4.6)	1.14	11
Sulfate-T mg/l	2.0 (2.0-2.0)	0.00	11	2.0 (2.0-2.0)	0.0	9	2.0 (2.0-2.0)	0.00	11
Turbidity NTU	3.75 (1.8-7.0)	2.16	11	13.5 (6.0-24.0)	5.20	9	18.82 (7.0-29.0)	7.47	11
TSS mg/l	5.69 (4.6-10.0)	1.87	11	11.52 (4.6-23.0)	5.64	9	20.31 (4.5-59.0)	14.7	11

TABLE 9. Means, standard deviations, and number of observations for physico-chemical parameters measured at the GADS site.

	GADS 1			GADS 3		
	X (Min-Max)	Standard Deviation	No. Obs.	X (Min-Max)	Standard Deviation	No. Obs.
Conductivity umhos/cm	36.0 (20-60)	10.7	10	72.5 (10-120)	36.5	10
Alkalinity mg/l $CaCO_3$	6.0 (0-25)	8.43	10	19.5 (0-40)	15.5	10
Hardness mg/l	11.50 (5-30)	8.83	10	22.50 (5-55)	17.0	10
pH SU	5.27 (4.8-6.5)	.53	10	6.01 (5.1-6.3)	.45	10
TKN-T mg/l	.39 (.09-.56)	.23	10	.55 (.14-1.02)	.26	10
NH_3-T mg/l (as N)	.08 (.01-.15)	.04	10	.21 (.06-.61)	.16	10
NO_2 + NO_3-T mg/l (as N)	.015 (.01-.04)	.01	10	.06 (.01-.11)	.04	10
Phos-T mg/l	.06 (.02-.15)	.05	10	.08 (.01-.15)	.06	10
Chloride-T mg/l	5.46 (2.5-6.1)	.48	10	5.39 (4.1-6.3)	.69	10
Sulfate-T mg/l	2.02 (2.0-2.2)	.06	10	2.0 (2.0-2.0)	0.000	10
Turbidity NTU	28.90 (7.0-102.0)	28.0	10	17.50 (9.0-34)	8.07	10
TSS mg/l	21.82 (4.7-80.0)	22.0	10	11.63 (4.6-56.0)	15.8	10

Mean pH values at the upstream sites were 4.47 at MOSS 5, 4.45 at MOSS 1, 4.12 at CRES 1, 4.87 at QUIN 1 and 5.27 at the GADS 1 site. Soil characteristics may play a role in the slightly elevated pH values at the QUIN 1 and GADS 1 sites. The sandy soils in proximity to the MOSS and CRES stations are highly leached, have low cation exchange and thus posess very little buffering capacity and tend to be acidic. In contrast, the soils at the QUIN and GADS stations are dominated by clays, which have an increased buffering capacity and thus resist alterations in pH more effectively (Brady 1974,).

Pond pH values were higher than upstream values for those ponds which have had time to stabilize. For example, mean pH values at MOSS 2 and MOSS 3 were 4.9 and 5.2, respectively, vs. 4.45 at MOSS 1. However, pH in the CRES and QUIN ponds, both of which had recently filled, did not vary greatly from upstream pH values. Mean pH at CRES 2 was 4.0 while that measured at QUIN 2 was 5.1. Observed mean upstream values at CRES 1 and QUIN 1 were 4.12 and 4.87 respectively.

Downstream pH values were higher than upstream values, however they did not vary from pond values at three of four sites. At the CRES site though, where pond water was discharged into a series of empty pond basins before reaching an outlet to the downstream, the pH rose to a mean of 5.2 from 4.0. The general increase in pH from upstream to downstream is likely the result of increased plankton productivity, which effectively decreases CO_2 concentrations and boosts pH (Stewart 1974).

Alkalinity

Alkalinity is the ability of water to neutralize acids and is implicitly related to pH (Bouwer 1978). Alkalinity values ranged from 0 to 40 mg/l $CaCO_3$. Mean alkalinities at all stations, except the GADS 3 site, were 6.0 mg/l or less. Mean alkalinity at the GADS 3 station was 19.5 mg/l. Perturbation of the environment upstream from GADS 3 in the form of pond construction may explain the increase in alkalinity levels downstream. The alkalinity values noted at the other study sites are indicative of the type of water supplied by surficial aquifer to streams in the area (Kaufman 1970, Bouwer 1978).

Conductivity

Specific conductance is a measure of the capacity of water to conduct an electric current and serves as an indicator for the presence of inorganic ions. Conductivity is affected by drought, precipitation and the concentration of biologically active organisms, among other factors, and can be utilized as an early indicator of changes in water quality (Flora and Rosendahl 1982, Slack and Kaufman 1972).

Conductivity values did not appear to follow any seasonal trends and, with the exception of the GADS stations, remained relatively stable through the year. An occasional peak in conductance at the CRES sites appears to reflect a combination of effects from drought and perturbation of the surrounding uplands. Mean values for specific conductance ranged from 9.27 to 22.27 umhos/cm^2 for all but one site. These results reflect values expected for the panhandle region of Florida (Slack and Kaufman 1975).

In contrast to the other sites, conductivity values of 36 umhos and 72.5 umhos/cm^2 were observed at GADS 1 and GADS 3, respectively. This suggests the possibility of influence from the Floridian aquifer (F.D.E.R 1985, Kaufman 1975) along with possible perturbation effects upstream from GADS 3. The alkalinity and pH measurements also parallel the conductivity values. The type of incoming water and stream topography along with the presence of iron bacteria may account for these higher values. Although specific bacteriological tests were not conducted, visual inspections indicated a large population of iron bacteria was thriving at the GADS site. This may indicate the presence of increased levels of iron in the area and thus might explain the higher conductivities.

Hardness

The presence of large concentrations of alkaline earths (i.e. calcium, and magnesium) dissolved in water and combined with carbonates, sulfates or chlorides is defined as hardness. The U.S. Geological Survey defines softwater as water with a hardness of < 60 ppm (Shampine 1975) while Miller et al. (1974) regard softwater as water with a hardness of $\leq$ 75 ppm. Florida waters are generally soft in nature and exhibit mostly carbonate hardness (Shampine 1975, Shannon and Brezonik 1972). All stations displayed hardness values well under the interpreted maximum for a softwater classification. Stations GADS 1 and GADS 3 had the highest mean hardness values at 11.5 mg/l and 22.5 mg/l, respectively. The remaining stations had mean hardness values of 10 mg/l or less. No spatial differences between upstream, pond, and outfall were apparent with respect to hardness during the study.

Turbidity

Turbidity is a measurement of suspended solid content caused by particulate matter present in the water column. A trend of increasing turbidity as water moved from upstream through the impoundment to the outfall area was observed in newly formed impoundments (see Stations CRES and QUIN, Tables 6 and 8). Erosion from cleared land adjacent to pond basins accounted for a major portion of the increased turbidity in these recently completed impoundments. However, biogenic turbidity will generally become more prominent as algal communities and zooplankton populations are established and abiotic materials settle to the bottom of the pond.

Spatial differences in turbidity appear to be offset as time progresses and the impoundments stabilize. For example, mean turbidity in the MOSS ponds (MOSS 2 = 5.17 FTU, MOSS 3 = 5.67 FTU), which are the oldest impoundments in the study, did not vary significantly from that noted upstream (MOSS 1 = 2.71 FTU) or in the control stream (MOSS 5 = 3.52 FTU).

Turbidity at the GADS sites reflected the influence of local geology and ecology. The presence of large amounts of clay and silt particles and ongoing pond construction account for the turbidity values observed here. The GADS 1 site had the highest single turbidity value of 102 FTU's, however the mean turbidity for GADS 1 was substantially lower (28.9 FTU's). The occurrence of this peak in turbidity may be related to the appearance of large quantities of iron bacteria in the stream or an unknown perturbation upstream of the sampling site.

Short term effects of increased turbidity in the newer impoundments may result in temporary changes in water quality and biological activity. The persistance of high turbidities can only exacerbate other water quality problems and prevent the return of conditions similar to that of pre-impoundment.

Sulfate

Sulfate occurrence is the result of decaying organic material and dissolution of evaporites, i.e. gypsum and anhydrite, which are found in the Floridan aquifer (Bouwer 1978, Crane 1983). Sulfate is also present in rainwater. The results of chemical analysis suggest that sulfate may not play a significant role in the overall ecology of the impoundments since sulfate values were just above the limit of detection at all stations during the study.

Chloride

The primary sources of chloride in natural water are precipitation, marine aerosols, and geologic contributions from minerals such as apatite (Hem 1959). Mean concentration of chloride at the study sites ranged from 2.86 to 5.46 mg/l, though no spatial or seasonal trends were observed.

Total Suspended Solids

Total suspended solids (TSS) is a dry weight measurement of inorganic particles in the water column. Mean TSS values ranged from 4.65 to 21.82 mg/l. Variation of values appears to be a function of soil composition and ground litter on adjacent land. Soils around the QUIN and GADS stations are dominated by clays while the MOSS and CRES sites are surrounded by land characteristically sandy in nature. The highest TSS values were recorded at the sites dominated by clay soils. At the QUIN stations, significant differences in TSS were observed from the upstream

area (5.46 mg/l), to the pond (11.52 mg/l), and outfall (20.31 mg/l). TSS at the GADS stations was also relatively high as compared with the MOSS and CRES study sites. Average TSS at GADS 1 was 21.82 mg/l while TSS at GADS 3 was 11.63 mg/l. Mean TSS at the CRES stations fluctuated from 7.49 mg/l to 10.02 mg/l while those at the MOSS stations ranged from 4.65 mg/l to 6.22 mg/l. TSS and turbidity are inherently related and thus not surprisingly turbidity and TSS results reflect virtually identical conditions.

Rainfall

Rainfall data collected by the National Oceanic and Atmospheric Administration indicated extremely dry conditions for all stations during the first two months of sampling. During the next three months a slight increase in rainfall activity was noted, but rainfall was still below normal levels (Figure 8).

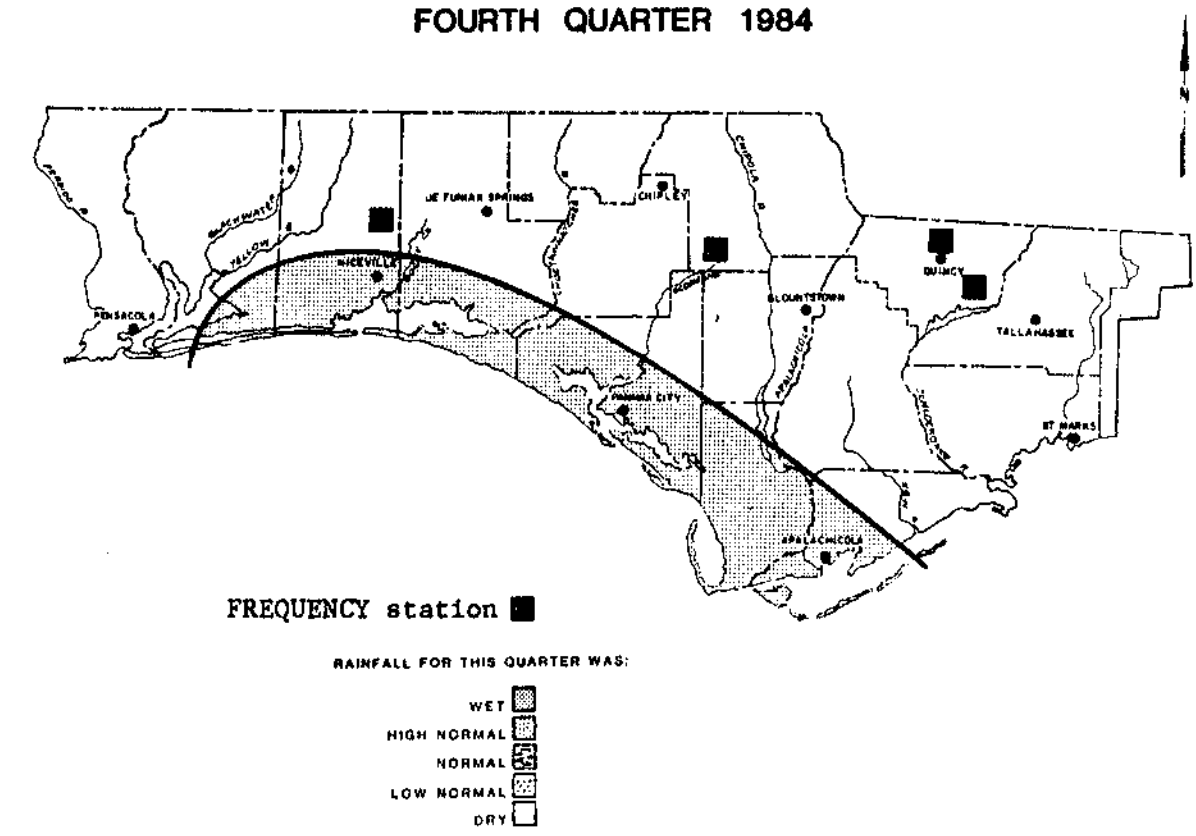
Below normal rainfall in the second quarter led to dry conditions at two sites, GADS and MOSS (MOSS 4), while rainfall reached normal levels at the QUIN and CRES sites. Third quarter rainfall activity reached normal levels at the GADS and MOSS sites and increased to above normal at the CRES and QUIN stations (Figure 9).

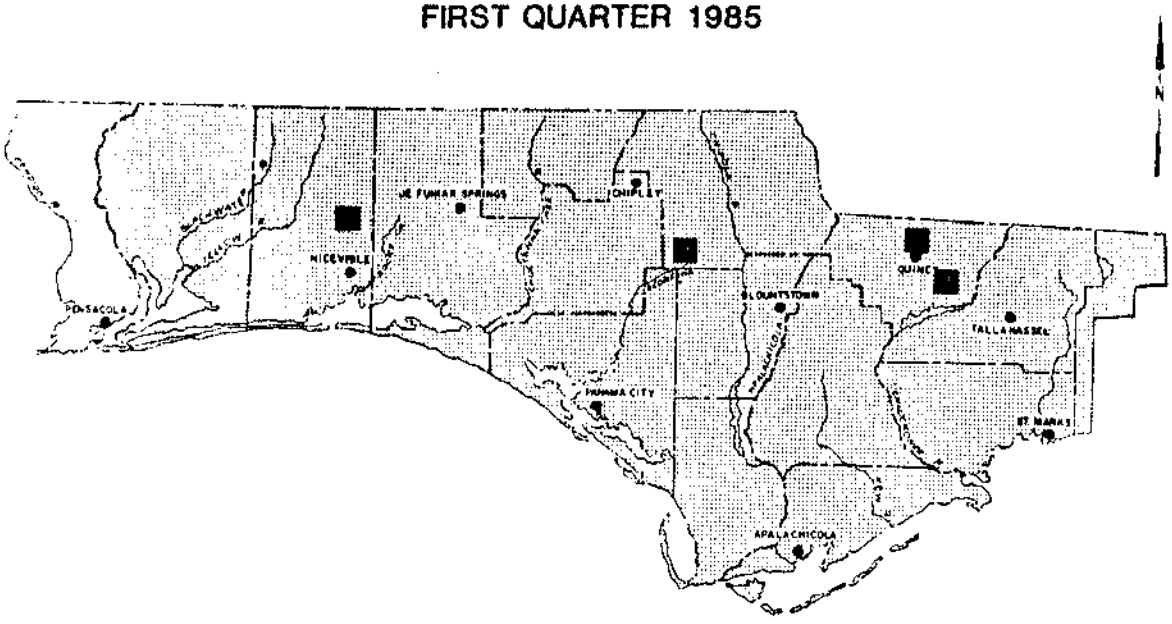
Temperature

Water temperature exerts a considerable influence on the dynamics of aquatic ecosystems. Temperature directly affects the growth rates and survival of many aquatic organisms, and chemical interactions and rates of reaction such as nitrification (i.e., bacterial metabolism), are subject to influence by water temperature as well (Odum 1971, Hutchinson 1957). Radiant/atmospheric heating creates a temperature gradient within an impoundment and strata of water of varying temperature may develop. Stratification of the water column inhibits mixing and creates the potential for anoxic conditions near the bottom (Wetzel 1975). Vertical mixing of the water column can be induced by wind, which tends to break down stratification (Wetzel 1975, Holloway 1980). However, local topography may shelter ponds from the action of wind and thus effectively inhibit the vertical mixing of stratified water. A turnover of water can also occur in the spring and fall as a result of seasonal temperature variations, which produce density gradients in the water. Thermal resistance to mixing is negligible when water reaches a particular density and any amount of wind will supply enough energy to drive the circulation of the water column.

Stream temperatures ranged from 4.2-29.0°C. In ponds somewhat less variability in temperature was observed due to the qualities of heat transport inherent to water, and values ranged from 9.0 to 29.0°C. Temperature ranges reflected seasonal variation. The ponds were all generally well mixed from November through February and displayed the

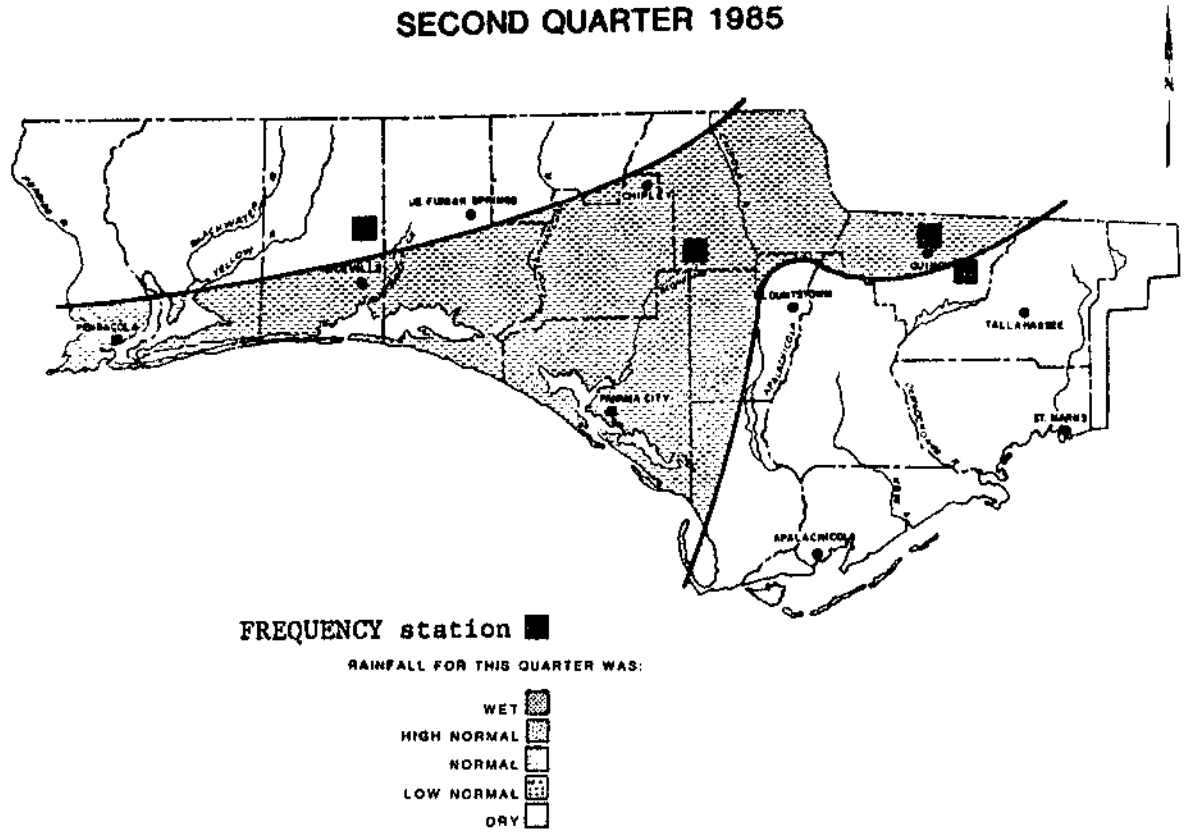
FIGURE 8. Rainfall data from October 1984 through March 1985.





Data Source: Northwest Florida Water Management District

FIGURE 9. Rainfall data from April through September 1985.



Data Source: Northwest Florida Water Management District

first signs of thermal stratification during late March or early April. By late April stratification was well established and continued through the duration of the study (Figures 10-13). Mean temperatures downstream of the ponds were slightly elevated (Table 10). This condition is due to the warming effect of the sun on surface waters in the ponds and its eventual release to downstream reaches through surface discharge mechanisms, which service all of the FREQUENCY ponds.

Dissolved Oxygen

Dissolved oxygen (D.O.) is essential to the metabolic functions of aquatic organisms that respire aerobically. The amount of dissolved oxygen found in water is mainly a function of water temperature and atmospheric partial pressure, although other factors such as salinity, hydrostatic pressure, and phytoplanktonic oxygen production have varying degrees of influence over D.O. solubility and concentration (Wetzel 1975).

The distribution of D.O. in streams is basically uniform over depth due to the generally well mixed condition of water in small turbulent stream systems (Hynes 1970). In contrast, lakes and ponds exhibit cyclic changes in D.O. distribution in response to seasonal weather conditions, wind perturbation, atmospheric heating, depth related temperature gradients, algal and macrophytic productivity and basin morphometry (Wetzel 1975, Charlton 1980, Papst et al. 1980).

Dissolved oxygen concentration in oligotrophic lakes is regulated to a great extent by the physical characteristics of the water and its surrounding environment. The oxygen levels increase as water temperature decreases. Dissolved oxygen levels in eutrophic lakes are the result of the interaction of physical characteristics with the by-products of elevated nutrient loads and the subsequent range of processes which follow in turn. The model oxygen curve depicting eutrophic lake conditions is termed clinograde. The increased amount of organic matter created under eutrophic conditions results in a rapid depletion of D.O. in the hypolimnion, which may remain anoxic for long periods of time. The resulting effects on bottom dwelling organisms may create a wide range of impacts on the lake or pond as well as areas downstream.

Dissolved oxygen levels at the upstream sites ranged from 6.3-11.0 mg/l, with the exception of the GADS 1 station which varied considerably over the course of study, ranging from 2.4-9.4 mg/l. The anomalous D.O. characteristics of the GADS site suggest possible perturbations further upstream.

FIGURE 10. Pond temperature profile for station CRES 2.
(1° C intervals)

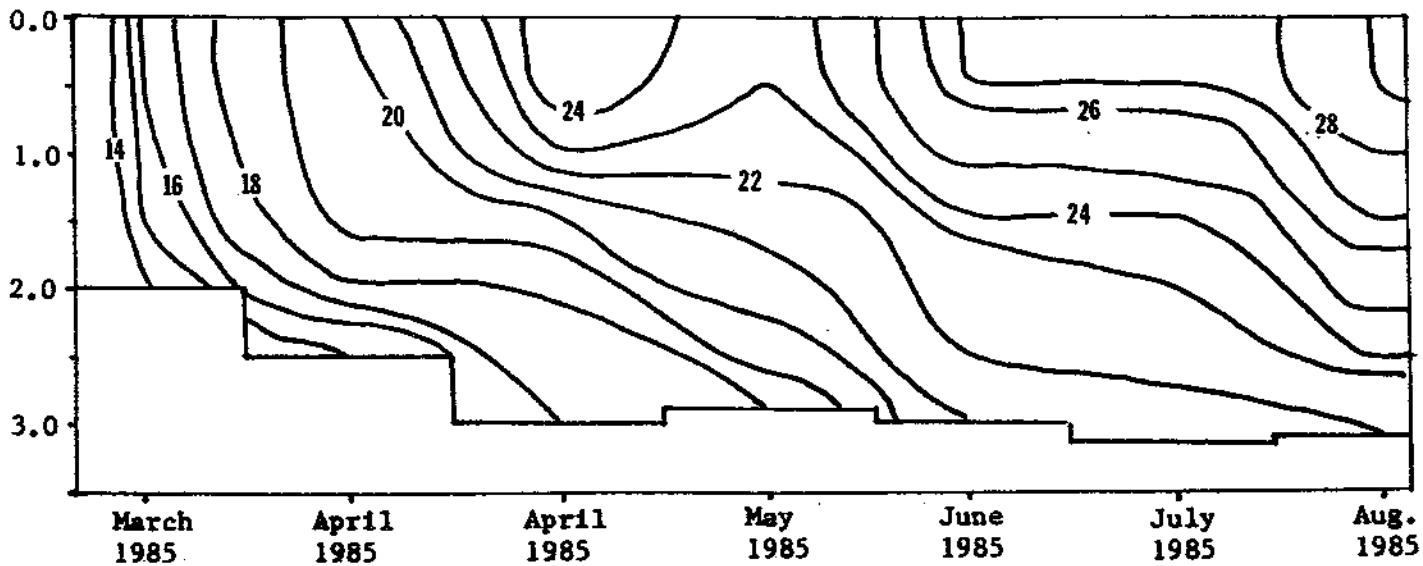


FIGURE 11 . Pond temperature profile for station MOSS 2.
(1°C intervals)

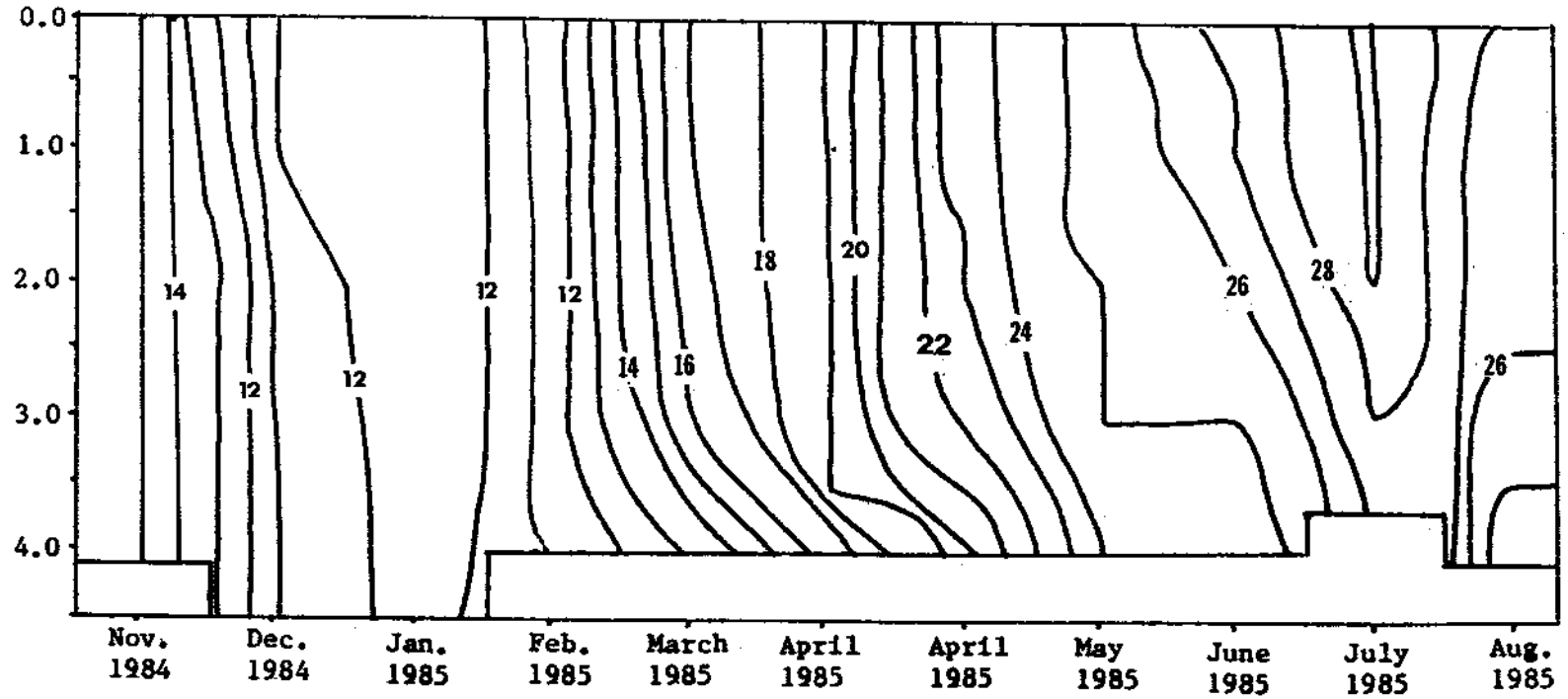


FIGURE 12. Pond temperature profile for station MOSS 3.
(1°C intervals)

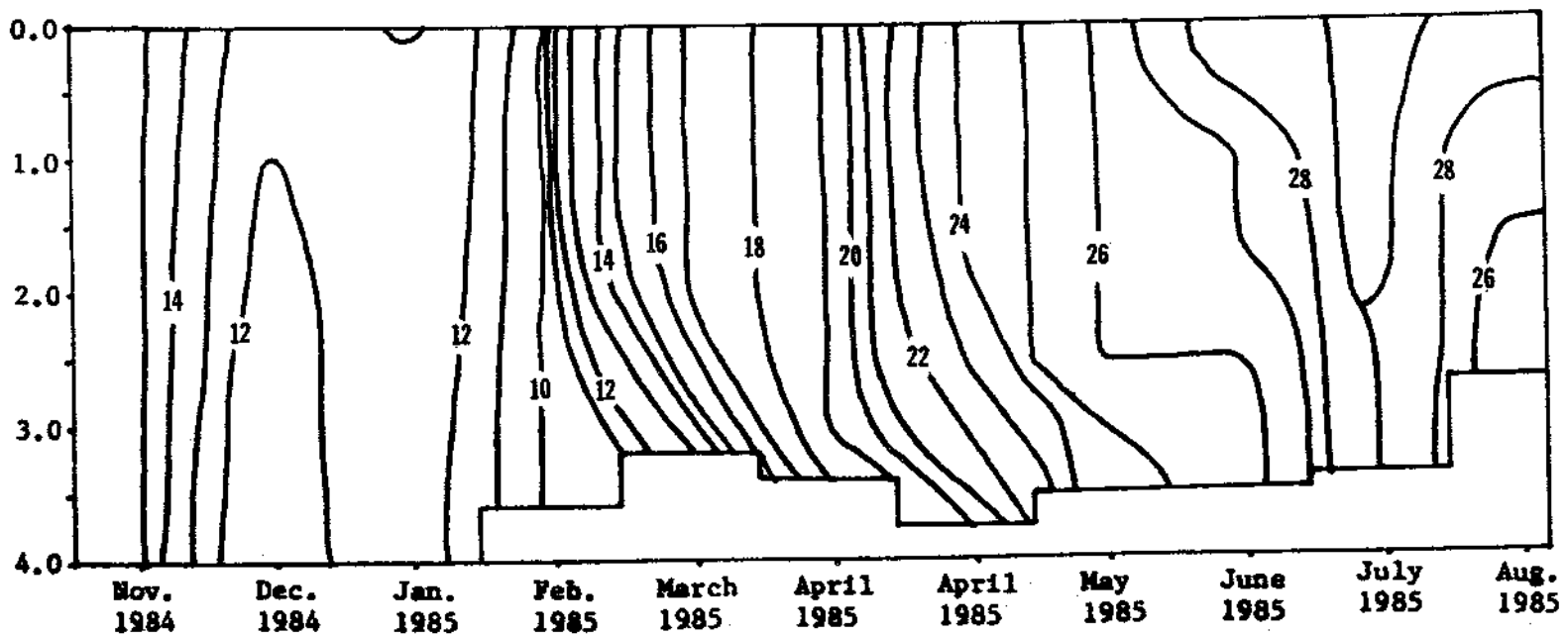


FIGURE 13. Pond temperature profile for station QUIN 2.
(1°C intervals)

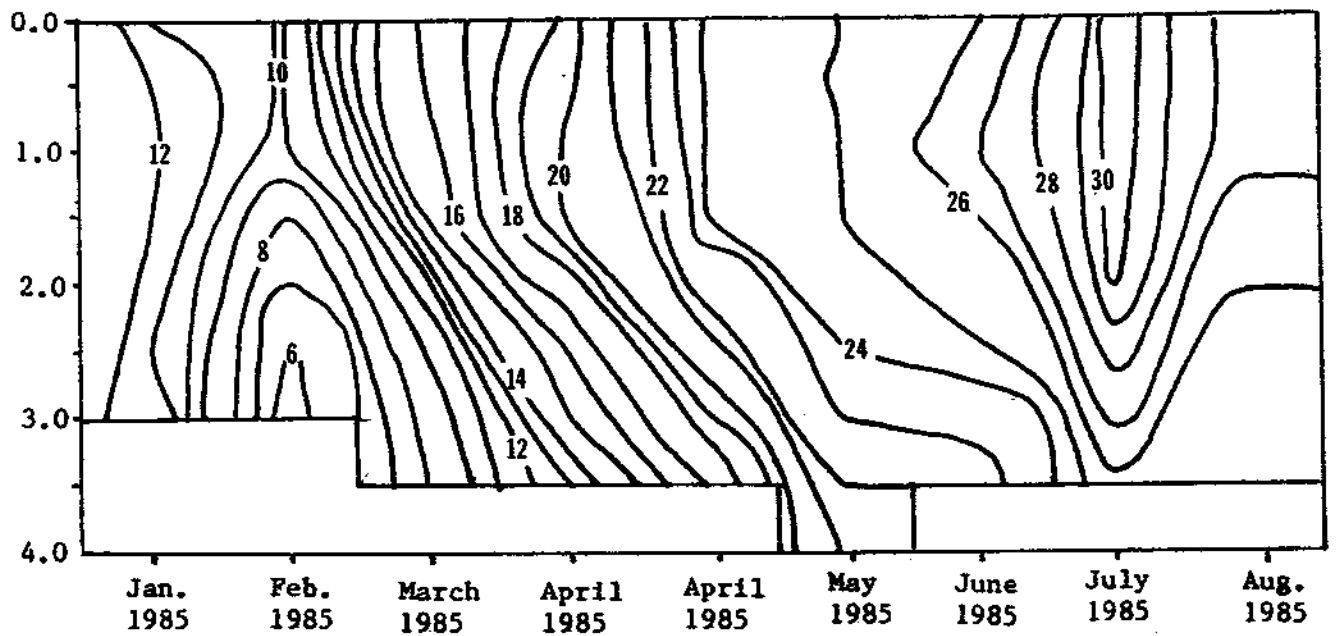


TABLE 10. FREQUENCY station temperature ranges and means.

Station	Temperature Range (°C)	Mean Temperature (°C)
CRES 1	8.5 - 22.0	14.95
CRES 2	14.0 - 22.0	18.29
CRES 3	8.2 - 26.0	15.95
GADS 1	10.6 - 25.0	18.36
GADS 3	10.3 - 26.5	18.73
MOSS 1	4.2 - 23.6	16.48
MOSS 2	11.0 - 27.2	18.06
MOSS 3	10.5 - 29.0	18.65
MOSS 4	12.0 - 28.1	17.57
MOSS 5	9.0 - 24.0	16.09
QUIN 1	5.4 - 26.1	16.03
QUIN 2	9.0 - 25.8	16.76
QUIN 3	9.0 - 28.0	17.54

FIGURE 14. Pond dissolved oxygen profile for station CRES 2.
(1ppm intervals)

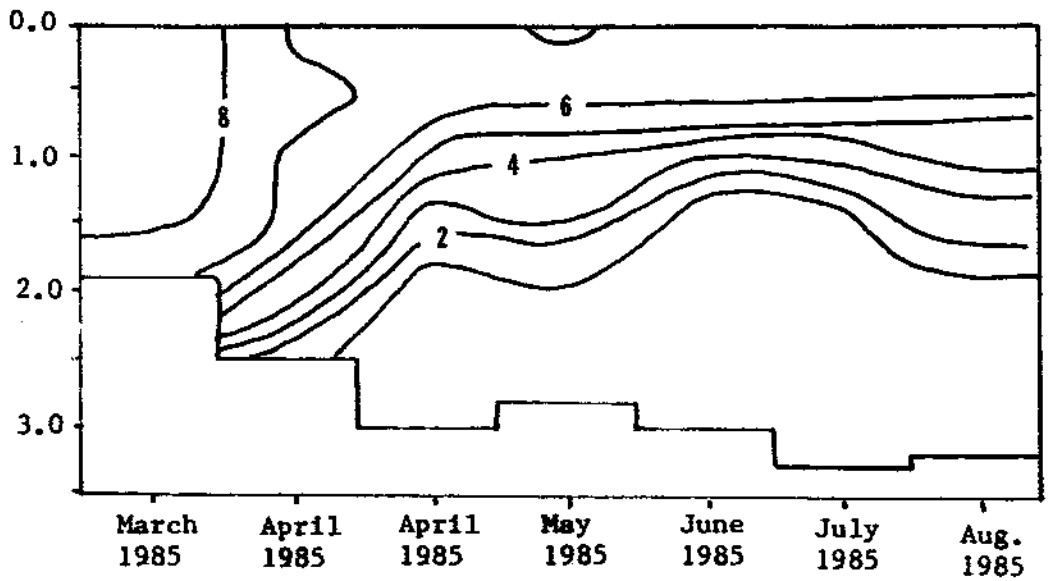


FIGURE 15. Pond dissolved oxygen profile for station MOSS 2.
(1ppm intervals)

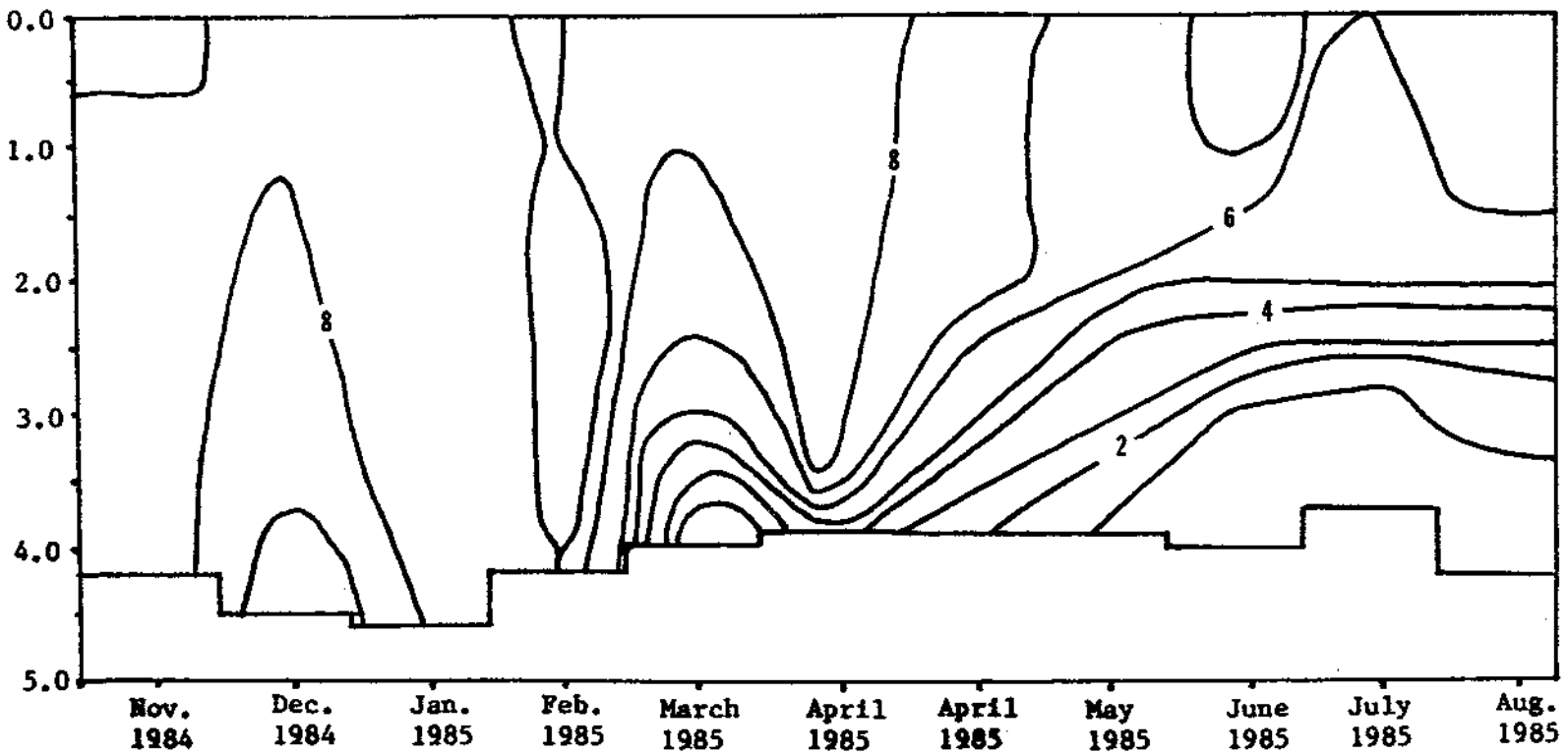


FIGURE 16. Pond dissolved oxygen profile for station MOSS 3.
(1ppm intervals)

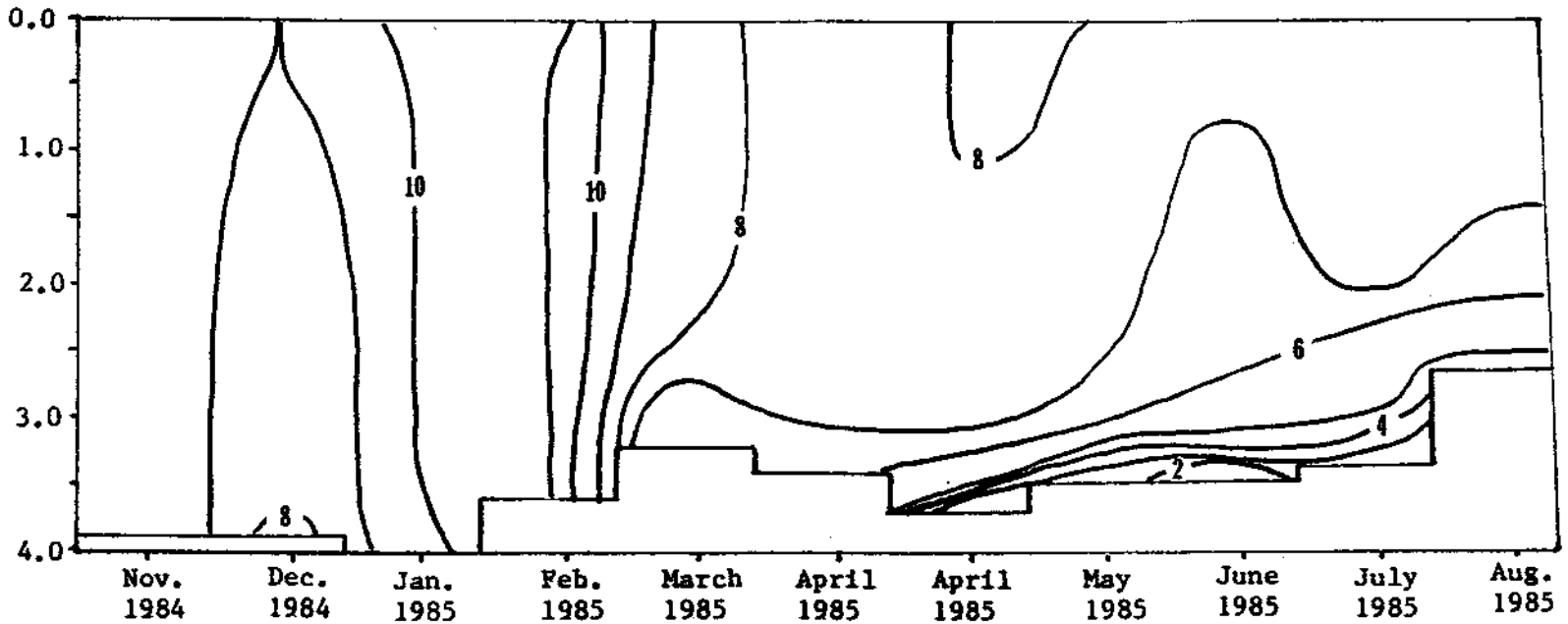
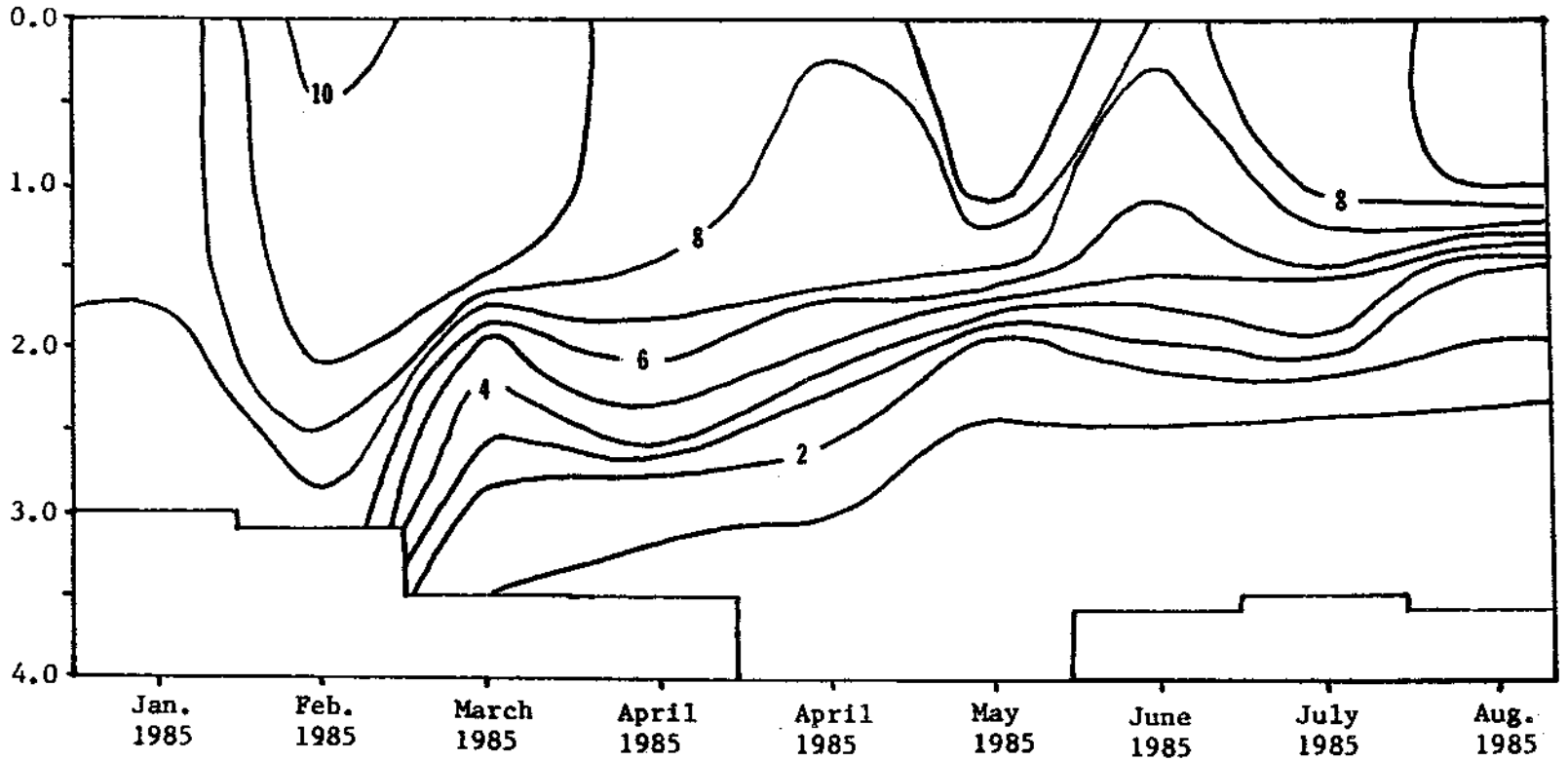


FIGURE 17. Pond dissolved oxygen profile for station QUIN 2.
(1ppm intervals)



Sampling Date

TABLE 11. FREQUENCY ponds means and standard deviation for surface and bottom dissolved oxygen.

Pond Station	Bottom D.O. Mean (mg/l)	sd	Surface D.O. Mean (mg/l)	sd
QUIN 2	1.8	2.6	8.9	1.0
CRES 2	1.5	2.7	6.9	.5
MOSS 2	4.0	3.5	7.8	1.2
MOSS 3	6.1	3.0	8.6	1.3

TABLE 12. FREQUENCY streams means and standard deviations for stream dissolved oxygen

Stream Station	Stream D.O. Mean (mg/l)	sd
QUIN 1	7.8	1.2
QUIN 3	6.7	1.5
CRES 1	8.5	1.2
CRES 3	8.5	1.6
GADS 1	6.4	2.4
GADS 3	8.2	1.1
MOSS 1	8.2	1.2
MOSS 4	8.6	1.6
MOSS 5	8.8	1.3

Pond D.O. levels reflected the influence of thermal stratification. Dissolved oxygen remained well distributed within the water column from November through February. However, with the onset of thermal stratification in late March, hypoliminion oxygen depletion became apparent in all of the ponds (Figures 14-17). Since all of the ponds are somewhat sheltered from wind action, low concentrations of D.O. in the hypolimnion remained constant throughout the summer months. Downstream D.O. reflected more variability though a trend toward lower concentrations was noted at the CRES and QUIN sites (range = 4.5-10.7 mg/l, Tables 11 and 12).

Phosphorus

Phosphorus is a primary nutrient that regulates aquatic plant growth in freshwater systems. Studies by numerous investigators (e.g., Ruttner 1953, Schindler et al. 1973, Devey and Harknes 1973, Wetzel 1975) suggests convincingly that, for the majority of situations, the nutrient limiting plant growth in freshwater is phosphorus.

Phosphorus is found in nature almost exclusively in the fully oxidized form of phosphate (Hutchinson 1957, Stumm and Morgan 1970, Wetzel 1975). Natural processes of groundwater percolation, precipitation of atmospheric particulates and terrestrial runoff are the primary modes of transportaion of phosphate to natural water (Keup 1968, Wetzel 1975, Chapin and Uttormark 1973). Industrial, agricultural and domestic activities can also affect phosphate levels through direct discharge and natural transport processes.

The inorganic phosphates are the most important in biological terms, since it appears that algae can assimilate phosphate in the inorganic form most readily (Wetzel 1975, Stumm and Morgan 1972, FDER 1985). There has been some discussion pertaining to the existance of cellular phosphatases which would allow algal cells access to organic phosphates (Owens and Esaias 1976), but this is not considered to be a significant source of phosphate to algae.

Many researchers now accept total phosphorus as the index of choice in judging trophic status (Dye and Jones 1978). This is due to the observation that inorganic phosphate is rapidly utilized and even stored in excess by phytoplankton (Gerloff and Skoog 1954, Dobson et al. 1974). The cycling of phosphate within an aquatic system is directed by a set of complex interactions: Bacterial activity, pH, sediment composition, benthic fauna, dissolved oxygen, algal growth and cultural inputs all have an appreciable effect on the exchange equilibria of phosphate (Elwood et al. 1981, Stumm and Morgan 1970, Wetzel 1975, Bates and Neafus 1980, Lean and Nalewajko 1976, Matisoff et al. 1985)

It is well known that changes in water quality often accompany the impoundment of a waterway (Dendy 1966, Neel 1966, Baxter 1977). The trophic imbalance resulting from impoundment has been described by numerous authors (e.g., Baranov 1961, Rodhe 1964, Lowe-McConnel 1973, Ostrofsky 1978) and can be attributed to the release of nutrients, especially phosphates, from flooded soil and drowned vegetation (Wilson et al. 1975, Maystrenko and Denisova 1972). Increased nutrient availability in a flooded basin can create alterations in water quality in the reservior and more importantly in downstream reaches of the stream.

Total phosphate (PO_4-T) values for all stations ranged from .01 to .36 mg/l, while bio-available or dissolved phosphate (PO_4-P) varied from .01 to .29 mg/l. The highest mean concentrations of total and dissolved phosphate were recorded at the QUIN stations. Conditions at the QUIN site, i.e., extremely high chlorophyll a values for periphyton in the upstream and phytoplankton in the pond reflected increasing levels of phosphate as water traveled downstream (Table 8 and Figures 18-20). This trend was also noted at the GADS site (Table 9 and Figures 21-22). Slight increases in mean total and dissolved phosphorus from the upstream station to the pond were noted at the CRES site, though mean phosphate levels at the downstream station were similar to values observed in the pond (Table 6 and Figures 23-25). Phosphate levels, both total and dissolved, were virtually identical at the upstream, pond and downstream stations at the MOSS site (Table 7 and Figures 26-30).

The recorded phosphate levels at the QUIN and GADS sites both reflect varying degrees of influence from agricultural run-off and remobilization of phosphate previously locked up in vegetation or in pond sediments. Agricultural effects appeared to be more pronounced at the QUIN site.

The slightly increased level of total and dissolved phosphate at the CRES site reflects the absence of agricultural activity in proximity to the pond. However, future activities associated with golf course grooming, in particular the fertilizing of fairways and greens, should be considered a potential source of water quality deterioration.

The MOSS site is surrounded by forested land and fields and is virtually free of agricultural influence. The age of the ponds and their ability to respond adequately to natural levels of phosphate suggest that an equilibrium has been reached. Whether the ponds equilibrium can withstand the pressures of additional introduced nutrients is not known, but continuing development in the area will eventually test the durability of the water quality in these ponds.

Nitrogen

Like the phosphate species, the various compounds of nitrogen are integral to the biological and chemical activities in natural waters. While some studies implicate phosphorus as the primary limiting nutrient in freshwater (Jordan and Bender 1973, Welch et al. 1978), other

FIGURE 18. Dissolved phosphorus by sampling date, QUIN 1.

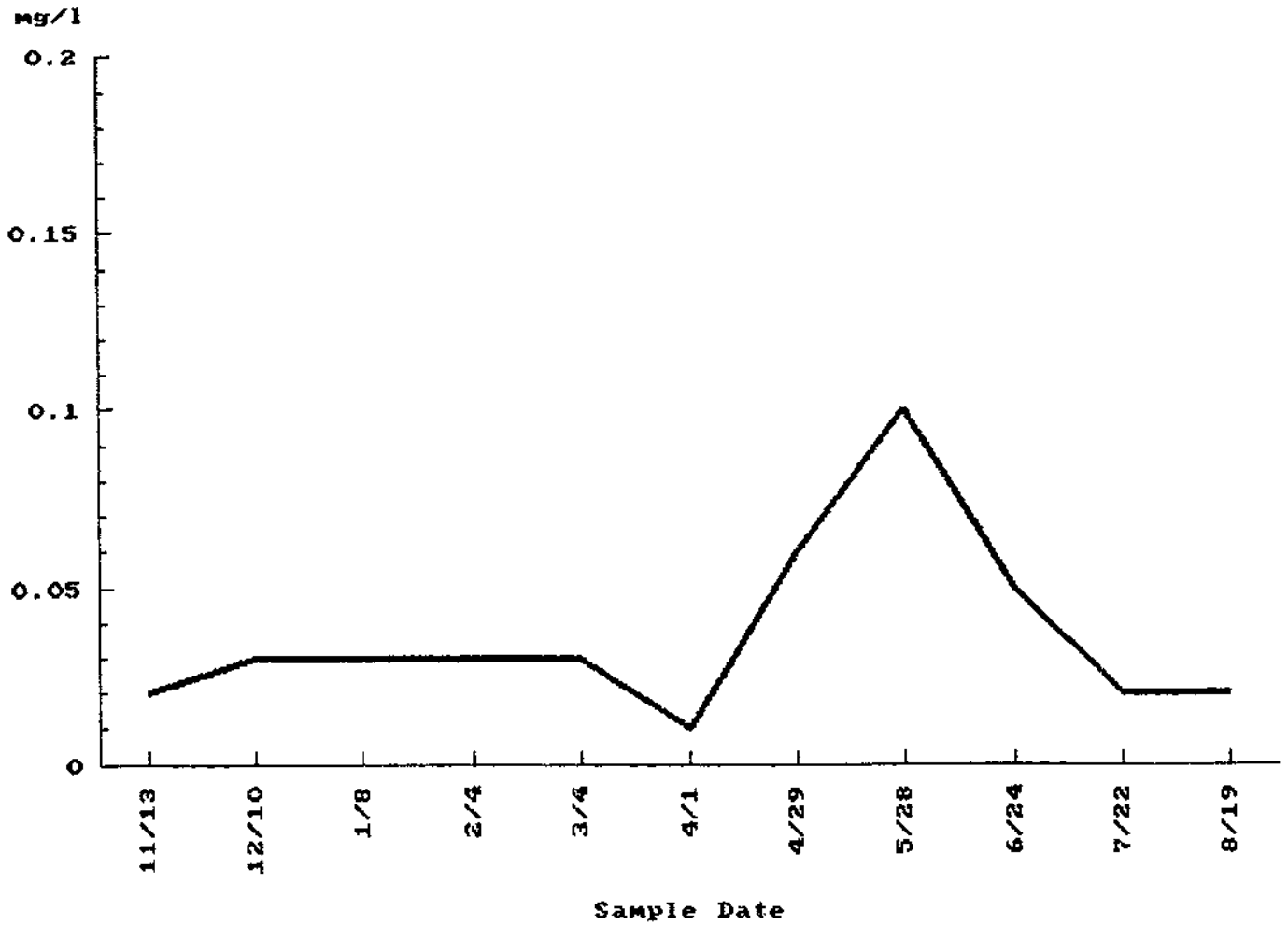


FIGURE 19. Dissolved phosphorus by sampling date, QUIN 2.

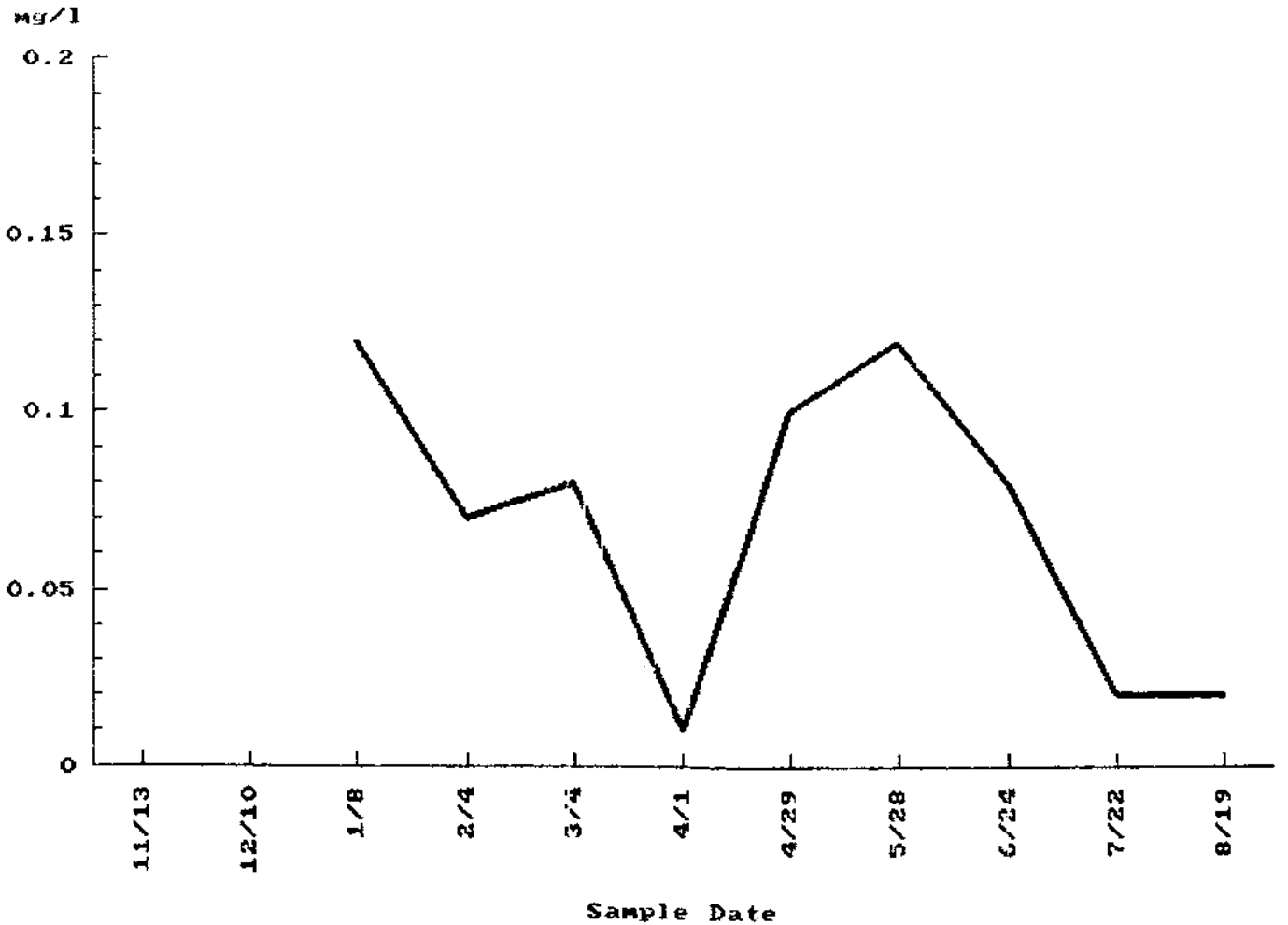


FIGURE 20. Dissolved phosphorus by sampling date, QUIN 3.

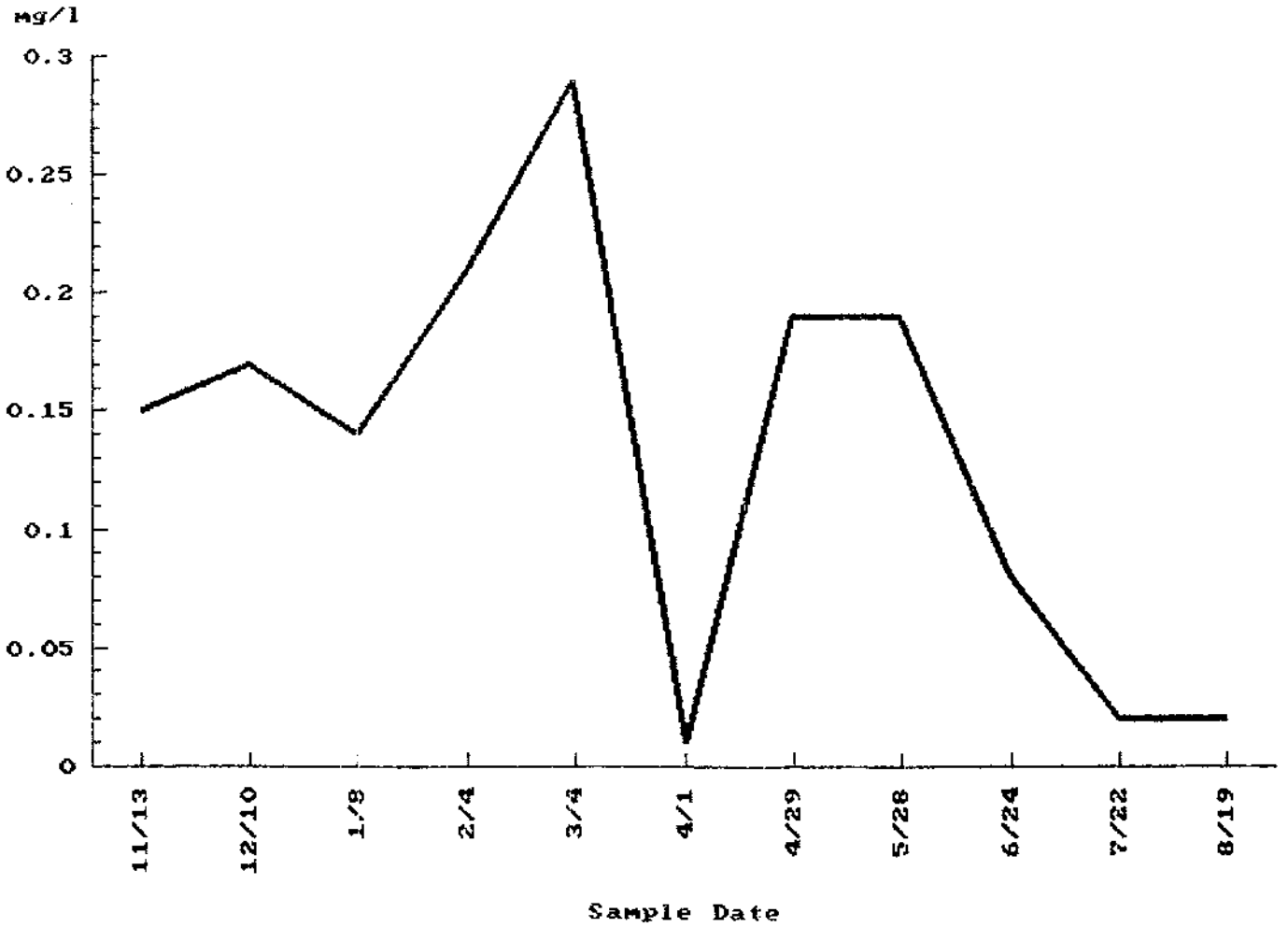


FIGURE 21. Dissolved phosphorus by sampling date, GADS 1.

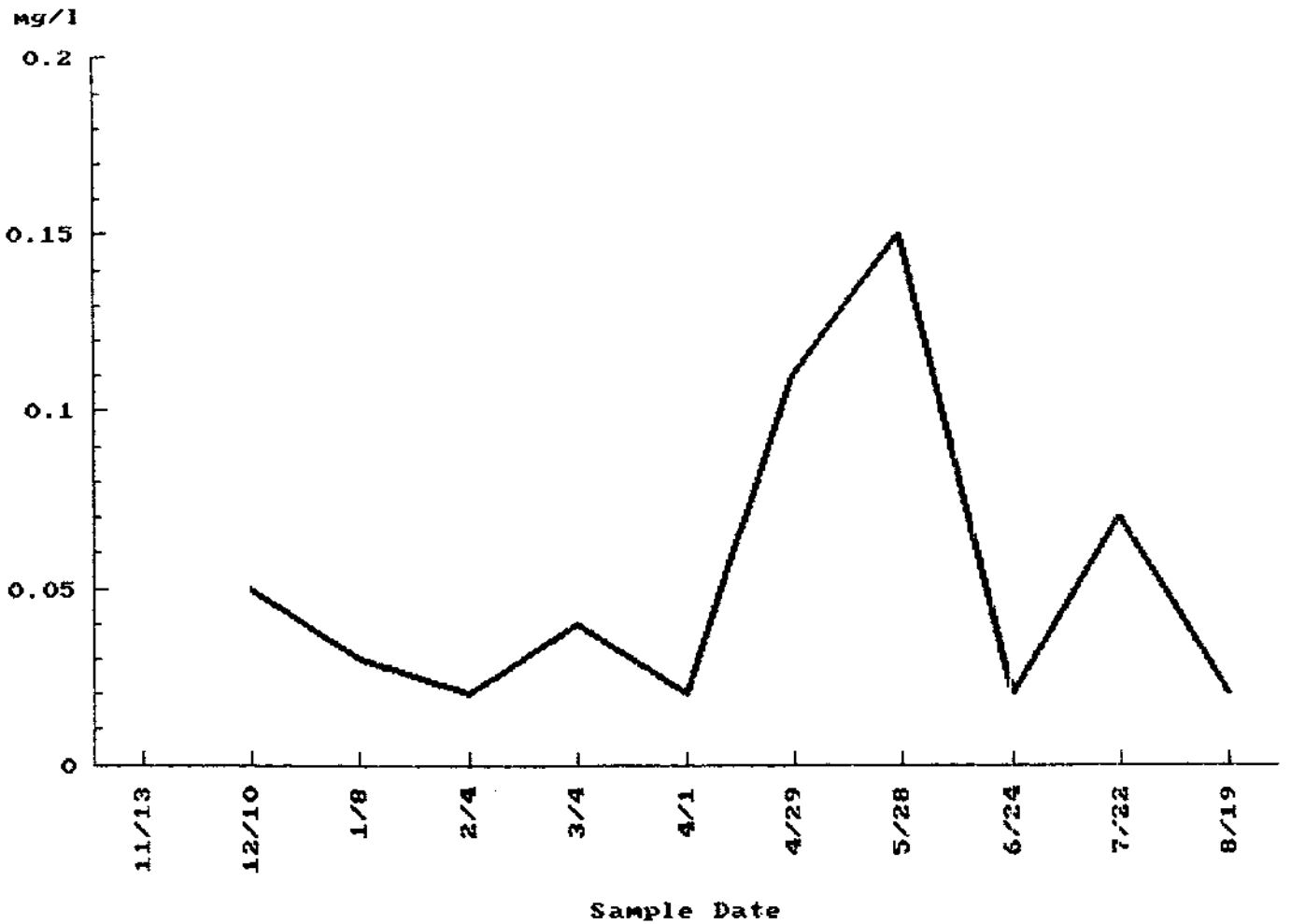


FIGURE 22. Dissolved phosphorus by sampling date, GADS 3.

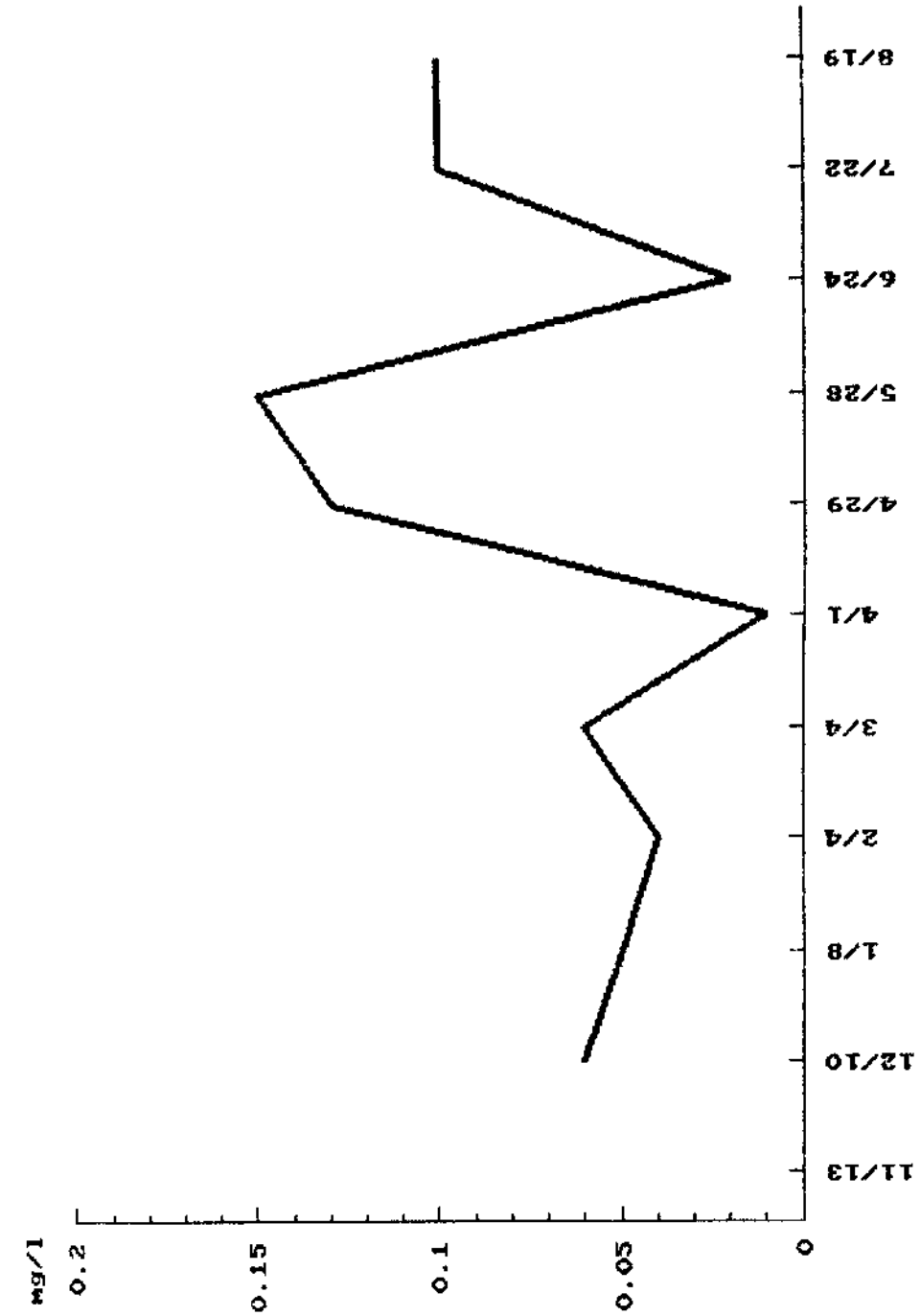


FIGURE 23. Dissolved phosphorus by sampling date, CRES 1.

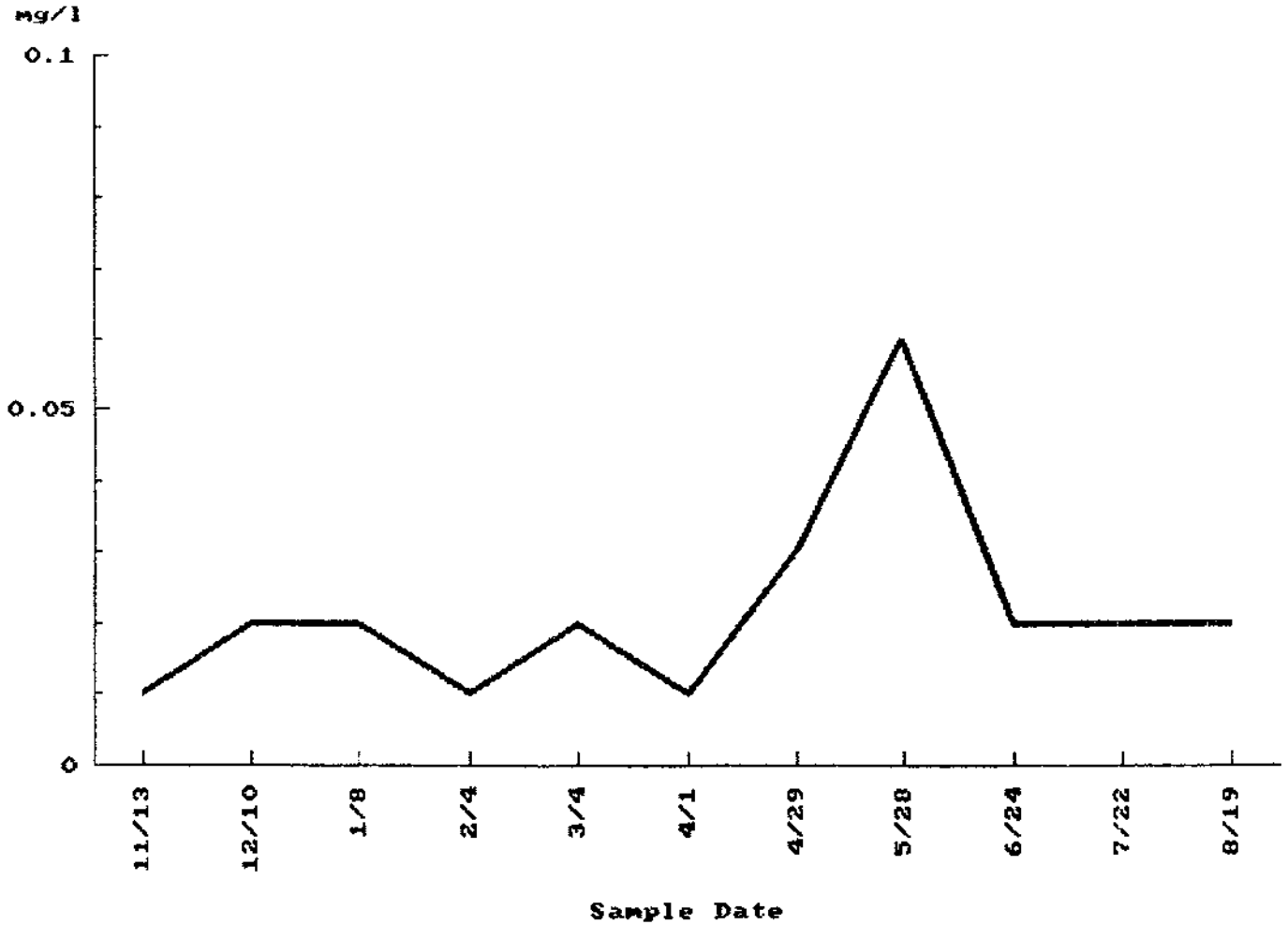


FIGURE 24. Dissolved phosphorus by sampling date, CRES 2.

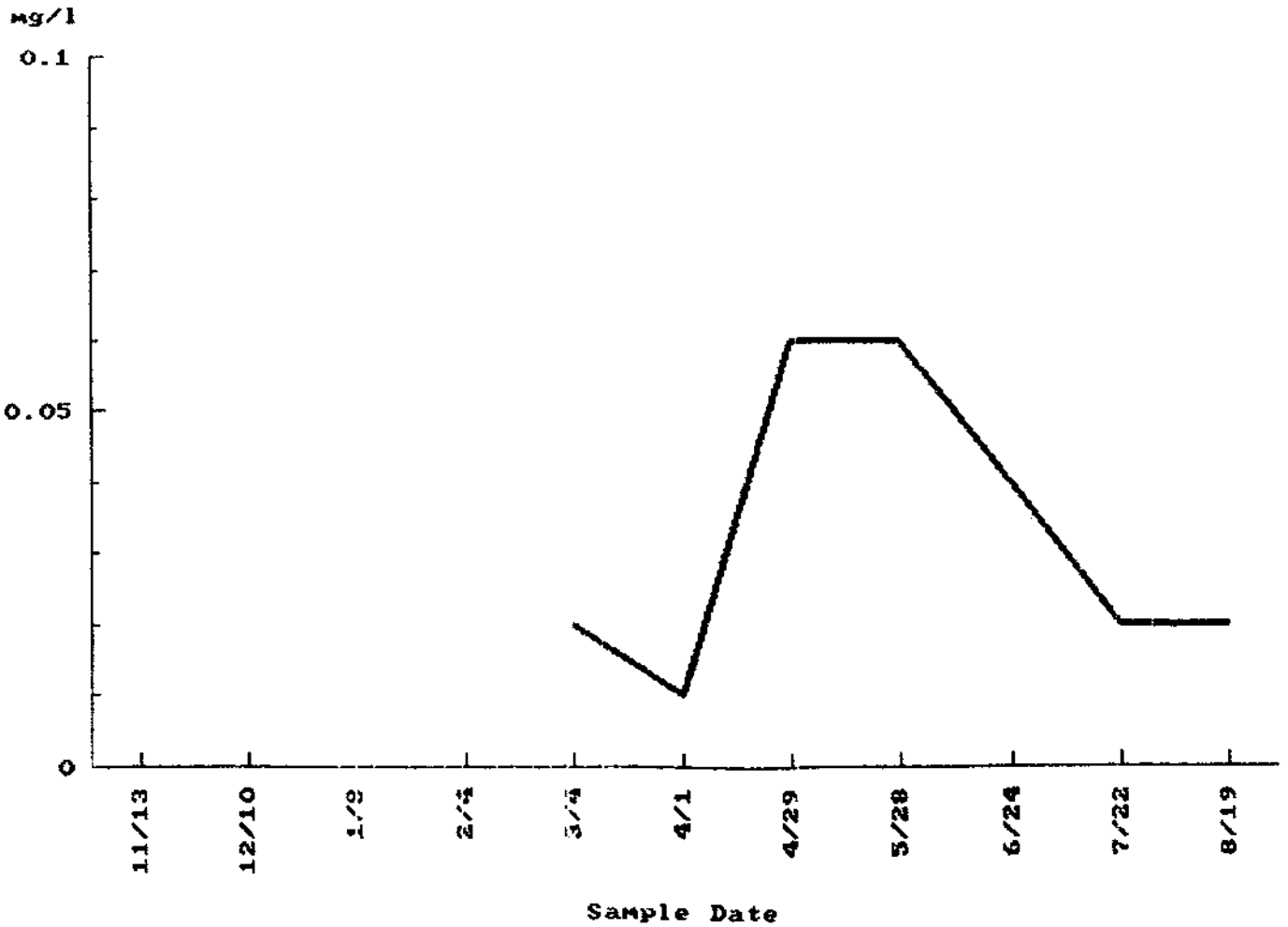


FIGURE 25. Dissolved phosphorus by sampling date, CRES 3.

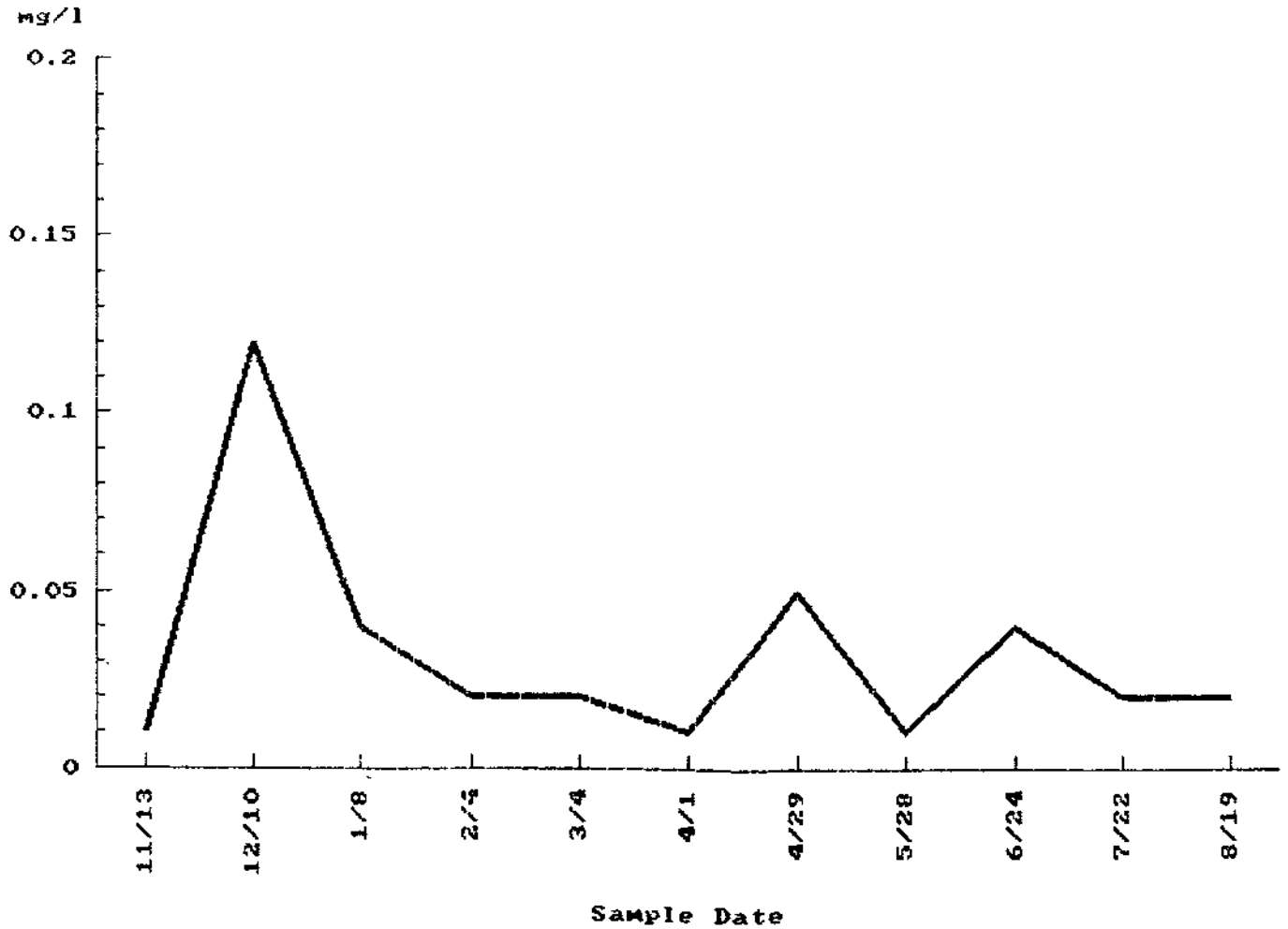


FIGURE 26. Dissolved phosphorus by sampling date, MOSS 1.

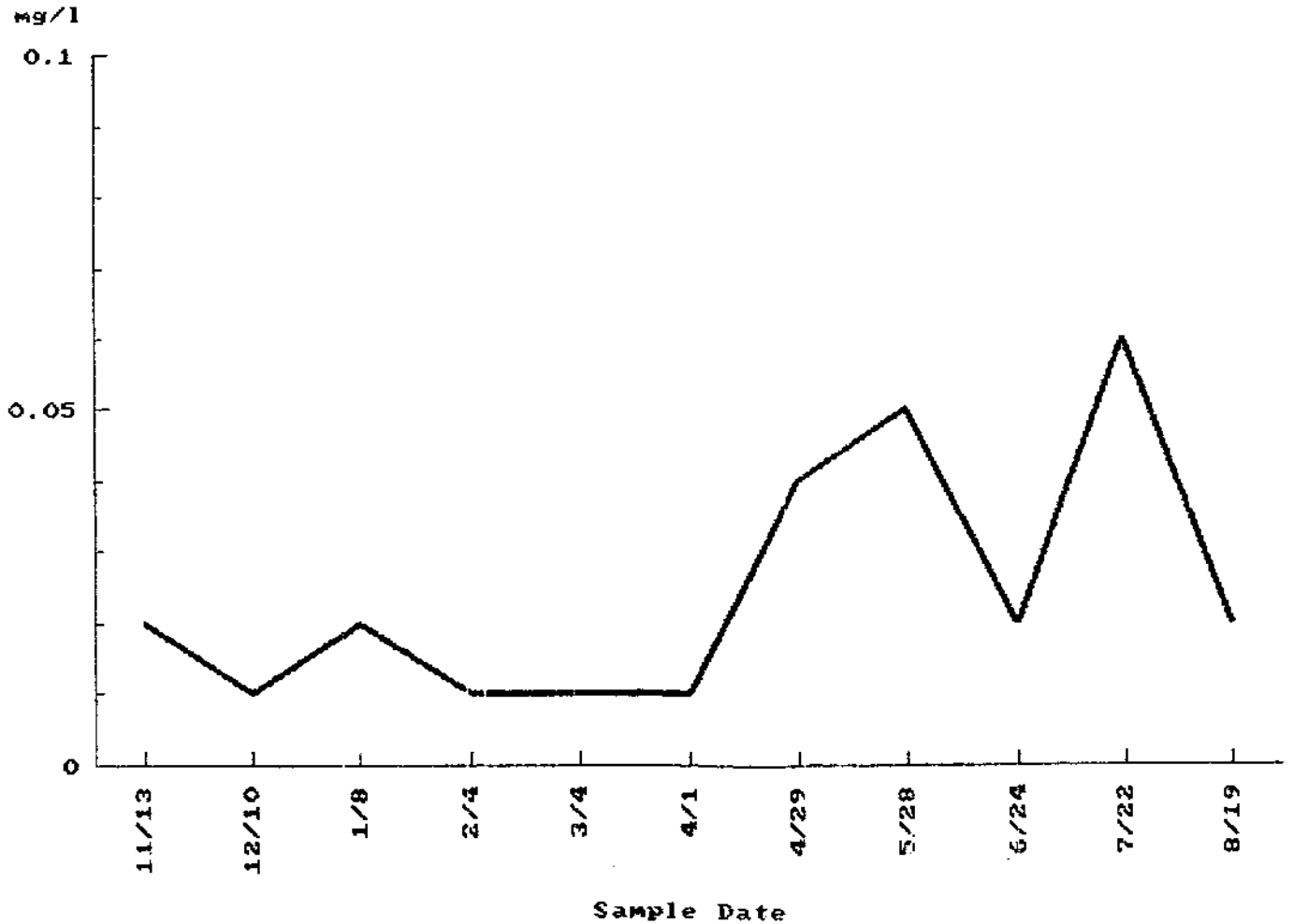


FIGURE 27. Dissolved phosphorus by sampling date, MOSS 2.

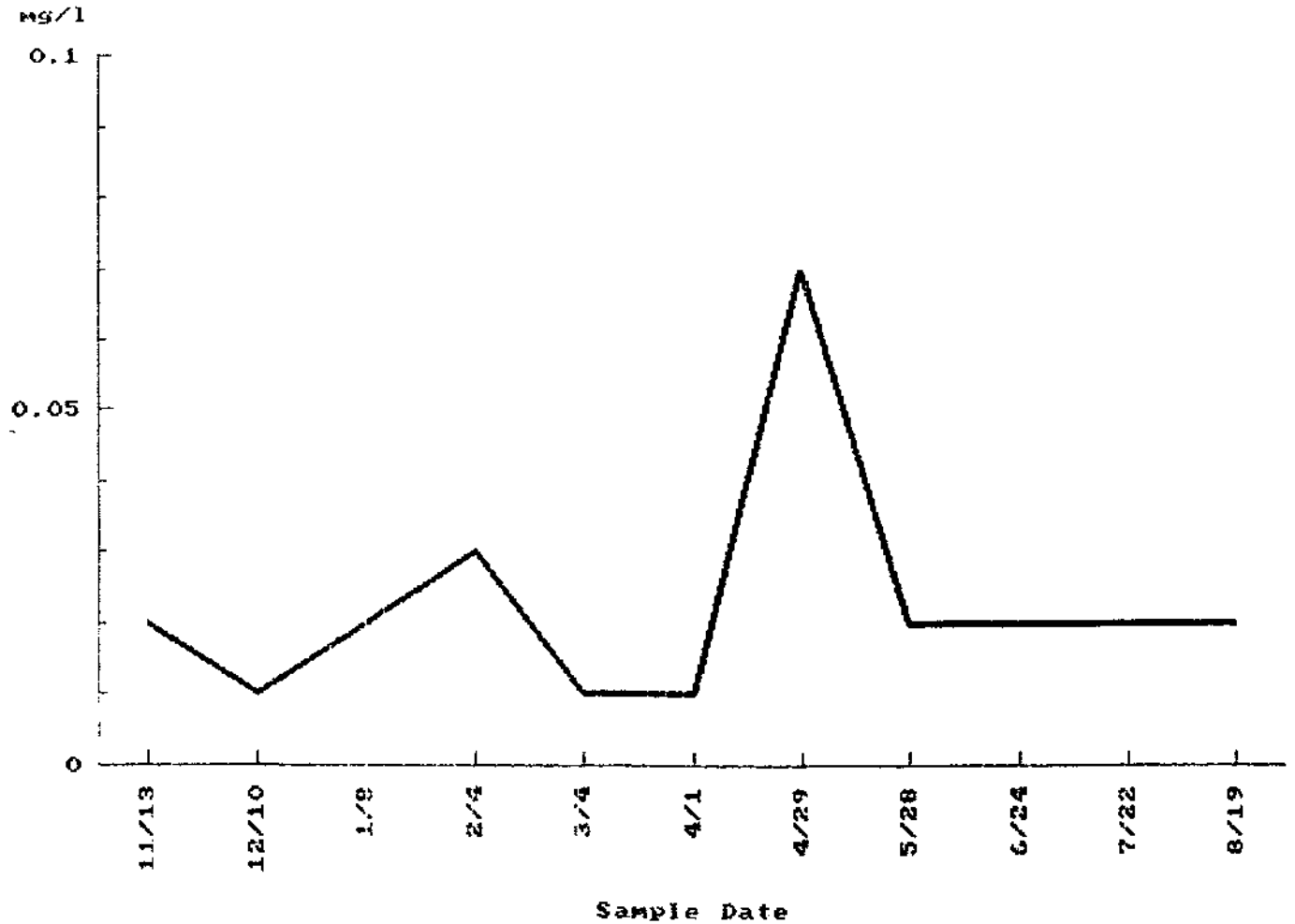


FIGURE 28. Dissolved phosphorus by sampling date, MOSS 3.

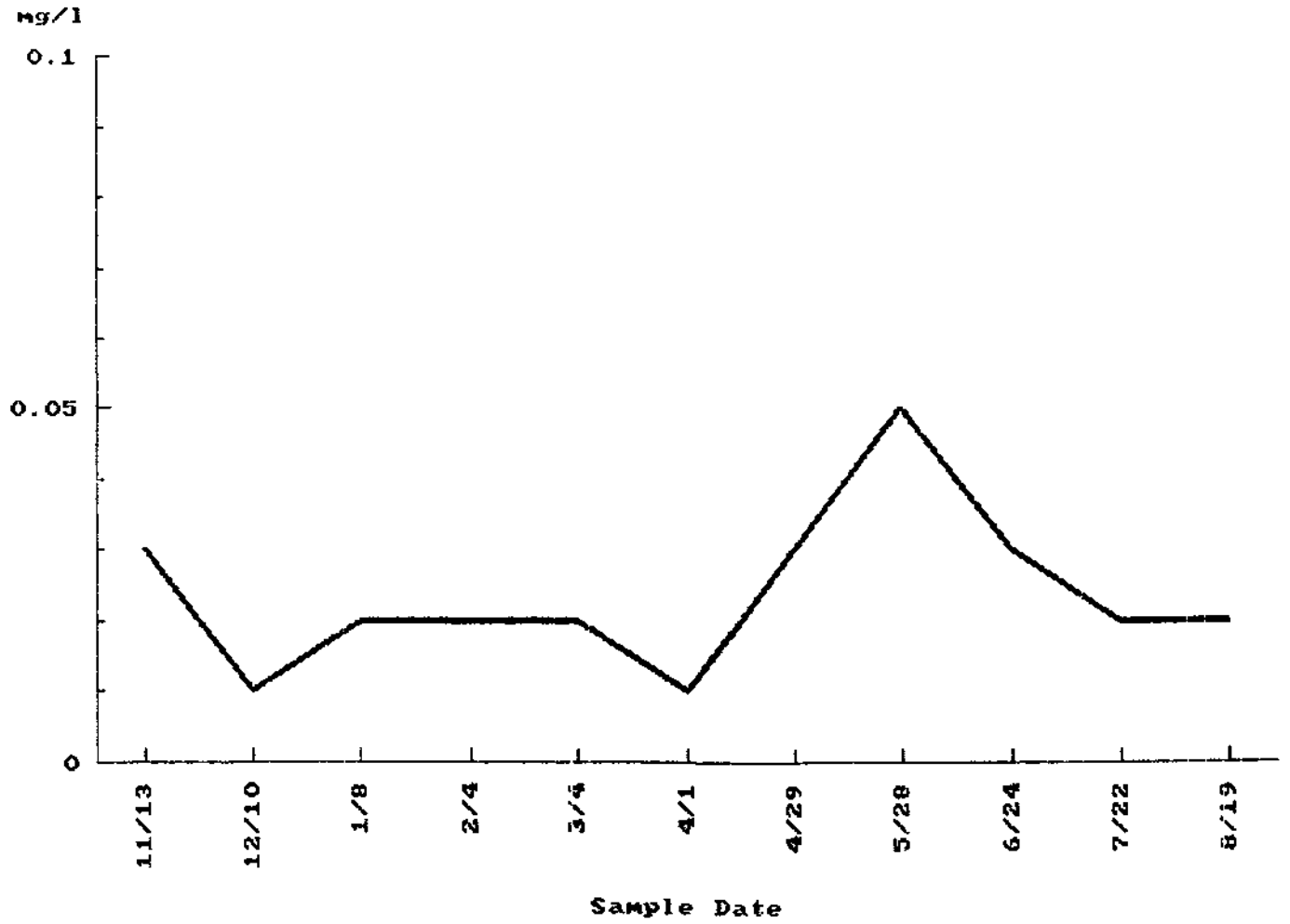


FIGURE 29. Dissolved phosphorus by sampling date, MOSS 4.

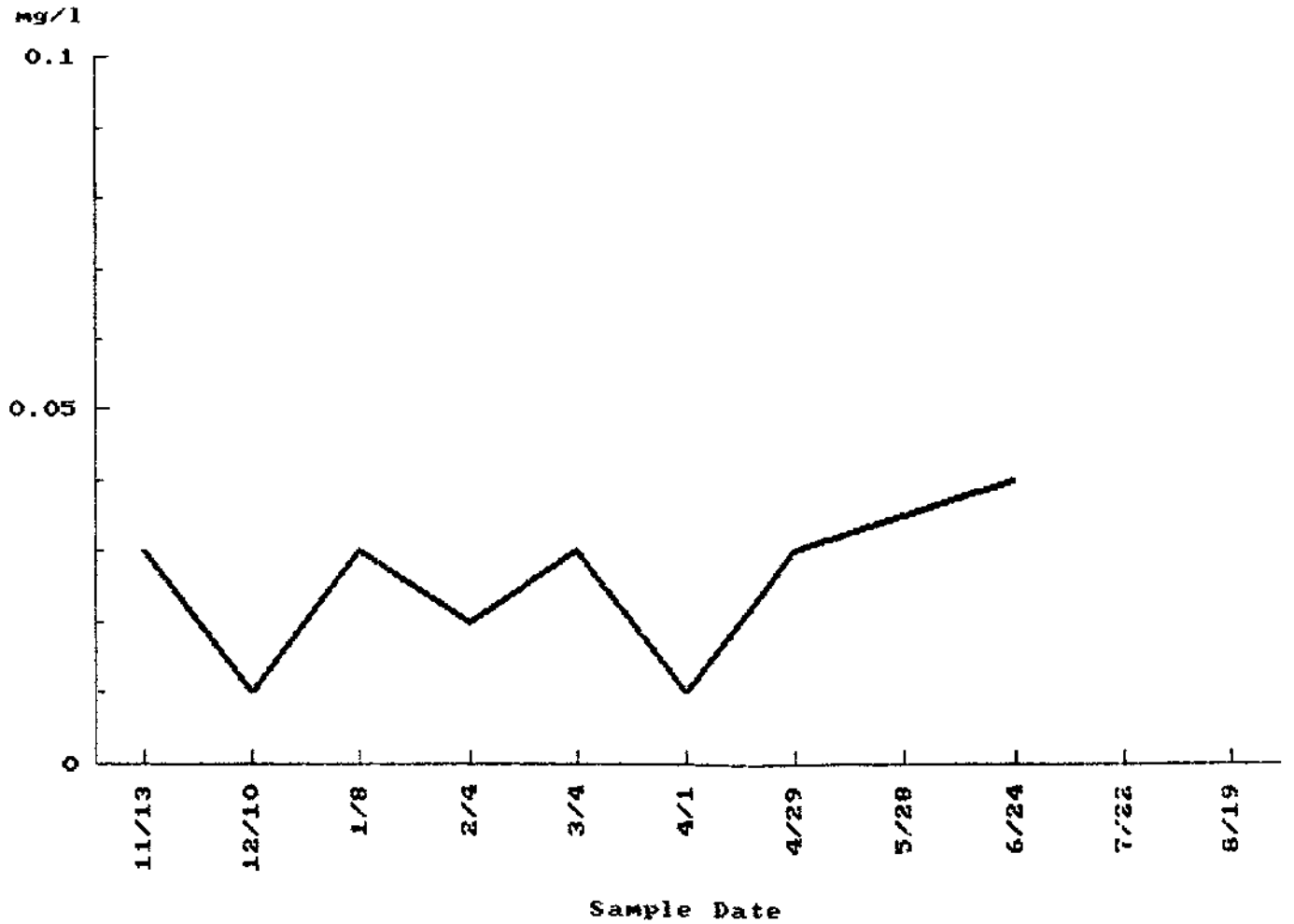
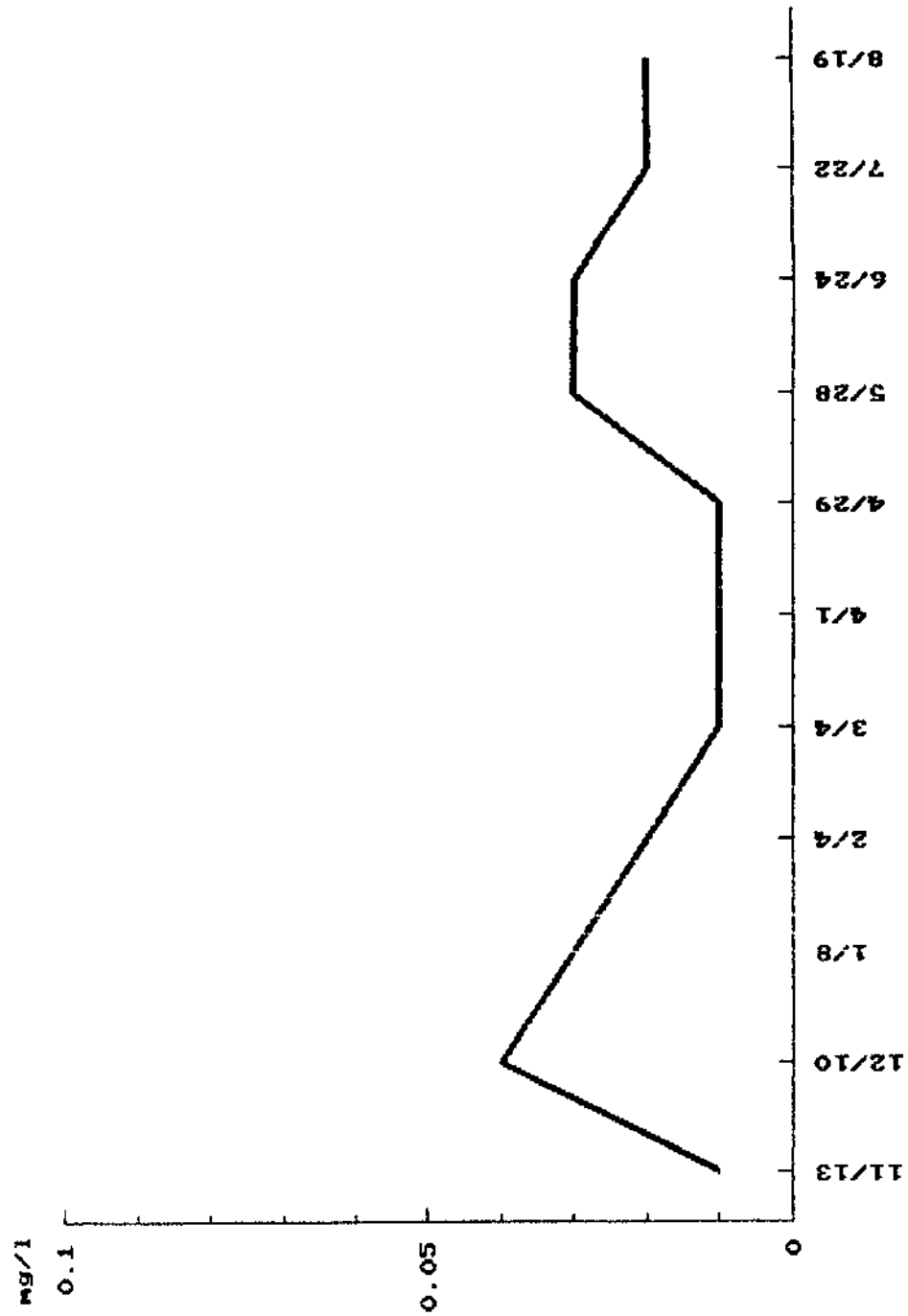


FIGURE 30. Dissolved phosphorus by sampling date, MOSS 5.



investigations point to nitrogen as the primary limiting nutrient or at least as a secondarily important nutrient (Talling 1966, Moss 1969, Robarts and Southall 1977, Henry et al. 1984). In freshwater, nitrogen exists in several forms: Dissolved molecular nitrogen, a large array of organic compounds (i.e., amino acids, amines, proteins and humic compounds), ammonia (NH_3/NH_4^++), nitrite (NO_2), and nitrate (NO_3).

Nitrogen can reach surface waters in several ways. Precipitation and atmospheric particle fallout, characterized widely as a minor source, vary greatly from region to region in relation to meteorological conditions and proximity to industrial areas (Wetzel 1975). Terrestrial surface runoff and subsurface groundwater movement are major contributors to the overall nitrogen budget of surface waters. These contributions are accentuated if soil and bedrock characteristics are biochemically conducive (Wetzel 1975).

Atomspheric nitrogen (N_2) becomes soluble in water in accordance with surface water temperature and atmospheric partial pressure. Additionally, atmospheric nitrogen can be fixed by certain heterocyst producing blue-green algae and a few genera of bacteria (Azotobacter, Clostridium). The amount of fixed nitrogen produced by blue-green alga populations appears to be dependent on the amount of bioavailable nitrogen, i.e., ammonia and nitrate. More readily available nitrogen in the environment corresponds to reduced production of biologically fixed nitrogen (Fogg 1971, Wolk 1973 in Wetzel 1975). In some cases nitrogen fixation by blue-green algae exerts considerable influence on the habitat. Horne and Goldman (1972) found that nitrogen fixation accounted for 43% of total nitrogen input to Clear Lake, California in 1970. Other studies by Dugdale and Goering (1967), Jones and Stewart (1969), and Granhall and Lundgren (1971) also suggest the importance of nitrogen fixing blue-green algae to the overall nitrogen budget in aquatic habitats.

Fixation of atmospheric nitrogen can also occur electrically or photochemically (Hutchinson 1957). Within the aquatic habitat the processes of nitrification, ammonification and assimilation occur under the constraints of the physio-chemical nature of the environment. Wetzel (1975) found that reductions in pH severely inhibit nitrification, while an increase in suspended solids can enhance it (Kholdebarin and Oertli 1977).

Again, bacteria function in a primary role. The genus Nitrobacter and to a lesser extent Nitrosomonas carry out the bulk of nitrification and ammonification (Wetzel 1975). Another source of nitrogen available to aquatic plant life can be found in the secretions of aquatic macrophytes (Wetzel and Manny 1972). Futhermore, as aquatic macrophytes die and decompose, organic nitrogen is released (Nichols and Keeney, 1973). Relatively minor amounts of ammonia and urea can also be contributed by aquatic animals.

Nitrogen exits the ecosystem through the mechanisms of outflow, volatilization and bacterial denitrification, or it may become bound and inert in bottom sediments. Nitrogen bound in bottom sediments may undergo remobilization due to benthic macroinvertebrate activitiy as demonstrated by Gardner et al. (1983).

Nitrogen data collected throughout the ten month course of this study are presented in summarized form in Table 13. Total Kjeldahl nitrogen (TKN-N), which is the sum of organic nitrogen and ammonia, was consistently higher in the ponds and outfalls than in the upstream areas of all study sites. The increase in TKN was particularly evident at the QUIN site. Mean TKN values for the upstream and downstream were .180 mg/l and .954 mg/l, respectively. This observation is paralleled by chlorophyll a data which show the same relationship and are a function of increased phytoplankton populations, as is frequently TKN.

Mean total ammonia concentrations were clearly elevated at the CRES site when upstream and downstream values were compared (.013 mg/l vs. .314 mg/l). Similar results were observed at all the other sites except the MOSS site where a slight decrease in ammonia was observed in the ponds and the outflow. This uptake of ammonia is expected since ammonia is the preferred nitrogen source for algal populations, and macrophytes, especially in well established ponds such as those at the MOSS site. Similar ammonia uptake can be expected if and when algae and macrophyte populations become a stable element in the other ponds.

Nitrite/nitrate levels exhibited the most variation from site to site. The QUIN 1 (upstream) station had the overall highest mean NO_2^-/NO_3^- concentrations ($\bar{x}$ = .288). The pond, however, showed a drastic decrease in NO_2/NO_3 concentration followed by a slight increase in the outfall (Figures 31-33). Nitrite/nitrate levels at the CRES and GADS stations exhibited sharp increases in concentration as water moved through the impoundment area (Figures 34-38). The MOSS control stream and upstream site also had high levels of NO_2/NO_3 though the pond and outfall maintained lower concentrations throughout the study (Figures 39-43). The uptake of nitrate recorded in the QUIN and MOSS ponds reflected the demands of phytoplankton communities for this nutrient. Nitrate uptake was not observed in the CRES and GADS ponds as a result of their recent completion and the destabilized nature of biological conditions.

Table 13. Mean, maximum and minimum values for TKN, NH_3 (as N), and NO_2-NO_3 (as N).

Station	TKN	NH_3-T	NO_2-NO_3 (as N)	
QUIN				
1	.180	.015	.288	mean
	(.03-.65)	(.01-.04)	(.21-.36)	(range)
2	.946	.037	.012	
	(.44-1.27)	(.01-.06)	(.01-.03)	
3	.954	.246	.029	
	(.22-1.76)	(.04-.64)	(.01-.13)	
CRES				
1	.196	.013	.011	
	(.03-.50)	(.01-.03)	(.01-.02)	
2	.559	.051	.097	
	(.23-.82)	(.01-.10)	(.01-.25)	
3	.599	.314	.117	
	(.25-1.19)	(.13-.60)	(.04-.19)	
GADS				
1	.388	.085	.014	
	(.09-.56)	(.01-.15)	(.01-.04)	
3	.547	.211	.060	
	(.14-1.02)	(.06-.61)	(.01-.11)	
MOSS				
1	.257	.022	.184	
	(.07-.49)	(.01-.06)	(.16-.23)	
2	.476	.020	.027	
	(.35-.65)	(.01-.05)	(.01-.09)	
3	.534	.013	.024	
	(.25-.95)	(.01-.03)	(.01-.08)	
4	.465	.010	.020	
	(.29-.69)	(.01-.01)	(.01-.08)	
5	.228	.010	.199	
	(.04-.39)	(.01-.01)	(.17-.24)	

FIGURE 31. Dissolved nitrate/nitrite as nitrogen by sampling date, QUIN 1.

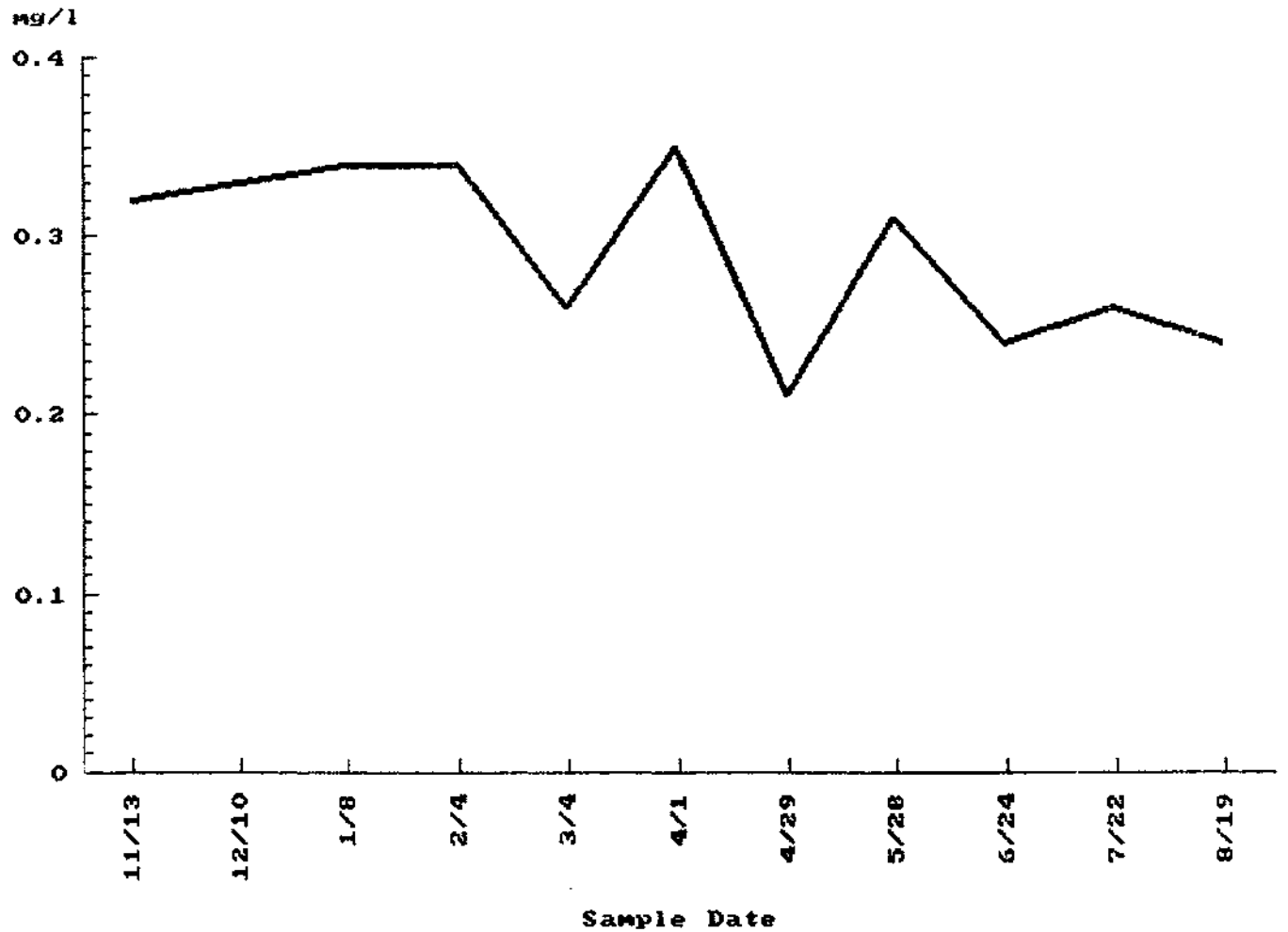


FIGURE 32. Dissolved nitrate/nitrite as nitrogen by sampling date, QUIN 2.

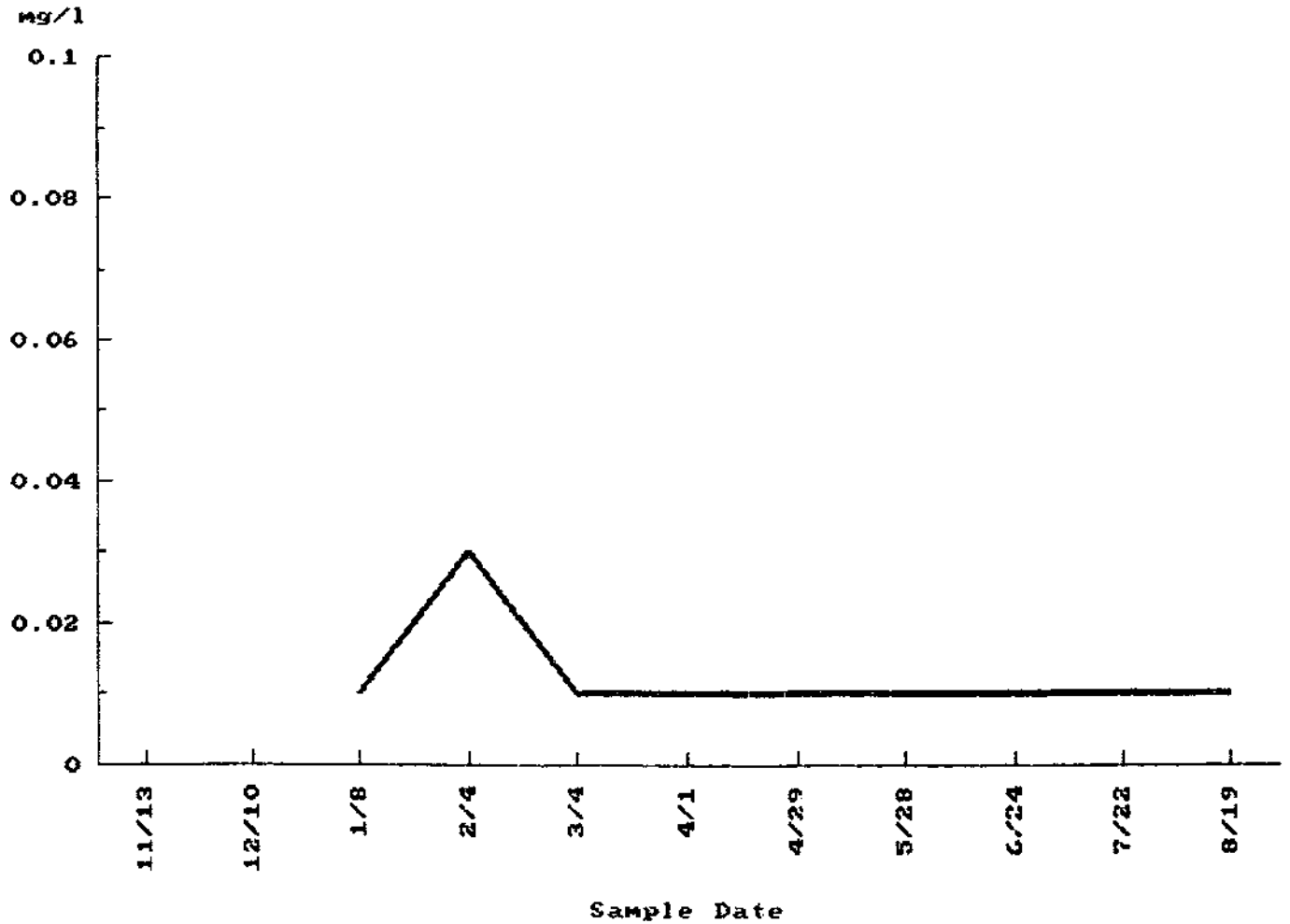


FIGURE 33. Dissolved nitrate/nitrite as nitrogen by sampling date, QUIN 3.

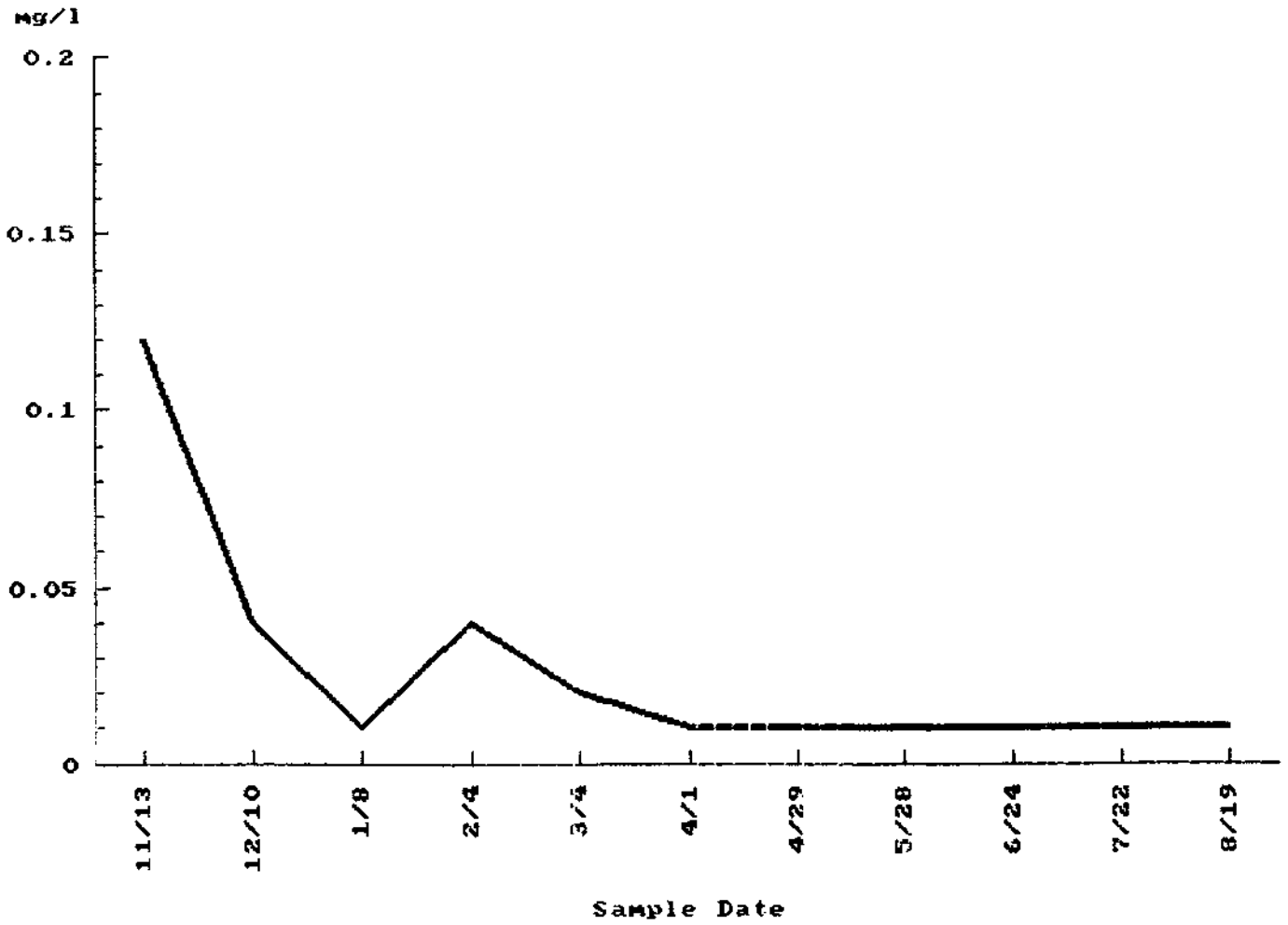


FIGURE 34. Dissolved nitrate/nitrite as nitrogen by sampling date, CRES 1.

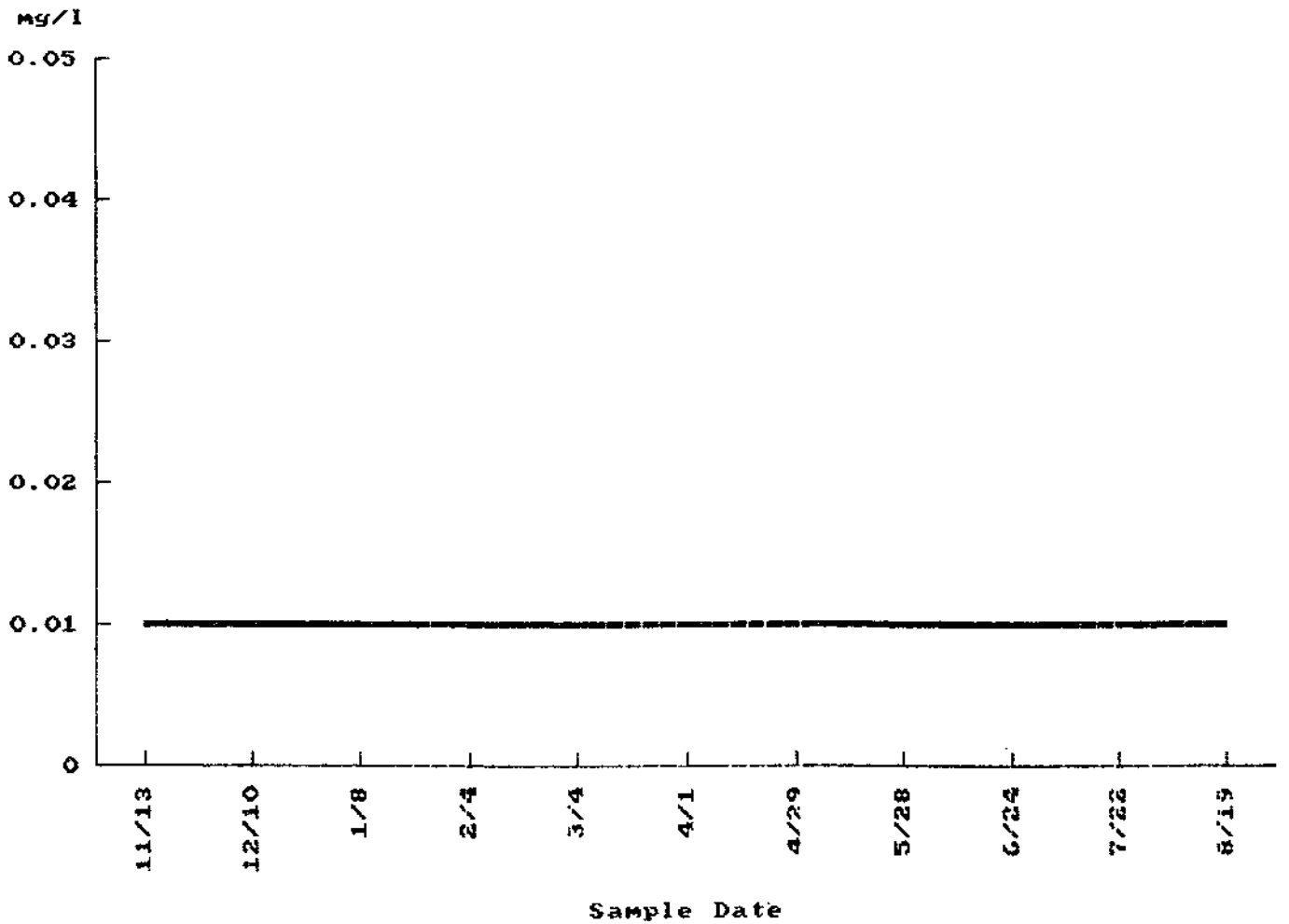


FIGURE 35. Dissolved nitrate/nitrite as nitrogen by sampling date, CRES 2.

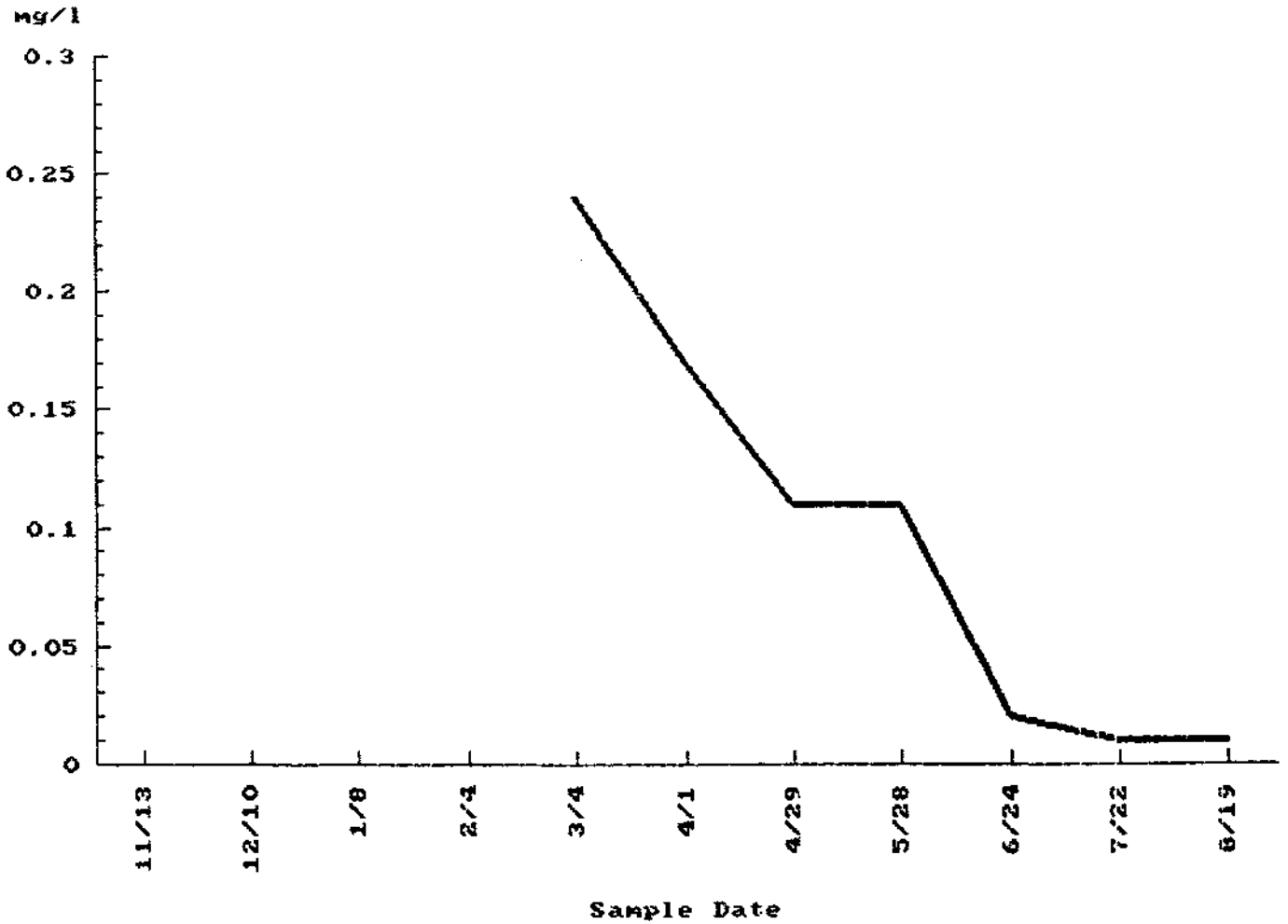


FIGURE 36. Dissolved nitrate/nitrite as nitrogen by sampling date, CRES 3.

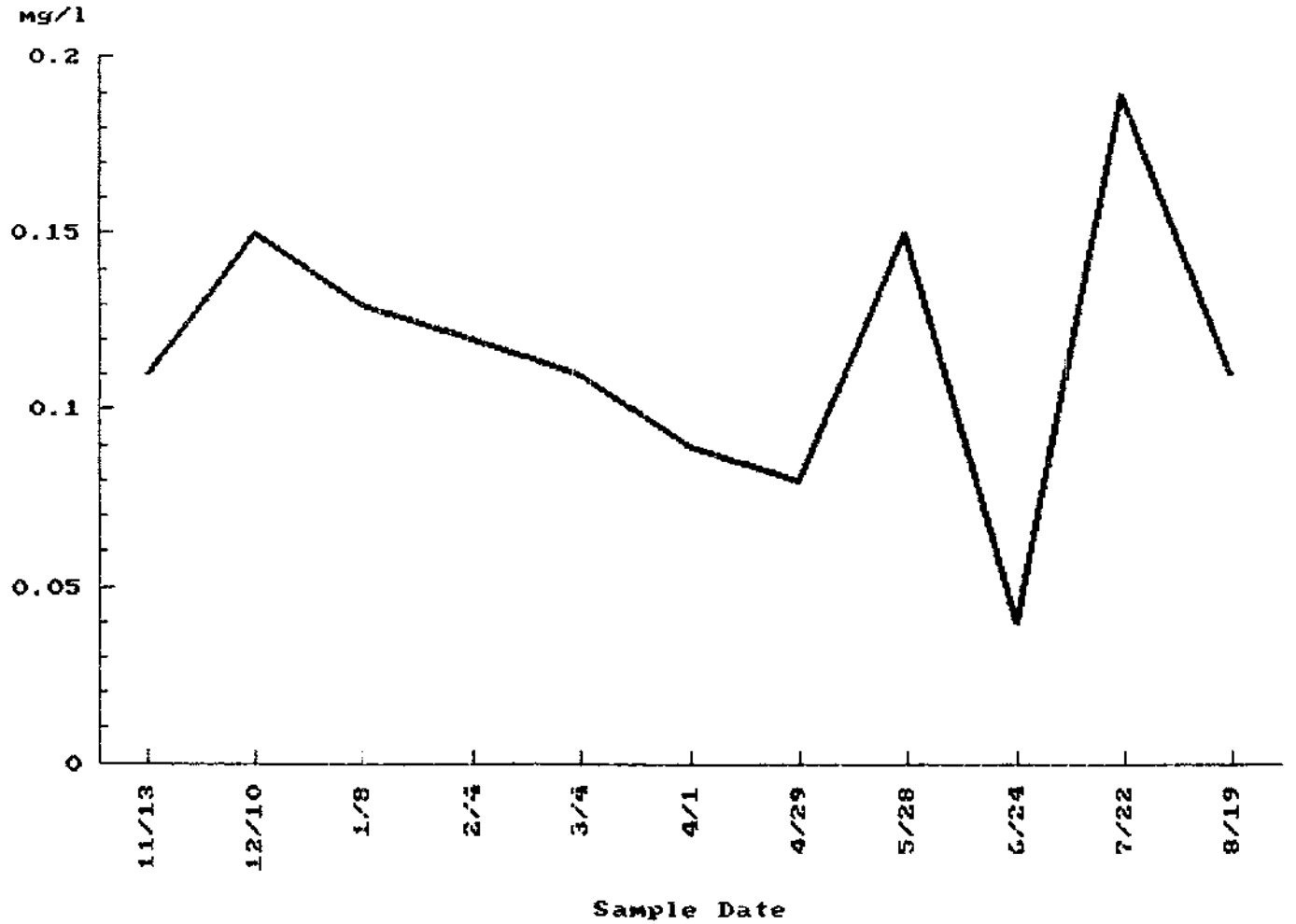


FIGURE 37. Dissolved nitrate/nitrite as nitrogen by sampling date, GADS 1.

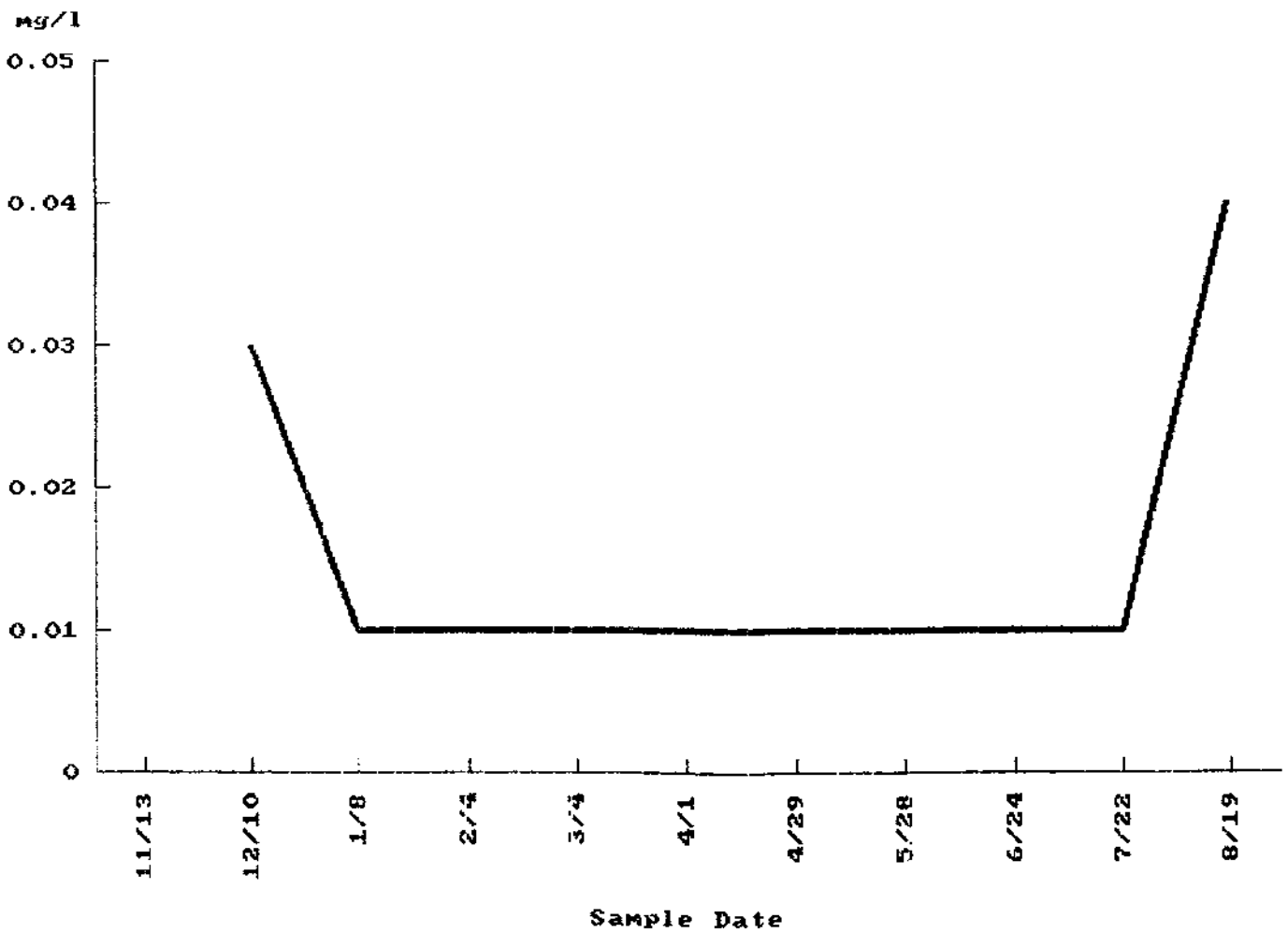


FIGURE 38. Dissolved nitrate/nitrite as nitrogen by sampling date, GADS 3.

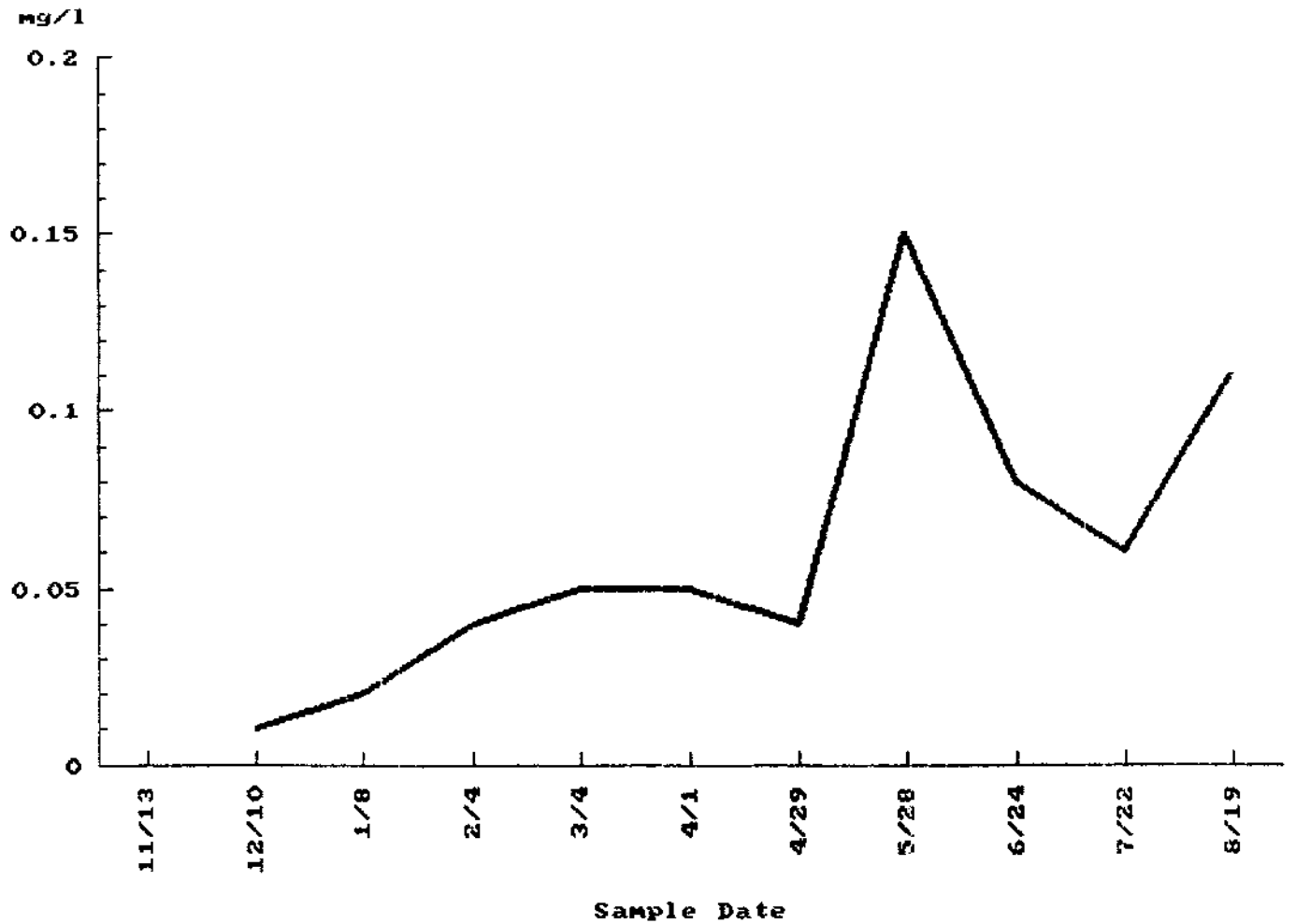


FIGURE 39. Dissolved nitrate/nitrite as nitrogen by sampling date, MOSS 1.

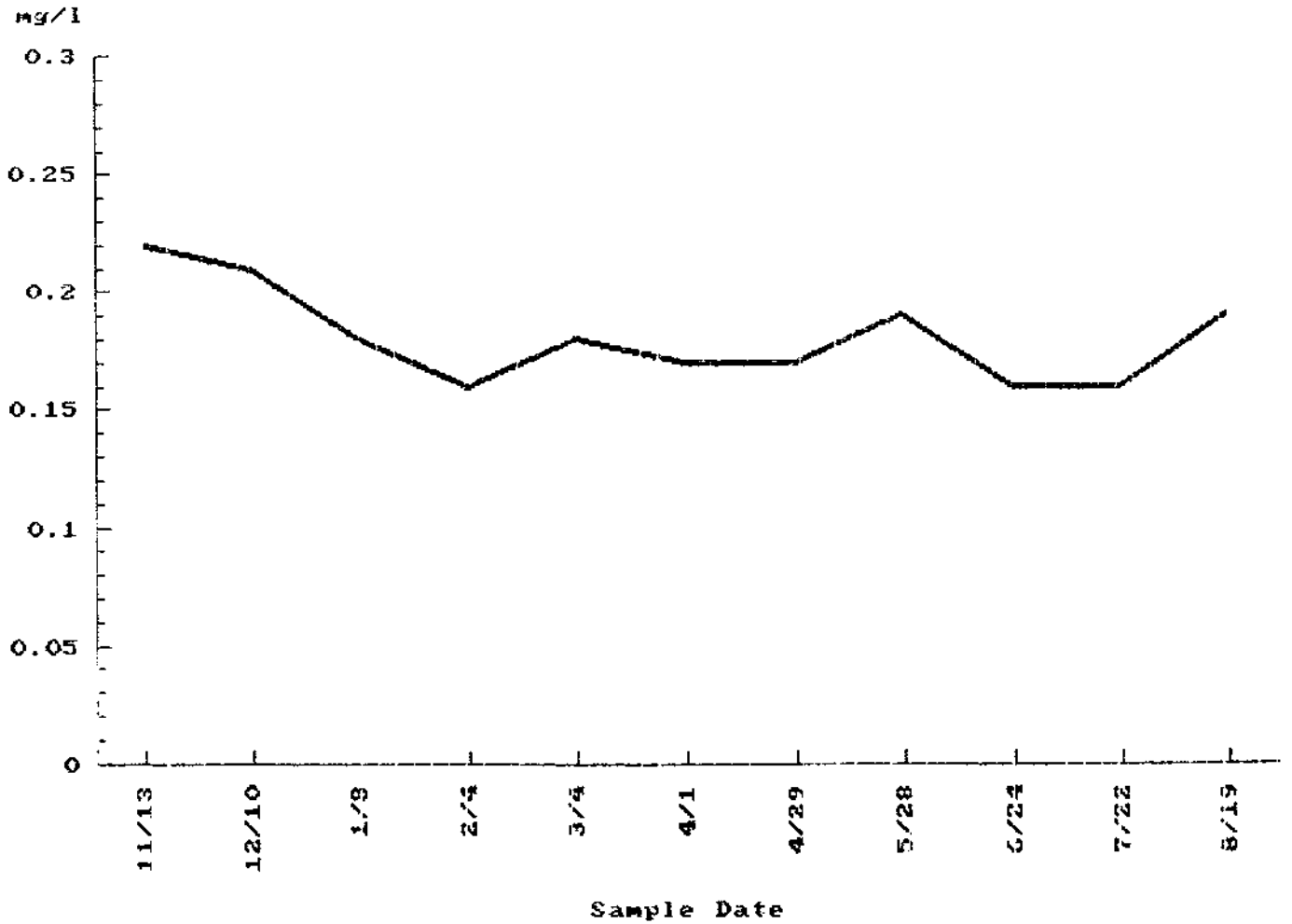


FIGURE 40. Dissolved nitrate/nitrite as nitrogen by sampling date, MOSS 2.

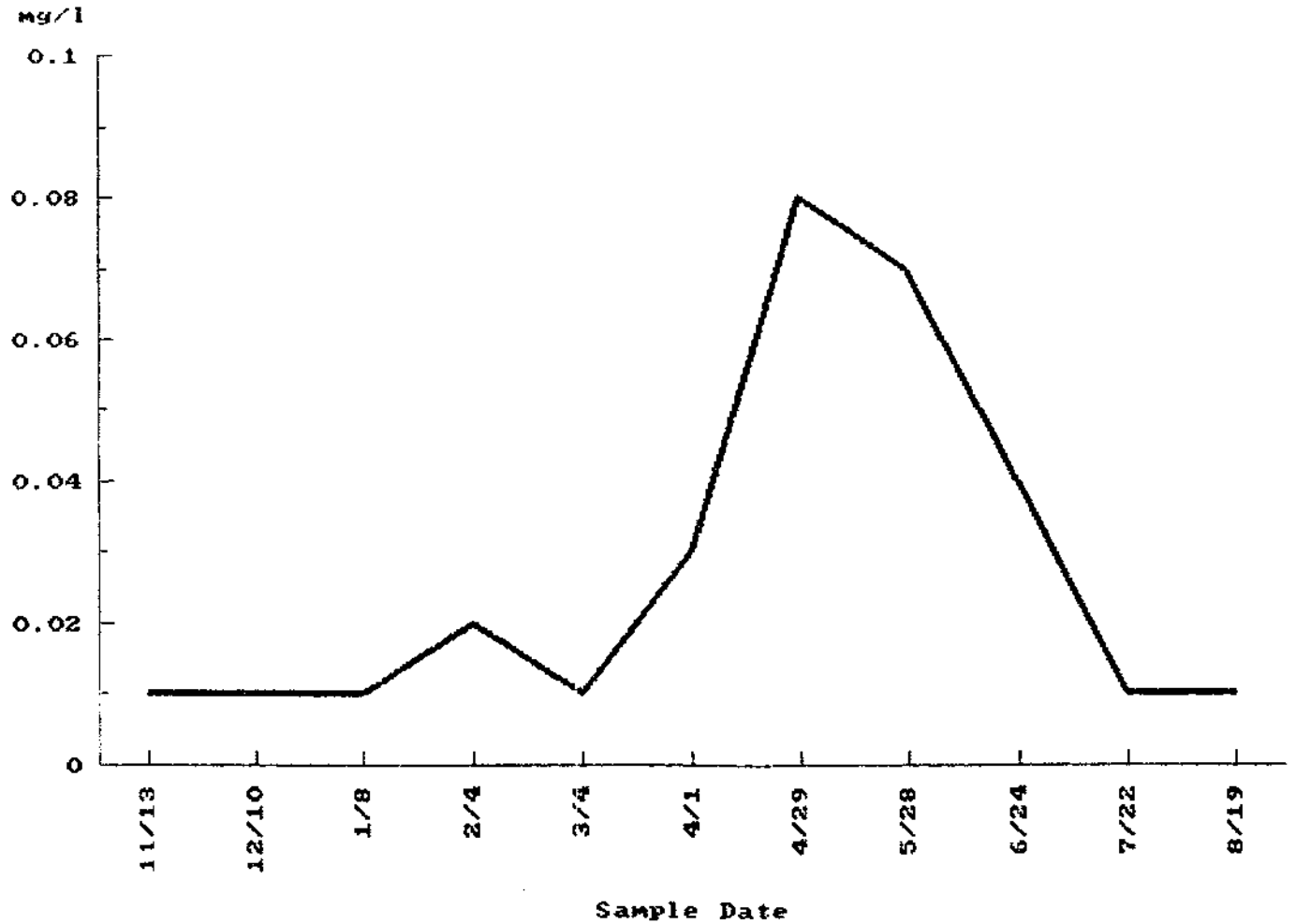


FIGURE 41. Dissolved nitrate/nitrite as nitrogen by sampling date, MOSS 3.

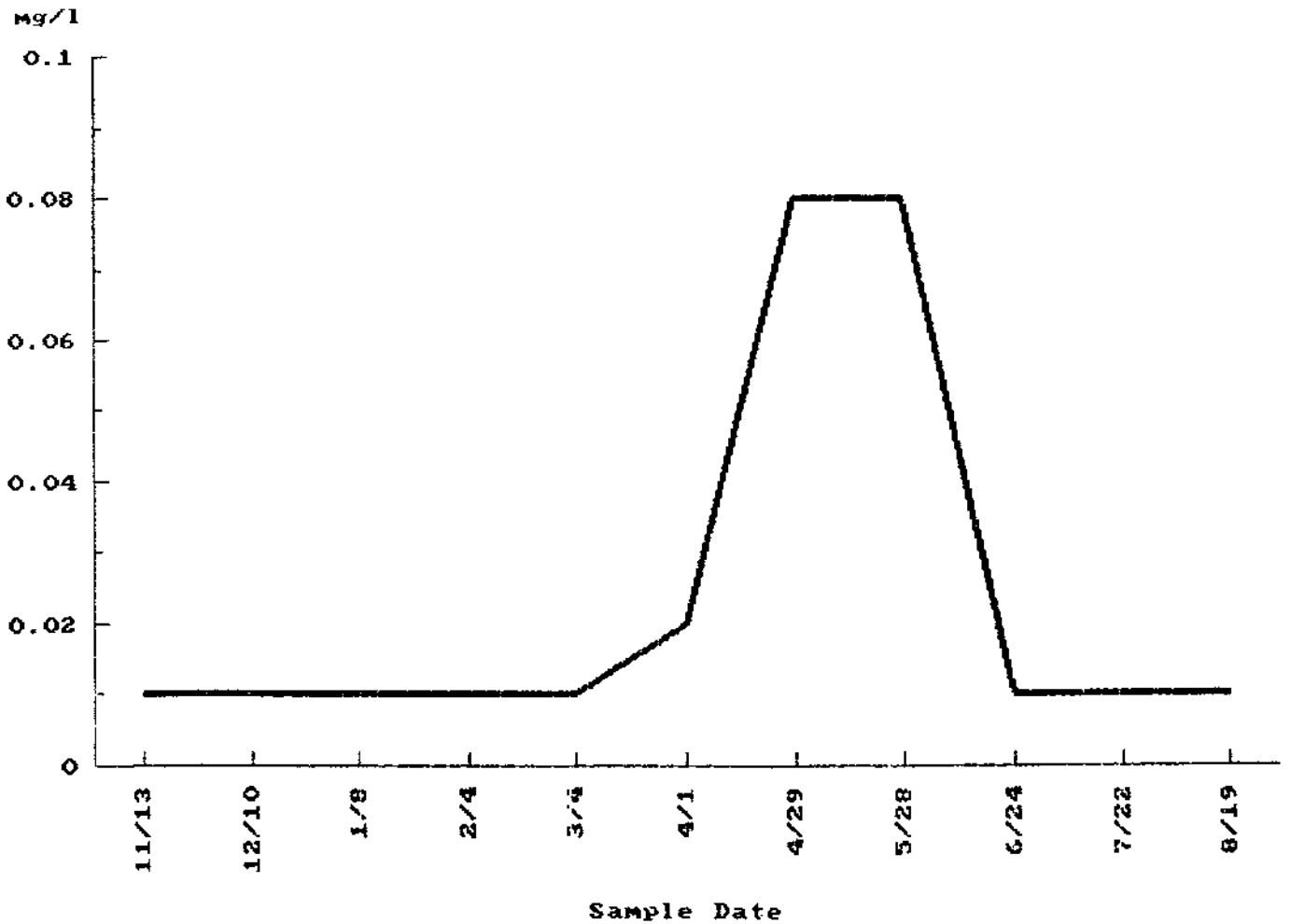


FIGURE 42. Dissolved nitrate/nitrite as nitrogen by sampling date, MOSS 4.

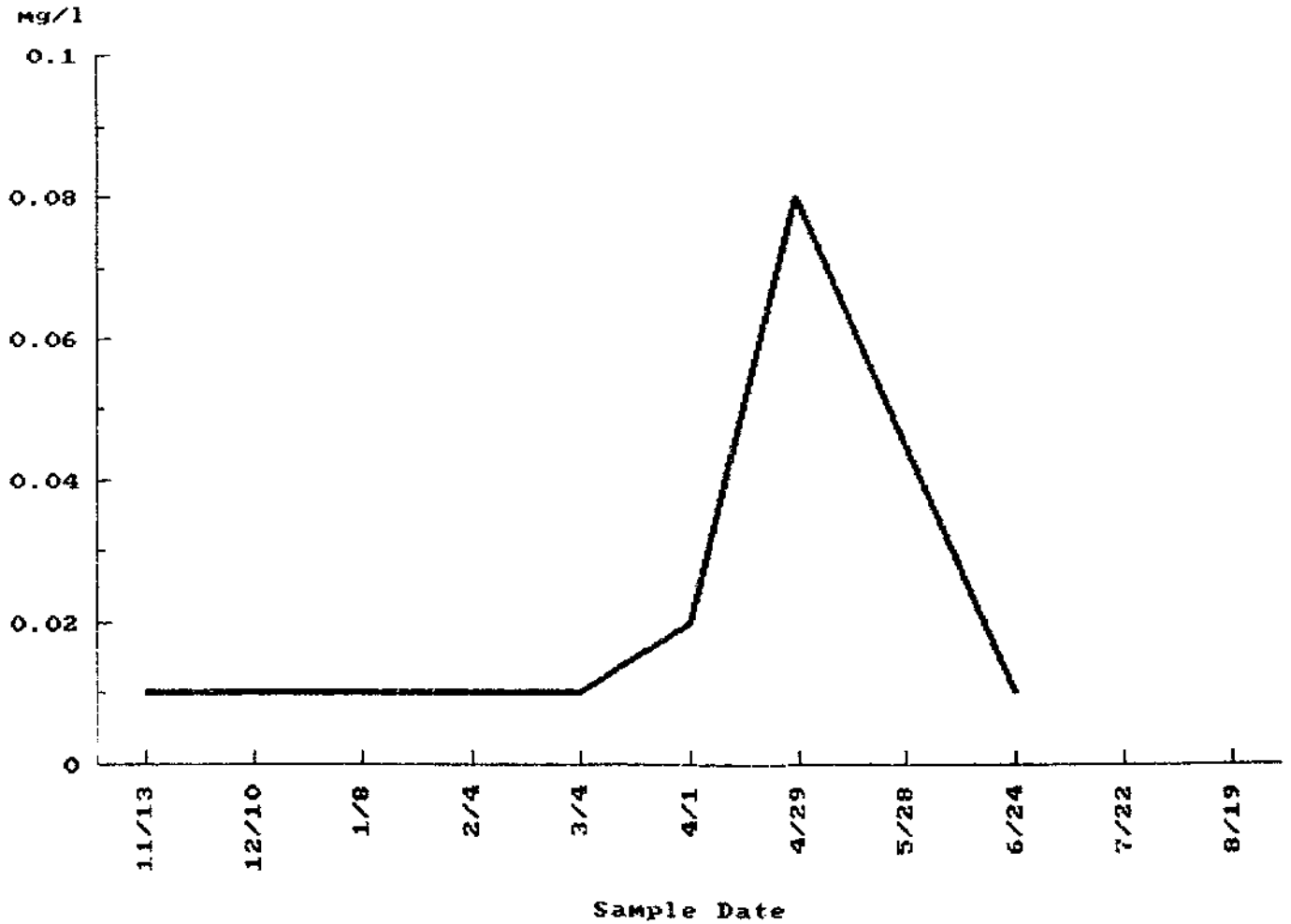
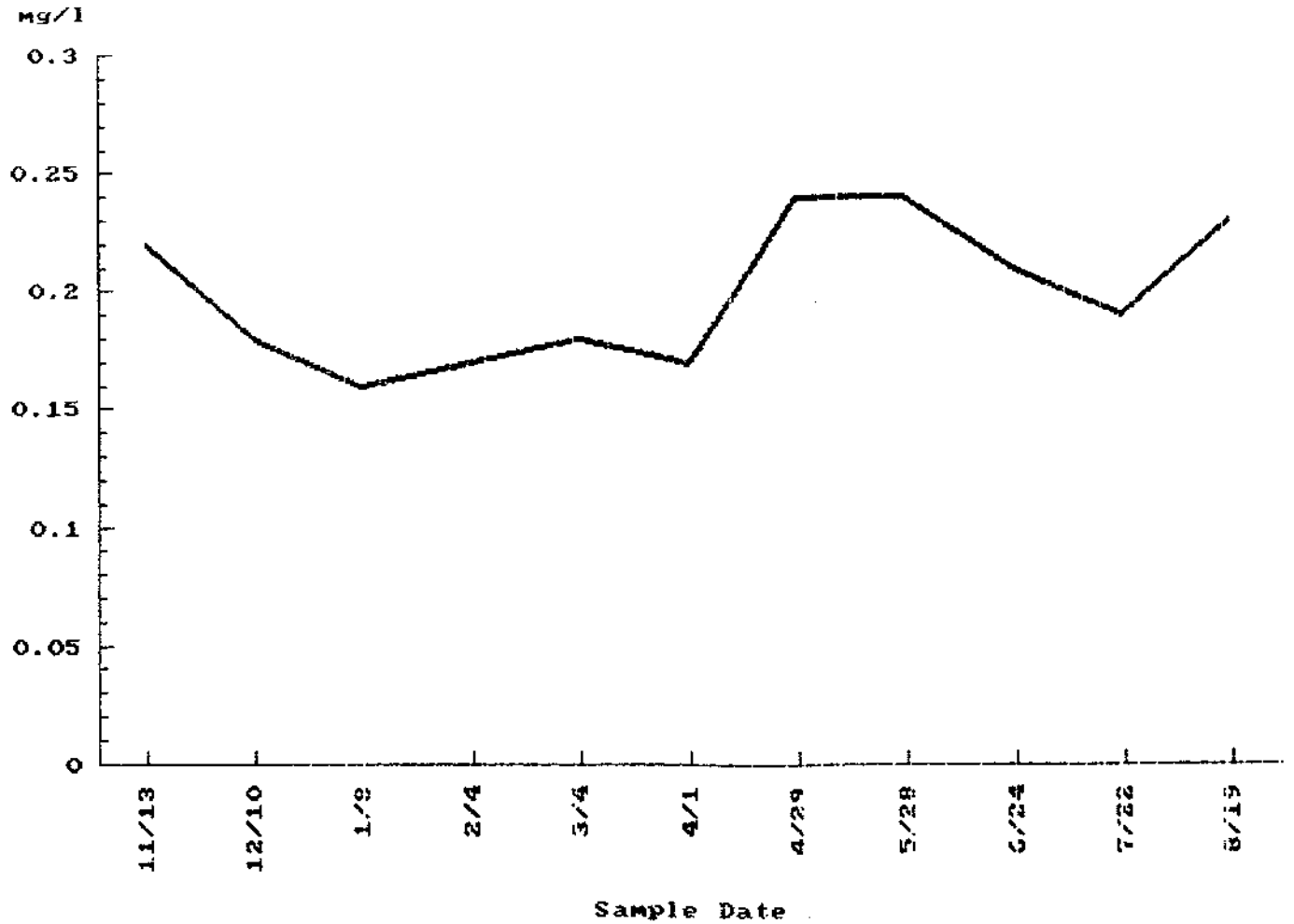


FIGURE 43. Dissolved nitrate/nitrite as nitrogen by sampling date, MOSS 5.



MASS Sites

The MASS pond sites were chosen to sample conditions which reflected situations common to Florida impoundments. Due to this high degree of variability and the limited amount of sampling, the salient points concerning water quality in these impoundments is presented in summary form. All chemistry data for these sites are listed in Table 14.

Mean concentrations of TKN and NH_3 increased downstream of impoundments at 10 of 13 sites relative to upstream and pond values. Mean nitrate/nitrite concentrations were higher in the upstream areas and the impoundments in a majority of the sites. Mean phosphate levels downstream of impoundment systems increased only slightly as compared to upstream values. The increased levels of several potential nutrient sources (TKN, NH_3, PO_4) correlates with an increased chlorophyll *a* production downstream of the impoundments in 85% of the cases. Thirty percent of the cases displayed extremely high mean chlorophyll *a* values ranging from 20.33 ug/l to 75.30 ug/l. This may be a result of algae typically found in ponds establishing communities in reaches of the stream beyond the outfall. This may be attributed to the increased amount of light available to the pond and a subsequent change in algal communities, as compared to the reaches of the streams which are shaded by trees and undergrowth. A more in-depth discussion of algal chlorophyll levels is available in the periphyton and phytoplankton section.

Turbidity and TSS increased downstream in 62% of all the impoundments (Table 15), and may have contributed significantly to increases in PO_4, since an increase in suspended solids has been implicated in the transportion of several chemical constituents, including phosphates. The characteristics of ponds and plankton productivity accounted for higher mean pH levels in the ponds as compared to upstream waters (Stewart 1974).

Conductivity was not observed to increase downstream of top discharge impoundments while 58% of bottom release impoundments exhibited elevated conductivities. Bottom discharge systems most likely contribute more water from the regions of sediment-water interface, which characteristically are areas of increased ion exchange.

Stream temperature ranged from 6.0-29.5°C while pond temperature varied from 6.5-28°C. Thermal stratification may appear some time in March or April. However, temperature and D.O. data were not taken between February and May, and thus the time of stratification can only be assumed.

Dissolved oxygen in stream water ranged from 1.6-13.2 mg/l, and for a majority of cases was higher in the upstream than in the impoundment or the downstream areas (Tables 16 and 17). Pond oxygen levels ranged from .1-13.2 mg/l. Hypolimnion oxygen depletion in the impoundments occurred in conjunction with thermal stratification. In a few of the impoundments

TABLE 14. Mean, range, and standard deviation, for MASS station nutrient chemistry and chlorophyll *a* data. (1 - upstream, 2 - pond, 3 - outfall).

Station	TKN mg/l	NH_3 mg/l	NO_3/NO_2 mg/l	PO_4 mg/l	Chl-a mg/m^3
A2	.544 (.23-.78) .237	.03 (.01-.11) .021	.036 (.01-.06) .021	.056 (.02-.08) .023	19.11 (12.85-24.47) 4.54
A3	1.27 (.116-1.44) .136	1.045 (.96-1.13) .078	.022 (.01-.04) .013	.032 (.01-.04) .015	9.48 (0-27.9) 15.86
B1	.164 (.09-.30) .087	.016 (.01-.03) .009	.366 (.33-.43) .038	.022 (.01-.04) .013	.586 (0-1.32) .590
B2	.382 (.24-.49) .096	.012 (.01-.02) .004	.04 (.01-.08) .027	.032 (.02-.05) .013	24.33 (10.31-.41.40) 13.96
B3	.44 (.23-.71) .178	.094 (.01-.34) .140	.05 (.02-.07) .029	.076 (.03-.19) .066	12.29 (3.05-29.51) 10.07
C1	.589 (.40-.97) .234	.096 (.03-.09) .06	.266 (.13-.45) .125	.084 (.06-.12) .029	9.37 (1.17-29.5.) 11.69
C2	.906 (.84-1.16) .234	.014 (.01-.03) .009	.036 (.01-.09) .032	.134 (.09-.19) .051	98.79 (65.66-115.36) 36.64
C3	1.09 (.55-2.23) .715	.148 (.01-.35) .167	.442 (.03-1.75) .736	.088 (.03-.16) .057	55.72 (1.20-162.08) 64.53
D2	.272 (.05-.51) .168	.014 (.01-.03) .009	.492 (.05-1.12) .518	.034 (.01-.08) .028	8.84 (1.05-20.06) 8.76
D3	.290 (.05-.39) .141	.018 (.01-.03) .011	.504 (.06-1.17) .531	.032 (.01-.07) .024	10.36 (.668-26.49) 10.544
E2	.54 (.31-.87) .238	.014 (.01-.03) .009	.028 (.01-.09) .035	.034 (.02-.07) .021	9.04 (2.64-12.94) 4.48
E3	.428 (.25-.79) .234	.026 (.01-.04) .011	.042 (.01-.08) .031	.57 (.04-2.42) 1.04	9.11 (2.83-24.38) 8.85

TABLE 14. Continued.

Station	TKN mg/l	NH_3 m/gl	NO_3/NO_2 mg/l	PO_4 mg/l	Chl-a mg/m^3
F2	.33 (.19-.43) .095	.01 (.01-.04) 0	.03 (.01-.08) .029	.044 (.02-.09) .027	13.10 (3.66-23.00) 8.86
F3	.986 (.22-1.64) .61	.476 (.02-.88) .42	.032 (.01-.08) .032	.182 (.03-.31) .13	33.4 (6.91-71.89) 27.57
G1	.195 (.07-.26) .089	.027 (.01-.04) .015	.175 (.02-.39) .185	.08 (.04-.11) .036	1.74 (1.05-2.78) .745
G2	.31 (.17-.41) .096	.01 (.01-.01) 0	.036 (.01-.09) .037	.054 (.02-.09) .034	9.87 (1.74-.18.92) 8.02
G3	.412 (.10-.65) .263	.137 (.02-.41) .184	.08 (.01-.20) .087	.057 (.02-.14) .055	14.83 (1.20-53.44) 25.74
H1	.156 (.06-.29) .092	.014 (.01-.02) .005	.096 (.01-.17) .060	.076 (.02-.11) .036	8.34 (.556-29.0) 11.88
H2	.286 (.16-.49) .134	.012 (.01-.02) .004	.026 (.01-.09) .036	.078 (.02-.11) .036	16.22 (5.64-33.99) 10.69
H3	.260 (.05-.47) .152	.084 (.01-.37) .160	.026 (.01-.09) .036	.144 (.07-.23) .071	15.76 (4.57-30.05) 11.20
I1	.215 (.06-.40) .140	.035 (.01-.09) .038	.065 (.04-.08) .019	.02 (.01-.03) .008	.854 (0-1.81) .824
I2	1.95 (.75-3.3) 1.11	1.48 (.04-2.90) 1.33	.06 (.01-.10) .042	.082 (.04-.12) .036	93.77 (21.27-170.05) 63.02
I3	1.92 (.64-3.56) 1.23	1.32 (.09-2.99) 1.37	.035 (.01-.08) .031	.082 (.04-.13) .038	75.30 (9.15-285.4) 88.65
J1	.132 (.03-.22) .087	.012 (.01-.02) .004	.53 (.41-.67) .157	.024 (.02-.03) .005	2.22 (.709-6.02) 2.21

TABLE 14. Continued.

Station	TKN mg/l	NH_3 mg/l	NO_3/NO_2 mg/l	PO_4 mg/l	Chl-a mg/m^3
J2	.25 (.16-.35) .079	.016 (.01-.04) .013	.172 (.01-.45) .201	.026 (.02-.03) .009	18.09 (15.15-21.88) 2.74
J3	.226 (.18-.34) .065	.016 (.01-.04) .009	.174 (.01-.45) .200	.034 (.02-.06) .019	15.89 (9.55-21.27) 4.82
K1	.344 (.05-1.28) .526	.01 (.01-.01) 0	.952 (.86-1.04) .065	.022 (.01-.04) .011	2.15 (.907-.5.34) 1.81
K2	.556 (.25-1.20) .375	.02 (.01-.03) .01	.196 (.05-.36) .129	.026 (.02-.05) .013	27.99 (5.96-.38.84) 13.33
K3	.512 (.30-.75) .160	.102 (.05-.11) .037	.240 (.10-.36) .102	.036 (.02-.06) .017	20.33 (6.54-34.40) 10.63
L1	.438 (.09-.130) .489	.066 (.01-.16) .064	.522 (.19-1.04) .354	.03 (.01-.07) .023	3.25 (0-10.22) 4.11
L2	.26 (.16-.34) .075	.01 (.01-.01) 0	.058 (.01-.01) .041	.028 (.01-.06) .019	10.90 (6.97-15.67) 3.31
L3	.252 (.15-.31) .062	.014 (.01-.03) .009	.068 (.01-.10) .045	.028 (.02-.05) .013	8.80 (4.45-12.86) 3.25
M1	.114 (.06-.17) .040	.012 (.01-.02) .004	.042 (.01-.10) .044	.032 (.02-.05) .013	.332 (0-.555) .227
M2	.434 (.18-.66) .186	.012 (.01-.02) .004	.04 (.01-.10) .04	.03 (.02-.05) .014	25.29 (11.36-41.01) 11.37
M3	.637 (.16-1.16) .497	.295 (.01-.67) .337	.01 (.01-.01) 0	.072 (.03-.12) .044	28.92 (13.89-41.47) 11.45

TABLE 15. MASS station chemistry (means and standard deviation, 1 - upstream, 2 - pond, 3 - outfall).

Station	pH SU	Turbidity FTU	TSS mg/l	Conductivity umhos/cm	Alkalinity mg/l	Hardness mg/l	Sulfate mg/l	Chloride mg/l
A2	4.98	18.20	7.2	21.0	1.0	8.0	5.30	5.20
	.42	4.97	2.2	2.24	2.24	5.7	3.70	1.39
A3	5.55	69.0	34.0	81.25	18.75	22.5	7.22	6.25
	.39	47.6	4.16	13.15	10.31	6.45	9.19	1.65
B1	4.30	3.52	4.94	16.0	1.0	3.0	2.0	2.56
	.32	1.82	.76	2.24	2.24	2.74	0	1.05
B2	4.42	6.36	5.16	14.0	1.0	5.0	2.68	3.04
	.48	3.78	1.25	5.48	2.24	3.53	1.09	1.61
B3	4.54	6.46	5.64	12.0	1.0	6.0	2.46	3.04
	.46	3.78	1.42	4.47	2.24	5.48	1.03	1.16
C1	5.14	12.56	6.04	55.0	9.0	17.0	10.3	2.0
	.30	16.49	1.98	20.3	4.18	4.47	2.64	0
C2	5.68	16.6	15.72	51.0	4.0	9.0	2.0	9.72
	.44	6.50	6.70	19.17	4.18	5.48	0	1.26
C3	5.30	12.56	12.04	34.0	5.0	13.0	2.2	9.66
	.16	11.54	7.85	19.17	3.53	4.47	.45	1.46
D2	5.18	7.0	8.76	22.0	22.0	10.0	2.0	4.84
	.13	4.41	5.74	2.74	2.74	8.66	0	1.49
D3	5.34	6.76	8.66	20.0	1.0	7.0	2.0	4.72
	.23	3.93	6.43	3.53	2.24	5.7	0	.71
E2	6.84	6.16	6.22	98.0	45.0	60.0	3.06	4.64
	1.03	1.89	2.71	15.25	5.0	7.07	1.08	.70
E3	6.42	550.2	869.7	98.0	47.0	59.0	2.8	20.1
	.47	1201.8	1917.6	13.51	5.70	5.48	.84	32.94
F2	5.22	4.30	6.32	18.0	1.0	4.0	2.0	4.54
	.722	3.83	3.21	2.74	2.24	2.24	0	.74
F3	5.39	21.0	18.04	31.0	8.0	13.0	2.0	5.3
	.30	18.85	21.45	10.84	10.37	8.54	0	1.25
G1	4.97	4.95	5.00	22.5	1.25	6.25	2.0	5.02
	.38	1.84	.67	6.45	2.50	4.79	0	1.54

TABLE 15. Continued.

Station	pH SU	Turbidity FTU	TSS mg/l	Conductivity umhos/cm	Alkalinity mg/l	Hardness mg/l	Sulfate mg/l	Chloride mg/l
G2	5.24	5.62	5.0	18.0	4.0	4.0	2.0	4.48
	.30	2.53	.89	2.74	4.18	4.18	0	.89
G3	5.2	10.25	9.95	27.5	7.55	5.00	2.0	5.15
	.26	8.81	10.04	11.9	9.58	4.08	0	1.44
H1	4.78	9.30	4.94	16.0	1.0	3.0	2.0	2.56
	.40	3.38	.76	2.24	2.24	2.74	0	1.05
H2	5.04	7.30	6.94	11.0	5.00	5.00	2.2	4.10
	.50	2.51	3.27	2.24	5.00	3.53	.45	.99
H3	5.0	21.0	25.3	12.0	6.00	3.00	2.0	4.36
	.54	17.89	34.31	2.74	5.48	4.47	0	.91
I1	4.82	4.65	5.20	17.5	1.25	5.00	2.62	5.37
	.33	4.38	1.20	5.0	2.5	7.07	1.25	1.31
I2	5.24	48.36	25.52	27.0	8.00	10.0	2.0	5.84
	.43	52.57	21.45	9.75	7.58	11.18	0	1.17
I3	5.37	76.75	34.25	28.75	11.25	10.0	2.0	5.5
	.25	46.27	28.58	13.15	8.54	10.0	0	.68
J1	5.00	7.72	15.70	15.00	4.00	8.00	2.0	4.26
	.21	4.83	12.78	0	4.18	10.37	0	1.00
J2	5.4	7.26	6.22	19.0	7.0	5.0	2.0	4.72
	.60	3.03	1.15	2.24	7.58	6.12	0	.71
J3	5.30	10.06	6.02	19.0	6.0	8.0	2.0	4.52
	.44	7.63	2.30	2.24	2.24	6.71	0	
K1	5.0	11.0	38.6	16.0	2.0	6.0	2.0	3.62
	.24	6.24	13.03	2.24	2.74	4.18	0	1.26
K2	5.50	5.74	6.68	16.0	7.0	8.0	2.0	4.26
	.48	1.70	2.21	4.18	5.7	9.75	0	.91
K3	5.26	8.54	10.14	20.0	7.0	8.0	2.0	4.26
	.28	1.61	3.97	0	7.58	4.47	0	.91
L1	5.38	21.44	38.56	41.0	11.0	12.0	2.1	9.98
	.22	34.37	61.77	20.74	11.4	13.0	.224	3.99

TABLE 15. Continued.

Station	pH SU	Turbidity FTU	TSS mg/l	Conductivity umhos/cm	Alkalinity mg/l	Hardness mg/l	Sulfate mg/l	Chloride mg/l
L2	5.56	7.08	5.04	22.0	8.0	9.0	2.0	5.78
	.40	1.90	.64	2.74	5.70	9.62	0	.93
L3	5.40	8.24	5.54	22.0	5.0	7.0	2.0	5.70
	.32	3.46	1.89	2.74	3.53	5.70	0	.93
M1	4.54	5.44	9.24	11.0	3.0	3.0	2.0	3.14
	.38	2.71	6.83	4.18	2.74	2.74	0	.75
M2	5.34	6.18	6.32	13.0	4.0	5.0	2.0	3.22
	.53	2.30	1.63	5.7	4.18	6.12	0	.722
M3	5.37	42.5	31.87	17.5	6.25	10.0	2.0	2.70
	.30	65.25	44.18	11.90	7.50	10.80	0	.39

TABLE 16 . MASS Pond means and standard deviation for surface and bottom dissolved oxygen.

Station	Bottom D.O. Mean (mg/l)	sd	Surface D.O. Mean (mg/l)	sd
A2	6.7	2.6	7.7	1.8
B2	3.5	4.9	7.6	3.0
C2	2.0	3.6	8.2	2.3
D2	4.3	5.0	8.9	2.0
E2	3.2	4.8	9.3	2.4
F2	2.1	3.2	5.8	2.9
G2	2.8	4.1	6.9	2.2
H2	3.3	5.1	8.8	1.9
I2	2.7	3.9	4.5	3.5
J2	4.0	4.8	9.1	2.0
K2	2.9	4.2	9.6	1.4
L2	2.6	4.6	8.9	2.2
M2	3.4	5.3	10.2	.8

TABLE 17. MASS streams means and standard deviation for surface and bottom dissolved oxygen.

Station	Type	Stream D.O. Mean (mg/l)	sd
A3	outfall	4.4	2.7
B1	upstream	8.1	.8
B3	outfall	7.8	3.4
C1	upstream	2.65	1.5
C3	outfall	4.1	1.7
D3	outfall	9.0	1.6
E3	outfall	5.6	2.9
F3	outfall	8.6	2.4
G1	upstream	8.2	1.3
G3	outfall	6.0	4.0
H1	upstream	9.3	1.8
H3	outfall	9.5	2.5
I1	upstream	7.3	3.3
I3	outfall	9.3	2.3
J1	upstream	7.8	.8
J3	outfall	8.1	2.2
K1	upstream	8.25	1.7
K3	outfall	8.3	2.1
L1	upstream	7.8	3.7
L3	outfall	8.6	3.3
M1	upstream	9.1	1.9
M3	outfall	10.1	2.6

the oxygen depletion was severe (Figures 44-46). The Suber pond (F2), which was covered with duckweed during the summer, exhibited virtually complete D.O. depletion below 2 meters. The D.O. from 2 meters depth to the bottom (approximately 6 meters) ranged from 0 mg/l to .4 mg/l for the months of May through August. The Hopper pond (C2), which receives run-off from a cattle feed lot, showed signs of oxygen depletion even in February, while the Scott pond (I2) was virtually devoid of O_2 in the bottom and surface water from April through August.

In some cases, (e.g., the Hopper pond (C2)), the mechanism involved in creating water quality problems is easily discerned. However, in some like the Scott pond (I2), the causes of deterioration are not so straightforward and would require further, more in-depth analysis due to the complex interactions governing trophic dynamics. The other chemical parameters included in the sampling regime revealed nothing in the way of significant trends and generally reflected random variability.

SUMMARY

The physical and chemical quality of the aquatic environment influences the overall health of the organisms which interact within the habitat. In all cases, water in the impoundments and the effluent streams possessed water quality characteristics which differed from upstream conditions. In a majority of the impoundments, agricultural inputs and drowned vegatation resulted in increased nutrient levels. Total Kjeldahl nitrogen (TKN) concentrations were especially high in the impoundments and the effluent streams. A general increase in pH from the upstream to the outfall was observed, which is probably the result of increased plankton productivity, which effectively decreases CO_2 concentrations and boosts pH. Temperature ranges generally reflected seasonal variations, although mean downstream temperatures were slightly elevated. Most importantly, hypolimnetic oxygen depletion was prevalent in all the ponds throughout the summer and, in some cases (deeper ponds in particular) throughout the whole study, indicating large quantities of decomposing organic material on the bottom. In a few impoundments oxygen depletion was not limited to the hypolimnion, but extended upward encompassing the entire water column.

Anthropogenic and natural factors regulating impoundment ecology are extremely varied and thus it is important to evaluate activities in proximity to an impoundment when they may be relevant to water quality.

FIGURE 44. Pond dissolved oxygen profile for station C2 (Hopper).
(1ppm intervals)

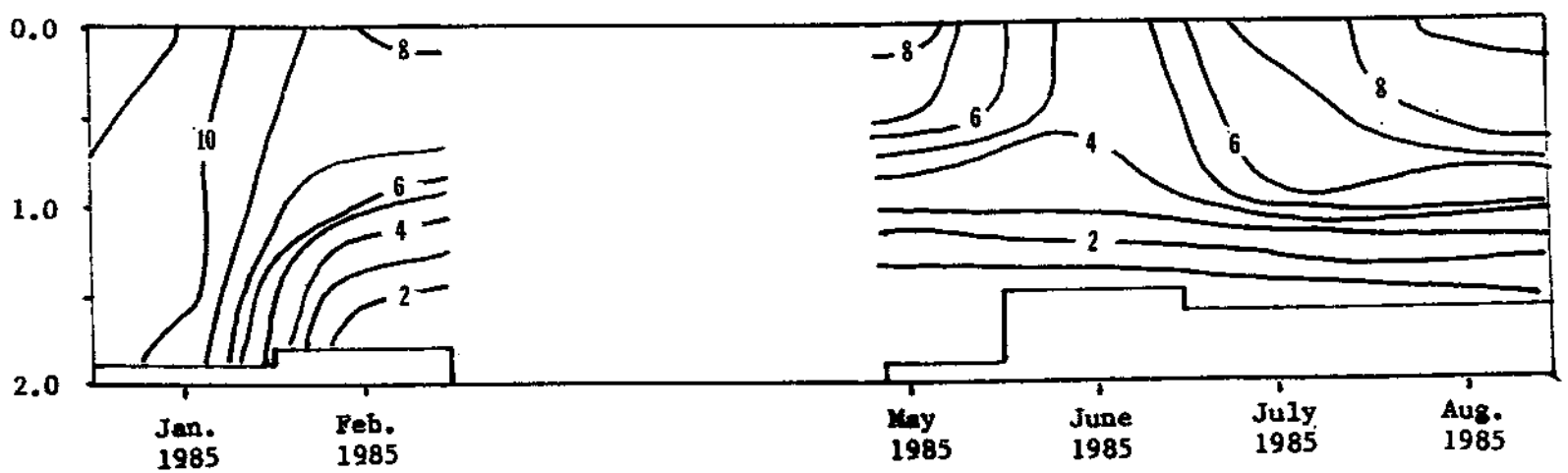


FIGURE 45. Pond dissolved oxygen profile for station F2 (Suber).
(1ppm intervals)

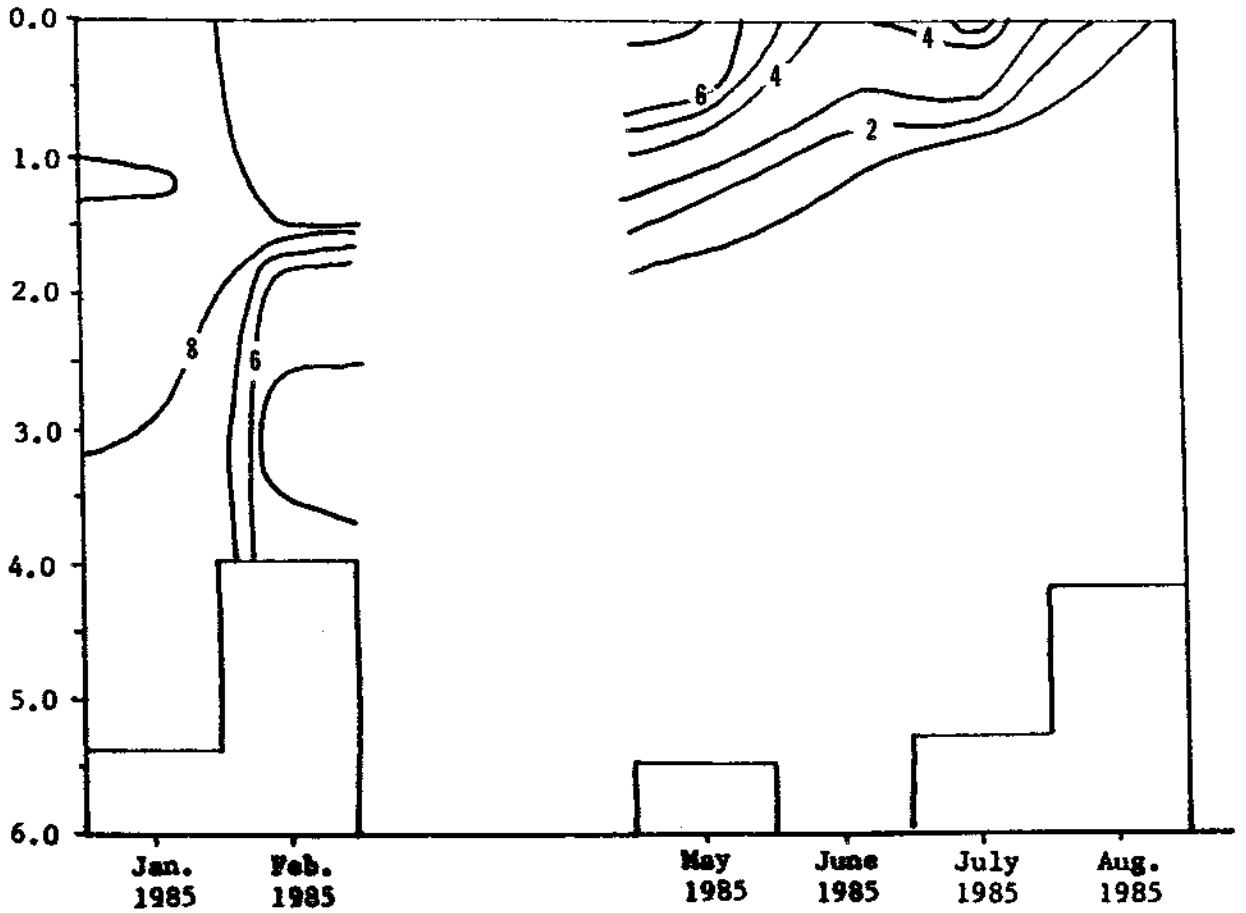
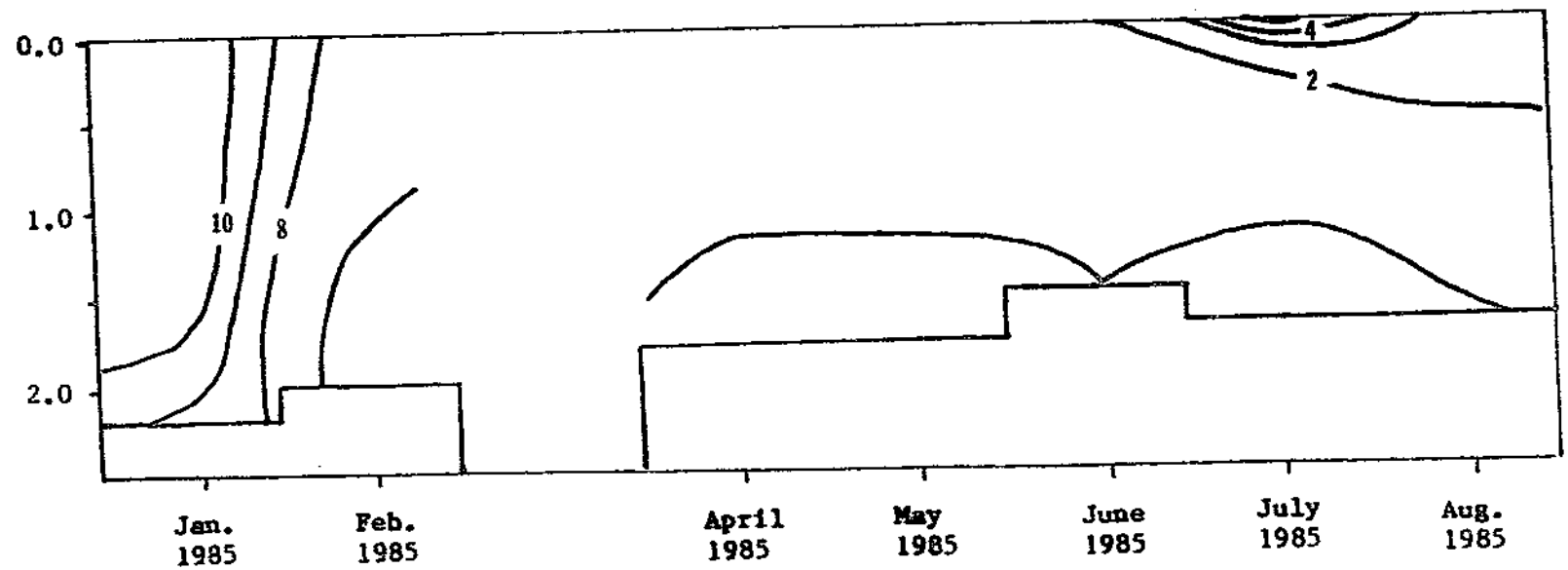


FIGURE 46. Pond dissolved oxygen profile for station I2 (Scott).
(1ppm intervals)



SEDIMENT

INTRODUCTION

Substrate composition has been shown to influence the hydrological characteristics exhibited in freshwater systems (Odum 1971). Evidence presented by several investigators (Golterman 1966, Canfield et al.) indicates that sediment composition can have an appreciable effect on overlying water chemistry under a variety of conditions.

Internal loading of sediment-bound nutrients produces effects which directly hinder the progress of measures taken to alleviate eutrophic conditions (Ahlgren 1977, Welch 1977, Jacoby et al. 1982). Internal regeneration of nutrients may affect algal growth and thus trophic conditions since, as some studies suggest, thermal stratification cannot prevent nutrient ions released in the hypolimnion from reaching surface waters (Premazzi et al. 1981). The regeneration of sediment-bound ions can be further enhanced by macroinvertebrate activity (Graneli 1979, Gallepp 1979, Nalepa et al. 1983), though the precise mechanism of release remains in question. Furthermore, distribution and abundance of macroinvertebrate populations have been correlated with substrate composition (Linduska 1942, McLachan 1969, DeMarch 1976), including sediment particle size and the quantity of organic detritus (Egglishaw 1964, Culp et al. 1983). The introduction of large loads of sediment from agricultural areas has also been shown to exacerbate water quality problems since the introduction of nutrient laden soils and the elimination of important habitats such as spawning grounds and beds of aquatic vegetation beds has detrimental effects both ecologically and economically (Duda 1985).

Sediment samples from the 17 ponds investigated were analyzed to determine the percent organic matter. The purpose of the sediment analysis was to: 1) determine if a relationship between organic content and trophic state exists in the ponds as noted by Flannery et al. (1982); 2) to analyze any trends relating macroinvertebrate distribution and abundance to sediment organic content.

METHODS AND MATERIALS

Samples for sediment analysis were collected on 3 and 7 May 1985. Two core samples were taken at each of the 17 pond sites, using a 3.5 cm diameter acrylic coring device. All cores collected were approximately 10 cm in depth (Ford 1962). The contents of each core were emptied into a single Whirlpak® bag, labeled, and frozen upon return to the laboratory. Prior to analysis core samples were thawed, dried, and weighed. Weighed samples were then ashed at 550°C in ceramic crucibles for 4 hours in a muffle furnace (Barnes 1959) and re-weighed to ascertain the loss of organics on ignition.

RESULTS AND DISCUSSION

The organic content of the sediment samples from the ponds ranged from .59% to 19.3%. The Hopper pond (C2) had the highest organic content, most likely due to the influence of cattle and run-off from a cattle feed lot. The McCormick and Crawford ponds (L2, D2) also exhibited relatively high organic content, 16.84% and 14.42%, respectively. These two ponds had no obvious anthropogenic influences other than possible agricultural run-off at the D2 site and potential for high turbidities at L2. However, both impoundments may have had large quantities of drowned vegetation in the basins before they were filled.

The impact that different sediment structure can have on benthic fauna was observed at the MOSS ponds and is indicative of the type of changes that can occur in modified habitats. The MOSS ponds, though adjacent to each other, had relatively different organic contents. The organic content of sediment from MOSS 2 was 10.06% while sediments from MOSS 3 were composed of 5.46% organics.

Differences in organic content in the sediments could potentiallly affect benthic macroinvertebrate populations (Linduska 1942, McLachlan 1969, DeMarch 1976). The differences reflected in the sediments of the MOSS ponds have apparently had an effect on macroinvertebrate populations: the MOSS 2 pond had a large population of oligochate worms, specifically Limnodrilus hoffmeisteri; while MOSS 3 was devoid of this particular worm. Since this animal is known to inhabit highly organic substrates (Stimpson et al. 1982) this finding is not too surprising. However, the fact that these two ponds are connected, have the same source, and are located in the same watershed, and yet have entirely different sediment characteristics and faunal populations, is noteworthy. These data suggest that the MOSS 2 pond may be acting as a settling basin for the fine particles and allochtonous organic material that may be entering the pond from the source stream (MOSS 1) as well as any runoff from the surrounding watershed. More specific data on the MOSS pond benthic community is available in the macroinvertebrate section.

PERIPHYTON

INTRODUCTION

Periphyton refers to the community of microorganisms inhabiting surfaces of underwater vegetation, rocks, and other submerged substrates. This community is also commonly referred to as "Aufwuchs" and, sometimes "epilithon" (Round 1964, U.S. EPA 1973, Swift 1981). Due to the sedentary nature of periphyton, its community composition, structure, and biomass are sensitive to changes in water quality and are often used as indicators of ambient conditions (Butcher 1947, Fjerdingstad 1964, Lowe 1974). Although periphyton communities are usually dominated by diatoms, they are generally quite diverse, often containing hundreds of taxa (Sládecková 1962, Hutchinson 1957).

The objectives of this portion of the project were to assess differences in community composition and structure of periphyton that may be associated with impoundment of streams. If any changes were observed we could then relate these differences to changes in water quality by comparing upstream, pond and outfall stations and by making comparisons among pond stations.

METHODS AND MATERIALS

Artificial substrates were utilized for sampling of periphyton in this study. Numerous studies have indicated that communities grown on artificial substrates, though not identical, are comparable to those grown on natural substrates (Flemer 1970, Hynes 1970, Tuchman 1979, Thompson *et al.* 1982). Glass slides were chosen due to the uniformity of their construction, the ease of procuring them in quantity, and because of their widespread use in similar studies (Yount 1956, Hufford and Collins 1976, Swift 1981, Thompson *et al.* 1982, FDER 1985). Additionally, the use of glass slides in a uniform sampling rack (periphytometer) reduces variability associated with substrate, water depth, and current (Patrick *et al.* 1954, Brown 1976, Pryfogle and Lowe 1979).

Nine standard 75x25 mm microscope slides were placed in stainless steel racks, and were floated approximately 15 cm below the surface. Samples were taken at all FREQUENCY stations, all MASS ponds, and at all MASS upstream stations where other biological samples were taken (Table 3).

After 28 days incubation, the slides were removed and placed in one of two tubes for analysis of phaeopigment-corrected chlorophyll *a*, and for taxonomic identification and enumeration. The slides for chlorophyll *a* analysis were placed in deionized water and stored on ice. The others were placed in water collected at the site and preserved in 5% formalin.

Pigment analysis was conducted within 24 hours of collection, using the following method: Four or five slides were scraped into deionized water and divided into two subsamples of equal volume. The two replications were then filtered through 0.45 um glass fiber filters (Whatman GF/C®) and rinsed with magnesium carbonate solution. The filters were then macerated with a fluted Teflon® tissue grinder, and extracted in 90% aqueous acetone/magnesium carbonate mixture for 18 to 24 hours. Optical density of the supernatant was measured with a Beckman Model 35 double beam spectrophotometer at 664 nm for chlorophyll a. The samples were then acidified with two drops of 1.0N HCl to degrade the chlorophyll a molecules into phaeopigment compounds. Optical density was then measured at 665 nm. The monochromatic equation of Strickland and Parsons (1972) was used to calculate phaeopigment-corrected chlorophyll a.

For algal identification, periphyton was scraped from the preserved slides and diluted to a known volume. These samples were used both for identification of the total algal community and for analysis of the diatom fraction. The portion of the sample used to identify the algal community was diluted with deionized water until proper counting densities were achieved. Ütermöhl counting chambers and a Wild® M-40 inverted microscope were used for identification and enumeration; 50 to 100 fields were counted, according to algal density. The taxonomic keys listed in the Literature Cited were used for algal identification. Densities, in number of cells/mm^2, were determined from raw counts using the known volumes and dilutions.

The portions of the samples for diatom analysis were mixed with approximately 20 ml of 50% hydrogen peroxide and heated for 20 minutes on a warm laboratory hot plate. Potassium dichromate (1-2 g) was added to the mixture to complete the oxidation of the sample. After cooling, the sample was diluted with approximately 500 ml of deionized water, allowed to settle for 24 hours, and decanted. After several dilutions and settlings of cells, a measured portion of the concentrate was air dried onto a 0.17 um coverslip and permanently mounted onto a glass slide with Hyrax® mounting medium.

For each sample, 200-250 frustules (except where diatom density was very low) were identified to the lowest taxonomic level possible using the references in the Literature Cited. An oil immersion lens (Zeiss®) was used at 500x and 1250x, and raw counts were then used to determine the percent composition of each diatom taxon. These proportions were then applied to the number of diatoms found in the total periphyton identification portion, and densities in number of cells/mm^2 were calculated. In the following text, diatoms (Bacillariophyta) are considered as an independent division. Chrysophytes other than diatoms are referred to as chrysophytes.

Statistical analyses performed on the periphyton data included normal and inverse numerical classification (cluster analysis) using the 50 most dominant taxa. These taxa constituted 92.2% and 95.8% of the FREQUENCY and

MASS groups, respectively. Multiple discriminant analysis was used to identify physical-chemical factors most directly associated with the station groupings that were derived from biological data. This technique was used to relate species abundance and distribution patterns to abiotic parameters.

RESULTS AND DISCUSSION

FREQUENCY Sites

QUIN Site

The effects of stream impoundment can be demonstrated as differences between the upstream and pond stations. For the QUIN site, total and mean number of periphytic taxa decreased at QUIN 2 by 23% and 27%, respectively, while mean abundance (# of individuals/mm^2) increased by 72% (Table 18). Because community diversity measurements are often utilized as a tool for evaluation of water quality (Patrick et al. 1954, Hohn 1961, Pryfogle and Lowe 1979), the Shannon-Weaver diversity index ($\bar{d}$) was calculated for each sample. This index is based on the number of taxa and the equitability of their distribution. Pooled $\bar{d}$ was also calculated for each station as described in the Macroinvertebrates section. Although monthly measurements were quite variable, the average $\bar{d}$ was 3.1 for QUIN 1 and 2.2 for QUIN 2, a 29% reduction (Table 18). The same trend in diversity was also observed for pooled $\bar{d}$, which decreased from 3.8 to 2.5 (34%). The lower $\bar{d}$ noted at QUIN 2 probably reflects the overwhelming dominance of Gomphonema parvulum (representing > 56% of the total), a cosmopolitan diatom species typical of nutrient-rich waters (Patrick and Reimer 1975, Lowe 1974). In contrast, at QUIN 1 three species were relatively dominant: Eunotia pectinalis, E. curvata, and Gomphonema parvulum. These constituted 37%, 6% and 13% of the total, respectively. Both species of Eunotia are typical of acid waters with low mineral content (Patrick and Reimer 1966).

Since algal cells vary in size, cell counts may not give a totally accurate measure of biomass (Swift 1981). In contrast, chlorophyll a has been widely used as an indirect measure of biomass (Yount 1956, Sladecek and Sladeckova 1964, Odum 1971, Hooper-Reid and Robinson 1978). Although there appears to be no consistent trend with respect to mean abundance and mean chlorophyll a at QUIN 1 and QUIN 2 (Table 18), the measured values over the sampling period varied together (Figures 47 and 48). Simple linear regression performed on these data resulted in r^2 values of .631 ($p = .01$) and .660 ($p = .02$) for QUIN 1 and QUIN 2, respectively. This positive correlation implies that the variance in the chlorophyll a values can be explained by the changes in algal abundance.

In Table 19, the number of taxa for each QUIN station has been separated into algal divisions. The most significant changes occurred in the number of chlorophytes (green algae) and bacillariophytes (diatoms). Although the average abundance of chlorophytes was 55.5/mm^2 for both stations (Table 18), eight more genera were identified at QUIN 2 and the

TABLE 18. Temperature, number of taxa, Shannon-Weaver diversity index, abundance, and chlorophyll a values for upstream, pond, and outfall stations, QUIN site, November 1984 to August 1985. Numbers in parentheses are minimum and maximum values for the sample period.

	QUIN 1	QUIN 2	QUIN 3
$\bar{x}$ Temp (C°) (range)	16.0 (5.4-20.1)	21.0 (10.0-30.2)	17.5 (9.0-28.0)
Total # taxa	86	66	85
$\bar{x}$ # taxa (range)	23.2 (13-31)	16.9 (12-27)	18.2 (12-29)
$\bar{x}$ $\bar{d}$ (range)	3.1 (0.9-4.2)	2.2 (0.7-3.3)	2.9 (1.6-3.9)
pooled $\bar{d}$	3.8	2.5	3.8
$\bar{x}$ abundance (#/mm^2) (range)	592.5 (10.9-1869.0)	1016.4 (78.6-4864.7)	312.7 (2.6-807.7)
# Cyanophyta	43.6	42.1	118.3
# Chlorophyta	55.5	55.5	14.6
# Chrysophyta	0.0	4.3	6.3
# Bacillariophyta	493.3	911.4	173.4
# Pyrrhophyta	0.0	3.1	0.0
chl-a (mg/mm^2) (range)	7.0 (0.7-16.8)	4.1 (0.2-8.3)	2.7 (0.02-8.6)

FIGURE 47. Periphyton log-transformed abundance and chlorophyll a, QUIN 1.

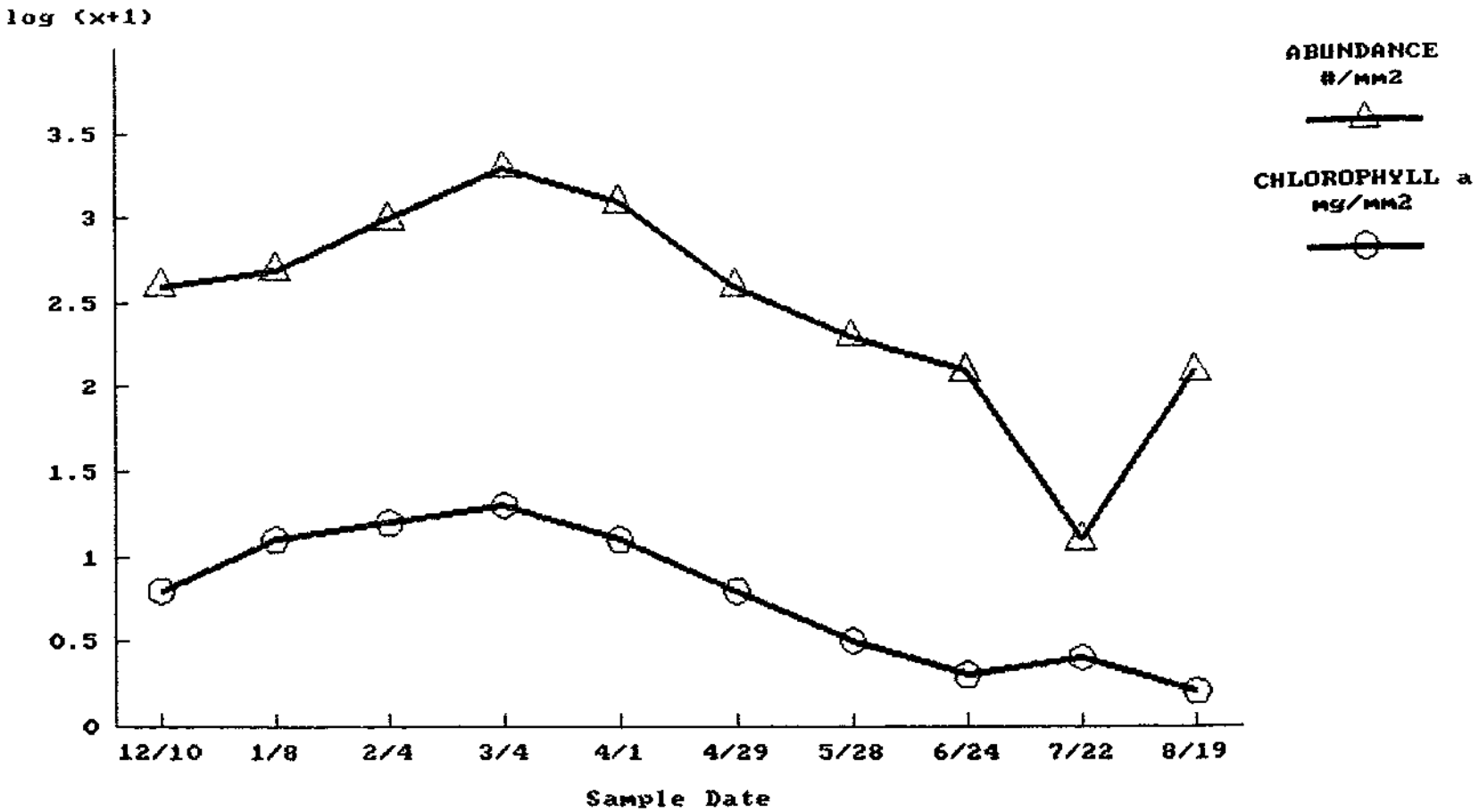


FIGURE 48. Periphyton log-transformed abundance and chlorophyll a, QUIN 2.

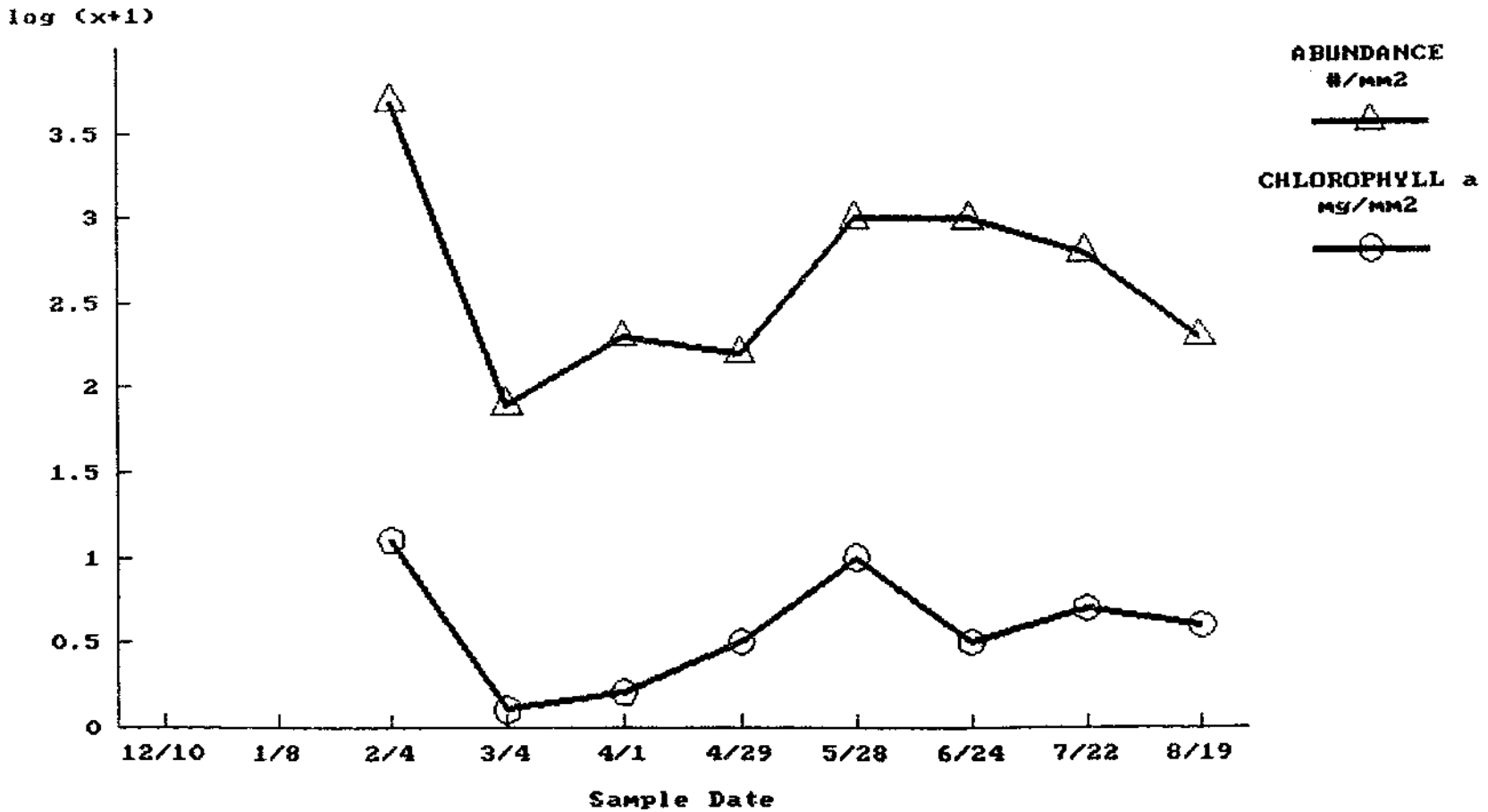


TABLE 19. Numbers of periphyton taxa identified and average percent composition of selected major algal divisions, QUIN Site, November 1984 to August 1985.

No of Taxa	QUIN 1	QUIN 2	QUIN 3
Cyanophyta	6	6	10
Chlorophyta	13	21	14
Chrysophyta	0	2	3
Bacillariophyta	67	35	55
Euglenophyta	0	1	3
Pyrrhophyta	0	1	0
% Composition			
Cyanophyta (range)	11.0 (0.4-32.9)	6.2 (0.0-21.8)	36.4 (9.5-89.2)
Chlorophyta (range)	5.5 (0.7-22.0)	10.7 (1.2-31.1)	6.8 (0.0-22.2)
Chrysophyta (range)	0.0	0.7 (0.0-3.4)	2.2 (0.0-15.9)
Bacillariophyta (range)	83.5 (60.0-98.7)	81.7 (63.0-98.2)	54.7 (8.6-85.2)
Pyrrhophyta	0.0	0.7	0.0

FIGURE 49. Periphyton log-transformed abundance and chlorophyll a, QUIN 3.

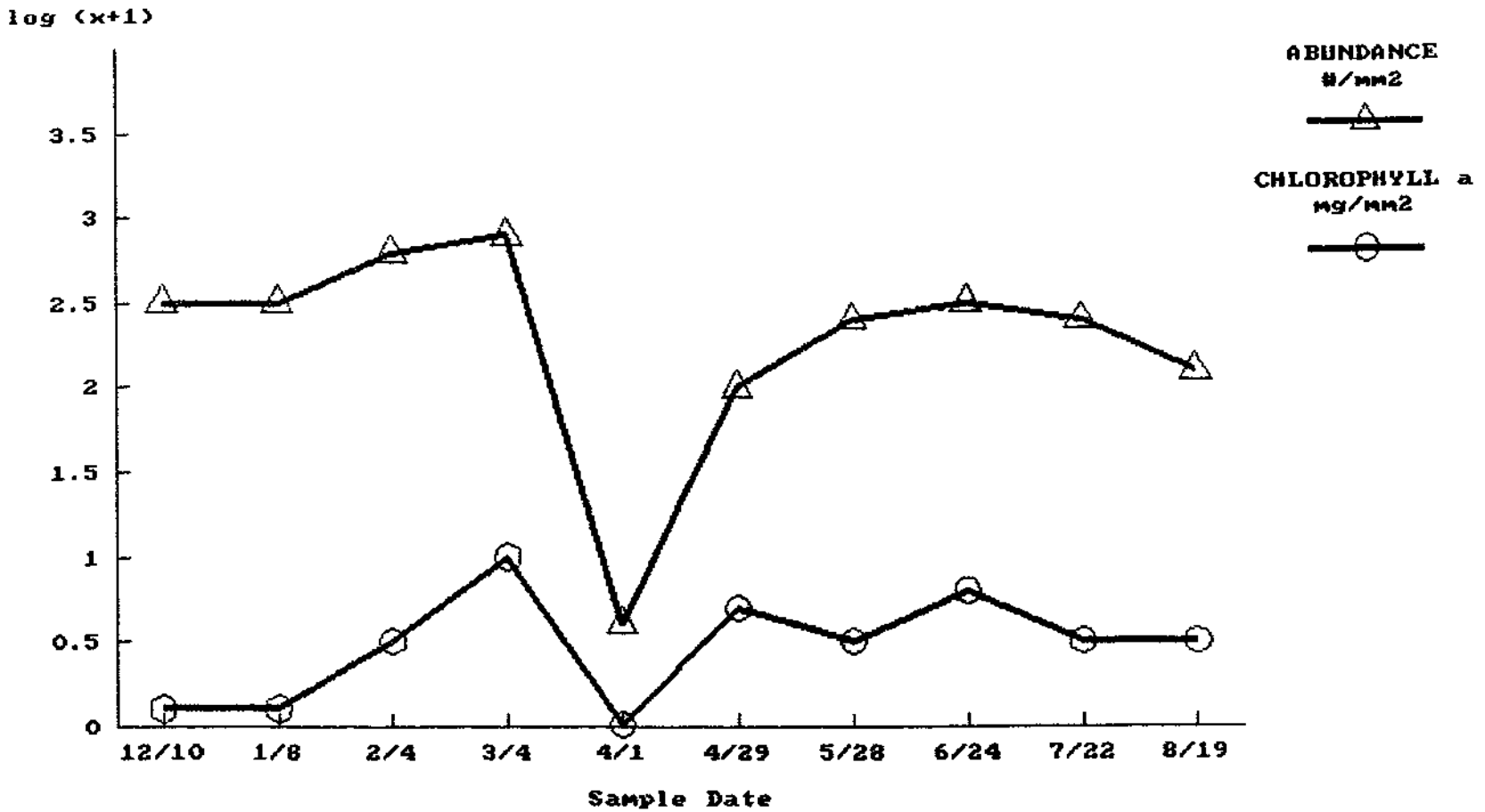


TABLE 20. Periphyton algae identified and number of occurrences at the QUIN Site, November 1984 to August 1985.

	Number of Occurrences		
	QUIN 1	QUIN 2	QUIN 3
CYANOPHYTA			
Anabaena sp.	4	5	3
Aphanocapsa sp.	-	1	1
Aphanotheca sp.	-	-	4
Chroococcus sp.	-	-	1
Lyngbya sp.	1	1	3
Oscillatoria sp.	3	-	2
Phormidium sp.	9	2	8
Plectonema sp.	-	-	4
Spirulina sp.	1	1	1
Unknown Cyanophyte sp.	3	1	3
CHLOROPHYTA			
Ankistrodesmus sp.	-	2	1
Aphanochaeta sp.	-	1	-
Arthrodesmus sp.	-	-	1
Bulbochaete sp.	1	-	-
Chaetosphaerium sp.	1	1	-
Closterium sp.	1	-	1
Cosmarium sp.	-	2	1
Cylindrocapsa sp.	1	-	-
Dictyosphaerium sp.	-	1	-
Euastrum sp.	-	2	-
Gloeocystis sp.	-	1	1
Gonatozygon sp.	-	1	-
Microspora sp.	-	1	-
Mougeotia sp.	1	3	1
Netrium sp.	2	1	-
Oedogonium sp.	7	1	1
Oocystis sp.	1	1	1
Pandorina sp.	-	1	-
Protoderma sp.	3	1	-
Rhizocolonium sp.	-	1	-
Scenedesmus sp.	-	1	-
Spirogira sp.	-	3	1
Staurastrum sp.	4	4	4
Stigeocolonium sp.	1	3	3
Tetraedron sp.	-	-	1
Ulothrix sp.	5	-	1
Zygnema sp.	1	-	-
Unknown Chlorophyte sp.	2	5	4

	QUIN 1	QUIN 2	QUIN 3
CHRYSOPHYTA			
Centritractus sp.	-	2	-
Dinobryon sp.	-	1	2
Mallomonas sp.	-	-	1
Bacillariophyta			
Achnanthes affinis	-	-	1
A. exigua	-	2	-
A. lanceolata	-	-	2
A. lanceolata v. dubia	-	-	1
A. linearis	3	-	-
A. saxonica	1	1	-
Amphora perpusilla	1	-	-
Anomoeoneis serians v. brachysira	-	1	-
Asterionella formosa	-	3	4
Cocconeis fluviatilis	-	-	1
Cymbella sp.	1	-	1
C. aspera	-	-	1
C. diluviana	1	-	-
C. lunata	1	-	2
C. lanceolata	1	-	-
C. minuta	5	6	4
C. minuta v. silesiaca	-	1	-
C. naviculiformis	-	-	1
Epithemia sp.	-	1	1
Eunotia sp.	2	1	2
E. curvata	9	5	7
E. diodon	-	-	1
E. fallax	-	-	1
E. flexuosa	2	2	1
E. incisa	-	2	-
E meisteri	-	-	1
E. microcephala	-	-	1
E. monodon	1	-	-
E. naegelii	-	1	1
E. pectinalis	10	5	6
E. perminuta	1	1	-
E. perpusilla	5	2	3
E. tenella	6	2	2
E. valida	-	-	1
E. vanheurckii	1	-	-
E. vanheurckii v. intermedia	3	-	-
Fragilaria sp.	1	-	-
F. crotonensis	1	-	-

	QUIN 1	QUIN 2	QUIN 3
Frustulia rhomboides	8	2	5
F. rhomboides v. amphipleura	-	-	1
F. rhomboides v. capitata	2	-	1
F. rhomboides v. crassinervia	1	-	1
F. rhomboides v. saxonica	3	1	1
Gomphonema angustatum	-	-	1
G. gracile	5	8	5
G. parvulum	9	7	10
Meridion circulare v. constricta	-	1	-
Navicula sp.	1	1	-
N. angusta	3	-	-
N. capitata	2	-	-
N. capitata v. luneburgensis	1	-	-
N. cryptocephala	1	-	-
N. gregaria	-	-	1
N. lateropunctata	6	1	2
N. notha	1	-	-
N. radiosa	8	3	6
N. rhynchocephala	2	-	1
N. viridula	3	1	1
Neidium sp.	2	-	1
N. affine v. amphirhynchus	1	-	-
N. apiculatum v. constrictum	2	-	-
N. dubium v. constrictum	2	-	-
N. ladogense v. densestriatum	1	-	-
Nitzschia sp.	1	1	2
N. acicularis	1	-	1
N. filiformis	6	1	4
N. fonticola	1	-	-
N. hantzchiana	-	-	1
N. obtusa	1	-	-
N. palea	6	6	6
N. parvula	-	1	1
N. sigma	-	-	1
N. subtilis	-	1	-
Pinnularia sp.	9	1	5
P. abaujensis	1	-	1
P. appendiculata	-	-	1
P. braunii	-	1	2
P. braunii v. amphicephala	1	-	-
P. divergens	2	-	2
P. mesogonglya	1	-	-
P. microstauron	1	-	1
P. subcapitata	2	-	2
P. viridis	1	-	-
Rhopalodia gibba v. ventricosa	1	1	-
Stauroneis sp.	1	-	-
S. anceps	2	-	-

	QUIN 1	QUIN 2	QUIN 3
S. fluminea	1	-	-
S. phoenicenteron	4	-	1
S. smithii	4	-	-
Surirella sp.	1	-	-
S. angustata	-	-	1
Synedra sp.	7	1	-
S. fasciculata	-	-	1
S. ulna	1	5	6
Tabellaria fenestrata	3	-	3
EUGLENOPHYTA			
Euglena sp.	-	-	1
Phacus sp.	-	1	1
Trachelomonas sp.	-	-	1
PYRRHOPHYTA			
Peridinium sp.	-	2	-

relative proportion of this group increased by 95% (Table 19). Station QUIN 1, however, contained greater numbers of filamentous chlorophytes (Table 20), which make up more of the biomass. This may partially explain the greater amount of chlorophyll a observed at QUIN 1 (Table 18).

The most dramatic changes occurred with the diatoms: Although the proportion of diatoms was largely unchanged, their abundance increased by 85% while the number of diatom taxa was reduced by 32, or 48% (Table 19). Table 20 lists all taxa identified at this site, along with the number of occurrences of each at each QUIN station. Although most diatom genera were identified at both upstream and pond stations, 46 species were eliminated or not detected at QUIN 2. Clearly, a dramatic ecological alteration occurred following impoundment at this site.

Stations QUIN 1 and QUIN 3 were observed to be fairly similar in terms of total and mean number of taxa of periphyton, average $\bar{d}$ and pooled $\bar{d}$ (Table 18). The types of taxa present, however, changed dramatically at QUIN 3: The abundance of cyanophytes increased by 171%, and that of chlorophytes and diatoms decreased by 74% and 65%, respectively. This change in species composition is also reflected by the proportions of cyanophytes (11% at QUIN 1; 36.4% at QUIN 3) and diatoms (83.5% at QUIN 1; 54.7% at QUIN 3). The most dominant taxon was the blue-green alga, Phormidium sp., which constituted 29% of the total, followed by the diatom, Gomphonema parvulum (27%).

Mean abundance was decreased by 47%, from 592.5/mm^2 at QUIN 1 to 312.7/mm^2 at QUIN 3. As shown in Figure 49, a dramatic decrease in abundance and chlorophyll a occurred at QUIN 3 on the April 1st sampling date. A similar depression in dissolved phosphorus occurred simultaneously (Figure 19), which may be related to the population crash. Regression analysis on algal abundance and chlorophyll a yielded an r^2 value of .198 for QUIN 3, which was not significant. This lack of correlation implies that the variation in chlorophyll a cannot be explained in terms of algal numbers. The discrepancy between abundance and chlorophyll a is likely due to the increase in proportion of cyanophytes at QUIN 3. Berman and Pollingher (1974) reported that species composition was the primary cause of chlorophyll a fluctuation in Lake Kinneret and Jones (1977) found that blue green algae have a much lower chlorophyll content per unit volume than diatoms.

CRES Site

At the CRES site, total number of taxa decreased by 36% from upstream to the pond. Mean number of taxa, as well as average and pooled $\bar{d}$, however, remained relatively unchanged (Table 21). Although CRES 1 was habitat for a larger number of taxa than CRES 2, it was only consistently dominated by four species of Eunotia, primarily E. pectinalis, which constituted 19% of the total. Eunotia naegelii, E. flexuosa, and E. valida were secondarily dominant, particularly from February to early April, and represented 4%, 12% and 5%, respectively, of the total taxa. At station CRES 2, sporadic blooms were observed at different times of the sampling period. For example, the diatoms Eunotia curvata (25%), Synedra ulna (6%), and Frustulia rhomboides (3%) were most dominant on the late

TABLE 21. Temperature, number of taxa, Shannon-Weaver diversity index, abundance, and chlorophyll a values for upstream, pond, and outfall stations, CRES site, November 1984 to August 1985. Numbers in parentheses are minimum and maximum values for the sample period.

	CRES 1	CRES 2	CRES 3
$\bar{x}$ Temp (°C) (range)	15.0 (8.5-22.0)	23.9 (16.0-29.0)	16.0 (8.0-26.0)
Total #taxa	80	51	72
$\bar{x}$ #taxa (range)	19.4 (12-37)	18.5 (14-23)	17.4 (11-29)
$\bar{x}$ $\bar{d}$ (range)	3.3 (2.5-4.5)	3.0 (2.4-4.1)	3.4 (2.8-4.2)
pooled $\bar{d}$	4.7	4.1	4.4
$\bar{x}$ abundance (#/mm^2) (range)	50.6 (7.8-235.5)	174.3 (38.1-428.4)	88.5 (4.9-266.0)
# Cyanophyta	3.0	0.8	37.1
# Chlorophyta	3.3	55.0	3.7
# Chrysophyta	0.0	15.9	0.0
# Bacillariophyta	44.2	92.5	47.8
# Pyrrhophyta	0.02	10.1	0.0
chl-a (mg/mm^2) (range)	0.2 (0.0-0.7)	1.6 (0.5-3.1)	0.4 (0.0-0.7)

April and May sampling dates. During this time a bloom of Netrium sp. also occurred; this chlorophyte genus accounted for 14% of the total. Four other genera of green algae (Euastrum, Elakatothrix, Mougeotia and Staurastrum) were abundant (53.2, 23.9, 10.6 and 7.9 individuals/mm^2, respectively) on May 28, as well as an unidentified chrysophyte species (66.5 individuals/mm^2). Later in the sampling period, the diatoms Navicula radiosa and Gomphonema gracile, and the pyrrhophyte Peridinium, were dominant.

The increase in algal density from CRES 1 to CRES 2 was notably dramatic; mean abundances were 50.6 individuals/mm^2 at CRES 1 and 174.3 at CRES 2, a 245% increase (Table 21). The greatest increase observed was in the abundance of chlorophytes. The change in abundance from upstream to pond was 1567%, and the change in proportion of chlorophytes increased from 6.3% (CRES 1) to 28.4% (CRES 2), or 351% (Table 22).

This increase in the abundance of green algae may also be reflected in the chlorophyll a values. At CRES 1, abundance and chlorophyll a were generally low (0.2 mg/mm^2), as was abundance relative to CRES 2 (Figures 50 and 51). Regression analysis showed no correlation (r^2 = .122). At Station CRES 2, on the other hand, a very strong correlation was observed between algal abundance and chlorophyll a, with an r^2 of .853 ($p = .01$). This indicates that chlorophyll a fluctuations can be largely explained by algal numbers.

Several changes in the diatom fraction from upstream to pond were noted. Although a 109% increase in abundance was observed (Table 21), the relative proportion of diatoms decreased from 86.0% to 54.1% (Table 22). The number of diatom taxa, however, decreased from 61 at CRES 1 to 31 at CRES 2, or 49% (Table 22). Of the 46 diatom taxa identified at CRES 1 but not detected at CRES 2 (Table 23), five genera were not represented at the pond station. The decrease in diversity and greater density of algae observed at CRES 2 after impoundment of CRES 1 is typical of nutrient-enriched waters (Rawson 1956, Williams 1964, Grimes et al. 1984).

In comparing the upstream and outfall stations at the CRES site, no major differences were observed in total number of taxa, mean number of taxa, average or pooled $\bar{d}$. Mean abundance was 75% higher at CRES 3, increasing from 50.6/mm^2 to 88.5/mm^2 (Table 21). The only major algal division affected, in terms of abundance, were the cyanophytes, or blue-green algae. Cyanophyte abundance was 3.0/mm^2 at CRES 1 and 37.1/mm^2 at CRES 3, a 1133% difference (Table 21).

This increase in the cyanophyte population is also reflected in the proportion of blue-green algae relative to other groups. The proportion of cyanophytes increased 310%, from 7.7% at CRES 1 to 31.6% at CRES 3 (Table 22). The most dominant taxon identified at CRES 3 was Phormidium sp., which constituted 31% of the total. The proportion of diatoms decreased at CRES 3 from 86% to 64.2%.

FIGURE 50. Periphyton log-transformed abundance and chlorophyll a, CRES 1.

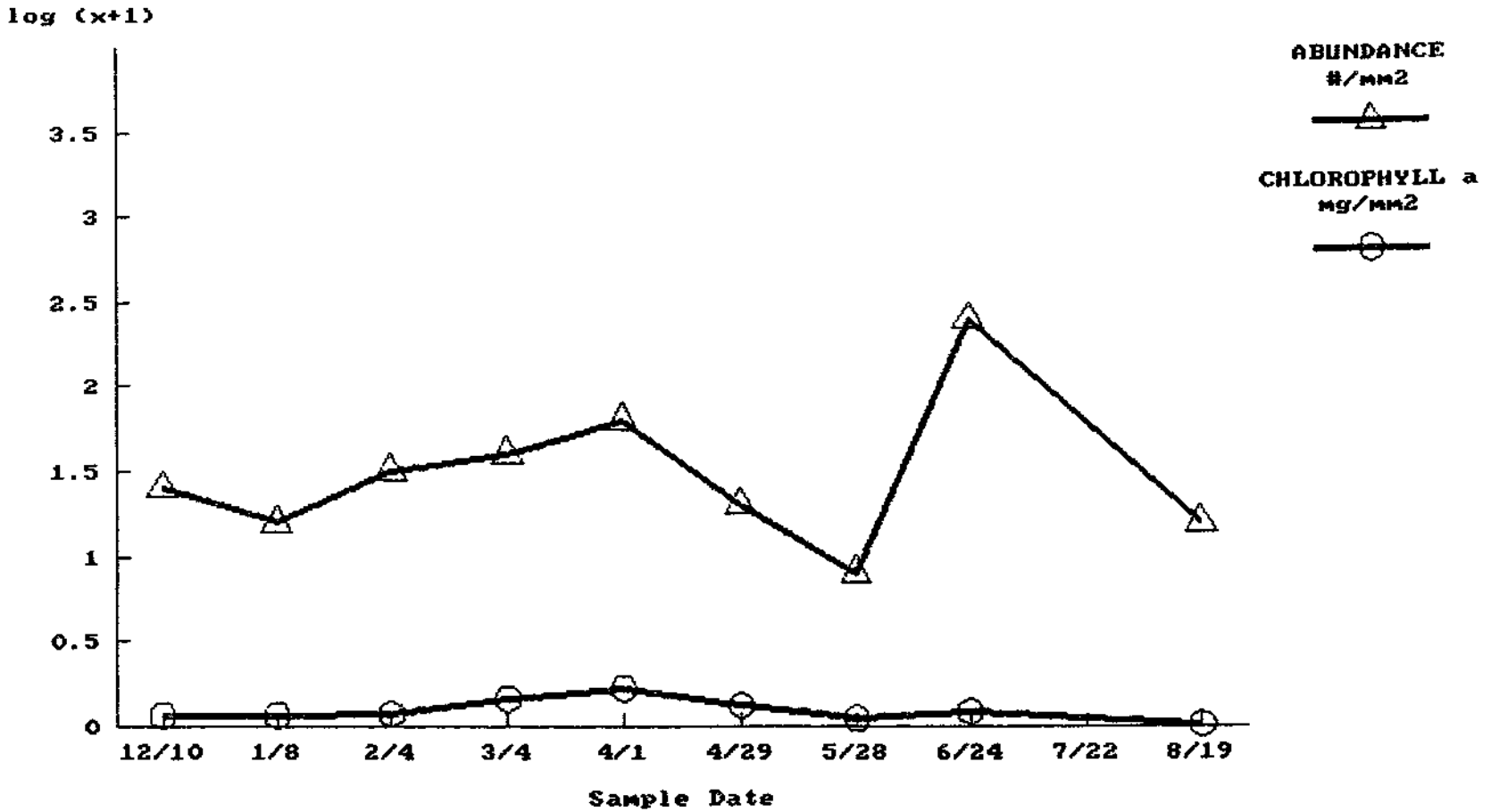


FIGURE 51. Periphyton log-transformed abundance and chlorophyll a, CRES 2.

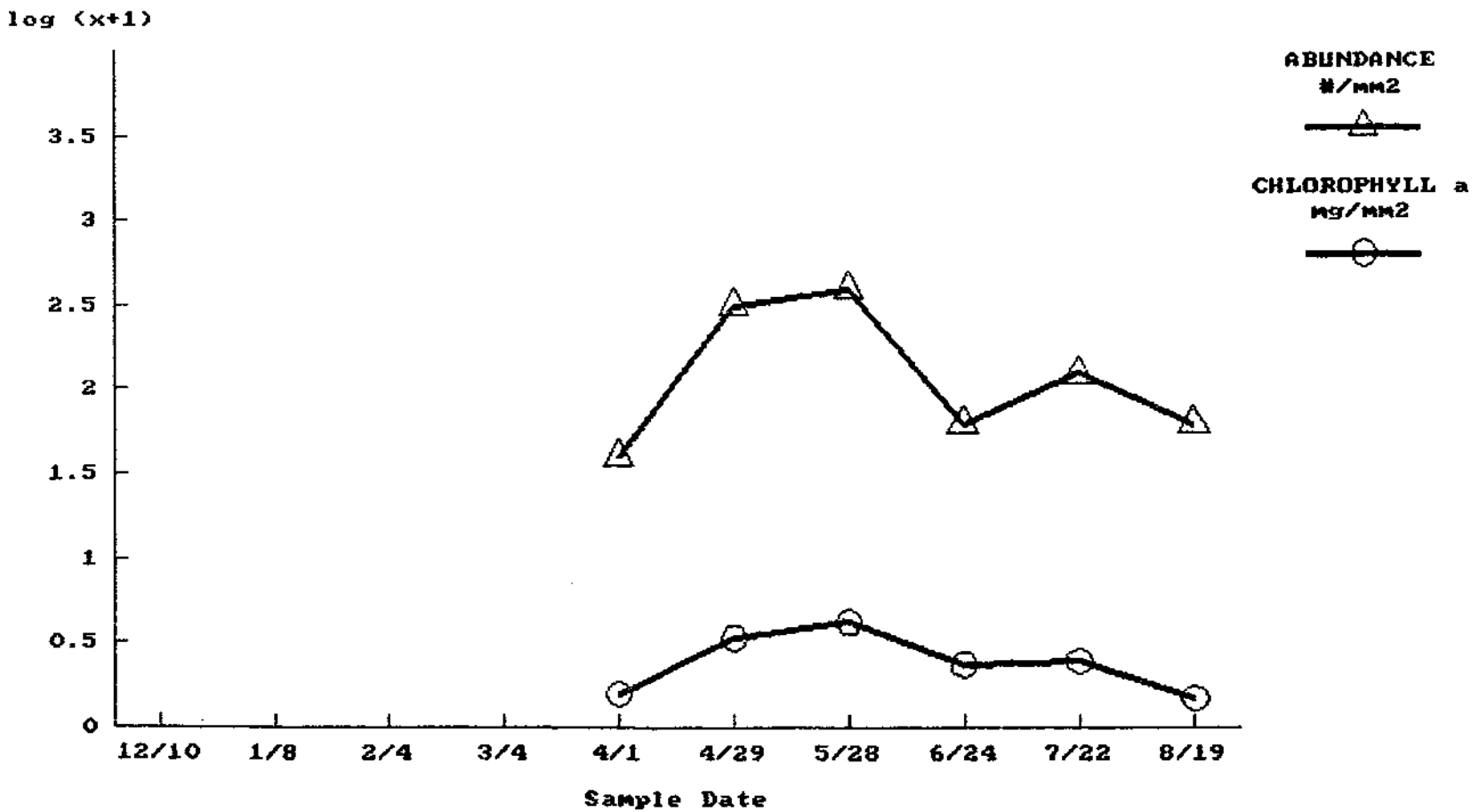


FIGURE 52. Periphyton log-transformed abundance and chlorophyll a, CRES 3.

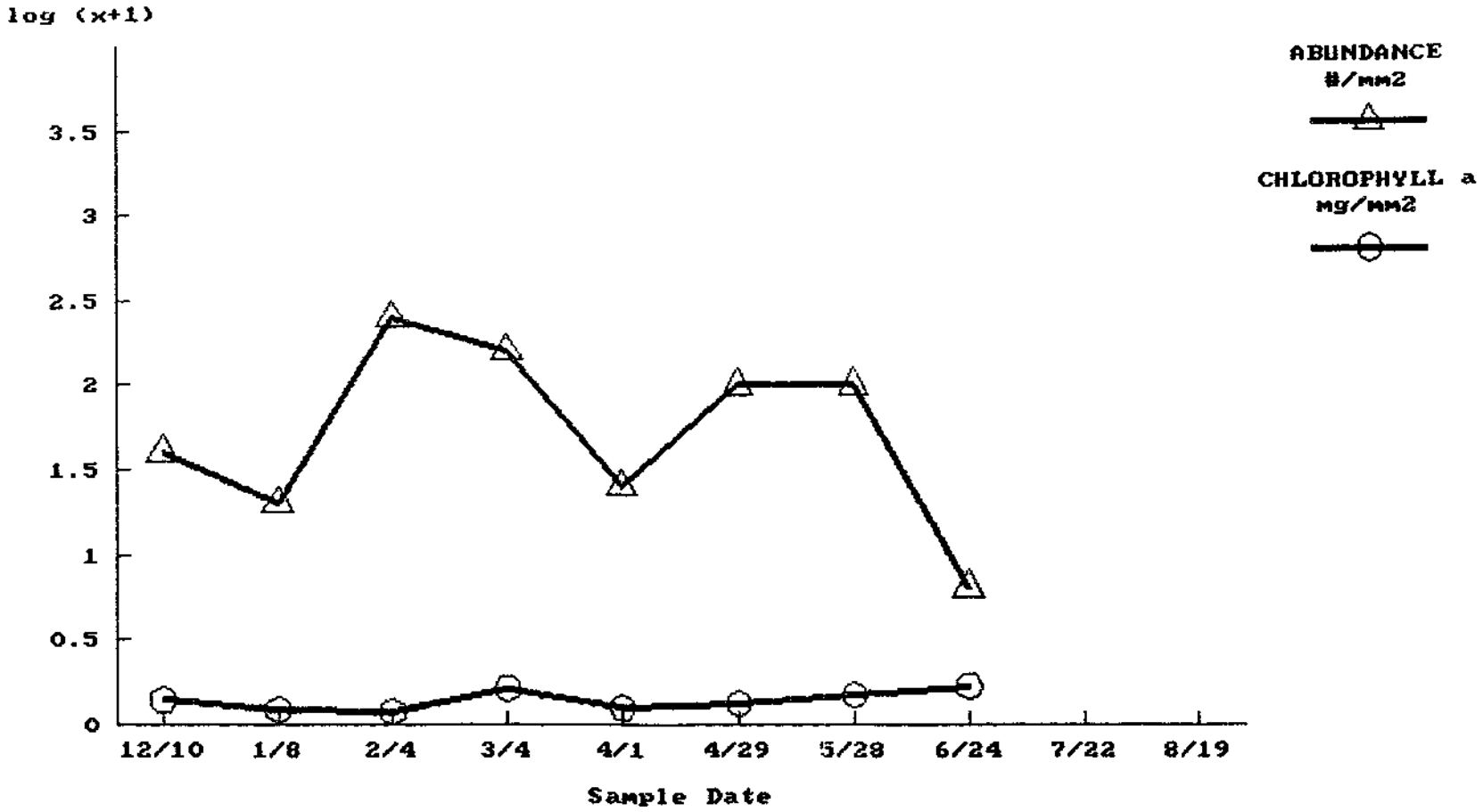


TABLE 22. Numbers of periphyton taxa identified and average percent composition of selected major algal divisions, CRES Site, November 1984 to August 1985.

No. of Taxa	CRES 1	CRES 2	CRES 3
Cyanophyta	6	2	7
Chlorophyta	12	13	6
Chrysophyta	0	3	0
Bacillariophyta	61	31	59
Euglenophyta	0	0	0
Pyrrhophyta	1	2	0
% Composition			
Cyanophyta (range)	7.7 (0.0-44.0)	1.2 (0.0-5.7)	31.6 (0.0-66.3)
Chlorophyta (range)	6.3 (0.0-26.4)	28.4 (2.3-54.0)	4.2 (0.0-12.9)
Chrysophyta (range)	0.0	7.2 (0.0-18.0)	0.0
Bacillariophyta (range)	86.0 (55.2-99.0)	54.1 (43.4-66.7)	64.2 (32.5-88.3)
Pyrrhophyta (range)	0.09 (0.0-0.8)	9.1 (0.0-31.6)	0.0

TABLE 23. Periphyton algae identified and number of occurrences at the CRES Site, November 1984 to August 1985.

	Number of Occurrences		
	CRES 1	CRES 2	CRES 3
CYANOPHYTA			
Anabaena sp.	2	1	1
Aphanocapsa sp.	-	1	-
Aphanotheca sp.	1	-	-
Lyngbya sp.	3	-	2
Merisimopedium sp.	-	-	1
Oscillatoria sp.	-	-	1
Phormidium sp.	3	-	6
Pseudoanabaena sp.	-	-	1
Spirulina sp.	1	-	-
Unknown Cyanophyte sp.	2	-	3
CHLOROPHYTA			
Ankistrodesmus sp.	-	1	-
Arthrodesmus sp.	1	-	-
Closterium sp.	2	3	2
Cosmarium sp.	1	1	2
Cylindrocapsa sp.	3	1	-
Elakatothrix sp.	-	1	-
Euastrum sp.	1	4	-
Gloeocystis sp.	-	1	-
Mougeotia sp.	5	6	1
Netrium sp.	1	3	1
Oedogonium sp.	-	-	2
Oocystis sp.	2	3	-
Penium sp.	1	-	-
Staurastrum sp.	1	4	-
Ulothrix sp.	1	-	-
Xanthidium sp.	-	1	-
Unknown Chlorophyte sp.	2	2	4
CHRYSOPHYTA			
Dinobryon sp.	-	5	-
Mallomonas sp.	-	1	-
Unknown Chrysophyte sp.	-	1	-

	CRES 1	CRES 2	CRES 3
Bacillariophyta			
Achnanthes exigua	2	-	-
A. exigua v. heterovalva	1	-	-
A. lanceolata v. dubia	1	-	-
A. microcephala	-	-	1
A. nollii	-	-	1
Actinella punctata	2	-	-
Cocconeis sp.	1	-	-
C. fluviatilis	1	-	1
C. placentula	1	-	-
Cymbella diluviana	-	-	1
C. lunata	2	-	1
C. microcephala	-	-	2
C. microcephala v. crassa	-	-	1
C. minuta	-	1	2
Eunotia sp.	4	-	2
E. bidentula	4	-	-
E. carolina	4	-	-
E. curvata	6	6	1
E. diodon	3	-	-
E. elegans	1	-	-
E. exigua	1	1	-
E. fallax	1	1	2
E. flexuosa	7	3	2
E. incisa	5	-	3
E. lunaris	1	-	-
E. monodon	1	-	-
E. naegelii	6	4	1
E. nymanniaca	-	1	-
E. parallela	1	-	-
E. pectinalis	9	5	8
E. rostellata	1	-	1
E. sudetica	1	-	-
E. tautonensis	3	-	-
E. tenella	6	1	-
E. trinacria	3	1	-
E. valida	6	2	-
E. vanheurckii	3	-	-
E. vanheurckii v. intermedia	2	-	2
E. zygodon	2	-	-
Fragilaria crotonensis v. oregona	1	-	-
Frustulia rhomboides	7	4	7
F. rhomboides v. capitata	-	1	-
F. rhomboides v. crassinervia	1	2	1
F. rhomboides v. saxonica	2	2	1
Gomphonema gracile	1	2	2
G. parvulum	1	3	4

	CRES 1	CRES 2	CRES 3
Navicula sp.	1	1	1
N. angusta	-	-	1
N. cryptocephala	-	1	2
N. gottlandica	-	-	1
N. halophlia v. tenuirostris	-	-	1
N. lanceolata	-	-	1
N. mutica v. stigma	-	-	1
N. notha	1	2	2
N. pupula	-	-	1
N. pupula v. rectangularis	-	-	2
N. radiosa	1	2	5
N. rhynchocephala	-	-	1
N. seminulum	1	-	-
N. subtilissima	-	1	-
N. viridula	-	-	1
Neidium affine	1	1	1
N. affine v. amphirhynchus	-	-	1
N. apiculatum	1	-	-
N. bisulcatum	-	-	1
N. iridis	-	-	1
N. iridis v. amphigomphus	1	-	-
N. ladogense v. densestriatum	1	-	-
Nitzschia sp.	-	1	-
N. acicularis	-	-	1
N. faciculata	-	-	1
N. filiformis	1	-	2
N. fonticola	1	-	1
N. holsatica	1	-	-
N. obtusa	-	-	2
N. palea	1	5	6
N. romana	1	-	-
N. sigma	-	-	1
N. subtilis	-	1	-
Perona fibula	3	-	-
Pinnularia sp.	2	2	7
P. abaujensis	1	-	1
P. appendiculata	-	-	1
P. biceps	-	1	3
P. burkii	1	-	1
P. gibba	-	-	1
P. mesogonglya	-	-	2
P. microstauron	-	-	1
P. subcapitata	2	2	1
Stauroneis phoenicenteron	-	-	2
Surirella linearis v. constricta	1	-	-
Synedra sp.	2	-	-
S. ulna	4	5	1
Tabellaria fenestrata	6	2	5
PYRRHOPHYTA			
Peridinium sp.	1	3	-
Unknown Pyrrhophyte sp.	-	1	-

Generally, average algal abundance was reflected by average chlorophyll *a* values at both stations, and was lower at CRES 1. There was no consistent trend or significant correlation between algal density and chlorophyll *a* at CRES 3 (Figure 52). As was observed at the QUIN outfall, the increased proportion of cyanophytes may have been partially responsible for this lack of correlation.

MOSS Site

The MOSS site consists of one instream, two successive ponds, and an intermittent outfall (MOSS 1-MOSS 4). Additionally, a nearby stream was included for comparison with MOSS 1 and to serve as a control (MOSS 5). In the following discussion, each relevant station comparison will be addressed separately.

When comparing the upstream and first pond stations at the MOSS site, several trends are suggested which are opposite those observed at the QUIN and CRES sites. Total and mean number of taxa at MOSS 2 increased by 15% and 65%, respectively, and algal abundance was reduced by 18% (Table 24). The abundance and proportion of cyanophytes were greater at MOSS 2, while the abundance of diatoms was reduced (Tables 24 and 25).

The greatest difference between MOSS 1 and MOSS 2 was observed in the density and proportion of green algae. The number of individuals/mm^2 increased from 14.8 at MOSS 1 to 58.2% at MOSS 2 (293%; Table 24), and the percent chlorophytes of total algae was 5.6 at MOSS 1 and 26.5 at MOSS 2, a 373% increase (Table 25).

Mean algal abundance and chlorophyll *a* values were both decreased from upstream to pond (Table 24). Within each station the monthly measurements varied together (Figures 53 and 54), although the correlation between abundance and chlorophyll *a* was considerably higher at the pond station. Regression analysis yielded r^2 values of .238 (NS) and .904 ($p = .01$) for MOSS 1 and MOSS 2, respectively. It is possible that the increased proportion of chlorophytes at MOSS 2 is reflected by this high correlation, as was observed at the CRES site.

Unlike the reductions in diversity between the upstream and pond stations observed at the QUIN and CRES sites, mean $\bar{d}$ values were 59% greater at MOSS 2; and pooled $\bar{d}$ was 42% larger (Table 24). This higher diversity in the pond was also demonstrated by a 65% increase in mean number of taxa (17.6 and 29.1 for MOSS 1 and MOSS 2, respectively), and differing patterns of dominating species. Station MOSS 1 was constantly dominated by *Eunotia pectinalis*, which made up 42% of the total number of individuals, and was secondarily dominated by *E. curvata* and *Tabellaria fenestrata*, representing 16% and 14% of the total, respectively. Station MOSS 2 was not as strongly dominated by any one species; the green alga *Mougeotia* sp. was most common, particularly from May to August, and made up 17% of the total number of individuals.

TABLE 24. Temperature, number of taxa, Shannon-Weaver diversity index, abundance, and chlorophyll *a* values for upstream, pond, outfall, and control stations MOSS Site, November 1984 to August 1985. Numbers in parentheses are minimum and maximum values for the sample period.

	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
$\bar{x}$ Temp (°C) (range)	16.5 (4.2-24.0)	20.0 (11.5-29.2)	20.3 (10.0-29.9)	17.6 (12.0-23.0)	16.1 (9.0-24.0)
Total # taxa	87	100	84	68	83
$\bar{x}$ #taxa (range)	17.6 (11-27)	29.1 (20-43)	20.5 (10-34)	20.8 (15-25)	20.0 (10-30)
$\bar{x}$ $\bar{d}$ (range)	2.2 (0.8-3.6)	3.5 (2.3-4.6)	2.6 (1.3-4.0)	2.7 (2.3-3.1)	3.1 (1.8-3.9)
pooled $\bar{d}$	3.3	4.7	3.7	3.6	3.9
$\bar{x}$ abundance (#/mm^2) (range)	209.9 (40.5-484.3)	173.2 (13.2-464.7)	306.2 (9.4-1610.4)	285.0 (48.5-875.8)	80.8 (4.4-192.3)
# Cyanophyta	3.9	9.6	7.7	6.0	0.5
# Chlorophyta	14.8	58.2	109.5	31.7	6.8
# Chrysophyta	0.0	3.2	0.6	1.2	0.1
# Bacillariophyta	191.1	97.4	184.8	240.5	73.4
# Pyrrhophyta	0.0	4.8	3.6	5.7	0.0
chl-a (mg/mm^2) (range)	1.6 (0.5-3.2)	1.4 (0.1-5.2)	3.0 (0.7-14.3)	1.9 (0.5-5.5)	1.4 (0.2-3.8)

TABLE 25. Numbers of periphyton taxa identified and average percent compostion of selected major algal divisions, MOSS Site, November 1984 to August 1985.

No. of Taxa	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
Cyanophyta	8	10	7	6	5
Chlorophyta	19	22	22	23	16
Chrysophyta	0	1	2	1	1
Bacillariophyta	58	64	50	36	60
Euglenophyta	1	1	0	0	1
Pyrrhophyta	0	2	3	2	0
Rhodophyta	1	0	0	0	0
% Composition					
Cyanophyta (range)	3.0 (0.0-18.8)	4.0 (0.0-6.7)	2.2 (0.0-8.5)	2.7 (0.5-5.3)	5.1 (0.0-46.2)
Chlorophyta (range)	5.6 (0.0-19.5)	26.5 (4.1-40.9)	27.1 (2.8-64.8)	14.0 (7.9-32.2)	7.8 (0.0-22.4)
Chrysophyta (range)	0.0	1.2 (0.0-3.7)	0.3 (0.0-1.6)	0.6 (0.0-1.9)	0.08 (0.0-0.8)
Bacillariophyta (range)	91.3 (78.9-99.7)	66.3 (46.0-95.9)	68.8 (30.3-96.8)	78.8 (63.3-89.6)	87.1 (50.0-100.0)
Pyrrhophyta (range)	0.0	2.0 (0.0-14.5)	1.6 (0.0-4.7)	3.9 (0.0-16.2)	0.0

FIGURE 53. Periphyton log-transformed abundance and chlorophyll a, MOSS 1.

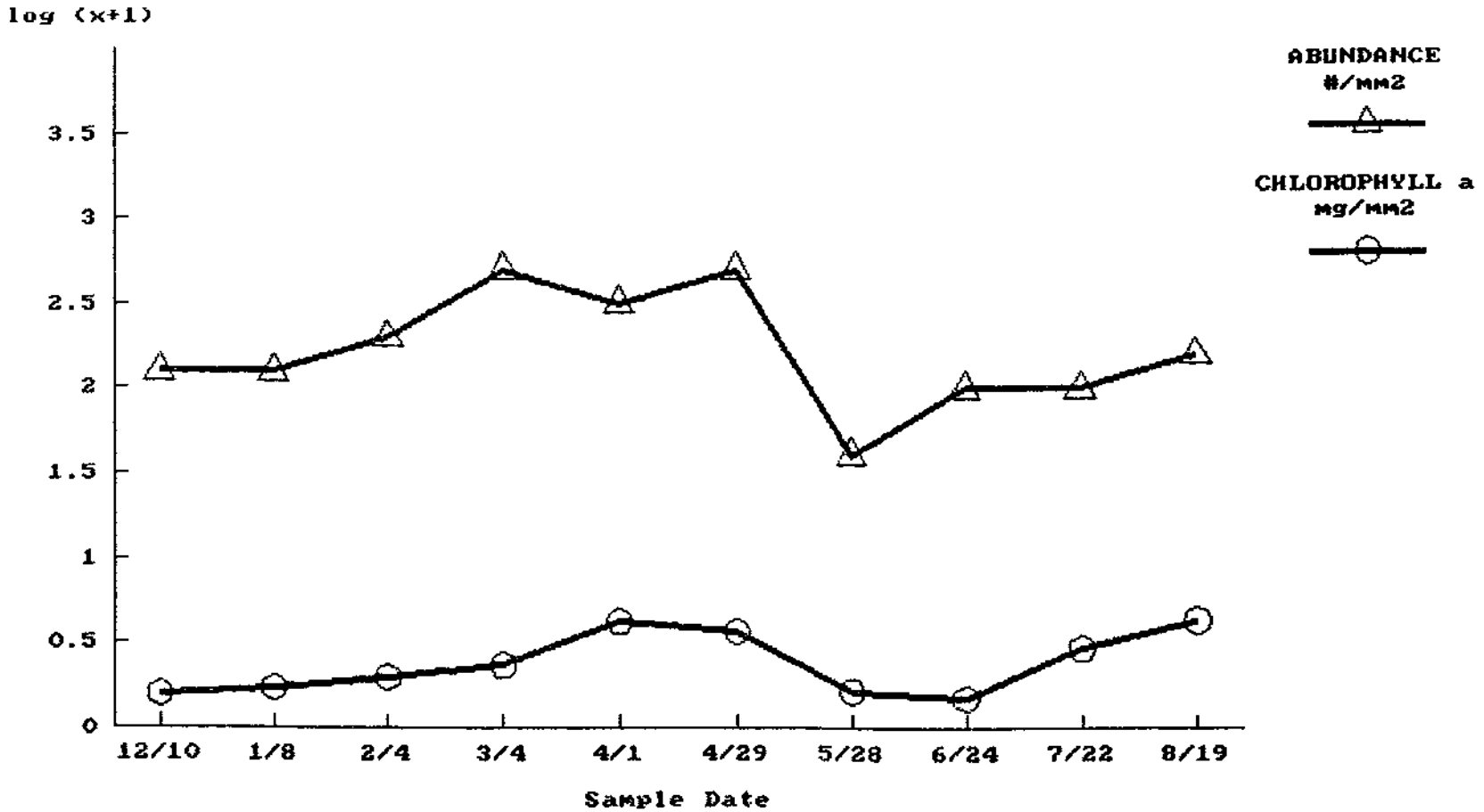
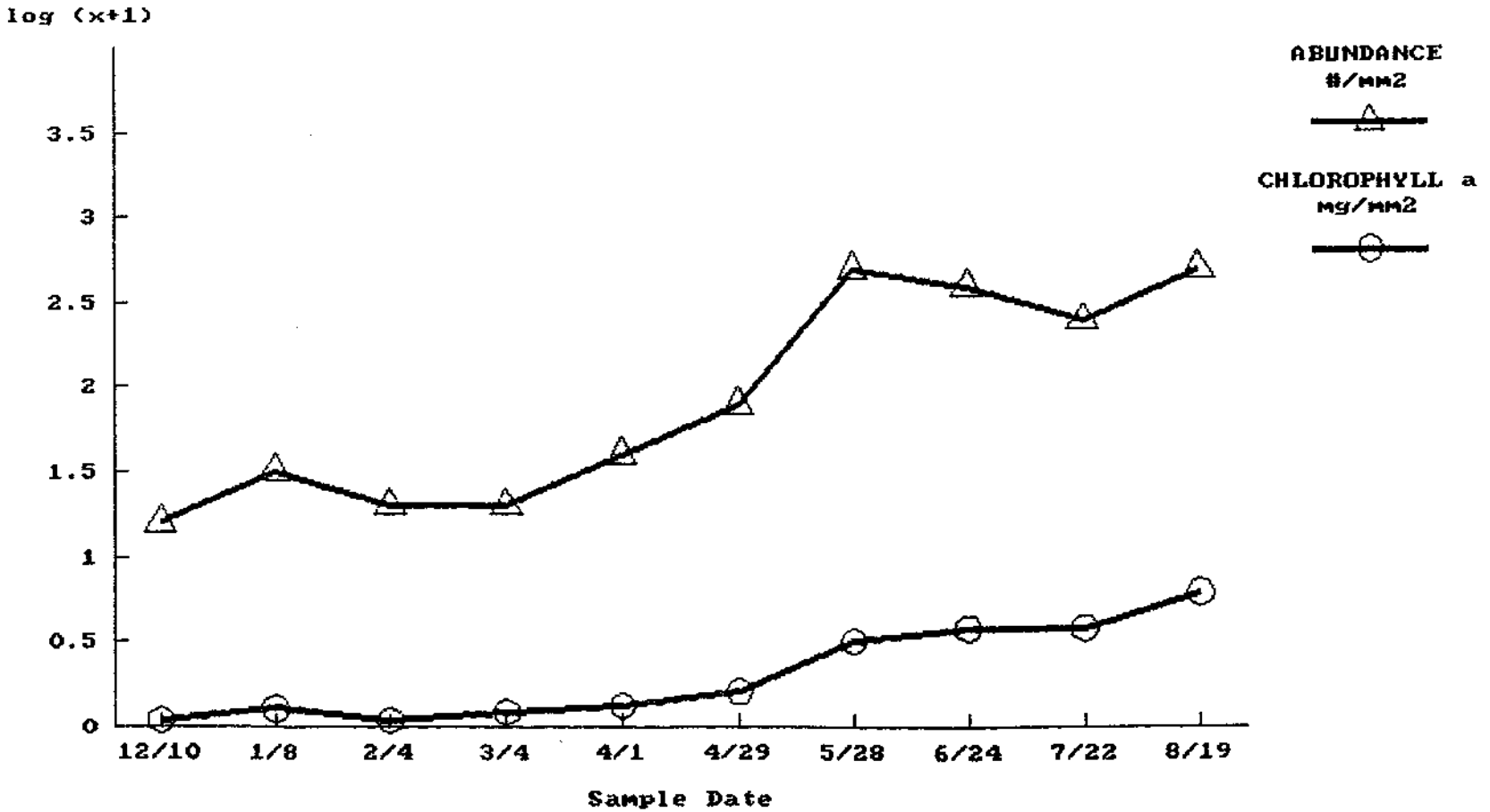


FIGURE 54. Periphyton log-transformed abundance and chlorophyll a, MOSS 2.



The differences in the periphyton community were generally not as great between Stations MOSS 1 and MOSS 3 for most parameters, although some changes were observed that were similar to those observed in comparing MOSS 1 and MOSS 2. Total number of taxa was slightly lower at MOSS 3, and mean number of taxa was somewhat higher (Table 24). The difference in mean abundance was significant, increasing from 209.9 individuals/mm^2 at MOSS 1 to 306.2 ind/mm^2 at MOSS 3, a gain of 46%. As was observed in the MOSS 1-MOSS 2 comparison, the density and proportion of chlorophytes was increased, though the degree of change in abundance was much more dramatic between MOSS 1 and MOSS 3. The number of chlorophytes/mm^2 increased by 639%, from 14.8 at MOSS 1 to 109.5 at MOSS 3 (Table 24), and the proportion of chlorophytes increased by 383% (Table 25).

The increase in chlorophyte abundance at MOSS 3 was significantly larger than was observed at MOSS 2, and the correlation between algal abundance and chlorophyll *a* was equally as strong. The r^2 value resulting from regression analysis was .640 ($p = .01$), considerably higher than the r^2 of .238 observed at MOSS 1, which was not significant.

The difference in diversity between these two stations was minor; mean $\bar{d}$ increased from 2.2 at MOSS 1 to 2.6 at MOSS 3, and pooled $\bar{d}$ increased from 3.3 at MOSS 1 to 3.7 at MOSS 3 (Table 24). The strong dominance of *Eunotia pectinalis* at MOSS 1 (> 41% of total) was discussed in the previous section. Station MOSS 3 was dominated by three species: *Tabellaria fenestrata*, *Mougeotia* sp., and *Synedra ulna*, accounting for 25.4%, 21.4% and 13.1% of the total number of individuals, respectively. *Synedra ulna* is a widely distributed fresh water diatom, and *T. fenestrata* generally prefers lakes or ponds which are mesotrophic to eutrophic (Patrick and Reimer 1966).

Stations MOSS 1 and MOSS 4 compare in much the same fashion as stations MOSS 1 and MOSS 3; this is probably due to the close proximity of MOSS 4 to the outfall of MOSS 3. Algal abundance increased at MOSS 4 by 36%, accompanied by a 19% increase in mean chlorophyll *a* (Table 24). These two parameters were strongly correlated by regression analysis ($r^2 = .805$, $p = .02$), and are represented graphically in Figures 53 and 56. This positive correlation indicates that the variation in chlorophyll *a* can be explained by the changes in algal abundances. Total number of taxa dropped by 22%, from 87 at MOSS 1 to 68 at MOSS 4, while mean number of taxa increased from 17.6 at MOSS 1 to 20.8 at MOSS 4, or 18% (Table 24). The decrease in total number of taxa was largely made up of diatoms, as 19 more species were identified at MOSS 1 (Table 26). Although the density of diatoms was greater at MOSS 4 (26%; Table 24) the percent composition of diatoms decreased, from 91.3% at MOSS 1 to 78.8% at MOSS 4 (Table 25).

Two diatom species were dominant at MOSS 4 during the sampling period. *Tabellaria fenestrata* was consistently dominant and represented 33.4% of the total, while *Synedra ulna*, which accounted for 20%, appeared in strong pulses, particularly on the December and early April sampling

FIGURE 55. Periphyton log-transformed abundance and chlorophyll a, MOSS 3.

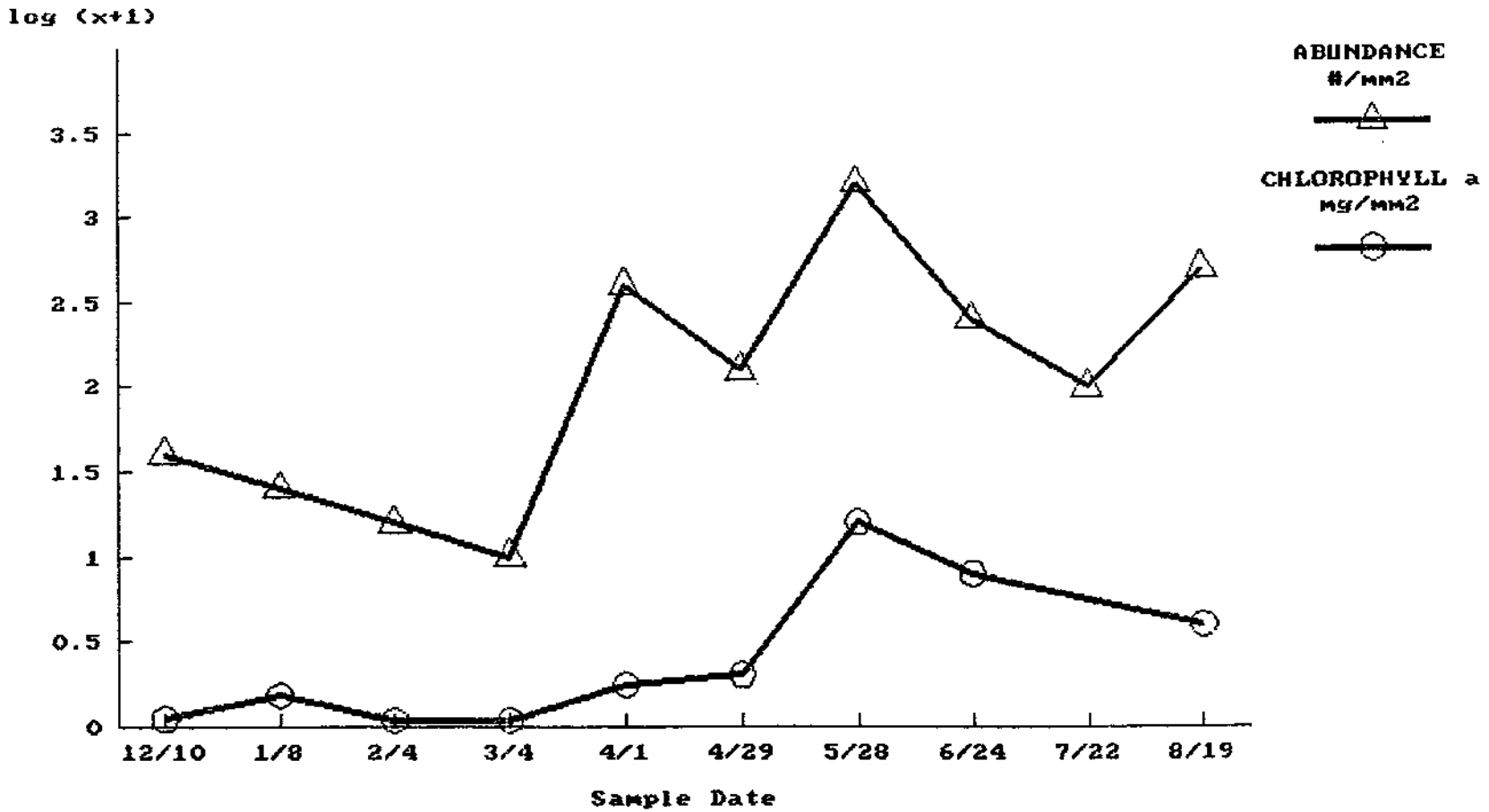
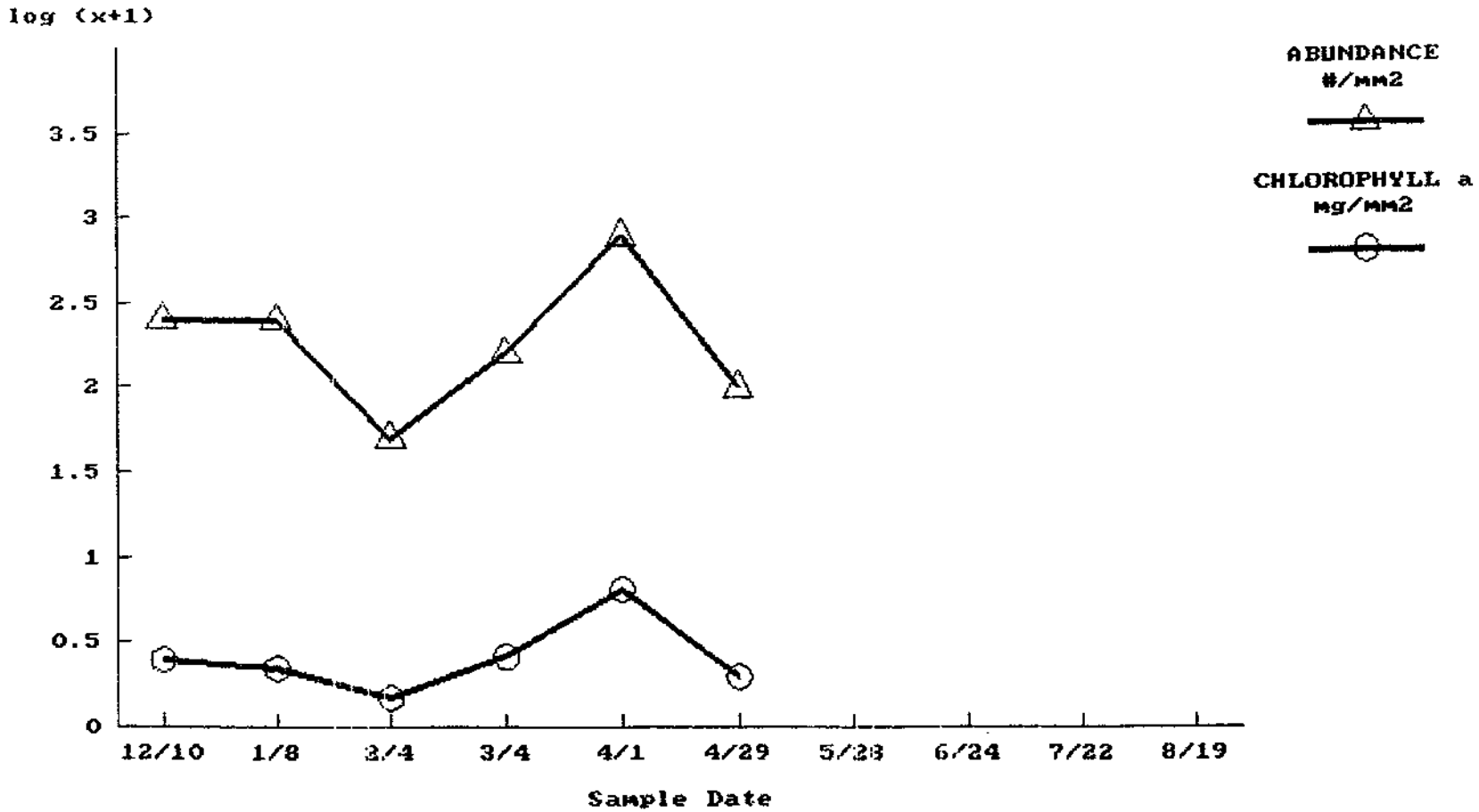


FIGURE 56. Periphyton log-transformed abundance and chlorophyll a, MCSS 4.



dates. Although the diversity was fairly low at MOSS 4, average and pooled $\bar{d}$ values were 23% and 9% higher, respectively (Table 24); the lower $\bar{d}$ at MOSS 1 was likely a reflection of the strong dominance of Eunotia pectinalis.

Stations MOSS 1 and MOSS 5 were observed to be very similar with respect to most parameters studied, with the exception of abundance and diversity. Mean number of individuals/mm^2 was 209.9 for MOSS 1 and 80.8 for MOSS 5. Chlorophyll a values, however, were very similar (1.6 mg/mm^2 for MOSS 1 and 1.4 mg/mm^2 for MOSS 5) as were correlation coefficients resulting from regression of abundance vs. chlorophyll a (r^2 = .238 and .373 for MOSS 1 and MOSS 5, respectively). The correlation of these parameters for MOSS 5, though, was significant at the p = .10 level, while that for MOSS 1 was not significant, indicating that the chlorophyll a fluctuations are not due to the changes in algal abundance.

Although the greatest difference in density was in the number of diatoms/mm^2, the proportion of this algal division was essentially the same, 91% for MOSS 1 and 87% for MOSS 5. Relative proportions of cyanophytes and chlorophytes were slightly higher in MOSS 5, though not significantly (Table 25).

Mean $\bar{d}$ values were 2.2 and 3.1 for MOSS 1 and MOSS 5, respectively and pooled $\bar{d}$ was 3.3 at MOSS 1 and 3.9 at MOSS 5 (Table 24). Both stations had three dominant diatom species: Eunotia pectinalis, E. curvata, and Tabellaria fenestrata at MOSS 1 and E. pectinalis, E. curvata, and E. flexuosa at MOSS 5. The strongest and most constant dominance occurred at MOSS 1, where E. pectinalis constituted > 41% of the total number of individuals, while E. curvata was most dominant at MOSS 5, (> 22% of the total). The lower $\bar{d}$ at Station MOSS 1 is probably a reflection of the dominance of E. pectinalis.

The MOSS 1-MOSS 5 comparison raises some interesting points. Although both were considered as upstream stations, the differences between MOSS 1 and MOSS 5 were substantial. MOSS 1 was very slow-flowing, and the existing vegetation was much like that of the littoral zone of MOSS 2. Station MOSS 5, however, was situated in a fast-moving stream in a forested setting, very similar to the upstream stations at the QUIN and CRES sites. Although MOSS 1 was not an adequate control for the MOSS pond stations, had MOSS 5 been used instead the comparisons would have been generally the same, with the magnitude of change being different (greater or smaller). The MOSS 1-MOSS 5 comparison serves to illustrate the changes in the periphytic community in response to light, vegetation, and movement of water.

Although these two pond stations would be expected to be very similar, some fairly substantial differences were observed during our sampling period. Total and mean number of taxa decreased at MOSS 3 by 16% and 30%, respectively; this depressed diversity is also reflected by the $\bar{d}$

FIGURE 57. Periphyton log-transformed abundance and chlorophyll a, MOSS 5.

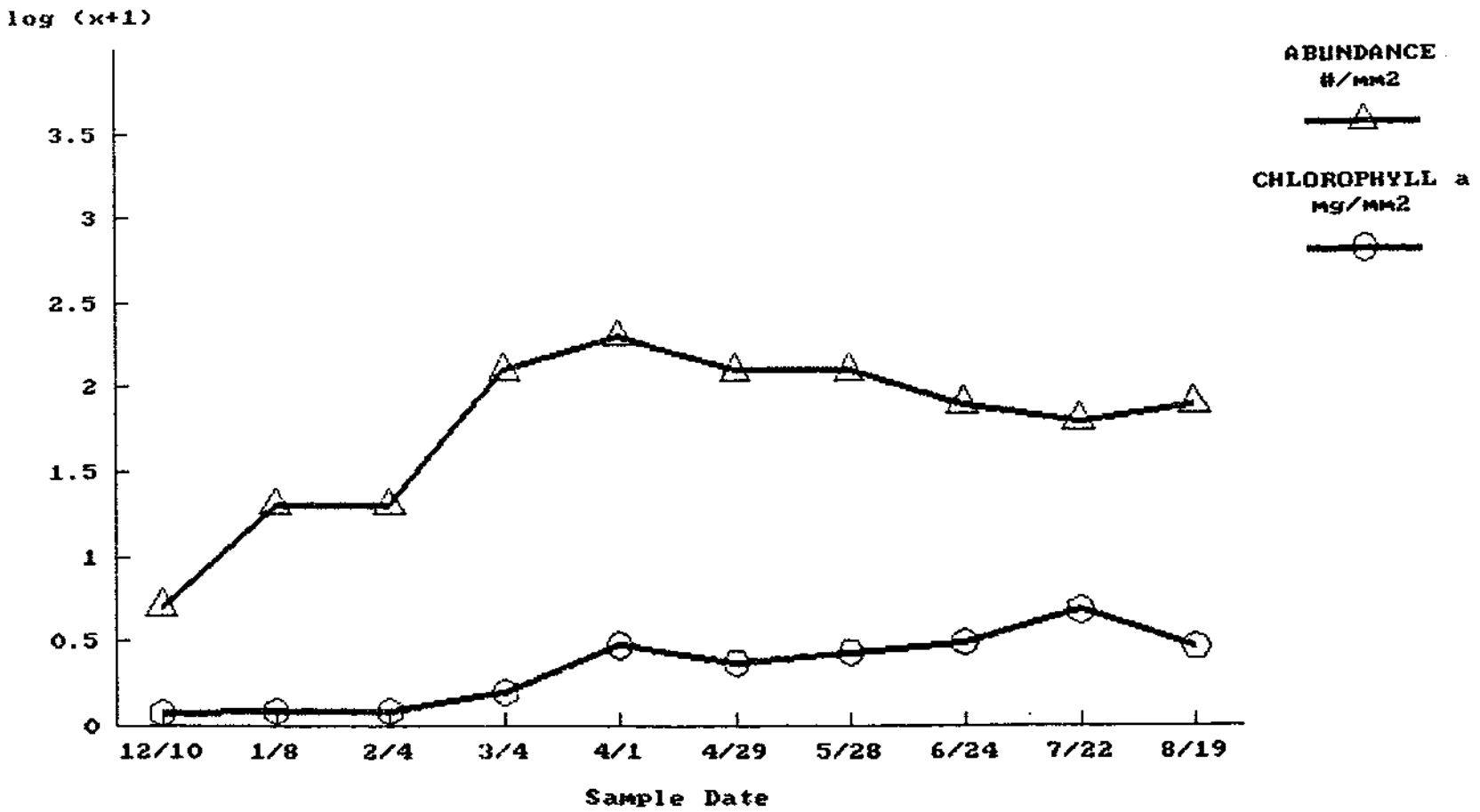


TABLE 26. Periphyton algae identified and number of occurrences at the MOSS Site, November 1984 to August 1985.

	Number of Occurrences				
	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
CYANOPHYTA					
Anabaena sp.	2	3	4	1	1
Aphanocapsa sp.	1	2	1	-	-
Aphanotheca sp.	3	-	-	-	2
Chroococcus sp.	-	3	2	-	-
Dactylococcopsis sp.	-	2	-	-	-
Gloeocapsa sp.	-	-	-	2	-
Lyngbya sp.	2	3	3	2	1
Merismopedium sp.	1	5	-	2	-
Oscillatoria sp.	2	1	3	-	-
Phormidium sp.	3	3	-	4	1
Spirulina sp.	-	1	1	-	-
Unknown Cyanophyte sp.	1	3	2	3	2
CHLOROPHYTA					
Ankistrodesmus sp.	-	1	1	1	-
Aphanochaeta sp.	-	-	-	1	-
Arthrodesmus sp.	-	2	4	2	-
Bulbochaete sp.	3	-	-	3	1
Chaetosphaerium sp.	-	-	-	1	-
Characium sp.	-	-	-	1	-
Chlamydomonas sp.	1	-	-	-	-
Chlorococcum sp.	-	-	-	-	1
Closterium sp.	3	4	3	2	2
Coelastrum sp.	-	4	-	-	-
Coleochaeta sp.	-	-	1	-	-
Cosmarium sp.	3	8	8	4	1
Cosmocladium sp.	-	-	1	-	-
Crucigenia sp.	-	-	1	-	-
Cylindrocapsa sp.	3	-	-	-	4
Desmidium sp.	-	-	-	1	-
Dictyosphaerium sp.	-	-	1	-	-
Elakatothrix sp.	-	1	3	-	-
Euastrum sp.	2	8	4	1	-
Eudorina sp.	-	1	-	-	-
Gloeocystis sp.	2	1	-	1	1
Gonatozygon sp.	1	-	-	-	-
Gonium sp.	1	-	-	-	-
Kirchneriella sp.	-	-	1	-	-
Micrasterias sp.	-	1	-	-	-

	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
Microspora sp.	1	-	-	1	1
Mougeotia sp.	6	10	9	6	7
Netrium sp.	3	3	1	-	2
Oedogonium sp.	2	3	2	2	3
Oocystis sp.	-	2	1	-	-
Pediastrum sp.	-	3	5	-	-
Penium sp.	1	-	-	1	1
Pleurotaenium sp.	-	5	-	-	-
Scenedesmus sp.	-	4	3	1	-
Selenastrum sp.	-	1	-	1	-
Sphaerocystis sp.	-	-	-	1	-
Spirogyra sp.	1	-	-	4	5
Spondylosium sp.	-	-	1	-	-
Staurastrum sp.	1	6	6	5	2
Stigeocolonium sp.	1	-	-	-	1
Tetraedron sp.	-	1	1	-	-
Ulothrix sp.	1	-	-	2	1
Xanthidium sp.	-	2	2	1	-
Unknown Chlorophyte sp.	4	6	3	4	3
CHRYSOPHYTA					
Dinobryon sp.	-	6	2	3	1
Mallomonas	-	-	1	-	-
Bacillariophyta					
Achnanthes affinis	-	1	-	-	-
A. exigua	1	-	3	2	1
A. exigua v. constricta	-	-	1	-	-
A. exigua v. heterovalva	-	-	1	-	-
A. flexella	-	1	-	-	-
A. lanceolata	-	1	-	-	1
A. lanceolata v. dubia	-	-	1	-	-
A. linearis	-	2	2	1	-
A. linearis v. curta	1	-	-	-	-
A. microcephala	1	-	-	1	-
A. nollii	-	-	1	1	1
Actinella punctata	-	-	-	-	5
Asterionella formosa	1	3	1	-	-
Cocconeis sp.	-	1	-	-	-
C. fluviatilis	2	-	-	-	-
C. placentula v. euglypta	-	1	-	-	-
C. placentula v. lineata	-	1	-	-	-
Cyclotella sp.	1	-	-	1	-
Cymbella sp.	1	-	-	-	-
C. angustata	-	-	1	-	-

	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
C. lunata	1	8	7	4	-
C. minuta	1	2	1	2	1
Desmogonium rabenhorstanium v. elongatum	-	-	-	-	1
Diatoma elongatum	-	1	-	-	-
Eunotia sp.	3	2	2	-	1
E. arcus	1	-	-	-	1
E. carolina	1	-	-	-	4
E. curvata	9	8	6	1	10
E. diodon	-	2	-	-	3
E. elegans	-	-	-	-	1
E. exigua	2	-	1	1	3
E. fallax	2	-	1	-	1
E. fastigiata	1	-	-	-	2
E. flexuosa	4	5	2	1	8
E. flexuosa v. eurycephala	2	1	-	-	-
E. incisa	1	-	-	-	1
E. meisteri	2	-	-	-	-
E. monodon	1	2	-	-	-
E. naegelii	5	4	1	-	6
E. nymanniaca	-	-	-	-	1
E. pectinalis	10	9	4	3	10
E. pectinalis v. undulata	-	3	-	-	-
E. perminuta	-	-	-	-	1
E. quaternaria	-	-	-	-	1
E. rostellata	-	1	-	-	-
E. septentrionalis	-	-	-	-	1
E. sudetica	2	1	-	1	-
E. tautoniensis	1	-	-	-	-
E. tenella	3	1	4	1	6
E. trinacria	-	-	1	-	-
E. valida	1	-	-	-	-
E. vanheurckii v. intermedia	1	-	1	1	2
E. zygodon	-	-	-	-	1
Fragilaria crotonensis	1	-	-	-	-
Frustulia sp.	1	-	-	-	-
F. rhomboides	6	9	5	1	7
F. rhomboides v. capitata	1	3	1	-	1
F. rhomboides v. crassinervia	2	2	3	-	3
F. rhomboides v. saxonica	2	2	3	-	3
Gomphonema angustatum	1	1	-	-	-
G. gracile	4	-	6	2	3
G. parvulum	2	6	3	1	1
G. subclavatum	1	-	-	-	-
Melosira sp.	-	-	1	-	-
M. ambigua	1	-	-	-	-
M. distans	-	-	-	1	-
M. varians	-	1	-	-	-
Navicula sp.	-	4	3	1	2

	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
N. sp. 1	-	1	-	-	1
N. convergens	-	-	-	-	1
N. minima	-	1	1	-	-
N. mutica v. stigma	-	1	-	-	-
N. notha	1	4	2	-	3
N. paucivisitata	-	1	-	-	-
N. pupula	-	-	1	-	-
N. pupula v. rectangularis	-	2	-	-	-
N. radiosa	3	6	3	4	5
N. rhynchocephala	-	-	-	1	-
N. seminulum	-	-	-	-	1
N. subtilissima	-	2	-	-	-
Neidium sp.	1	-	-	-	1
N. affine	1	-	1	1	-
N. affine v. amphirhynchus	-	-	-	-	1
N. apiculatum	1	-	-	-	3
N. bisulcatum	-	-	-	-	1
N. iridis v. amphigomphus	-	-	-	-	1
N. ladogense v. densestriatum	-	-	-	-	1
Nitzschia sp.	-	1	-	-	-
N. acicularis	-	2	1	1	2
N. filiformis	-	2	2	1	-
N. fonticola	1	2	1	1	1
N. holsatica	-	-	-	1	-
N. obtusa	-	1	-	-	-
N. palea	-	6	4	1	-
N. sigma	-	2	1	-	-
N. subtilis	-	-	1	-	1
Perona fibula	-	-	-	-	2
Pinnularia sp.	3	1	-	1	6
P. abaujensis	-	-	-	1	-
P. accuminata	-	1	-	-	-
P. braunii	1	3	-	-	1
P. braunii v. amphicephala	-	1	-	-	-
P. burkii	1	-	-	-	-
P. divergens	-	-	1	-	-
P. mesolepta	-	1	-	-	-
P. mesogonglya	1	-	-	-	-
P. obscura	1	-	-	-	-
P. subcapitata	1	2	1	-	4
Stauroneis sp.	-	1	1	-	-
S. anceps	1	2	-	-	-
S. phoenicenteron	1	3	1	-	1
Stephanodiscus hantzschii	-	4	3	1	-
S. invisitatus	-	1	1	-	-
Surirella sp.	-	1	-	-	-
Synedra sp.	-	2	1	-	-
S. acus	1	-	-	1	1
S. fasciculata	-	-	1	-	-

	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
S. gaillonii	-	-	-	-	1
S. nana	-	1	-	1	1
S. ulna	5	8	8	4	7
Tabellaria sp.	1	-	-	-	1
T. fenestrata	6	10	10	6	7
T. flocculosa	4	9	4	1	5
Unknown Diatom sp.	1	-	-	1	1
EUGLENOPHYTA					
Euglena sp.	1	1	-	-	1
PYRRHOPHYTA					
Ceratium sp.	-	2	2	3	-
Peridinium	-	4	4	3	-
Unknown Pyrrhophyte sp.	-	-	1	-	-
RHODOPHYTA					
Bactrachospermum sp.	1	-	-	-	-

values, 3.5 at MOSS 2 and 2.6 at MOSS 3. As discussed earlier, the periphyton at Station MOSS 2 was dominated by the chlorophyte, Mougeotia sp. (> 17%), and the diatoms Tabellaria fenestrata and Eunotia naegelii (both > 11% of the total). Periphyton at Station MOSS 3 was also dominated by Mougeotia sp. and T. fenestrata, though they represented > 21% and > 25% of the total, respectively. The diatom species Synedra ulna was also common, and constituted > 13% of the total. This trend of more highly dominant species partially explains the reduced d values calculated for MOSS 3.

The density of individuals found in MOSS 3 tended to be greater than that in MOSS 2. Mean abundance increased from 173.2/mm^2 at MOSS 2 to 306.2/mm^2 at MOSS 3, or > 76% (Table 24). The most significant increases occurred in the number of chlorophytes (> 88%) and diatoms (> 89%). This dramatic increase in the number of chlorophytes is probably reflected in the sharp increase in chlorophyll a, from 1.4 mg/mm^2 to 3.0 mg/mm^2.

Although the mean abundance of individuals was quite different at these two pond stations, it is interesting to note that the number of taxa identified in each algal division was very similar, with the exception of a 22% decrease in the number of diatoms noted at MOSS 3. Additionally, the percent composition of all major divisions was essentially equivalent (Table 25).

GADS Site

The fourth site monitored in our study was under construction during most of the sampling period. The area was subjected to a great deal of environmental perturbation from natural (stream diversion due to heavy rain) and unnatural (tree-clearing, pond and dam construction) sources. Only an instream and an outfall station was sampled; pond-filling occurred too late in the sampling period to allow us to gather enough information to be meaningful.

Although neither site appeared to be particularly 'healthy', the upstream Station GADS 1, seemed to be the more severely stressed. Total and mean number of taxa were 38% and 34% lower, respectively (Table 27). Similar d's were calculated for both stations (means were 2.7 at GADS 1 and 2.9 at GADS 3, and pooled d was 3.5 at GADS 1 and 3.2 at GADS 3), however, 17 more species of diatoms were identified at the latter station (Tables 28 and 29). Both stations were dominated by filamentous blue-green algae: Lyngbya sp. represented 40% of total at GADS 1 and Phormidium sp. was dominant at GADS 3, making up 25%. Some species of Lyngbya have been associated with high organic content (Singh 1960) and pollution (Palmer 1959).

TABLE 27. Temperature, number of taxa, Shannon-Weaver diversity index, and chlorophyll a values for upstream, and outfall stations at the GADS Site, November 1984 to August 1985. Numbers in parentheses are minimum and maximum values for the sample period.

	GADS 1	GADS 3
$\bar{x}$ Temp (°C) (range)	18.4 (10.6-25.0)	18.7 (10.3-26.5)
Total # taxa	55	76
$\bar{x}$ #taxa (range)	11.8 (4-22)	15.8 (8-22)
$\bar{x}$ $\bar{d}$ (range)	2.7 (1.6-4.0)	2.9 (0.8-4.0)
pooled $\bar{d}$	3.5	3.2
$\bar{x}$ abundance (#/mm^2) (range)	68.7 (0.7-289.9)	140.5 (5.2-526.8)
# Cyanophyta	41.5	66.7
# Chlorophyta	8.6	3.9
# Chrysophyta	0.3	0.0
# Bacillariophyta	18.3	70.0
# Pyrrhophyta	0.0	0.0
chl-a (mg/mm^2) (range)	0.5 (0.1-1.5)	1.2 (0.05-6.8)

FIGURE 58. Periphyton log-transformed abundance and chlorophyll a, GADS 1.

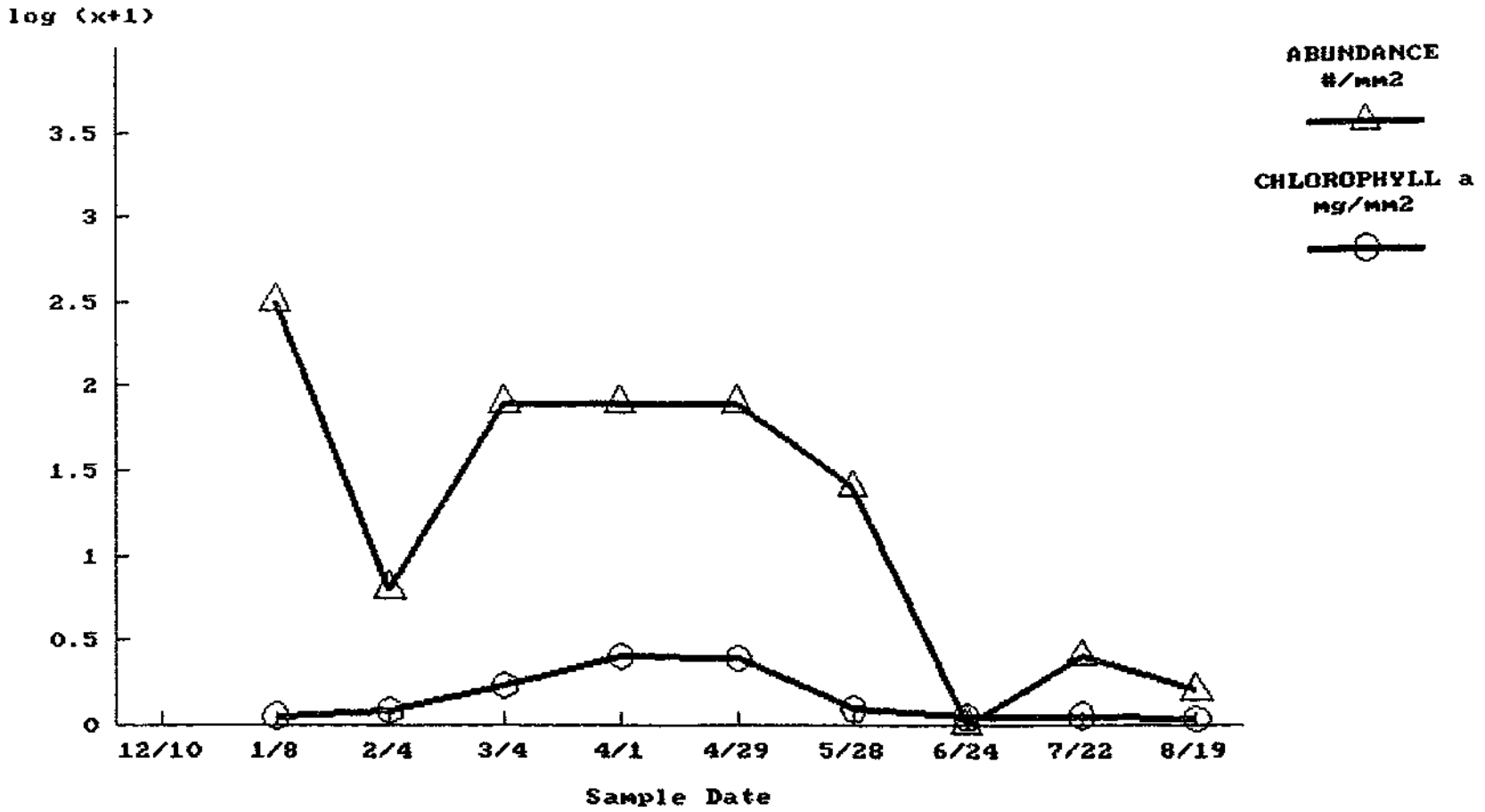


FIGURE 59. Periphyton log-transformed abundance and chlorophyll a, GADS 3.

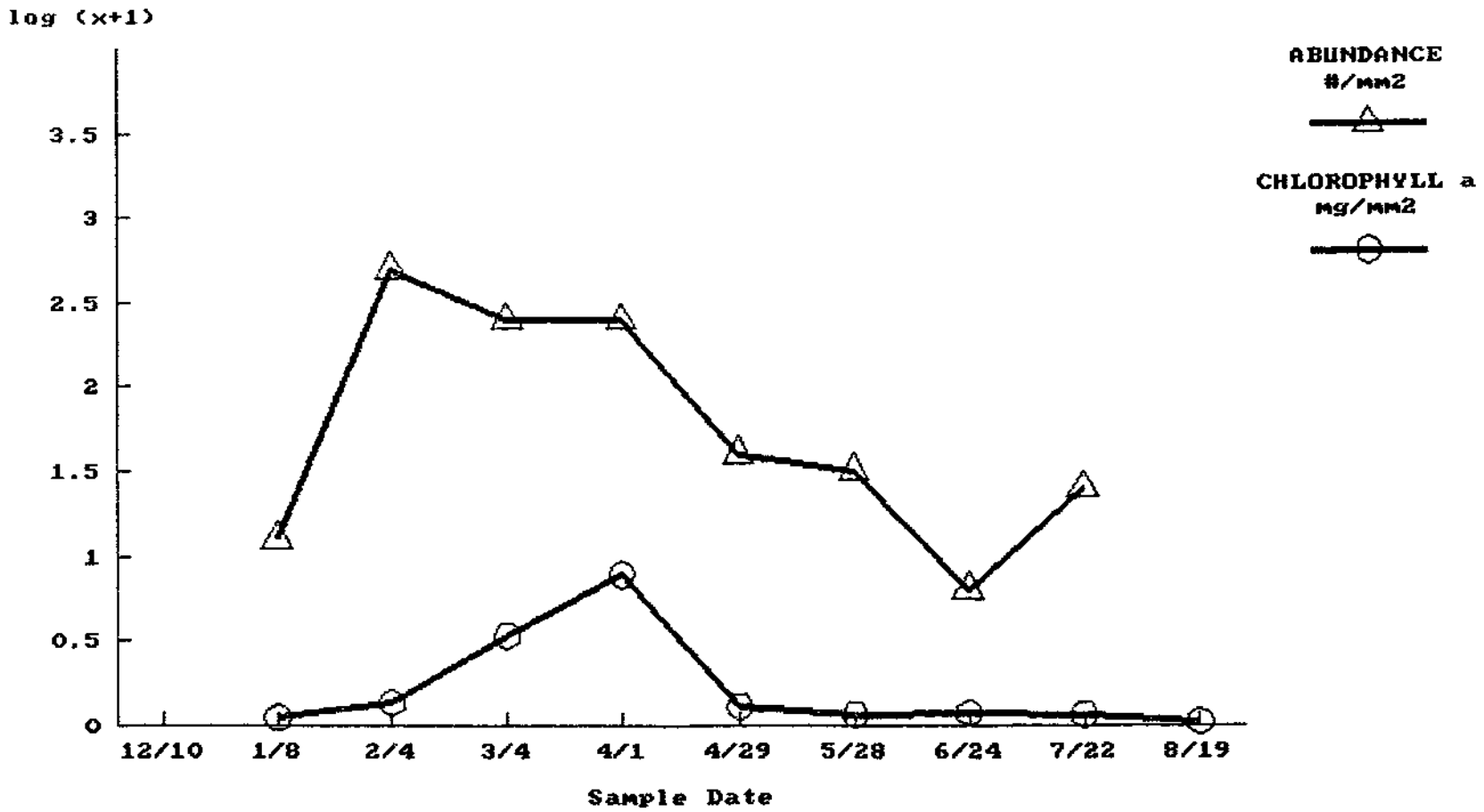


TABLE 28. Numbers of periphyton taxa identified and average percent composition of selected major algal divisions, GADS Site, November 1984 to August 1985.

No. of Taxa	GADS 1	GADS 3
Cyanophyta	3	6
Chlorophyta	4	7
Chrysophyta	1	0
Bacillariophyta	43	60
Euglenophyta	1	3
Pyrrhophyta	0	0
% Composition		
Cyanophyta (range)	34.8 (0.0-91.9)	27.8 (0.0-88.2)
Chlorophyta (range)	13.1 (0.0-38.2)	7.1 (0.0-34.6)
Chrysophyta (range)	0.4 (0.0-2.9)	0.0
Bacillariophyta (range)	51.8 (4.8-100.0)	65.1 (9.1-99.0)
Pyrrhophyta	0.0	0.0

TABLE 29. Periphyton algae identified and number of occurrences at the GADS Site, November 1984 to August 1985.

	Number of Occurrences	
	GADS 1	GADS 3
CYANOPHYTA		
Calothrix sp.	-	1
Lyngbya sp.	3	3
Oscillatoria sp.	3	1
Phormidium sp.	4	6
Plectonema sp.	-	1
Unknown Cyanophyte sp.	1	2
CHLOROPHYTA		
Microspora sp.	-	1
Mougeotia sp.	1	1
Netrium sp.	1	1
Oocystis sp.	-	1
Stigeocolonium sp.	-	1
Ulothrix sp.	1	1
Unknown Chlorophyte sp.	5	5
CHRYSOPHYTA		
Stipitococcus sp.	1	-
Bacillariophyta		
Achnanthes exigua	-	1
A. exigua v. constricta	-	1
A. lanceolata	-	1
A. linearis	-	1
A. microcephala	1	-
A. nollii	1	-
Cocconeis fluviatilis	-	1
Cymbella amphicephala	-	1
C. angustata	-	1
C. aspera	-	4
C. lunata	1	1
C. minuta	-	1
Diploneis pseudovalis	-	1
D. puella	-	1
Eunotia sp.	1	-
E. arcus	-	1

	GADS 1	GADS 3
E. curvata	5	6
E. exigua	1	-
E. fallax	1	1
E. flexuosa	3	2
E. pectinalis	5	6
E. tenella	1	1
E. trinacria	1	-
E. vanheurckii	-	1
E. vanheurckii v. intermedia	-	1
Frustulia sp.	-	1
F. rhomboides	4	2
F. rhomboides v. amphipleuroides	-	1
Gomphonema angustatum	1	1
G. gracile	-	2
G. parvulum	5	7
Hantzschia amphioxys	1	-
Navicula sp.	1	-
N. angusta	-	1
N. cinta	-	1
N. contenta v. biceps	1	-
N. exigua	1	-
N. falaisensis v. lanceolata	-	1
N. gregaria	1	-
N. lanceolata	-	1
N. lateropunctata	-	3
N. notha	1	2
N. pupula	-	2
N. pupula v. rectangularis	-	2
N. pusilla	-	1
N. radiosa	3	2
N. rhynchocephala	-	2
Neidium affine v. amphirhynchus	1	2
N. dubium	1	-
N. iridis	1	-
Nitzschia sp.	-	1
N. acicularis	1	-
N. filiformis	1	1
N. fonticola	1	-
N. ignorata	-	1
N. palea	3	7
N. parvula	1	1
N. subtilis	-	1
Pinnularia sp.	4	1
P. abaujensis	1	-
P. acrosphaeria	1	-
P. appendiculata	1	-
P. biceps	1	-
P. borealis	-	1
P. borealis v. rectangularis	-	1

	GADS 1	GADS 3
P. braunii v. amphicephala	-	1
P. divergens	-	1
P. mesogonglya	1	-
P. microstauron	-	1
P. obscura	1	-
P. subcapitata	1	1
P. sudetica	1	-
Rhopalodia gibberula v. vanheurckii	-	1
Stauroneis sp.	1	1
S. acuta	-	1
S. anceps	1	1
S. anceps v. gracilis	1	-
S. phoenicenteron	4	-
S. smithii	-	1
Surirella linearis	-	1
Synedra sp.	1	-
S. miniscula	-	1
S. radians	-	1
S. ulna	-	2
Tabellaria fenestrata	2	-
EUGLENOPHYTA		
Euglena sp.	-	1
Phacus sp.	-	1
Trachelomonas	1	2

The composition of major algal divisions did not differ much between the two stations, but was more typical of what has been observed at outfall stations. At the QUIN and CRES sites, a larger proportion of cyanophytes was found at outfall stations than at their upstreams (Tables 19 and 22) and percent cyanophytes was very close to the 34.8% and 27.8% at GADS 1 and GADS 3, respectively (Table 28). The proportion of diatoms at the QUIN and CRES outfalls was within the range observed at GADS 1 and GADS 3.

Algal abundance generally declined at both stations over the sampling period, as did chlorophyll a (Figures 58 and 59). Regression analysis provided no significant correlation; r^2 was .143 for GADS 1 and .267 for GADS 3. This was another example of the similarity between these two GADS stations and the QUIN and CRES outfalls (lack of correlation of abundance and chlorophyll a accompanied by an increase in the proportion of cyanophytes).

Cluster/Discriminant Analyses

Numerical classification (normal cluster analysis) of periphyton data from the FREQUENCY stations indicated the presence of three station groups (Figure 60). Group I contains all of the pond stations (MOSS 2, MOSS 3, QUIN 2 and CRES 2), and the outfall of MOSS 3 (MOSS 4). Although Station MOSS 4 is not a pond station, its close proximity to the outfall of MOSS 3 and similarity in periphyton community characteristics (Table 24), warrants its inclusion in this group. Group II consists of the upstreams CRES 1 and MOSS 1, along with the parallel control at the MOSS site, MOSS 5. The remainder of the stations make up Group III; the three outfall stations CRES 3, QUIN 3 and GADS 3, along with the upstream stations QUIN 1 and GADS 1.

A dendrogram of the results of an inverse cluster analysis (Figure 61) reveals six major groups. The five taxa constituting Group I were found in greatest abundance at the outfall stations QUIN 3 and GADS 3, with the exception of Ulothrix sp., a filamentous chlorophyte which was most abundant at QUIN 1. The diatom Gomphonema angustatum, found almost exclusively at GADS 3, is a cosmopolitan species which is typical of eutrophic waters. Three taxa make up Group II: The diatoms Navicula cryptocephala and N. lateropunctata, and the green alga Protoderma sp. These three were almost exclusively found at Station QUIN 1. Group III is made up of only one taxa, an unknown chrysophyte. Group IV, consisting of 14 taxa, is dominated by chlorophytes and diatoms. These taxa were most abundant and often only found at the pond stations. Group V, made up of four diatoms and one chlorophyte, was found almost exclusively at Stations MOSS 3 and MOSS 4. The remainder of the taxa fall into Group VI, represented by 15 diatoms, four cyanophytes and three chlorophytes. This group ranges from the very abundant to the relatively rare. It is interesting to note, however, that although most species were found at nearly all stations, they were clearly more abundant at all three of the QUIN stations.

FIGURE 60. Station cluster of FREQUENCY periphyton taxa.

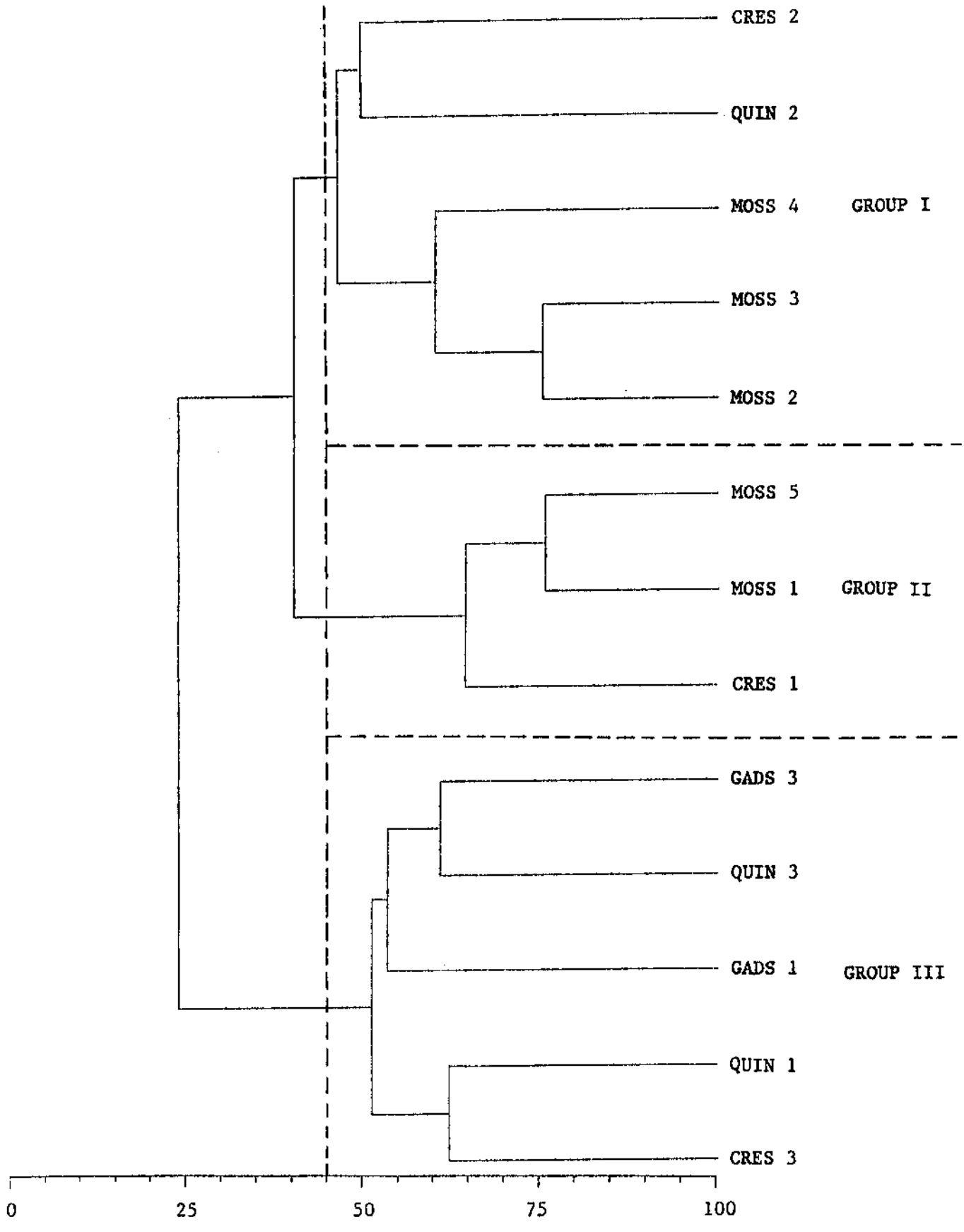


FIGURE 61. Species cluster of FREQUENCY periphyton taxa.

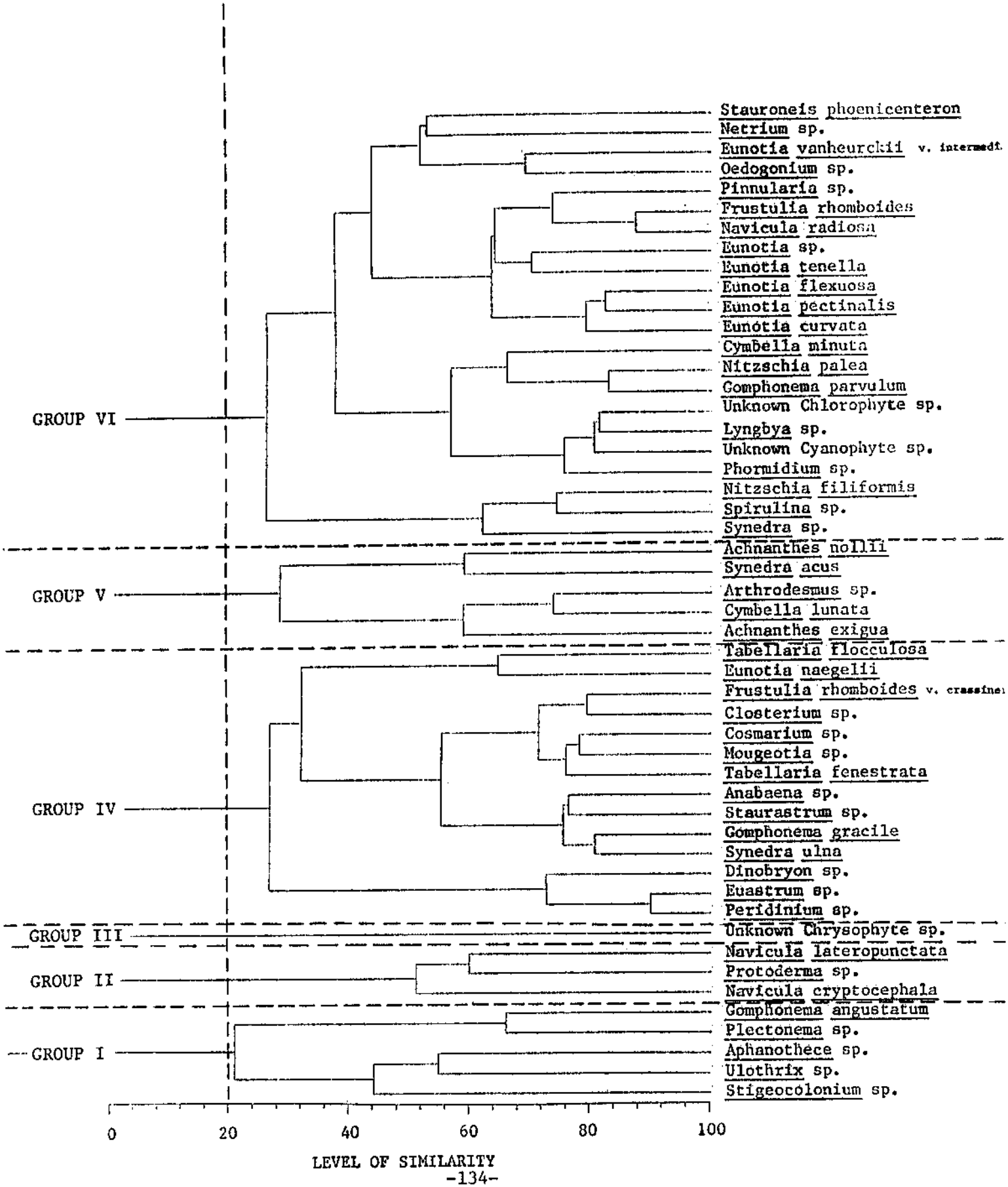
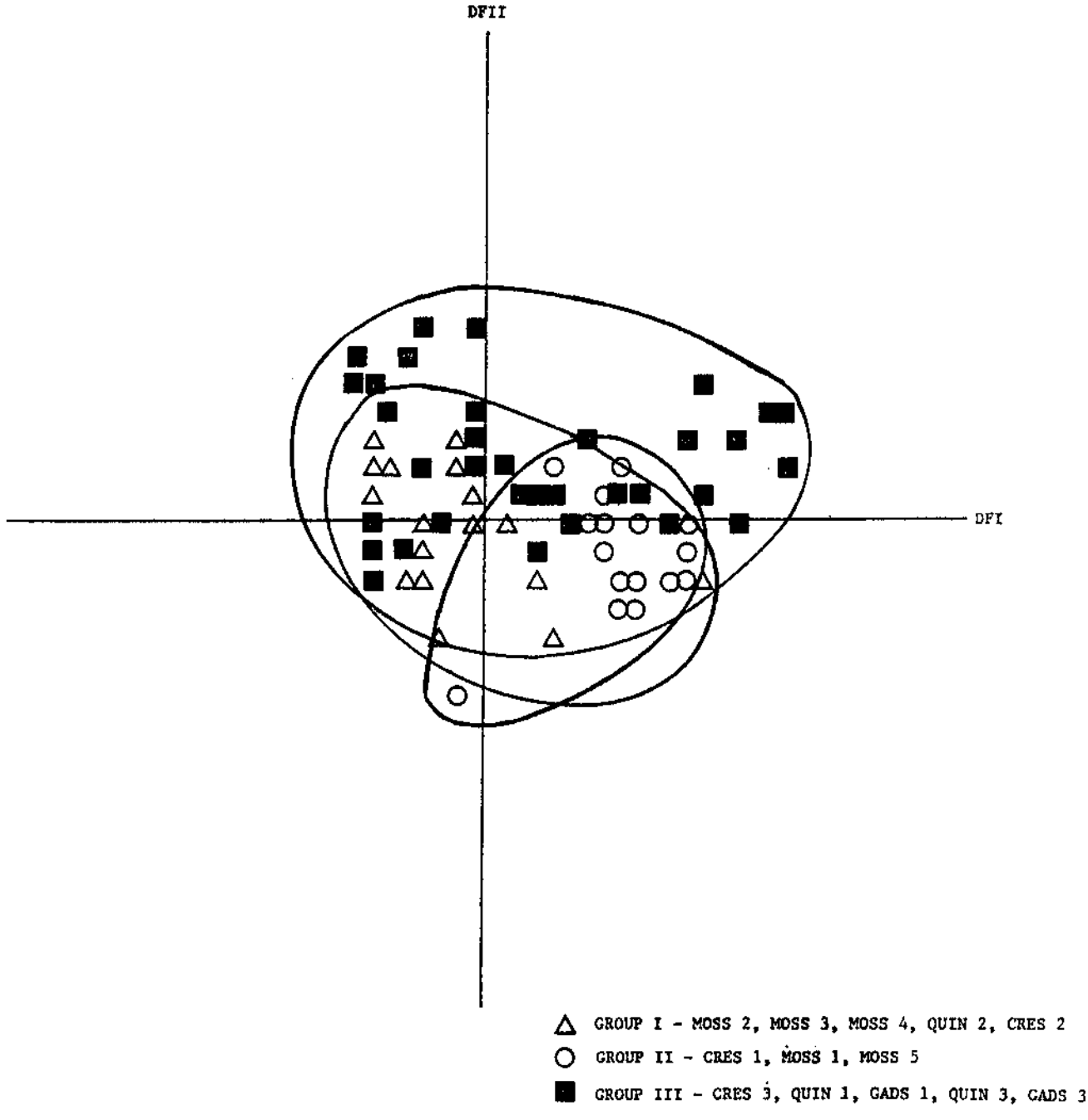


FIGURE 62 . Orientation of FREQUENCY periphyton groups in discriminant space.



Multiple discriminant analysis of surface temperature, pH, nitrate plus nitrite, total phosphorus, and total suspended solids (parameters considered likely to account for periphyton distribution) was used as a means to indicate some of the abiotic factors that might have contributed to the observed station groupings. Results indicated that 69.64% of among group variance could be explained by Discriminant Function I (DFI). The most important variable within DFI was nitrate plus nitrite. The addition of Discriminant Function II (DFII) increased the explained variance to 90.85%. The parameter contributing most to among group separation in DFII was pH.

The distribution of the stations groups in discriminant space (Figure 62) indicates a reasonably distinct separation of Group II (CRES 1, MOSS 1, MOSS 5) and Group III (CRES 3, QUIN 1, QUIN 3, GADS 1, GADS 3) based on the second discriminant function (primarily pH). This may partially explain the inclusion of Station QUIN 1 in the group consisting of primarily outfall stations. The average pH of the upstream group (Group II) was 4.4, whereas the mean pH of the Group III stations was 5.3. The mean pH of Station QUIN 1 was 4.9; perhaps a great enough increase to cause the distribution of periphyton to be more similar to the outfall stations than the upstreams.

Figure 62 also illustrates a fair separation between Group I (ponds) and Group II (upstream stations) based on DFI (primarily nitrates plus nitrites). Generally, the ponds were observed to be lower in nitrates plus nitrites than the upstreams (Tables 6-9), and the mean NO_2+NO_3 levels were 0.04 mg/l for Group I and 0.13 mg/l for the upstream group (II).

MASS Sites

Five of the thirteen MASS sites had upstreams which were suitable for placement of a periphyton rack: Kever (B1 and B2); Lett (G1 and G2); Whittle (H1 and H2); Scott (I1 and I2); and McCormick (L1 and L2). At most, three samples were obtained from any site, and because of the intermittent nature of some upstream stations, in some cases only one data point is available. Because of the paucity of data collected from these sites, it is difficult to identify trends or draw any conclusions as to the effects of stream impoundment.

A substantial increase in abundance of algae from upstream to pond was observed at most sites (Table 30), the one exception being Lett (G), from which only one upstream sample was collected. Average chlorophyll *a* values appeared to coincide with mean abundances for all stations. The relative abundances for the different algal divisions and percent compositions did not follow any consistent pattern, except that for most sites there were more chlorophytes at the pond stations and more diatoms at the upstream stations (Tables 30 and 31).

TABLE 30. Temperature, number of taxa, Shannon-Weaver diversity index, abundance, and Chlorophyll *a* for upstream and pond stations at all MASS Sites. Numbers in parentheses are minimum and maximum values for the sample period.

	B1	B2	G1	G2	H1	H2	I1	I2	L1	L2
$\bar{x}$ Temp (°C) (range)	17.6 (12.0-21.0)	21.3 (9.0-27.0)	20.2 (11.2-29.5)	23.6 (11.0-29.5)	16.9 (10.0-21.0)	21.4 (9.5-26.0)	15.0 (8.0-21.0)	20.7 (8.0-26.0)	19.0 (9.5-26.0)	22.2 (10.0-28.0)
Total # taxa	29	41	10	56	64	44	30	27	26	62
$\bar{x}$ #taxa (range)	17.0 (15.0-19.0)	20.3 (19.0-22.0)	10.0 (*)	27.7 (20.0-31.0)	29.7 (20.0-43.0)	25.3 (23.0-28.0)	17.5 (12.0-23.0)	17.0 (16.0-18.0)	16.0 (16.0-16.0)	32.3 (29.0-39.0)
$\bar{x}$ $\bar{d}$ (range)	2.2 (1.8-2.6)	2.6 (2.0-3.4)	1.0 (*)	3.7 (3.2-4.3)	3.8 (3.0-4.5)	3.4 (2.8-3.8)	3.1 (2.0-4.2)	2.7 (2.6-2.8)	2.2 (2.0-2.5)	4.1 (3.6-4.5)
pooled $\bar{d}$	2.6	3.1	1.0	4.5	4.4	4.4	2.5	3.1	2.8	4.7
$\bar{x}$ abundance (#/mm^2) (range)	29.8 (12.3-47.3)	609.8 (201.5-961.0)	1732.1 (*)	474.7 (245.8-6.5.6)	48.3 (21.3-39.7)	328.1 (217.5-505.3)	197.8 (38.1-357.6)	463.7 (172.4-755.0)	150.0 (88.6-211.3)	225.0 (117.4-290.9)
# Cyanophyta	0.2	8.1	0.0	82.7	1.3	27.9	10.0	21.1	40.7	5.9
# Chlorophyta	0.7	220.1	39.9	72.8	4.4	44.3	1.4	116.7	4.2	69.8
# Chrysophyta	0.0	8.0	0.0	5.1	1.0	13.0	0.0	0.8	0.0	3.4
# Bacillariophyta	28.9	372.5	1692.2	314.1	40.5	215.0	186.4	321.5	105.1	145.4
# Pyrrohphyta	0.0	1.1	0.0	0.0	1.1	27.9	0.0	3.6	0.0	0.4
chl-a (mg/mm^2) (range)	0.6 (0.4-0.7)	4.3 (2.3-6.2)	4.5 (*)	3.5 (1.7-7.0)	0.6 (0.1-1.2)	3.8 (0.8-6.3)	0.9 (0.2-1.5)	3.1 (1.7-4.4)	1.2 (0.2-2.1)	3.2 (1.0-6.4)

*only one sample

TABLE 31. Numbers of periphyton taxa identified and average percent compostion of selected major algal divisions, Mass Sites, January to August 1985.

No of Taxa	B1	B2	G1	G2	H1	H2	I1	I2	L1	L2
Cyanophyta	1	4	0	5	3	2	5	2	4	4
Chlorophyta	4	12	4	16	8	12	3	8	5	18
Chrysophyta	0	2	0	2	3	2	0	1	0	3
Bacillariophyta	23	22	6	32	49	26	22	15	16	33
Euglenophyta	1	0	0	1	0	0	0	0	1	2
Pyrrhophyta	0	1	0	0	1	2	0	1	0	1
% Composition										
Cyanophyta (range)	1.3 (0-2.6)	2.0 (1.0-4.0)	0	16.3 (0-40.4)	6.1 (0-17.6)	7.8 (1.7-12.2)	11.2 (3.6-18.9)	10.7 (0.9-20.4)	42.4 (5.1-79.7)	2.5 (1.9-3.6)
Chlorophyta (range)	2.5 (2.4-2.6)	37.9 (15.0-68.2)	2.3 (*)	14.4 (10.4-17.0)	10.0 (5.9-17.4)	11.5 (5.3-19.4)	2.1 (0.4-3.8)	35.8 (18.9-52.8)	2.8 (2.7-2.8)	28.1 (16.5-36.2)
Chrysophyta (range)	0	1.2 (0-3.6)	0	2.8 (0-5.2)	2.6 (0-6.5)	5.1 (0-13.5)	0	0.5 (0-0.9)	0	1.6 (1.2-1.9)
Bacillariophyta (range)	96.2 (94.8-97.6)	58.7 (27.2-83.7)	97.7 (*)	67.4 (42.6-83.8)	76.3 (59.5-94.1)	64.8 (51.9-73.4)	86.7 (77.4-96.0)	52.6 (25.9-79.2)	54.8 (17.6-92.1)	67.4 (60.1-78-6)
Pyrrhophyta (range)	0	0.1 (0-0.3)	0	0	5.0 (0-14.9)	10.8 (0-30.5)	0	0.5 (0-0.9)	0	0.3 (0-1.0)

*only one sample

TABLE 32. Periphyton algae identified and number of occurrences at the MASS Sites, January to August, 1985.

	Number of Occurrences									
	B1	B2	G1	G2	H1	H2	I1	I2	L1	L2
CYANOPHYTA										
Anabaena sp.	-	2	-	2	1	3	-	-	-	2
Aphanocapsa sp.	-	-	-	-	1	-	-	-	-	-
Aphanotheca sp.	-	-	-	-	-	-	1	-	1	2
Calothrix sp.	-	-	-	-	-	-	-	1	-	-
Coelosphaerium sp.	-	-	-	1	-	-	-	-	-	-
Hapalosiphon sp.	-	1	-	1	-	-	-	-	-	-
Lyngbya sp.	-	1	-	-	-	-	-	-	2	1
Merismopedium sp.	-	1	-	-	-	-	-	-	-	-
Oscillatoria sp.	1	-	-	2	-	-	1	-	1	-
Phormidium sp.	-	-	-	1	1	-	1	1	2	1
Rivularia sp.	-	-	-	-	-	-	-	-	-	1
Scytonema sp.	-	-	-	-	-	-	1	-	-	-
Unknown Cyanophyte sp.	-	-	-	-	-	2	1	-	-	-
CHLOROPHYTA										
Aphanochaeta sp.	-	-	-	1	-	-	-	-	-	-
Arthrodesmus sp.	-	-	-	-	-	-	-	-	-	2
Bambusina sp.	-	1	-	-	-	-	-	-	-	-
Bulbochaete sp.	1	2	-	-	-	-	-	-	-	1
Chaetosphaerium sp.	-	1	-	-	-	-	-	-	-	-
Cladophora sp.	1	-	-	-	-	-	-	-	-	-
Closterium sp.	1	-	-	-	2	1	-	1	-	2
Coleochaeta sp.	-	1	-	2	-	-	-	-	-	1
Cosmarium sp.	-	1	-	1	-	-	-	1	1	3
Desmidium sp.	-	-	-	-	-	-	-	-	-	2
Dictyosphaerium sp.	-	-	-	1	-	1	-	-	-	1
Eudorina sp.	-	-	-	-	1	-	-	-	-	-
Gloeocystis sp.	-	-	-	2	-	-	-	-	-	1
Gonatozygon sp.	-	-	-	-	-	2	-	-	-	1
Hyalotheca sp.	-	-	-	-	-	-	-	-	-	2
Mougeotia sp.	-	3	1	3	1	3	1	1	1	2
Oedogonium sp.	1	2	1	2	2	2	-	1	1	3
Oocystis sp.	-	-	-	1	1	1	1	-	-	-
Pediastrim sp.	-	-	-	1	-	-	-	-	-	1
Penium sp.	-	-	-	-	-	-	-	-	-	1
Pleurotaenium sp.	-	-	-	2	-	2	-	-	-	1
Scenedesmus sp.	-	-	-	1	-	-	-	2	-	-
Schroedaria sp.	-	-	-	1	-	-	-	-	-	-
Sphaerocystis sp.	-	-	-	-	-	1	-	-	-	-

	B1	B2	G1	G2	H1	H2	I1	I2	L1	L2
Spirogyra sp.	-	3	-	1	1	1	-	-	-	-
Staurastrum sp.	-	2	-	3	1	3	-	1	-	3
Stigeocolonium sp.	-	-	-	-	-	-	-	2	-	1
Ulothrix sp.	-	1	1	1	-	1	-	-	1	-
Volvox sp.	-	-	1	-	-	-	-	-	-	-
Xanthidium sp.	-	1	-	-	-	-	-	-	-	-
Unknown Chlorophyte sp.	-	3	-	2	1	2	1	1	1	3
CHRYSOPHYTA										
Centritractus sp.	-	-	-	1	-	-	-	-	-	1
Dinobryon sp.	-	1	-	2	1	2	-	-	-	1
Mallomonas sp.	-	-	-	-	1	-	-	1	-	-
Stipitococcus sp.	-	1	-	-	-	1	-	-	-	-
Synura sp.	-	-	-	-	1	-	-	-	-	1
Bacillariophyta										
Achnanthes sp.	1	-	-	-	-	-	-	-	-	-
A. lanceolata	-	-	-	-	-	-	-	-	1	-
A. linearis	-	-	-	-	1	-	-	-	-	-
A. linearis v. curta	-	1	-	-	1	2	-	-	-	-
A. microcephala	-	-	-	-	-	-	-	-	-	1
A. minutissima	-	-	-	-	-	-	-	-	-	1
A. saxonica	-	-	-	-	-	1	-	-	-	1
Actinella punctata	-	-	-	-	-	1	-	-	-	-
Anomoeoneis serians v. acuta	-	-	-	-	1	-	-	-	-	-
Asterionella formosa	-	1	-	1	2	1	-	2	-	1
A. ralfsii	-	2	-	1	-	-	-	-	-	-
Cocconeis placentula v. euglypta	-	-	-	-	1	-	-	-	-	-
Coscinodiscus sp.	-	-	-	1	-	-	-	-	-	-
C. lacustris	-	-	-	-	-	-	-	-	-	2
Cyclotella sp.	-	-	-	-	1	-	-	-	-	-
Cymbella sp.	-	-	-	-	-	1	1	-	-	-
C. lunata	1	-	-	3	2	3	-	-	1	3
C. microcephala	-	-	-	-	-	-	-	-	2	-
C. minuta	-	-	-	1	2	3	-	1	-	3
Eunotia sp.	-	1	-	-	1	-	-	-	-	-
E. curvata	2	3	1	3	3	2	2	2	1	3
E. exigua	1	-	1	-	2	-	1	-	-	-
E. fallax	-	-	-	-	1	-	-	-	-	-
E. flexuosa	1	-	-	1	2	1	2	1	-	2
E. meisteri	1	-	-	-	1	-	-	-	1	-
E. monodon	1	-	-	-	-	-	-	-	-	-
E. naegelii	2	-	-	1	-	-	-	-	-	2
E. parallela	1	-	-	-	-	-	-	-	-	-
E. pectinalis	2	3	1	2	3	3	2	2	2	2
E. perminuta	-	-	-	-	1	-	-	-	-	1

	B1	B2	G1	G2	H1	H2	I1	I2	L1	L2
E. perpusilla	-	-	-	-	-	-	-	1	-	-
E. septentrionalis	-	-	-	-	-	1	-	-	-	-
E. serra	-	-	-	-	1	-	-	-	-	-
E. tenella	-	1	-	-	1	-	2	-	-	-
E. valida	-	-	-	-	-	-	1	-	-	-
E. vanheurckii	-	-	-	1	-	-	-	-	1	1
E. vanheurckii v. intermedia	1	-	-	1	1	-	-	-	-	-
Fragilaria crotonensis	-	-	-	-	1	-	-	-	-	-
Frustulia rhomboides	-	2	-	2	1	-	1	1	-	1
F. rhomboides v. amphipleuroides	-	-	-	-	2	-	-	-	-	-
F. rhomboides v. capitata	-	1	-	1	-	-	-	-	-	-
F. rhomboides v. crassinervia	1	-	-	2	2	1	-	-	-	1
F. rhomboides v. saxonica	2	1	-	3	2	-	-	-	-	2
Gomphonema affine	-	-	-	1	-	-	-	-	-	1
G. gracile	2	1	-	1	2	3	1	2	1	3
G. parvulum	-	-	-	1	2	3	2	2	2	3
Melosira italica	-	1	-	2	-	-	-	-	-	-
Meridion circulare v. constricta	-	-	1	1	-	-	-	-	-	-
Navicula sp.	-	-	-	-	-	-	-	1	1	-
N. capitata v. hungarica	-	-	-	-	-	-	-	-	-	1
N. cryptocephala	-	-	-	-	-	-	1	-	-	1
N. halophila v. tenuirostris	-	-	-	-	1	-	-	-	-	-
N. lateropunctata	-	-	1	-	2	2	1	-	1	-
N. notha	-	3	-	1	-	-	-	-	-	1
N. protracta	-	-	-	-	-	-	1	-	-	-
N. pupula v. rectangularis	1	-	-	1	2	1	1	-	-	-
N. radiosa	1	-	-	2	2	3	1	1	-	3
N. subtilissima	-	-	-	-	-	-	-	-	1	-
Neidium sp.	-	-	-	-	1	-	1	1	-	-
N. affine	-	-	-	-	1	-	-	-	-	-
N. affine v. amphirhynchus	1	-	-	-	-	-	-	-	-	-
N. apiculatum	1	1	-	-	1	-	-	-	-	-
N. bisulcatum	1	-	-	-	-	-	-	-	-	-
N. iridis v. amphigomphus	1	-	-	-	1	-	-	-	-	-
N. iridis v. subundulatum	-	-	-	-	1	-	-	-	-	-
N. ladogense v. densestriatum	1	1	-	-	1	-	1	-	-	-
Nitzschia acicularis	-	-	-	-	-	-	-	-	-	1
N. filiformis	-	-	-	-	-	1	-	-	1	1
N. gracilis	-	-	-	1	-	-	-	-	-	-
N. palea	1	1	-	3	2	3	1	-	-	1
N. sigma	-	-	-	-	-	-	-	-	-	1
N. subtilis	1	1	-	1	-	2	-	1	-	2
Pinnularia sp.	-	1	-	1	1	-	-	1	-	1
P. abaujensis	-	-	-	1	-	-	1	-	-	-
P. biceps	-	-	-	-	2	-	-	-	-	-
P. braunii v. amphicephala	-	-	-	1	-	-	-	-	-	-
P. formica	-	-	-	-	1	-	-	-	-	-
P. polyonca	-	-	-	-	1	-	-	-	-	-
P. subcapitata	-	-	-	-	-	-	1	-	1	1
Rhopalodia gibba v. ventricosa	-	-	-	-	1	1	1	-	-	-

	B1	B2	G1	G2	H1	H2	I1	I2	L1	L2
Stauroneis sp.	-	-	-	-	1	-	-	-	-	-
S. phoenicenteron	-	-	-	-	-	1	-	-	-	1
Surirella sp.	-	1	1	-	1	-	-	-	-	-
Synedra sp.	-	-	-	-	1	-	-	-	-	-
S. radians	-	-	-	-	1	1	-	-	-	-
S. ulna	-	2	-	3	2	1	1	1	1	3
Tabellaria fenestrata	-	2	-	1	3	3	-	-	-	1
T. flocculosa	-	1	-	1	2	1	-	-	1	-
EUGLENOPHYTA										
Euglena sp.	1	-	-	-	-	-	-	-	2	-
Phacus sp.	-	-	-	1	-	-	-	-	-	1
Trachelomonas sp.	-	-	-	-	-	-	-	-	-	1
PYRRHOPHYTA										
Ceratium sp.	-	-	-	-	-	1	-	-	-	-
Peridinium sp.	-	1	-	-	1	1	-	1	-	1

There was also no apparent trend in changes from upstream to pond with respect to community diversity. Diversity indices were either very close (B, H, and I), or higher at the pond station (G and L). Most of the dominant species identified at these stations were diatoms. Eunotia pectinalis represented 42% at B1 and 40% at B2. The one sample collected from G1 contained 84% Eunotia curvata, which was also dominant at two other upstream stations (52% and 43% at I1 and L1, respectively). Gomphonema parvulum, a diatom characteristic of nutrient-rich water, constituted 37% at I2, and the blue green filament, Anabaena sp., represented 32% and 16% at H2 and G2, respectively. Table 32 contains a list with all taxa identified with the number of occurrences at each station.

Cluster/Discriminant Analyses

Normal cluster analysis of species composition and abundance data indicated two station groupings (Figure 63). Group I contains the upstream stations B1,G1,I1,L1, and the pond station I2. Group II comprises the remainder of the pond stations (B2,G2,H2,L2) and the upstream station H1.

Inverse cluster analysis resulted in the separation of five major groups; these are illustrated in Figure 64. Group I consists of six taxa, three chlorophytes and three diatoms, all of which were collected from four of the five pond stations. Two species of diatoms, Navicula notha and Eunotia naegelii, are typical of waters with low mineral content. Group II comprised only two taxa: The chlorophyte Scenedesmus sp. was almost exclusively found at Station I2 as was Calothrix sp., a cyanophyte. It is interesting to note that none of the six taxa from Group I were detected at Station I2, and only a few cells of Scenedesmus sp. were observed at one other pond (G2). During the sampling period, dissolved oxygen dropped to such low levels that this pond had to be mechanically aerated. This may partially explain the dramatic differences in the periphyton community between Station I2 and the other pond stations.

Group III is made up of one chlorophyte, three cyanophytes, and seven diatoms. They range from being collected only at ponds to being restricted to upstream stations, but were almost never detected at the Whittle (H) or Scott (I) sites. The range of environmental requirements or preferences is also wide; most taxa in this group are considered to be cosmopolitan, although several tend to prefer acid waters.

Group IV was the largest and most diverse: One each of cyanophytes, chrysophytes, and pyrrhophytes, seven chlorophytes, and 14 diatoms. This group also comprised individuals collected from pond stations. Although some species were collected chiefly, or only at, particular pond stations, all ponds were represented in the group. The range of typical environmental requirements appears to be wider than that of Group III in

FIGURE 63. Station cluster of MASS periphyton taxa.

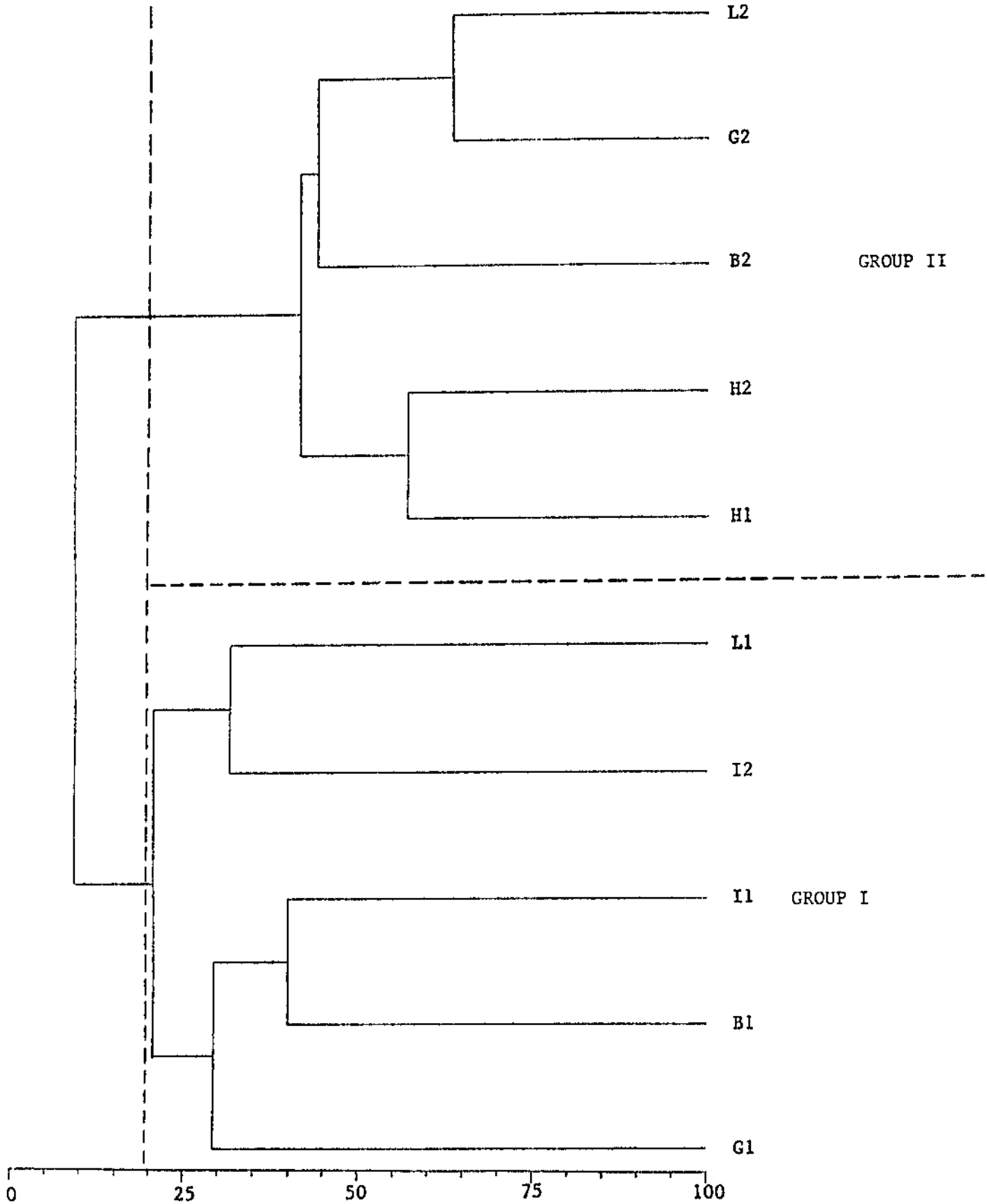


FIGURE 64. Species cluster of MASS periphyton taxa.

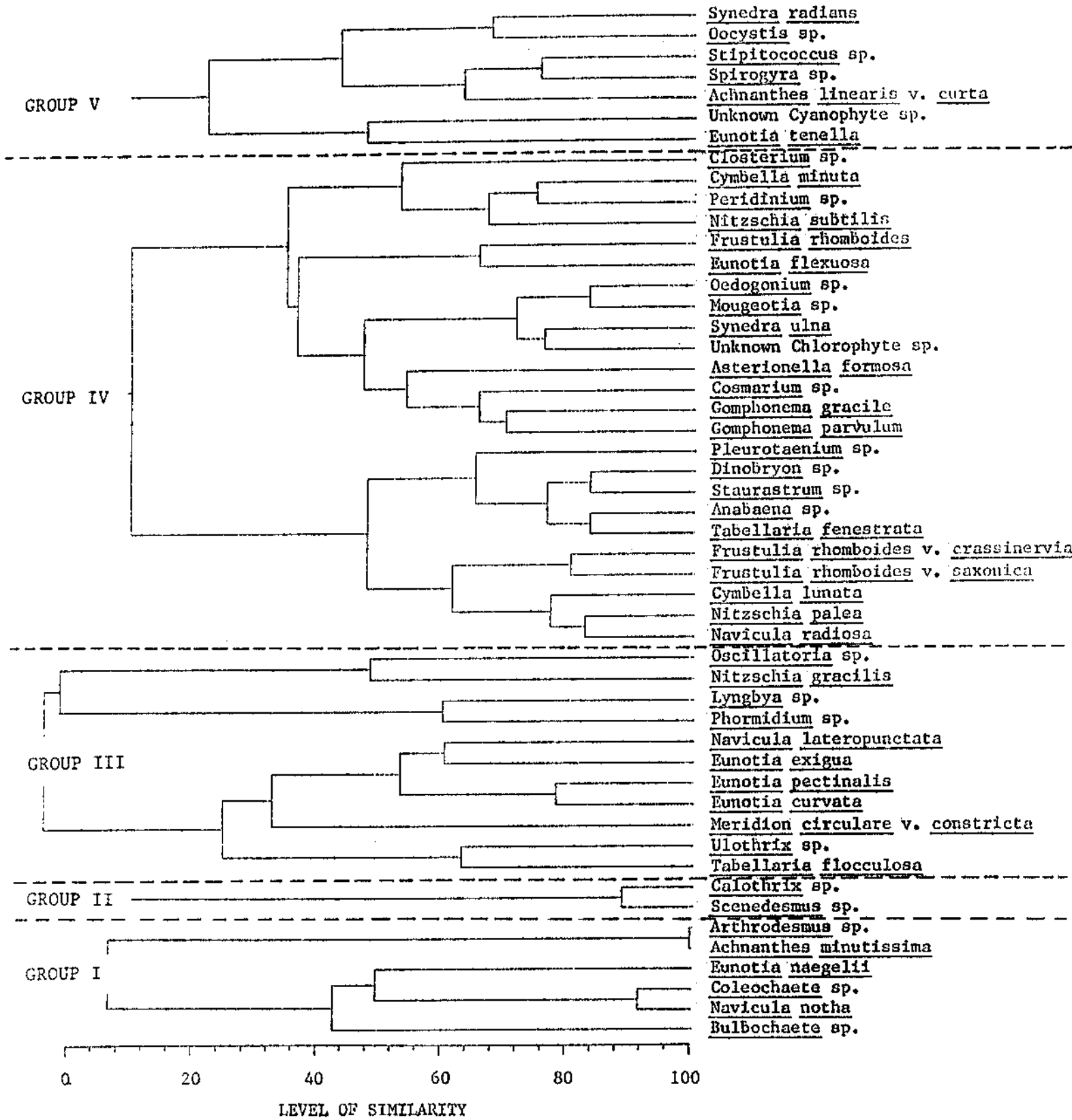
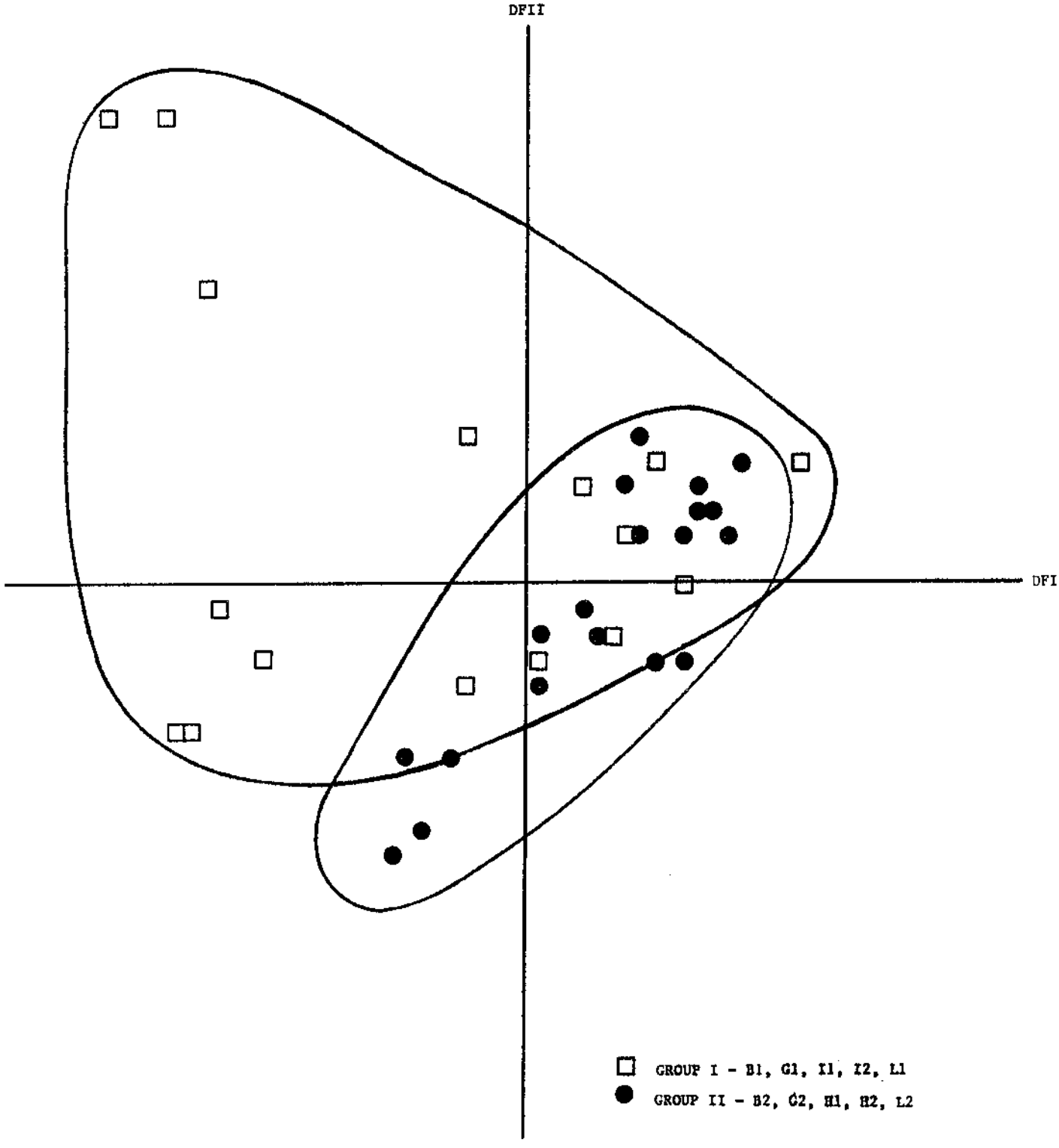


FIGURE 65. Orientation of MASS periphyton groups in discriminant space.



that most of these taxa are cosmopolitan and indifferent to pH, nutrient, and water velocity conditions. Some species, such as the diatom Synedra ulna, prefer alkaline, eutrophic waters, and others, such as the Frustulia rhomboides complex, are typically found in acid, oligotrophic waters.

Group V comprised seven taxa representing four major divisions. None of these algae were found in great abundance, and most were collected from the pond stations B2 and, primarily, H2. A few individuals of Eunotia tenella and Synedra radians were found at the upstream Stations I1 and H1, respectively. Common trends in environmental preferences among these individuals were not apparent.

Although the station groupings separated fairly distinctly into upstream and pond groups, the level of similarity was relatively low, particularly for the upstream group (.204, Figure 63). This is probably because of the small number of samples collected from the upstream stations, and is also reflected in the groupings resulting from inverse analysis. Because the top 50 species were used for these analyses, many of the taxa collected from the upstream stations were not included, and so these stations were not well represented. Therefore, inverse analysis groupings were chiefly based on algae collected from pond stations.

Multiple discriminant analysis was performed on the MASS periphyton data with the same parameters as were used on the FREQUENCY data (i.e., surface temperature, pH, nitrate plus nitrite, total phosphorus, and total suspended solids). Results indicated that 53.05% of the among group variance could be explained by Discriminant Function I (DFI); the most important variables being pH and nitrate plus nitrite. An additional 37.99% of the variance can be explained by Discriminant Function II (DFII), bringing the total amount of explained variance to 91.05%. Surface temperature was the parameter contributing the most to DFII.

Figure 65 illustrates the distribution of the groups in discriminant space. A considerable amount of overlap occurred between the two station groups; this is likely a reflection of the small number of samples and the relatively low level of similarity (Figure 63). The most distinct separation was along DFI, with Stations B1 and L1 being the most outstanding. This is probably due to the high nitrate plus nitrite levels observed at these upstream stations.

CONCLUSIONS

1. Total number of taxa decreased from upstream to pond at the QUIN and CRES sites, and increased at the MOSS site and most MASS sites. Total number of taxa decreased from upstream to outfall at all sites.

2. Mean number of taxa decreased from upstream to pond and from upstream to outfall at the QUIN and CRES sites. An increase was observed at the MOSS site. Mean number of taxa from upstream to pond increased at two and decreased at two of the MASS stations.

3. Algal abundance increased from upstream to pond at all FREQUENCY and MASS sites, and from upstream to outfall at all FREQUENCY sites.

4. Diversity indices ($\bar{d}$) decreased from upstream to pond at the QUIN and CRES sites; no consistent appreciable change was observed from upstream to outfall at these sites. Mean $\bar{d}$ increased from upstream to pond at the MOSS site. At the MASS sites, mean $\bar{d}$ was similar at upstream and pond stations except for one site, where an increase was observed.

5. The proportion of cyanophytes was greatly increased from upstream to outfall. Percent chlorophytes increased from upstream to pond at both FREQUENCY and MASS sites. The proportion of bacillariophytes (diatoms) decreased from upstream to pond and from upstream to outfall at all sites.

6. Chlorophyll *a* and algal abundance were well correlated over the sampling period, particularly at the pond stations where the proportion of chlorophytes was larger.

7. Normal cluster analysis separated the stations into upstream, pond and outfall groups.

8. Inverse cluster analysis indicated that the distribution of several species was related to the type of habitat (pond vs. stream and upstream vs. pond or outfall).

9. Multiple discriminant analysis indicated that most among group variation was based on differences in pH and NO_2+NO_3.

When streams are impounded, a number of changes in the periphyton community occur. Algal abundance increases, as does chlorophyll *a* at the pond stations. Diversity is reduced, as evidenced by the lower total number of taxa, mean number of taxa, and $\bar{d}$ at the pond and outfall stations relative to upstream stations. These changes are characteristic of eutrophic conditions (Rawson 1956, Grimes *et al.* 1984), and are typical of newly formed impoundments. Reduction in the rate of water flow allows the algal population to multiply before being swept away, and often very large populations can develop while the pond is filling and there is little outflow. Additionally, algal growth may be increased by the nutrients made available by leaching from the soil and by decomposition of drowned vegetation (Baxter 1977). Blooms are very common in new impoundments as opportunistic species outcompete others for resources and their populations explode. This phenomenon was observed at both the QUIN and CRES sites.

The changes in diversity indicative of eutrophic conditions were observed at the QUIN and CRES sites, but not at the MOSS site. Several explanations are possible. One relates to the general sediment type and soil composition of these sites. The MOSS and CRES sites can be characterized as sandhill ecosystems, while the soil at the QUIN site is composed largely of clay. Additionally, the presence of a developed littoral zone separates the MOSS site from the other two; the macrophytes in the littoral zone serve as habitat for algivorous species and compete with algae for nutrients.

This established littoral zone present at the MOSS site may be a reflection of the intended use of the impoundment or a characteristic of its age. The most profound difference between the MOSS site and the other two is that the QUIN and CRES ponds were filled during our study, while MOSS 2 and MOSS 3 were constructed in 1968 and 1971, respectively. The increased diversity and number of taxa observed at the MOSS site may be indicative of a recovery following the perturbations caused by impoundment, though the character of the algal community which develops in the pond remains distinctly different from that of the influent stream. Community composition is altered in that the proportion of cyanophytes increased from upstream to outfall, percent chlorophytes increased from upstream to pond, and that of diatoms is decreased from upstream to pond and from upstream to outfall. Multivariate analysis indicated that periphyton distribution was related to the type of habitat. Generally, substantial changes in the periphyton community occur following impoundment of a stream. With time, the periphyton in the pond may stabilize and evolve into a distinctly different population owing to the basic differences between lotic and lentic ecosystems.

PHYTOPLANKTON

INTRODUCTION

The phytoplankton community has been studied extensively in relation to many different hydrological parameters such as nutrients (Lund 1965, Fuhs 1969, Halemejko and Chrost 1984, Salonen et al. 1984), pH (Lazarek 1982, Shapiro 1984), light and temperature (Moss 1969, Berman and Pollingher 1974, Geddes 1984), degree of eutrophication (Ewing 1966, Shamess et al. 1985, Barko et al. 1984), and water column stability (Trimbee and Harris 1984). These variables can affect both the biomass and the composition of the community. Though the individual importance of these factors to community structure varies with the system studied, phytoplankton data have proven to be useful in analyzing and identifying water quality problems.

This portion of the study was designed to show how the phytoplankton community changes when streams are impounded. It also attempts to identify the physical, chemical and biological parameters which may have the greatest influence on the phytoplankton both within and between our different study sites.

METHODS AND MATERIALS

Phytoplankton samples were collected in the field by filtering water through a #20 (80 um) mesh plankton net (Wisconsin net, Wildco #40-B10). Although the use of a plankton net tends to underestimate the total standing phytoplankton crop (Zeitzchel 1978), the net method was chosen due to sampling logistics, and was considered adequate to obtain the information needed to fulfill the goals of this project. In streams, up to 20 liters of water were filtered; in ponds one vertical tow of the net was made from bottom to surface. The concentrated plankton was then fixed with neutralized formalin and stored in a graduated centrifuge tube.

In the laboratory, samples were either concentrated by removing water over the settled plankton, or diluted with deionized water, depending on plankton density. A portion of the resulting volume was thoroughly mixed and placed in an Utermöhl cell, allowed to settle for 5-10 minutes, and observed with a Wild® M-40 inverted microscope. Fifty to 100 fields were counted, depending on the algal density. Algal identifications were made to the generic level using the taxonomic keys listed in the Literature Cited. Densities, reported as cells, colonies, or filaments per ml, were determined from raw counts using the known volumes, concentrations, and dilutions. Phytoplankton samples were taken at all FREQUENCY stations, at all MASS ponds, and at the MASS influent streams where other biological data was also collected (Table 3).

Water samples for chlorophyll a were taken at the surface at all MASS stations and FREQUENCY upstream and outfall stations. The FREQUENCY pond chlorophyll a samples were a composite of surface, mid-depth and bottom grabs. The water was collected in opaque Nalgene® containers and iced immediately. Chlorophyll a determination was made according to the methods outlined in the periphyton section.

Statistical analyses performed on the phytoplankton data included normal and inverse cluster analysis and multiple discriminant analysis as described in the periphyton section. The 50 most dominant taxa were used for the cluster analyses. These taxa constituted 88.8% and 94.7% of the FREQUENCY and MASS groups, respectively.

RESULTS AND DISCUSSION

FREQUENCY Sites

QUIN Site

A total of 67 genera was identified at the QUIN site over the sampling period, including 11 cyanophytes, 30 chlorophytes, 22 chrysophytes (18 bacillariophytes), 3 euglenophytes and 1 pyrrhophyte. In the following text, the term chrysophyte is used to mean chrysophytes other than diatoms. The Bacillariophyta are treated as a separate division. Table 35 lists all genera identified and the number of occurrences of each at a particular station.

Total and mean number of taxa did not change significantly at this site. Mean $\bar{d}$, however, was decreased by 34% at QUIN 2, from 3.2 to 2.1, and pooled $\bar{d}$ was reduced by 30% (Table 33). The most obvious change in diversity was in the number of diatom genera identified; 18 at QUIN 1 and 13 at QUIN 2. Additionally, the proportion of diatoms decreased by 64% from 63.6% at QUIN 1 to 23.3% at QUIN 2 (Table 34). A substantial increase in the number and proportion of chlorophytes occurred at this site following impoundment, though only one additional genus was detected at QUIN 2; this also contributed to the depressed $\bar{d}$. Another factor which is probably responsible for the lowered $\bar{d}$ at this pond was a major bloom of the cyanophyte Anabaena sp., which occurred in May, and a bloom of the chlorophyte, Volvox sp., in March. Anabaena sp. and Volvox sp. accounted for 23% and 16% of the total number, respectively. Though diatoms constituted an average of 63.6% over the sampling period, no one genus represented more than 7% of the total.

Mean phytoplankton abundance increased from 3.2/ml at QUIN 1 to 12.5/ml at QUIN 2, or 291% (Table 33). Chlorophyll a values increased as well, from 1.0 ug/l to 28.9 ug/l at QUIN 1 and QUIN 2, respectively. Correlation of monthly chlorophyll a and abundance measurements was not quite as strong as was observed for periphyton. This is probably due to the use of a plankton net; the smaller nanoplankton pass through the net and are not included in the abundance measurement but are included in the

TABLE 33. Temperature, number of taxa, Shannon-Weaver diversity index, abundance, and chlorophyll a values for upstream, pond, and outfall stations, QUIN site, November 1984 to August 1985. Numbers in parentheses represent minimum and maximum values for the sample period.

	QUIN 1	QUIN 2	QUIN 3
$\bar{x}$ Temp (°C) (range)	16.0 (5.4-20.1)	19.5 (6.0-30.2)	17.5 (9.0-28.0)
Total # taxa	48	49	56
$\bar{x}$ #taxa (range)	13.5 (7-19)	11.8 (2-25)	12.2 (5-22)
$\bar{x}$ $\bar{d}$ (range)	3.2 (2.5-3.8)	2.1 (0.1-4.2)	2.5 (0.9-3.4)
pooled $\bar{d}$	4.4	3.1	3.4
$\bar{x}$ abundance (#/ml) (range)	3.2 (0.5-11.5)	12.5 (0.9-40.1)	27.1 (0.5-163.6)
# Cyanophyta	0.6	4.7	3.1
# Chlorophyta	0.5	5.1	19.5
# Chrysophyta	0.02	0.8	1.7
# Bacillariophyta	2.1	1.7	2.7
# Pyrrhophyta	0.0	0.2	0.1
Chl-a (ug/l) (range)	1.0 (0.0-3.0)	28.9 (5.5-105.4)	19.1 (0.8-61.1)

TABLE 34. Numbers of phytoplankton taxa identified and average percent composition of selected major algal division, QUIN site, November 1984 to August 1985. Numbers in parentheses represent minimum and maximum values for the sample period.

No. of Taxa	QUIN 1	QUIN 2	QUIN 3
Cyanophyta	8	9	9
Chlorophyta	18	19	23
Chrysophyta	1	3	4
Bacillariophyta	18	13	14
Euglenophyta	3	4	4
Pyrrhophyta	0	1	2
% Composition			
Cyanophyta (range)	19.3 (4.9-47.2)	17.9 (0.0-99.3)	13.8 (0.0-42.0)
Chlorophyta (range)	16.2 (0.0-39.0)	43.1 (0.5-93.1)	48.5 (1.6-84.0)
Chrysophyta (range)	0.9 (0.0-5.9)	14.0 (0.1-0.5)	8.6 (0.0-43.0)
Bacillariophyta (range)	63.6 (38.2-91.3)	23.2 (0.0-76.8)	28.5 (2.0-82.6)
Pyrrhophyta (range)	0	1.7 (0.0-8.9)	0.7 (0.0-4.0)

FIGURE 66. Phytoplankton log-transformed abundance and chlorophyll a, QUIN 1.

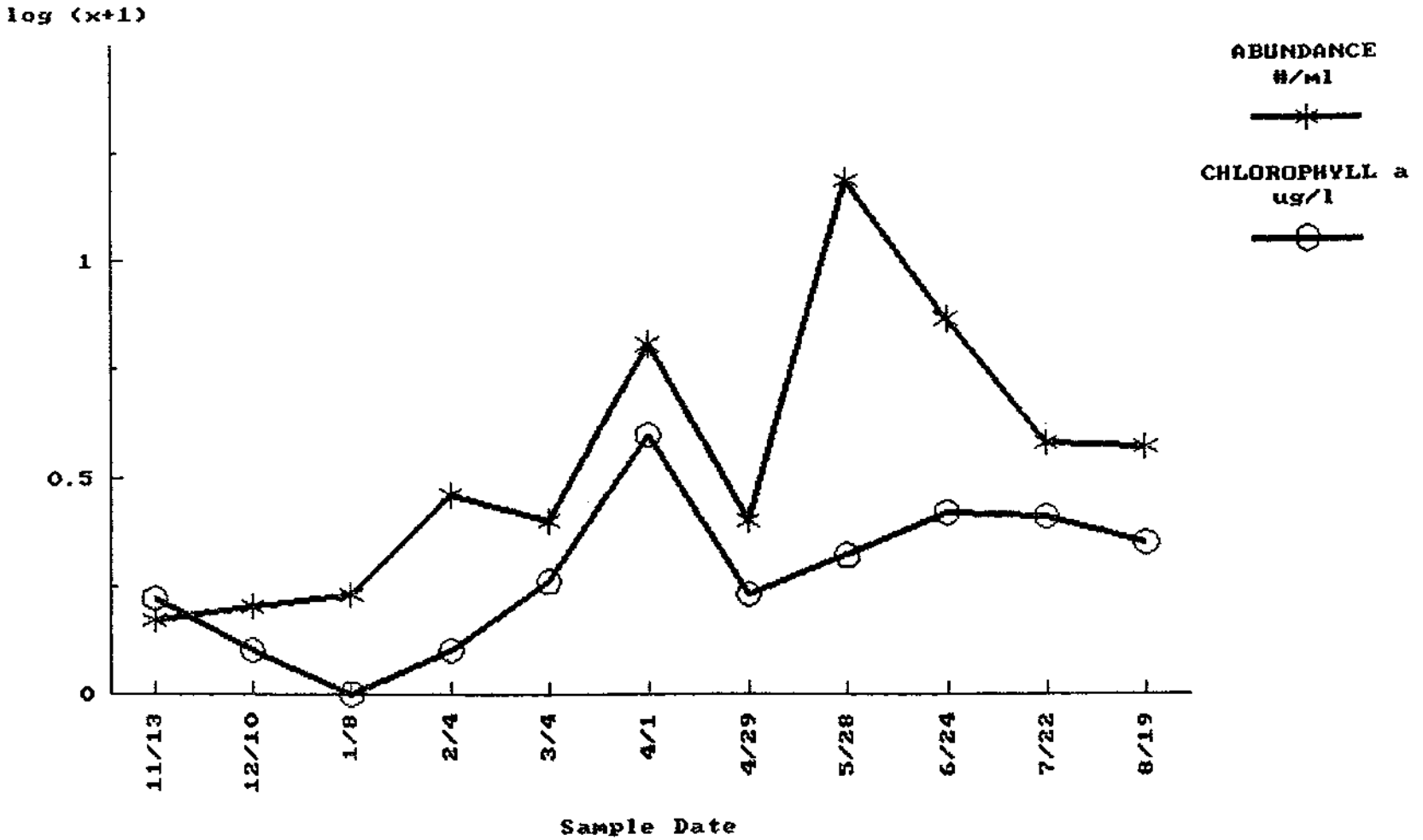


FIGURE 67. Phytoplankton log-transformed abundance and chlorophyll a, QUIN 2.

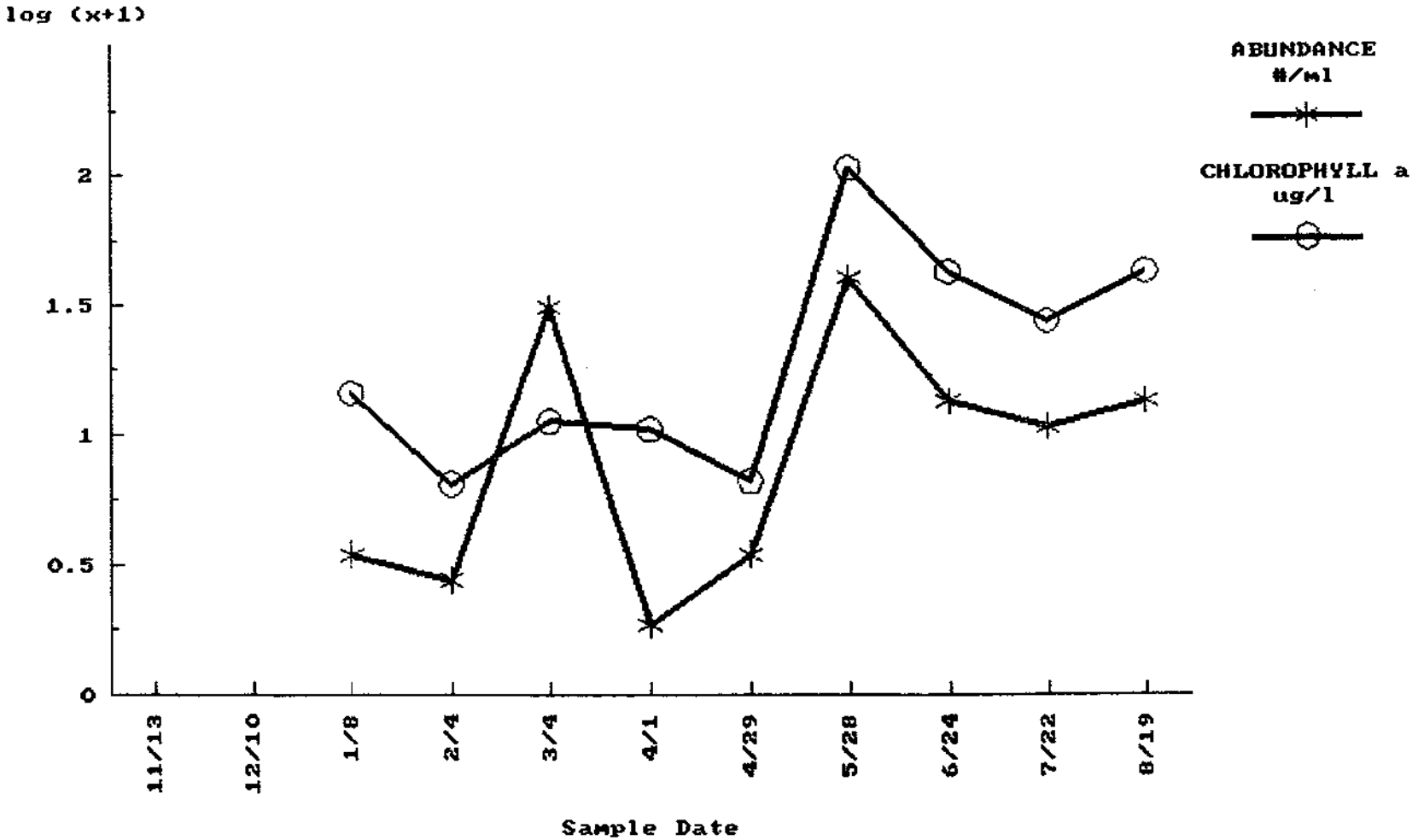


FIGURE 68. Phytoplankton log-transformed abundance and chlorophyll a, QUIN 3.

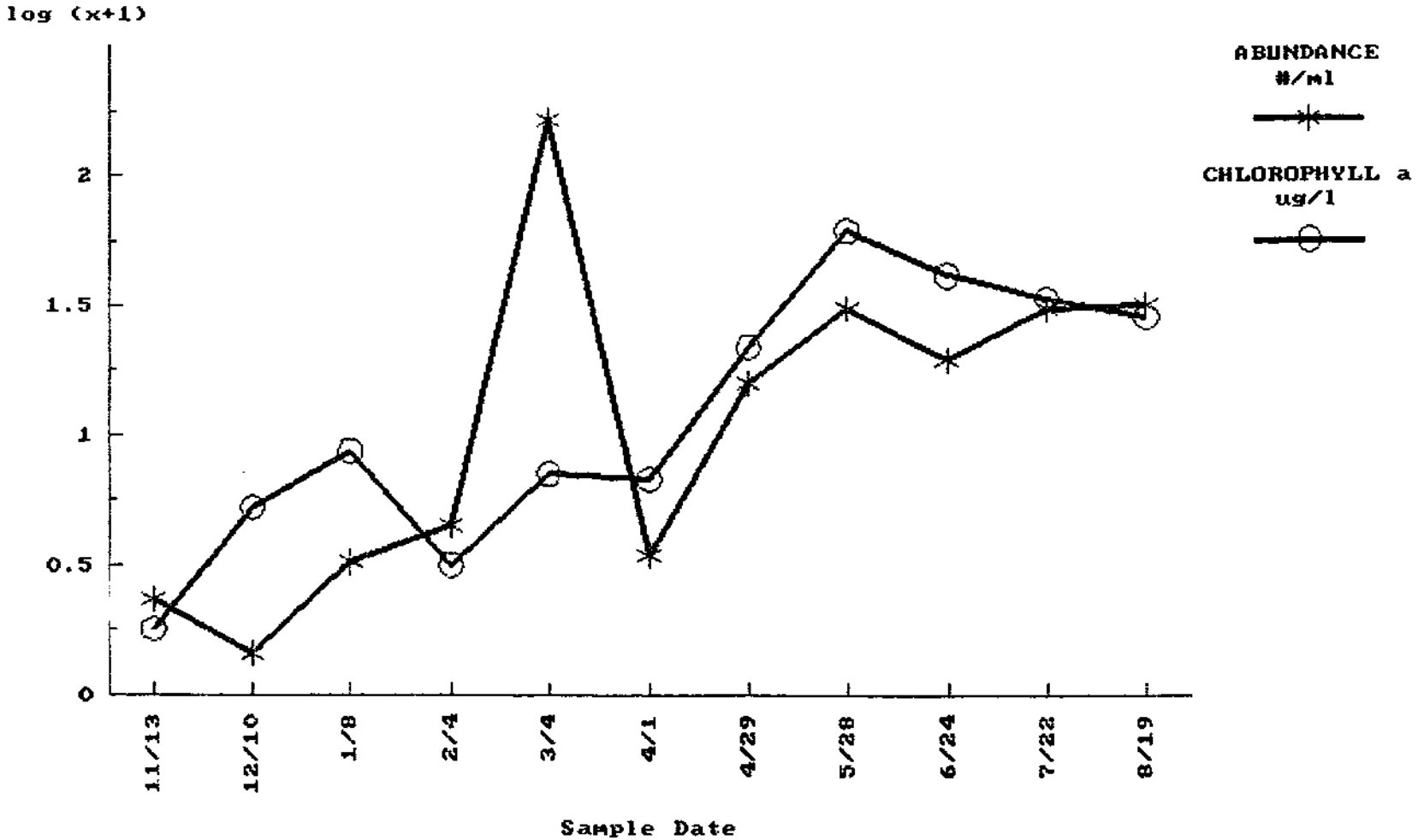


TABLE 35. Phytoplankton algae identified and number of occurrences at the QUIN site, November 1984 to August 1985.

	Number of Occurrences		
	QUIN 1	QUIN 2	QUIN 3
CYANOPHYTA			
Anabaena sp.	4	4	5
Aphanocapsa sp.	-	1	1
Aphanotheca sp.	1	-	3
Chroococcus sp.	-	-	1
Dactylococcopsis sp.	-	2	-
Lyngbya sp.	4	1	2
Merismopedium sp.	2	1	-
Oscillatoria sp.	5	1	2
Phormidium sp.	10	1	3
Plectonema sp.	3	-	-
Spirulina sp.	-	1	1
Unknown Cyanophyte sp.	5	2	4
CHLOROPHYTA			
Ankistrodesmus sp.	1	3	2
Arthrodesmus sp.	-	2	2
Carteria sp.	-	-	1
Cladophora sp.	-	-	1
Closterium sp.	3	2	4
Coelastrum sp.	1	-	-
Cosmarium sp.	2	2	2
Desmidium sp.	1	-	1
Dictyosphaerium sp.	1	4	2
Elakatothrix sp.	1	1	-
Eudorina sp.	-	2	2
Gloeocystis sp.	-	3	1
Gonium sp.	-	1	-
Gonatozygon sp.	-	-	1
Haematococcus sp.	-	-	1
Mougeotia sp.	1	1	4
Netrium sp.	1	-	-
Oedogonium sp.	2	-	-
Oocystis sp.	-	2	1
Pandorina sp.	-	1	-
Penium sp.	1	-	-
Pleurotaenium sp.	-	-	1
Rhizocolonium sp.	3	1	4
Scenedesmus sp	-	3	1
Staurastrum sp.	5	4	5
Stigeocolonium sp.	2	-	4
Tetraedron sp.	1	2	1
Ulothrix sp.	3	1	1

TABLE 35. Cont.

	Number of Occurrences		
	QUIN 1	QUIN 2	QUIN 3
Volvox sp.	1	3	2
Unknown Chlorophyte sp.	8	5	6
CHRYSOPHYTA			
Centritractus sp.	-	2	1
Dinobryon sp.	2	6	2
Mallomonas sp.	-	6	5
Tribonema sp.	-	-	1
Bacillariophyta			
Achnanthes sp.	2	-	4
Asterionella sp.	2	3	3
Cocconeis sp.	2	-	1
Cymbella sp.	2	-	-
Eunotia sp.	11	2	4
Fragilaria sp.	1	1	-
Frustulia sp.	6	1	-
Gomphonema sp.	2	3	-
Gyrosigma sp.	2	1	1
Melosira sp.	-	-	1
Navicula sp.	3	1	2
Nitzschia sp.	3	-	4
Pinnularia	4	-	2
Rhizosolenia sp.	1	2	2
Stauroneis sp.	1	-	-
Surirella sp.	2	1	1
Synedra sp.	6	5	6
Tabellaria sp.	10	1	1
Unknown Diatom sp.	9	4	7
EUGLENOPHYTA			
Euglena sp.	1	1	3
Phacus sp.	-	2	3
Trachelomonas sp.	3	2	4
Unknown Euglenophyte sp.	1	1	1
PYRRHOPHYTA			
Peridinium sp.	-	3	2
Unknown Pyrrhophyte sp.	-	-	1

bottle sample taken to measure chlorophyll *a*. Additionally, small flagellates which are present in the unpreserved chlorophyll *a* sample are often destroyed by fixation of the sample intended for enumeration (Semina 1978). Correlation coefficient (r^2) values resulting from linear regression were .416 ($p = .05$) and .462 ($p = .05$) for QUIN 1 and QUIN 2, respectively. The log-transformed abundance and chlorophyll *a* values measured over the sampling period are given in Figures 66 and 67.

The upstream and outfall stations were fairly similar with respect to mean number of taxa (13.5 and 12.2 at QUIN 1 and QUIN 3, respectively), though 17% more genera were identified at QUIN 3 (Table 33). These genera represented all algal divisions counted, but did not include the diatoms (Table 34). Mean $\bar{d}$, however, was decreased at QUIN 3 by 22%, and pooled $\bar{d}$ was 23% lower at the outfall. This reduced $\bar{d}$ can be partially explained by a bloom of the chlorophyte *Volvox* sp. in March. This one taxon represented 38% of the total individuals identified at this outfall station.

As was observed in the QUIN 1-QUIN 2 comparison, a substantial increase in the number and proportion of chlorophytes was observed, along with a corresponding decrease in the proportion of diatoms (Tables 33 and 34). Absolute diatom abundance, however, increased from 2.1/ml at QUIN 1 to 2.7/ml at QUIN 3. Although a greater change in abundance was observed (all divisions) between the upstream and outfall than between the upstream and pond stations, chlorophyll *a* values did not increase proportionately. This is illustrated in Figure 68; on the March 4th sampling date algal abundance at QUIN 3 peaked sharply, while the amplitude of the increase in chlorophyll *a* was much smaller. Though not as dramatic, a similar effect occurred in the same month at QUIN 2. Regression of chlorophyll *a* on abundance yielded an r^2 value of .292 ($p=.10$) for QUIN 3.

CRES Site

Fifty genera were identified at the CRES site, including 7 cyanophytes, 23 chlorophytes, 16 chrysophytes (13 bacillariophytes), 2 euglenophytes, and 2 pyrrhophytes (Table 38).

Little change was observed from upstream to pond in terms of total and mean number of taxa, or mean $\bar{d}$ (Table 36). Pooled $\bar{d}$, however, decreased at CRES 2 by 20%, from 4.0 to 3.2. Interestingly, four more genera of chlorophytes and four less of diatoms were identified at CRES 1; generally this trend is reversed in stream vs. pond comparisons.

Percent composition followed a different trend than was noted with number of taxa. An 80% decrease in the relative proportion of cyanophytes was observed from upstream to pond, as well as a 59% decrease in the proportion of diatoms (Table 37). The percent chlorophytes was largely unchanged, and a substantial increase in the proportion of chrysophytes was seen, from 0.6% at CRES 1 to 20.4% at CRES 2. *Dinobryon* sp., a widespread chrysophyte, accounted for 10.3% of the total. Populations of this genus were highest at CRES 2 in July.

TABLE 36. Temperature, number of taxa, Shannon-Weaver diversity index, abundance, and chlorophyll a values for upstream, pond, and outfall stations, CRES site, Novmeber 1984 to August 1985. Numbers in parentheses represent minimum and maximum values for the sample period.

	CRES 1	CRES 2	CRES 3
$\bar{x}$ Temp (°C) (range)	15.0 (8.5-22.0)	21.4 (14.0-29.0)	16.0 (8.0-26.0)
Total # taxa	30	31	33
$\bar{x}$ #taxa (range)	6.6 (1-12)	8.1 (4-11)	7.6 (3-11)
$\bar{x}$ $\bar{d}$ (range)	2.2 (0.0-3.3)	2.0 (0.7-3.0)	2.4 (1.2-3.2)
pooled $\bar{d}$	4.0	3.2	4.2
$\bar{x}$ abundance (#/ml) (range)	0.5 (0.04-0.9)	1.1 (0.2-2.6)	0.7 (0.1-1.1)
# Cyanophyta	0.1	0.02	0.2
# Chlorophyta	0.2	0.2	0.2
# Chrysophyta	0.004	0.4	0.04
# Bacillariophyta	0.2	0.1	0.3
# Pyrrhophyta	0.02	0.3	0.0
Chl-a (ug/l) (range)	0.4 (0.0-1.1)	10.2 (2.2-17.4)	1.3 (0.0-2.8)

TABLE 37. Numbers of phytoplankton taxa identified and average percent composition of selected major algal divisions, CRES site, November 1984 to August 1985. Numbers in parentheses represent minimum and maximum values for the sample period.

No. of Taxa	CRES 1	CRES 2	CRES 3
Cyanophyta	4	3	6
Chlorophyta	15	11	12
Chrysophyta	2	2	2
Bacillariophyta	7	11	12
Euglenophyta	0	2	1
Pyrrhophyta	2	2	0
% Composition			
Cyanophyta (range)	22.0 (0.0-81.5)	2.1 (0.0-11.6)	26.3 (0.0-63.6)
Chlorophyta (range)	30.4 (0.0-50.0)	25.5 (2.6-88.9)	29.4 (5.3-71.9)
Chrysophyta (range)	0.6 (0.0-3.6)	30.4 (0.0-78.6)	2.2 (0.0-12.1)
Bacillariophyta (range)	43.6 (3.7-100.0)	18.3 (0.0-41.9)	42.1 (9.4-94.7)
Pyrrhophyta (range)	3.3 (0.0-17.6)	23.6 (0.0-87.2)	0

FIGURE 69. Phytoplankton log-transformed abundance and chlorophyll a, CRES 1.

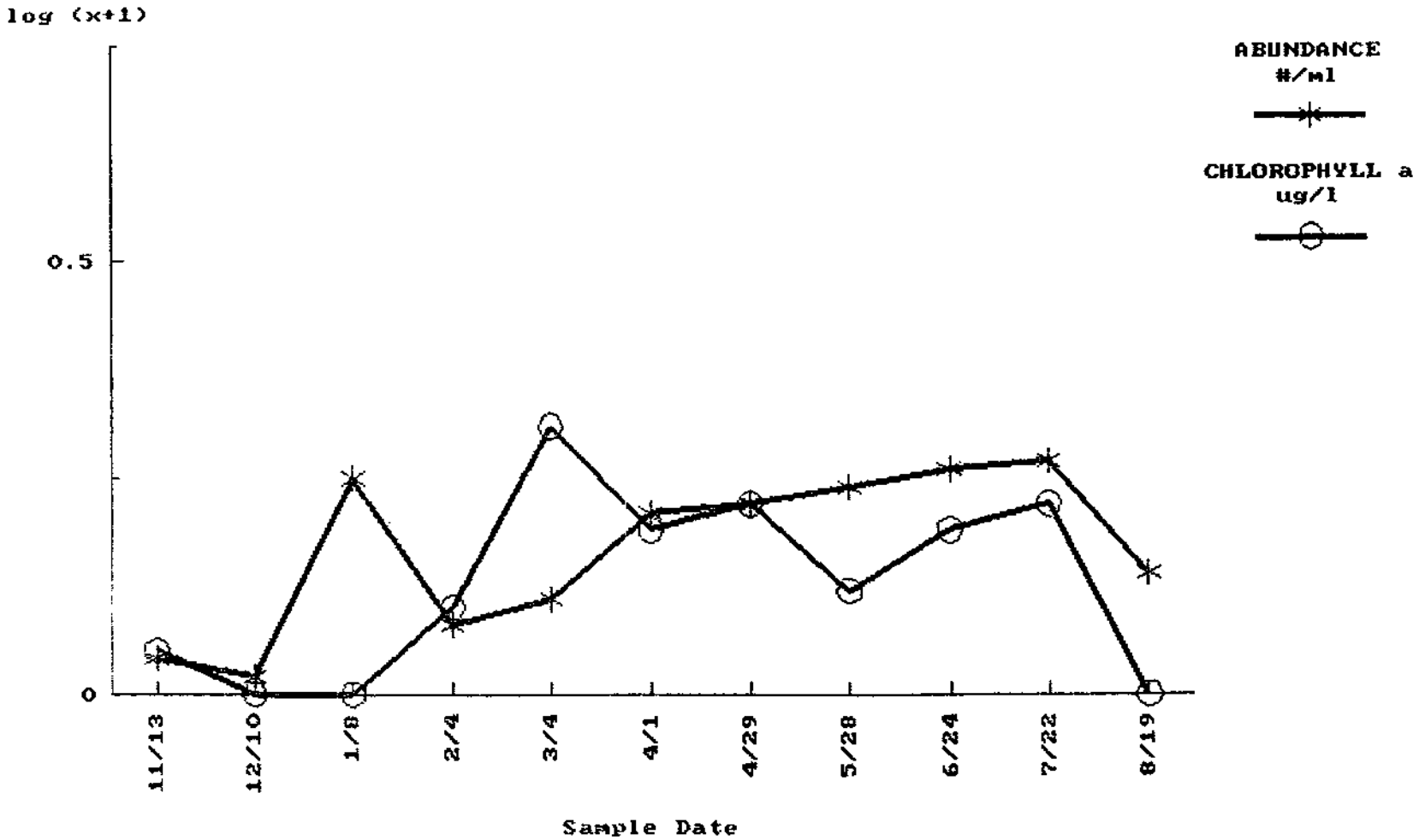


FIGURE 70. Phytoplankton log-transformed abundance and chlorophyll a, CRES 2.

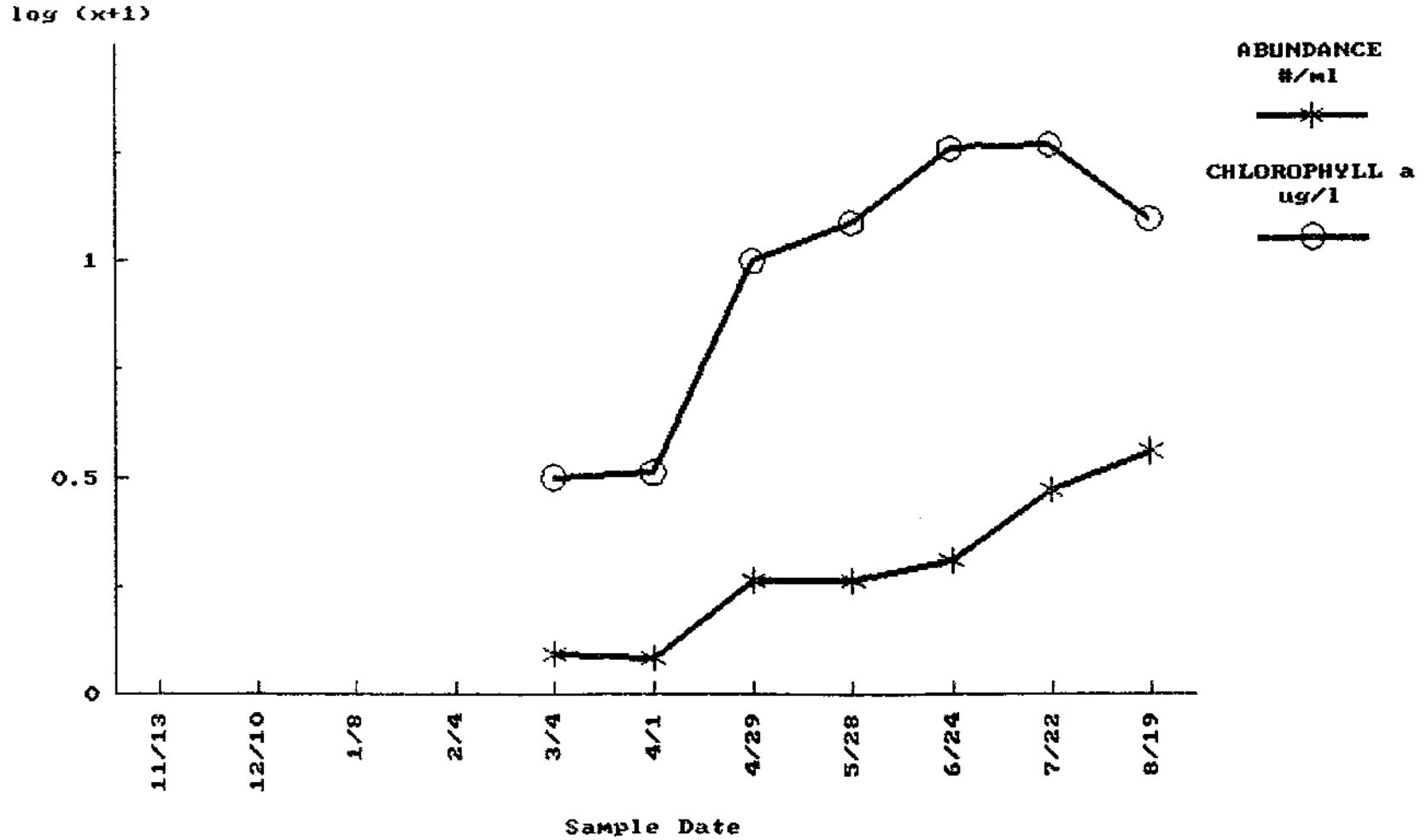


FIGURE 71. Phytoplankton log-transformed abundance and chlorophyll a, CRES 3.

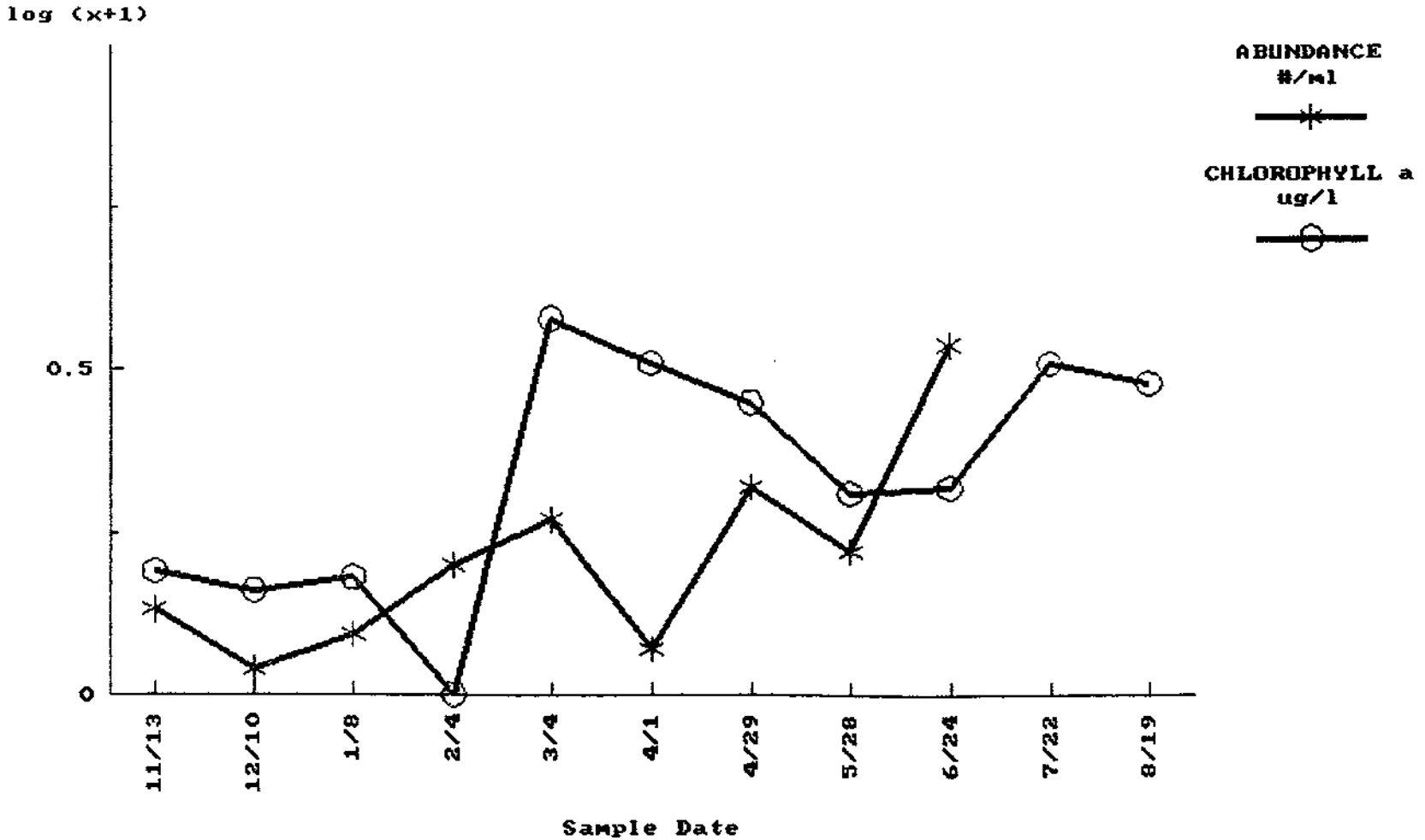


TABLE 38. Phytoplankton algae identified and number of occurrences at the CRES site, November 1984 to August 1985.

	Number of Occurrences		
	CRES 1	CRES 2	CRES 3
CYANOPHYTA			
Anabaena sp.	1	1	1
Aphanocapsa sp.	-	-	1
Chroococcus sp.	1	-	-
Dactylococcopsis sp.	-	-	1
Lyngbya sp.	3	-	5
Oscillatoria sp.	-	1	2
Phormidium sp.	-	-	3
Unknown Cyanophyte sp.	3	1	-
CHLOROPHYTA			
Ankistrodesmus sp.	-	1	1
Bambusina sp.	-	3	1
Botryococcus sp.	-	-	1
Bulbochaete sp.	-	1	-
Cladophora sp.	1	-	3
Closterium sp.	-	1	3
Cosmarium sp.	2	-	-
Dictyosphaerium sp.	1	-	-
Elakatothrix sp.	1	-	1
Gonatozygon sp.	1	-	-
Haematococcus sp.	-	1	-
Microspora sp.	1	-	-
Micrasterias sp.	-	1	-
Mougeotia sp.	8	6	5
Netrium sp.	1	-	-
Oedogonium sp.	2	1	1
Oocystis sp.	-	1	-
Rhizocolonium sp.	2	-	-
Spirogyra sp.	-	-	2
Staurastrum sp.	3	2	1
Stigeocolonium sp.	1	-	-
Tetraedron sp.	1	-	-
Ulothrix sp.	1	-	2
Unknown Chlorophyte sp.	7	2	4
CHRYSOPHYTA			
Centritractus sp.	1	-	-
Dinobryon sp.	1	6	1
Mallomonas sp.	-	1	1

Table 38. Cont.

	Number of Occurrences		
	CRES 1	CRES 3	CRES 3
Bacillariophyta			
Achnanthes sp.	-	1	1
Cocconeis sp.	1	2	1
Cymbella sp.	-	-	1
Eunotia sp.	7	3	3
Frustulia sp.	4	1	1
Gomphonema sp.	-	-	1
Melosira sp.	-	-	1
Navicula sp.	1	1	4
Neidium sp.	-	1	-
Nitzschia sp.	-	1	-
Pinnularia	2	3	2
Synedra sp.	-	1	1
Tabellaria sp.	2	2	2
Unknown Diatom sp.	10	4	9
EUGLENOPHYTA			
Euglena sp.	-	2	1
Phacus sp.	-	1	-
PYRRHOPHYTA			
Ceratium sp.	2	1	-
Peridinium sp.	1	3	-

The most obvious difference between these two stations was in algal abundance; although density was generally low throughout the sampling period, a 120% increase was observed at CRES 2, from 0.5/ml at CRES 1 to 1.1/ml at CRES 2 (Table 36). Biomass (chlorophyll *a*) and abundance were not significantly correlated at CRES 1 but were well correlated at CRES 2, with an r^2 of .580 ($p = .05$). As was noted in the QUIN discussion, the exclusion of nanoplankton could partially explain the discrepancies observed between chlorophyll *a* and abundance (Figures 69 and 70).

Stations CRES 1 and CRES 3 were observed to be very similar in terms of total number of taxa, mean number of taxa, and $\bar{d}$ (Table 36). These parameters were higher at the outfall station, though not significantly. The greatest difference in taxa was in the number of diatoms identified: Five more genera were detected at CRES 3 (Tables 37 and 38). Of these five genera, several species of Gomphonema, Melosira, and Synedra are typical of eutrophic conditions (Lowe 1974). Although more diatom genera were found at the outfall station, the relative proportions were essentially the same, 43.6% at CRES 1 and 42.1% at CRES 3 (Table 37). Percent compositions of the other algal divisions were also quite similar, except for cyanophytes, which were 20% higher at CRES 3.

Mean chlorophyll *a* and abundance were higher at CRES 3, although the percent increases were not proportional (abundance was 40% higher and chlorophyll *a* was 225% higher at the outfall) (Table 36). Abundance and chlorophyll *a* values are depicted in Figures 69 and 71; these measurements were not significantly correlated at either station.

MOSS Site

A total of 85 genera were identified at the MOSS site over the sampling period, including 11 cyanophytes, 46 chlorophytes, 23 chrysophytes (17 from the Bacillariophyta), 2 euglenophytes, 2 pyrrhophytes, and 1 rhodophyte (Table 41).

In comparing the upstream and first pond stations at the MOSS site, a small increase in total and mean number of taxa was observed at MOSS 2, 12% and 22%, respectively. Mean $\bar{d}$, however, was essentially the same, 3.1 at MOSS 1 and 3.0 at MOSS 2 and pooled $\bar{d}$ was only 7% lower at the pond station (Table 39). The greatest difference in the number of taxa was in the number of chlorophytes identified; six more genera were found at MOSS 2, or a 75% increase (Table 40). A closer look at the chlorophyte community reveals some interesting aspects. Although fewer genera, a smaller proportion (36.2% at MOSS 1 and 50% at MOSS 2), and lower abundance of chlorophytes were observed at MOSS 1, the correlation of algal abundance and chlorophyll *a* was much stronger than that at Station MOSS 2. Linear regression of chlorophyll *a* on abundance (Figures 72 and 73) yielded r^2 values of .512 ($p = .02$) and .167 (NS) at MOSS 1 and MOSS 2, respectively. Of the ten genera that were detected at MOSS 1 but not at MOSS 2, eight were filamentous forms, the most common being Ulothrix sp., Oedogonium sp., Spirogyra sp., and Bulbochaete sp. (Table 41). Perhaps the greater amount of biomass and thus chlorophyll *a* present in these algal forms was partially responsible for the stronger correlation.

TABLE 39. Temperature, number of taxa, Shannon-Weaver diversity index, abundance, and chlorophyll a values for upstream, pond, and outfall station, MOSS site, November 1984 to August 1985. Numbers in parentheses represent minimum and maximum values for the sample period.

	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
$\bar{x}$ Temp (°C) (range)	16.5 (4.2-24.0)	19.3 (11.0-29.2)	19.6 (10.0-29.9)	17.6 (12.0-23.0)	16.1 (9.0-24.0)
Total # taxa	51	57	51	61	46
$\bar{x}$ #taxa (range)	13.9 (4-20)	17.0 (9-24)	15.1 (11-19)	21.3 (16-27)	10.4 (3-15)
$\bar{x}$ $\bar{d}$ (range)	3.1 (1.8-3.9)	3.0 (2.4-4.1)	3.0 (2.4-3.6)	3.5 (3.3-3.8)	2.9 (1.4-3.5)
Pooled $\bar{d}$	4.4	4.1	3.9	4.3	4.4
$\bar{x}$ abundance (#/ml) (range)	2.3 (0.1-6.0)	2.9 (1.1-4.4)	3.7 (1.0-10.1)	8.5 (2.6-16.0)	0.7 (0.3-1.5)
# Cyanophyta	0.1	0.2	0.3	0.6	0.03
# Chlorophyta	0.8	1.4	1.9	4.5	0.2
# Chrysophyta	0.2	0.5	0.6	1.0	0.1
# Bacillariophyta	1.2	0.3	0.5	1.6	0.3
# Pyrrhophyta	0.03	0.4	0.3	0.8	0.05
Chl-a (ug/l) (range)	1.2 (0.0-6.3)	5.6 (2.4-15.7)	7.7 (3.3-13.6)	7.8 (3.6-12.0)	0.3 (0.0-0.8)

TABLE 40. Numbers of phytoplankton taxa identified and average percent composition of selected major algal division, MOSS site, November 1984 to August 1985. Numbers in parentheses represent minimum and maximum values for the sample period.

No. of Taxa	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
Cyanophyta	9	8	10	10	8
Chlorophyta	22	28	27	30	19
Chrysophyta	3	5	3	3	3
Bacillariophyta	13	10	7	13	12
Euglenophyta	1	3	2	2	1
Pyrrhophyta	2	3	2	3	3
Rhodophyta	1	0	0	0	0
% Composition					
Cyanophyta (range)	8.7 (0.0-24.1)	7.7 (0.0-24.5)	9.9 (0.0-41.8)	10.4 (0.6-43.5)	6.7 (0.0-40.0)
Chlorophyta (range)	36.2 (13.5-55.6)	50.0 (21.2-74.6)	50.2 (25.2-74.7)	46.2 (24.6-84.4)	35.0 (15.0-63.6)
Chrysophyta (range)	7.1 (0.0-55.4)	20.5 (1.7-52.9)	15.7 (2.0-38.9)	11.7 (0.6-41.5)	10.2 (0.0-45.9)
Bacillariophyta (range)	46.7 (26.6-71.7)	10.0 (3.1-22.3)	15.1 (2.0-37.8)	24.0 (10.6-45.7)	43.1 (26.2-71.1)
Pyrrhophyta (range)	1.2 (0.0-6.8)	11.9 (2.7-37.7)	9.2 (0.0-34.8)	7.9 (1.4-28.0)	5.0 (0.0-16.0)

FIGURE 72. Phytoplankton log-transformed abundance and chlorophyll a, MOSS 1.

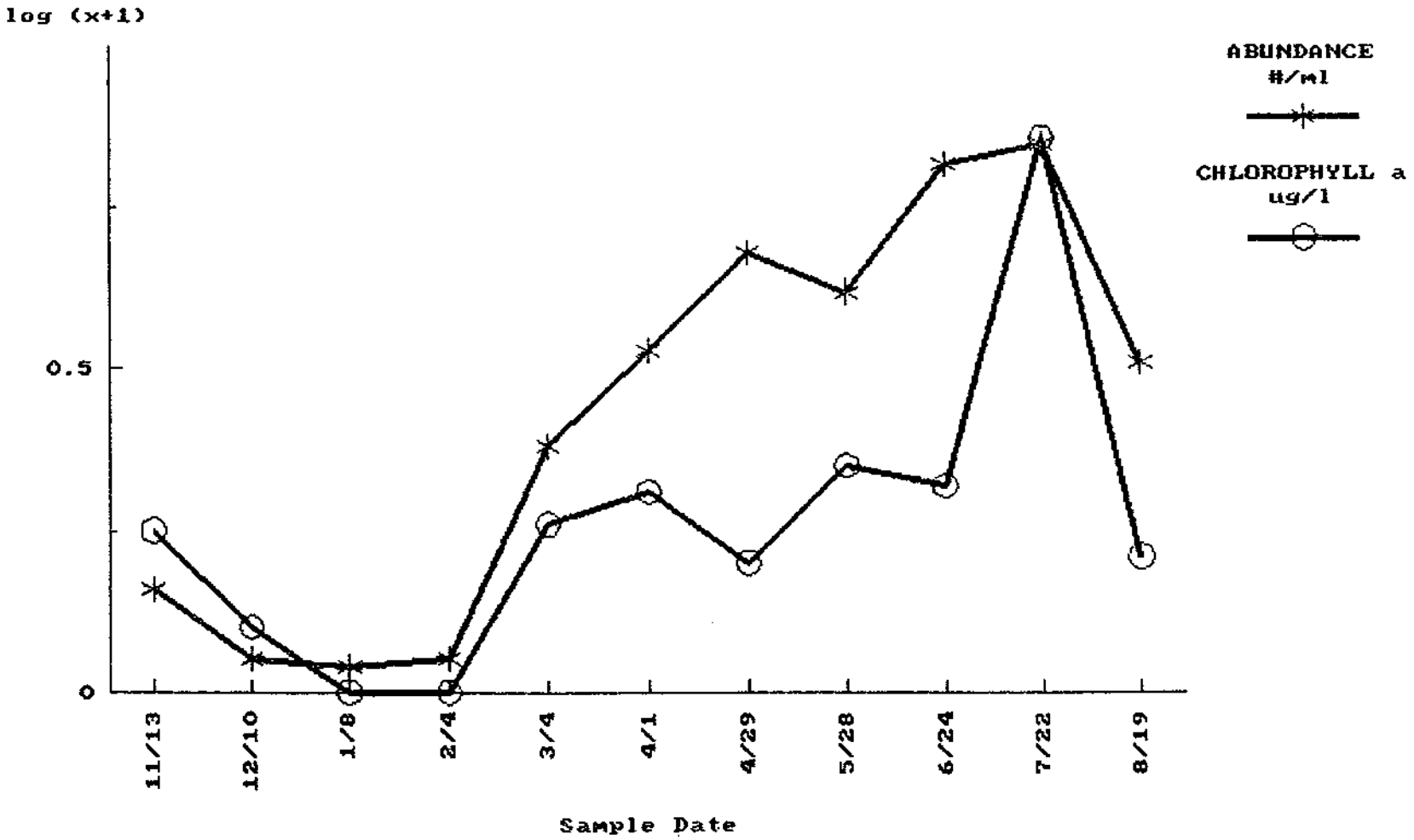
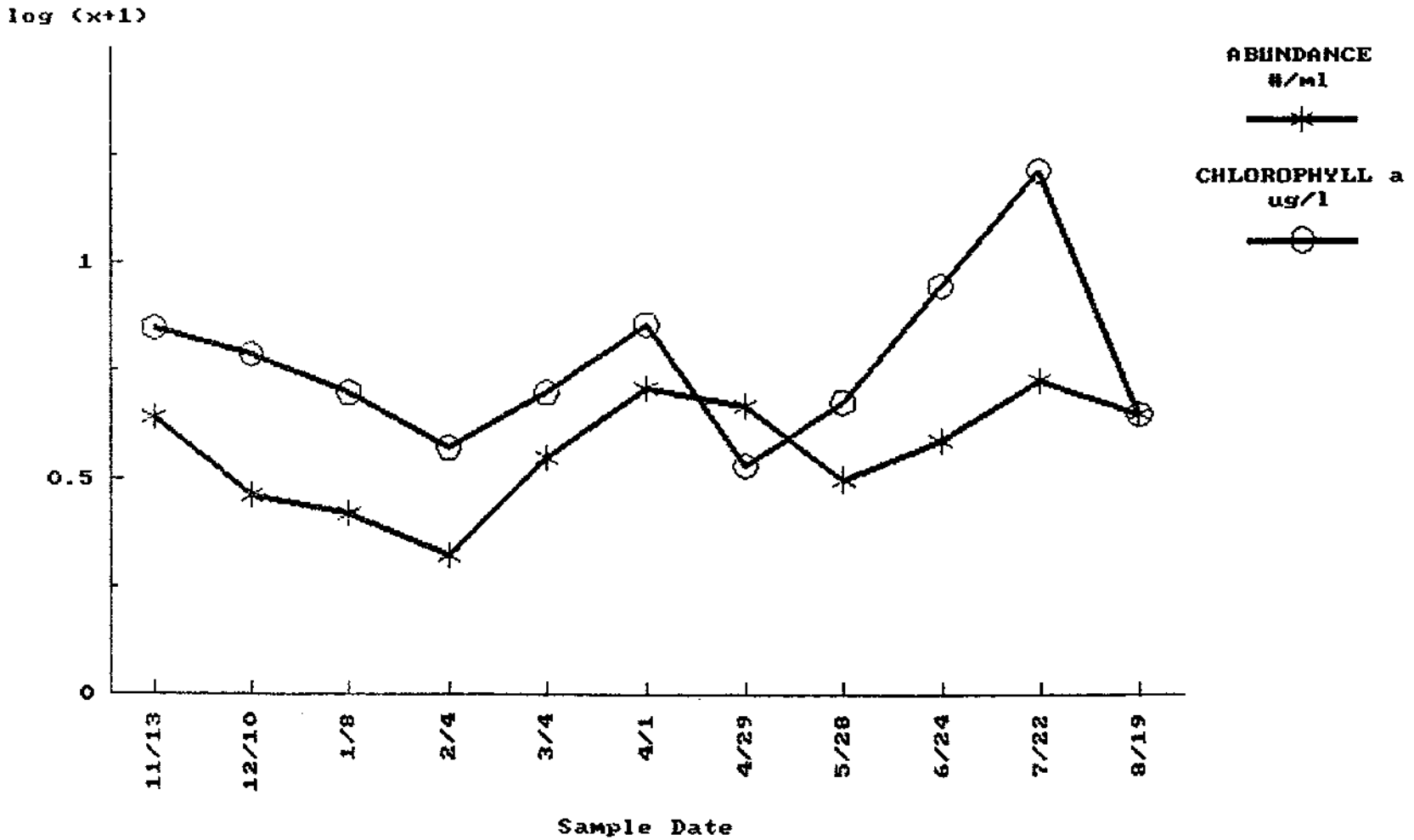


FIGURE 73. Phytoplankton log-transformed abundance and chlorophyll a, MOSS 2.



Another change observed from upstream to pond at this site was the differing proportions of chrysophytes and diatoms. The proportion of chrysophytes was 189% greater at MOSS 2; this is likely due to the population of Dinobryon sp., which made up nearly 6% of the total. The proportion of diatoms was greater at MOSS 1, representing 46.7% of the total, while this division constituted only 10% at the pond station. Eunotia sp., Tabellaria sp., and an unknown diatom made up 7.1%, 4.5% and 7.1% of the phytoplankton population at MOSS 1, respectively.

Stations MOSS 1 and MOSS 3 compare in much the same fashion as MOSS 1 and MOSS 2. Total number of taxa was exactly the same at each station, and mean number of taxa was only 8.6% higher at the pond station. Differences in number of taxa by division occurred chiefly in the chlorophyta and diatoms. Five more genera of green algae were identified at MOSS 3 and six more bacillariophytes at MOSS 1.

Relative proportions of these two algal divisions coincide with the number of taxa (Table 40). The percent composition of chlorophytes increased from 36.2% at MOSS 1 to 50.2% at MOSS 3, or 39%. The decrease in the proportion of diatoms from MOSS 1 to MOSS 3 was 68%, from 46.7% to 15.1%. As was observed in the previous comparison, the proportion of chrysophytes was larger at the pond station; this was also due to the Dinobryon population, which represented 7.4% of the phytoplankton population at MOSS 3.

The difference in algal abundance was 61%, from 2.3/ml at MOSS 1 to 3.7/ml at MOSS 3. Chlorophyll a increased at the pond by 542%, and regression of chlorophyll a on abundance yielded an r^2 of .373 ($p = .05$). As was discussed in the MOSS 1-MOSS 2 comparison, the chlorophyll a content of the "higher-biomass" filamentous forms at the upstream station may account for the higher correlation of chlorophyll a and abundance observed at MOSS 1.

Total number of taxa increased by 20% from upstream to outfall, and mean number of taxa increased from 13.9 at MOSS 1 to 21.3 a MOSS 4, or 53% (Table 39). Mean $\bar{d}$ values were correspondingly higher at MOSS 4, increasing from 3.1 to 3.5, or 13%, though pooled $\bar{d}$ was largely unchanged. The major division responsible for differences in number of taxa was the chlorophyta; eight more genera were identified at Station MOSS 4 (Table 40). Percent composition of green algae was 2.8% higher at MOSS 4, and the most dominant genus at this outfall station was Staurastrum sp., representing 10.6% of the total. The second most dominant taxon at MOSS 4 was the chrysophyte Dinobryon sp., which accounted for an additional 5.8%.

A similar trend was apparent in percent composition to that observed with the upstream pond comparisons, though the extent of change was not as great. The proportion of chlorophytes increased from 36.2% to 46.2% from upstream to outfall, and that of diatoms decreased from 46.7% to 24% (Table 40). Of the diatoms found at MOSS 4 but not at MOSS 1, the genera Asterionella and Fragilaria contain members which are typical of eutrophic conditions.

FIGURE 74. Phytoplankton log-transformed abundance and chlorophyll a, MOSS 3.

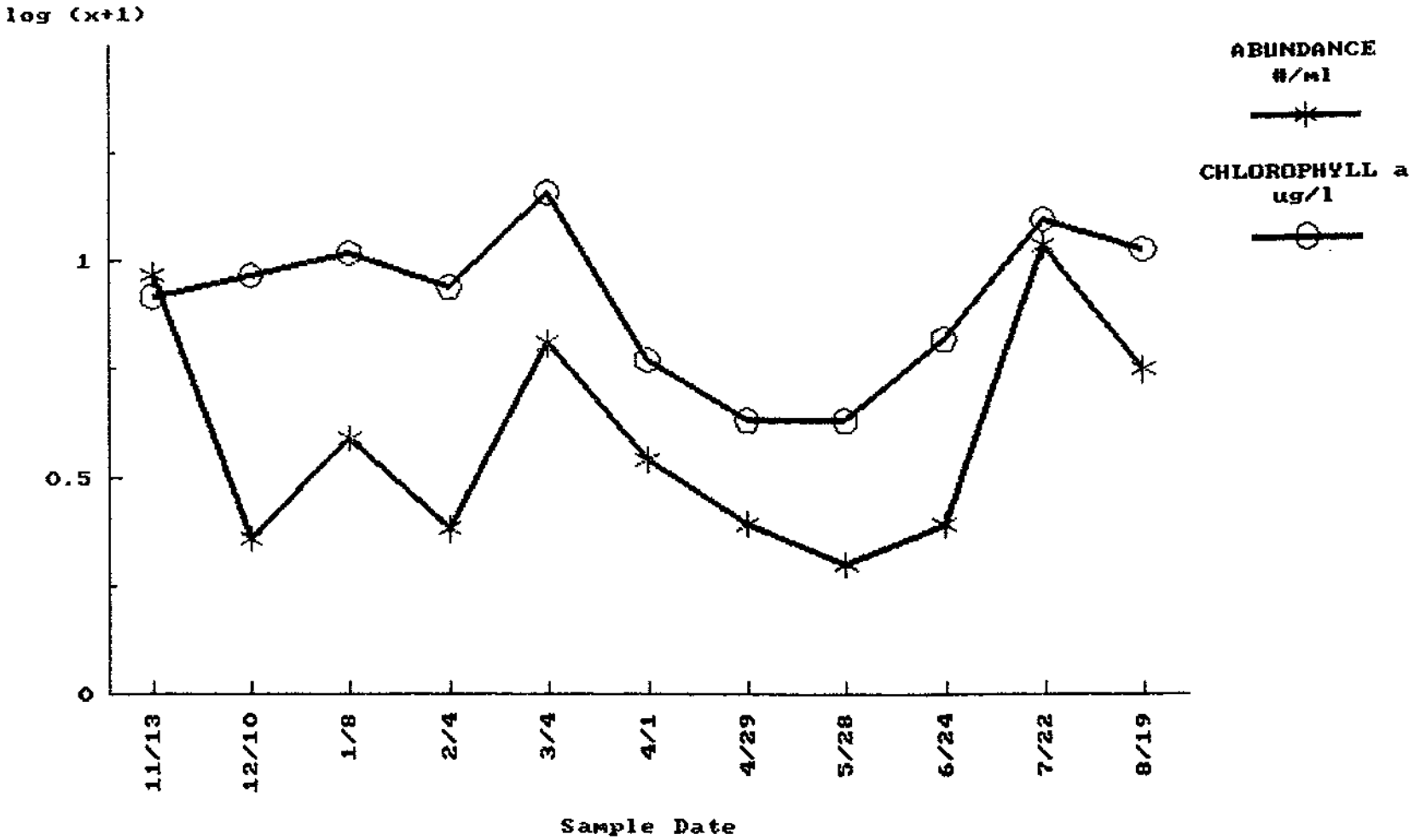
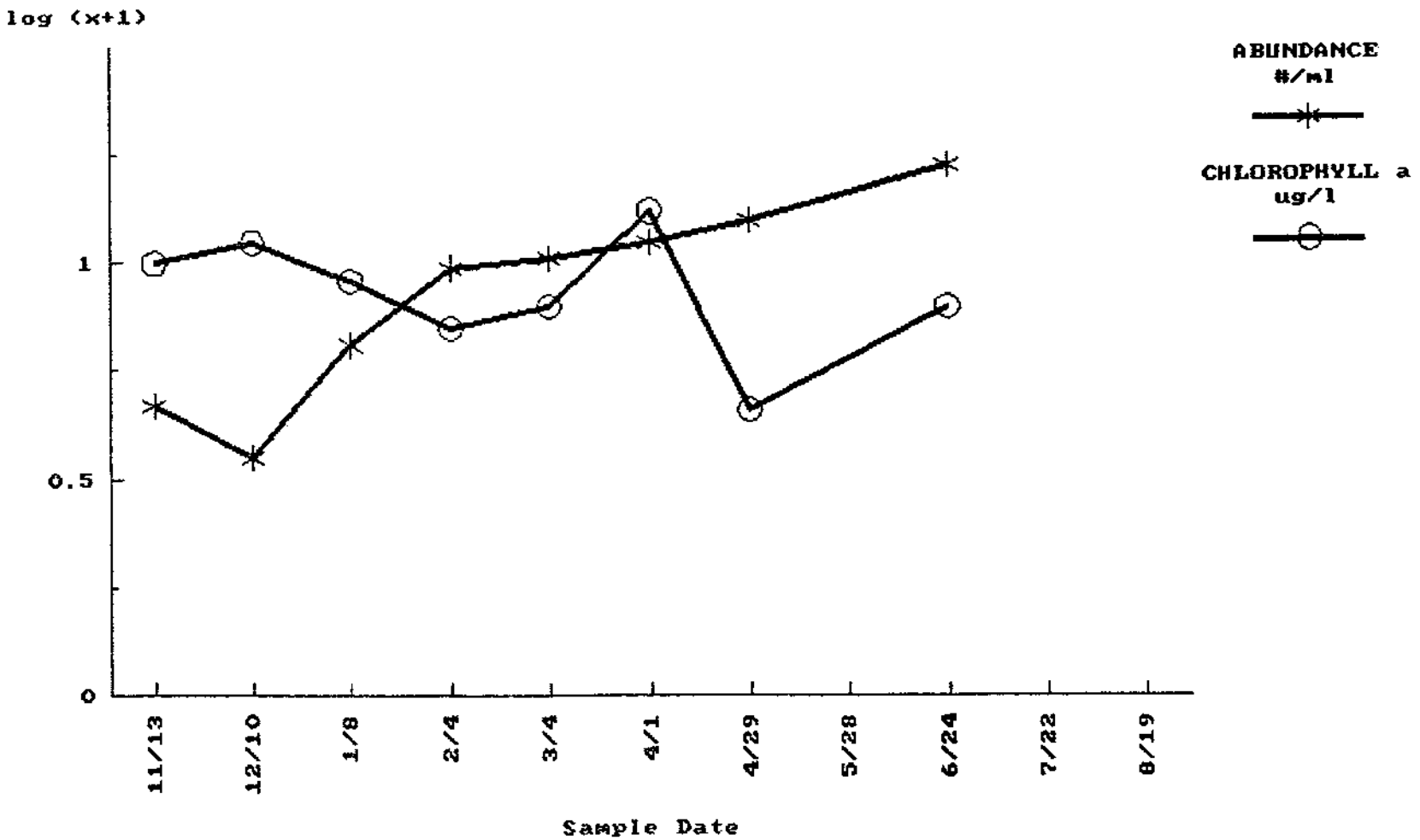


FIGURE 75. Phytoplankton log-transformed abundance and chlorophyll a, MOSS 4.



Mean abundance and chlorophyll a at MOSS 4 was considerably higher than that of MOSS 1, increasing by 270% and 550%, respectively. Correlation on a month-to-month basis of these measurements at MOSS 4 was nonsignificant. Figure 75 illustrates the lack of correspondence observed for these parameters at the MOSS outfall.

Because these two pond stations are discussed separately in prior sections, a brief mention of relevant similarities and differences will be presented here. Stations MOSS 2 and MOSS 3 were very similar in most all of the parameters examined; differences in total and mean number of taxa were both approximately 11%, with MOSS 3 being lower. Although the range was greater at MOSS 2, average $\bar{d}$ was 3.0 for both stations, and pooled $\bar{d}$ was 4.1 and 3.9 at MOSS 2 and MOSS 3, respectively (Table 39). Abundance was greater at MOSS 3 by 28%, and chlorophyll a by 38%, but these differences are very small compared to those observed at other stations, and are probably due to normal environmental or sampling variation.

Percent composition of the different algal divisions was very similar; the greatest difference was in the proportion of diatoms, which was 51% higher at MOSS 3 (Table 40). The same two genera were most dominant at both stations; the chlorophyte Staurastrum represented 6.3% and 6.9% of the total at MOSS 2 and MOSS 3, respectively, while the chrysophyte Dinobryon represented 5.8% at MOSS 2 and 7.4% at MOSS 4. Arthrodesmus sp., a chlorophyte which accounted for 6.9% at MOSS 3, was not found in appreciable quantity at MOSS 2.

Correlation of chlorophyll a and algal abundance was not significant at MOSS 2, but was significant at the .05 level at MOSS 3 (r^2 = .373). The lack of correlation of these parameters at MOSS 2 could be related to a high population of nanoplankton which were not counted in the abundance measurement. Additionally, on April 29 and July 22, the chlorophyll a and abundance were widely divergent (Figure 73). This would indicate that the variation in chlorophyll a cannot be explained by the change in abundance at MOSS 2.

Station MOSS 5, an unconnected stream very near the other MOSS stations, was included in our study to compare with MOSS 1 as a parallel control. These two stations were most different in abundance and chlorophyll a; abundance was 70% lower at MOSS 5 and mean chlorophyll a was lower by 75%. The abundances of nearly all algal divisions were correspondingly lower at MOSS 5 (Table 39). Total and mean number of taxa were also lower at MOSS 5 than at MOSS 1. Total number of taxa decreased from 51 to 46, or 10%, and mean number of taxa was 25% below that noted at MOSS 1.

Several other measurements were very similar. Average $\bar{d}$ was 3.1 and 2.9 for MOSS 1 and MOSS 5, respectively and pooled $\bar{d}$ was exactly the same (Table 39). Relative proportions of the different algal divisions were almost identical, particularly the Chlorophyta and Bacillariophyta (Table 40). Of particular interest is the range of the percent composition of diatoms, 26.6 to 71.7 at MOSS 1 and 26.2 and 71.1 at MOSS 5.

FIGURE 78. Phytoplankton log-transformed abundance and chlorophyll a, MOSS 5.

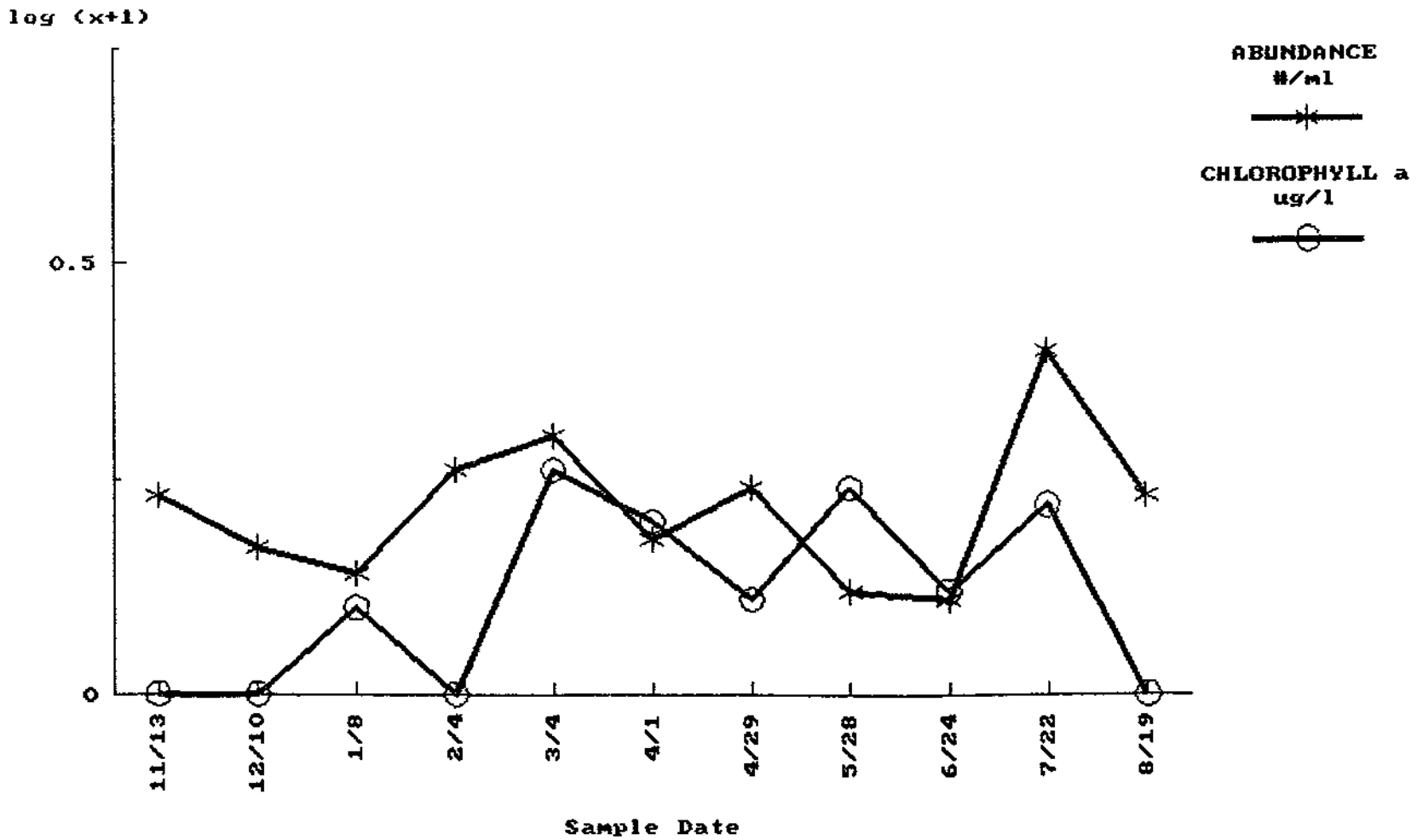


TABLE 41. Phytoplankton algae identified and number of occurrences at the MOSS site, Novmeber 1984 to August 1985.

	Number of Occurrences				
	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
CYANOPHYTA					
Anabaena sp.	3	3	2	2	1
Aphanocapsa sp.	2	1	1	1	1
Aphanotheca sp.	5	3	2	1	2
Chroococcus sp.	-	3	4	3	-
Gloeocapsa sp.	-	1	1	-	1
Lyngbya sp.	2	-	1	2	1
Merismopedium sp.	1	6	6	4	1
Oscillatoria sp.	2	1	1	1	-
Phormidium sp.	2	-	2	2	-
Plectonema sp.	1	-	-	-	-
Spirulina sp.	-	-	1	1	1
Unknown Cyanophyte sp.	3	1	-	1	3
CHLOROPHYTA					
Actinastrum sp.	-	-	-	1	-
Ankistrodesmus sp.	-	-	4	2	-
Arthrodesmus sp.	1	5	7	6	5
Bambusina sp.	-	1	-	-	-
Botryococcus sp.	-	-	1	-	-
Bulbochaete sp.	3	-	-	1	2
Characium sp.	-	-	1	-	-
Cladophora sp.	2	-	-	-	1
Closterium sp.	5	5	9	6	4
Coelastrum sp.	-	1	1	-	-
Cosmarium sp.	1	3	2	3	-
Crucigenia sp.	-	-	-	1	-
Cylindrocapsa sp.	2	-	-	-	1
Desmidium sp.	3	7	4	6	1
Dictyosphaerium sp.	-	1	2	1	-
Elakatothrix sp.	-	9	4	3	-
Euastrum sp.	-	2	1	1	1
Eudorina sp.	1	2	1	2	-
Gloeocystis sp.	1	2	1	-	-
Gonatozygon sp.	2	2	1	1	-
Gonium sp.	-	1	-	-	-
Groenbladia sp.	-	1	-	-	1
Hyalotheca sp.	1	-	-	1	-
Kirchneriella sp.	-	-	2	1	-
Micrasterias sp.	2	3	2	3	1

TABLE 41. Cont.

	Number of Occurrences				
	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
Microspora sp.	-	-	-	1	-
Mougeotia sp.	8	3	3	8	8
Netrium sp.	3	-	-	1	1
Oedogonium sp.	4	-	3	1	5
Onychonema sp.	-	-	1	-	-
Oocystis sp.	-	3	4	2	2
Pediastrum sp.	-	3	3	2	1
Penium sp.	2	-	-	-	-
Pleurotaenium sp.	-	3	-	-	1
Quadrigula sp.	-	1	-	-	-
Rhizocolonium sp.	1	-	-	-	-
Scenedesmus sp.	-	1	2	3	-
Sphaerocystis sp.	-	2	-	-	-
Spirogyra sp.	4	-	-	6	1
Spondylosium sp.	-	-	-	1	-
Staurastrum sp.	6	11	11	8	8
Tetraedron sp.	-	3	1	2	-
Ulothrix sp.	6	-	1	3	-
Volvox sp.	1	2	-	-	-
Xanthidium sp.	-	8	4	5	1
Zygnema sp.	-	1	-	-	-
Unknown Chlorophyte sp.	4	8	6	6	4
CHRYSOPHYTA					
Chlorobotrys sp.	-	1	-	1	-
Dinobryon sp.	5	11	10	8	6
Mallomonas sp.	3	2	3	-	1
Peroniella sp.	-	-	-	1	-
Synura sp.	-	3	1	-	1
Uroglenopsis sp.	-	1	-	-	-
Unknown Chrysophyte sp.	1	-	-	-	-
Bacillariophyta					
Achnanthes sp.	1	-	-	1	1
Asterionella sp.	-	2	-	1	1
Cocconeis sp.	1	-	1	-	3
Cymbella sp.	2	-	-	2	-
Eunotia sp.	10	6	2	5	7
Fragilaria sp.	-	-	-	1	-

TABLE 41. Cont.

	Number of Occurrences				
	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
Frustulia sp.	5	3	-	1	-
Gomphonema sp.	2	-	-	-	-
Gyrosigma sp.	-	-	-	1	1
Melosira sp.	2	-	-	1	1
Navicula sp.	4	3	2	2	3
Neidium sp.	1	-	-	-	-
Pinnularia sp.	1	1	-	3	1
Rhizosolenia sp.	-	1	2	-	1
Stauroneis sp.	-	1	-	-	-
Synedra sp.	4	5	8	8	7
Tabellaria sp.	7	6	8	8	5
Unknown Diatom sp.	11	7	9	6	7
EUGLENOPHYTA					
Euglena sp.	1	3	2	1	-
Trachelomonas sp.	-	1	1	1	1
Unknown Euglenophyte sp.	-	1	-	-	-
PYRRHOPHYTA					
Ceratium sp.	2	10	9	7	4
Peridinium sp.	2	4	5	4	3
Unknown Pyrrhophyte sp.	-	2	-	1	1
RHODOPHYTA					
Batrachospermum sp.	4	-	-	-	-

No correlation between chlorophyll a and abundance was noted at Station MOSS 5 (Figure 76). Month-to-month measurements of these two parameters often varied in opposite directions. It is not clear whether this lack of correlation is due to the exclusion of nanoplankton, changes in species composition, or differences in flow and light regimes.

GADS Site

Forty-two genera were identified at the GADS Site: 6 cyanophytes, 17 chlorophytes, 15 chrysophytes (13 bacillariophytes), 3 euglenophytes and 1 pyrrhophyte (Table 44). As was discussed in the periphyton section, this site was under construction during most of the sampling period. It is likely that the stress of environmental perturbation imposed on both upstream and outfall stations was largely responsible for the small number of taxa found at these stations, as well as the generally low algal abundance.

Total number of taxa increased from 28 at GADS 1 to 33 at GADS 3, or 18%. The reduction in mean number of taxa from GADS 1 to GADS 3 was only 7%, but measurements were very low at both stations (6.1 and 6.5 at GADS 1 and GADS 3, respectively). The greatest change in number of taxa was with blue-green algae; three more cyanophytes were detected at GADS 3 (Table 43).

Percent composition was highly variable throughout the sampling period. For example, not every algal division was represented on each of the sampling dates at each station. Averages, however, were relatively similar, though 5% more cyanophytes were found at GADS 3. The reduction in the proportions of chlorophytes and diatoms was similar, 19% and 24%, respectively.

Although algal abundance was very similar at both stations (0.8/ml and 0.7/ml at GADS 1 and GADS 3, respectively), chlorophyll a was 82% higher at GADS 3 (Table 42). Linear regression of chlorophyll a on algal density resulted in low correlations for both stations, with r^2 values of 0.273 and 0.136 for GADS 1 and GADS 3, respectively. Monthly variation in chlorophyll a and abundance is shown in Figures 77 and 78.

Because of the environmental stresses at this site over the sampling period, it is difficult to delineate any trends or draw any conclusions about the impact of impoundment on the phytoplankton population.

Cluster/Discriminant Analyses

Numerical classification (normal cluster analysis) of phytoplankton data from the FREQUENCY stations indicated the presence of two station groups (Figure 79). Group I comprises the upstream stations CRES 1, QUIN 1, and GADS 1, and the outfall stations CRES 3 and GADS 3. Group II contains all of the pond stations (QUIN 2, MOSS 2, MOSS 3, CRES 2), as well as the outfall station QUIN 3, the upstream MOSS 1, and the parallel control from the MOSS site, MOSS 5.

TABLE 42. Temperature, number of taxa, Shannon-Weaver diversity index, abundance, and chlorophyll a values for upstream and outfall stations, GADS site, November 1984 to August 1985. Numbers in parentheses represent minimum and maximum values for the sample period.

	GADS 1	GADS 3
$\bar{x}$ Temp (°C) (range)	18.4 (10.6-25.0)	18.7 (10.3-26.5)
Total # taxa	28	33
$\bar{x}$ #taxa (range)	6.1 (5-9)	6.5 (1-16)
$\bar{x}$ $\bar{d}$ (range)	2.2 (1.4-2.6)	1.9 (0.0-3.2)
pooled $\bar{d}$	4.1	3.8
$\bar{x}$ abundance (#/ml) (range)	0.8 (0.2-2.2)	0.7 (0.1-2.1)
# Cyanophyta	0.3	0.1
# Chlorophyta	0.3	0.1
# Chrysophyta	0.002	0.01
# Bacillariophyta	0.3	0.3
# Pyrrhophyta	0	0.002
Chl-a (ug/l (range)	1.7 (0.0-4.4)	3.1 (0.5-5.0)

TABLE 43. Number of phytoplankton and percent composition of selected major algal division, CRES site, November 1984 to August 1985. Numbers in parentheses represent minimum and maximum values for the sample period.

No. of Taxa	GADS 1	GADS 3
Cyanophyta	4	7
Chlorophyta	11	12
Chrysophyta	1	1
Bacillariophyta	11	9
Euglenophyta	1	3
Pyrrhophyta	0	1
% Composition		
Cyanophyta (range)	29.1 (0.0-77.4)	44.1 (0.0-98.7)
Chlorophyta (range)	36.2 (0.0-84.6)	29.4 (0.0-100)
Chrysophyta (range)	1.2 (0.0-11.1)	0.7 (0.0-7.3)
Bacillariophyta (range)	33.5 (0.0-66.7)	25.6 (0.0-58.2)
Pyrrhophyta (range)	0	0.2 (0.0-1.8)

FIGURE 78. Phytoplankton log-transformed abundance and chlorophyll a, GADS 3.

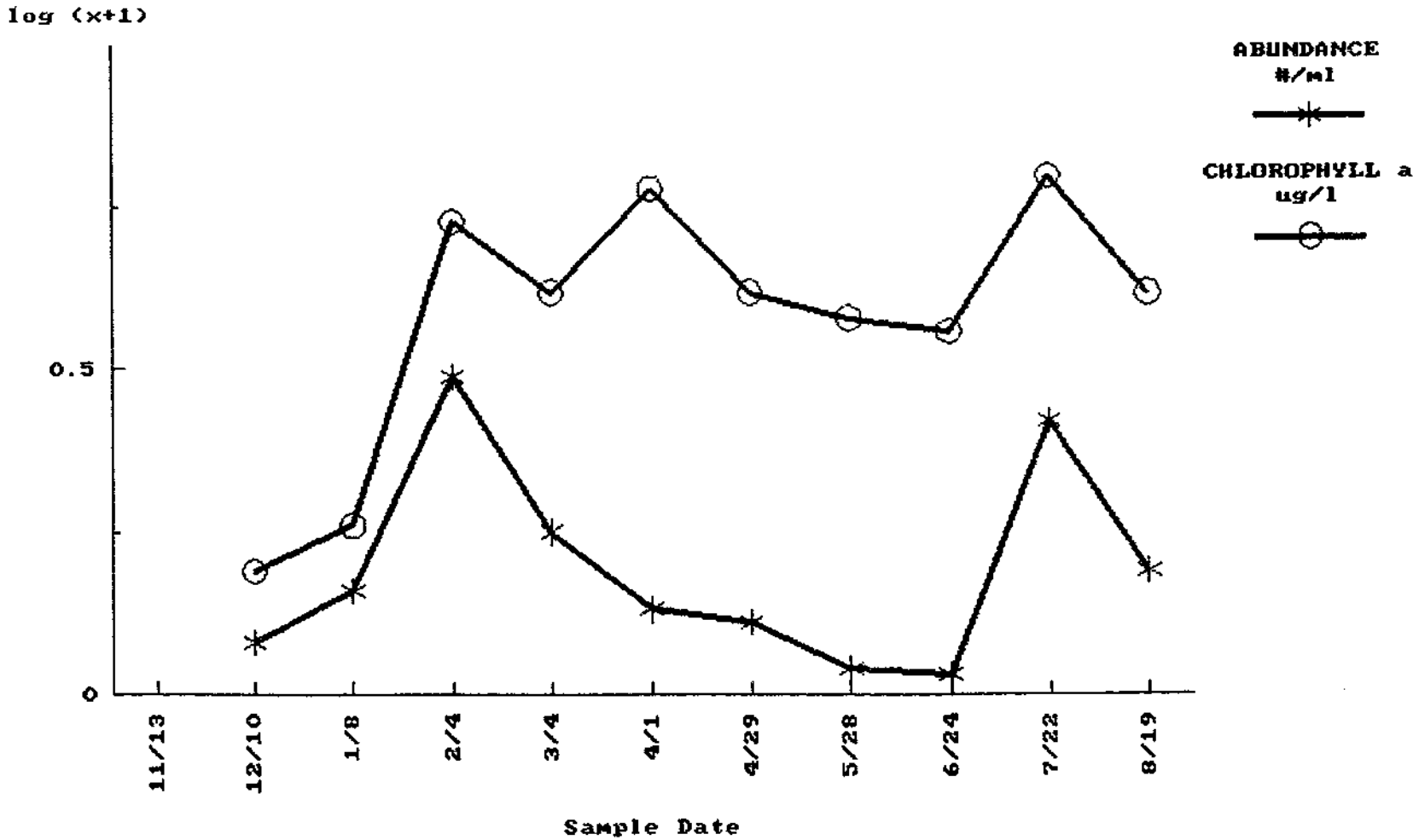


FIGURE 77. Phytoplankton log-transformed abundance and chlorophyll a, GADS 1.

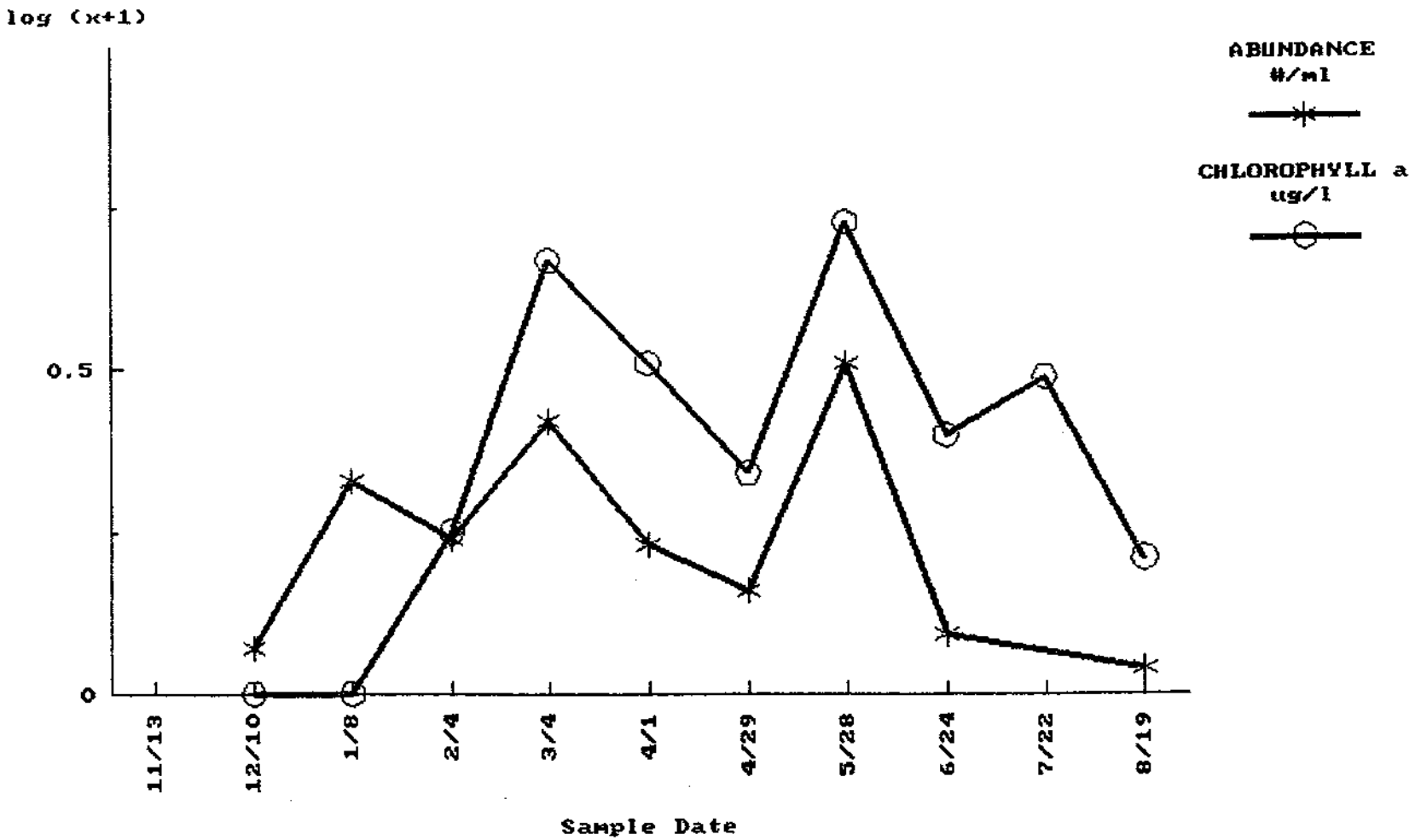


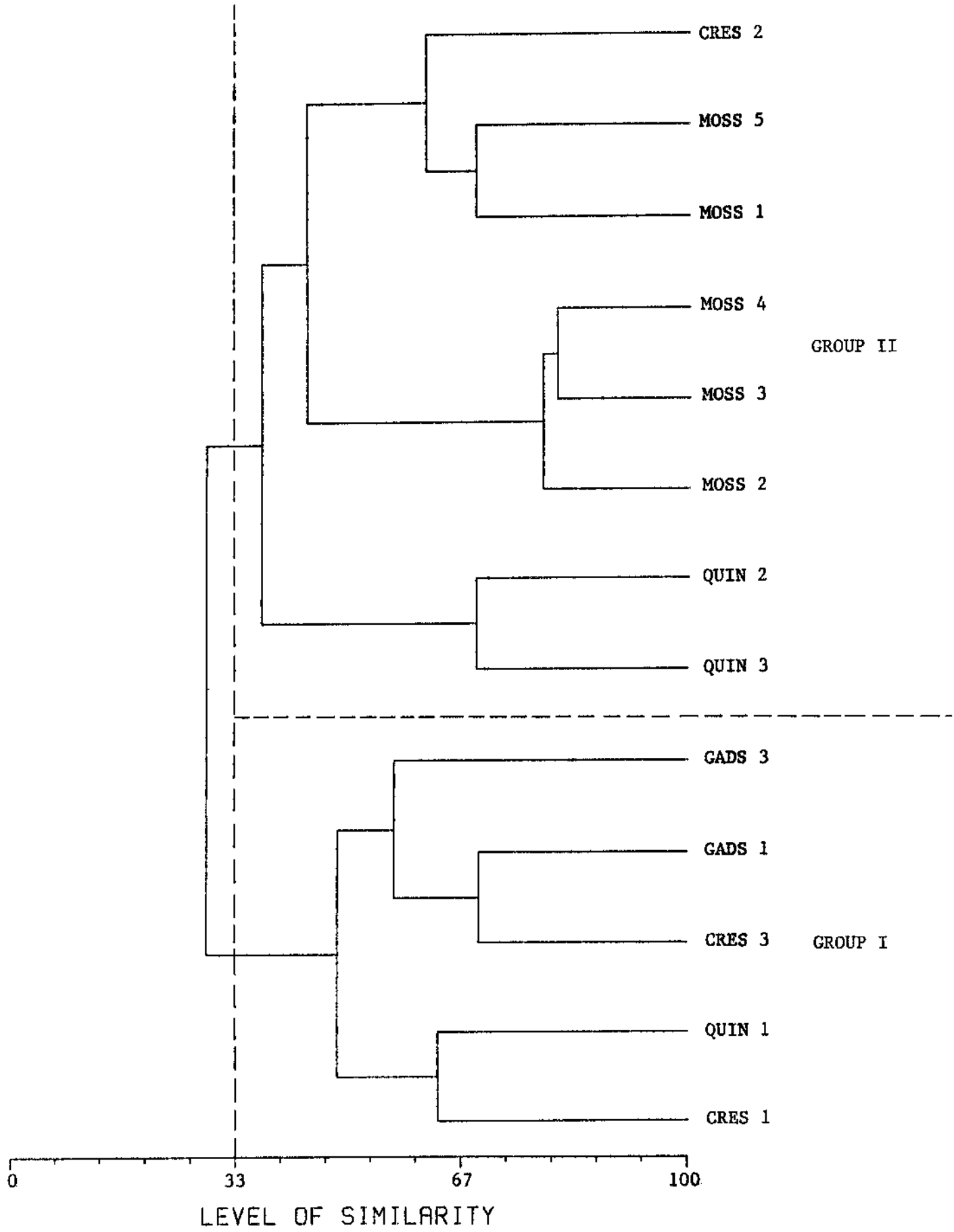
TABLE 44. Phytoplankton algae identified and number of occurrences at the GADS site, November 1984 to August 1984.

	Number of Occurrences	
	GADS 1	GADS 3
CYANOPHYTA		
Anabaena sp.	-	1
Aphanotheca sp.	-	3
Lyngbya sp.	2	1
Oscillatoria sp.	5	4
Phormidium sp.	3	6
Plectonema sp.	-	2
Unknown Cyanophyte sp.	3	2
CHLOROPHYTA		
Ankistrodesmus sp.	-	1
Arthrodesmus sp.	1	-
Chlamydomonas sp.	-	1
Cladophora sp.	1	-
Closterium sp.	3	4
Cosmarium sp.	-	3
Dictyosphaerium sp.	-	1
Euastrum sp.	-	1
Eudorina sp.	-	1
Kirchneriella sp.	-	1
Mougeotia sp.	2	2
Netrium sp.	1	-
Rhizocolonium sp.	1	-
Spirogyra sp.	2	1
Staurastrum sp.	1	2
Stigeocolonium sp.	1	-
Ulothrix sp.	4	-
Unknown Chlorophyte sp.	5	5
CHRYSOPHYTA		
Dinobryon sp.	1	-
Mallomonas sp.	-	1
Bacillariophyta		
Achnanthes sp.	1	-
Amphora sp.	-	1
Cymbella sp.	1	1

TABLE 44. Cont.

	Number of Occurrences	
	GADS 1	GADS 2
Eunotia sp.	1	1
Frustulia sp.	1	-
Gomphonema sp.	1	1
Melosira sp.	1	-
Navicula sp.	2	3
Neidium sp.	2	-
Nitzschia sp.	-	1
Pinnularia sp.	2	1
Stauroneis sp.	2	-
Synedra sp.	-	1
Unknown Diatom sp.	4	6
EUGLENOPHYTA		
Euglena sp.	-	2
Phacus sp.	1	2
Trachelomonas sp.	-	1
PYRRHOPHYTA		
Peridinium sp.	-	1

FIGURE 79. Station cluster of FREQUENCY phytoplankton taxa.



The results of inverse cluster analysis are illustrated in Figure 80; the top 50 taxa were separated into five major groups. Group I contains seven genera from three algal divisions. Four of the seven were chlorophytes, two were cyanophytes, and one pyrrhophyte was represented. These individuals were almost exclusively found at MOSS stations MOSS 2, MOSS 3, and MOSS 4, and particularly the pond stations.

Group II was considerably larger, and was represented by six major algal divisions. Again chlorophytes were dominant (nine out of 17). This group ranged in distribution from being collected almost exclusively at the outfall station QUIN 3 (e.g., Volvox, Spirulina) to being found at most all pond and outfall stations (e.g., Cosmarium). There were almost no instances of any of these genera being collected from upstream stations.

Group III comprises 16 genera, diatoms being best represented (8 genera). The majority of individuals in this group were collected from most of the stations. Some were found in greater abundance at the upstream stations, such as the diatoms Eunotia sp. and Frustulia sp. These two genera are known to be generally cosmopolitan and acidophilous (Lowe 1974). Some other interesting associations are apparent among the members of this group. The cyanophyte Lyngbya sp. was found in greatest abundance at the outfall CRES 3 and the upstream QUIN 1. This may partially explain the inclusion of QUIN 1 in Group I, which was comprised primarily of outfall stations. Similarly, the chlorophyte Staurastrum sp. was most common at MOSS 2-MOSS 4 and QUIN 3. This, along with the population of Volvox which unites the QUIN pond and outfall, can probably account for the inclusion of station QUIN 3 in Group III. Additionally, the chrysophyte Dinobryon sp. was collected from all MOSS stations and the pond stations QUIN 2 and CRES 2; this may partially explain the inclusion of MOSS 1 and MOSS 5 in the pond group.

Group IV comprises three chlorophytes and one diatom. The green algae are all filamentous, and were collected almost exclusively at station QUIN 3. The diatom, Achnanthes sp., was found at several stations, but chiefly at QUIN 3 and QUIN 1. The remainder of the top 50 algal genera fell into Group V, which contains two each of chlorophytes, cyanophytes, and diatoms. These individuals were collected from most stations, but the ones found in greatest abundance were generally from non-pond stations. The two cyanophytes, Phormidium sp. and Oscillatoria sp., were collected primarily from QUIN 1 and the stations at the GADS site. This may further explain the association of QUIN 1 with the outfall stations.

Multiple discriminant analysis was used in an attempt to isolate some of the abiotic factors that may have contributed to the observed station groupings. Parameters were the same as those used for periphyton (temperature, pH, NO_2+NO_3, PO_4, total suspended solids) except the average temperature of the water column was used for pond stations rather than surface temperature. Results indicated that 69.82% of the among

FIGURE 80. Species cluster of FREQUENCY phytoplankton taxa.

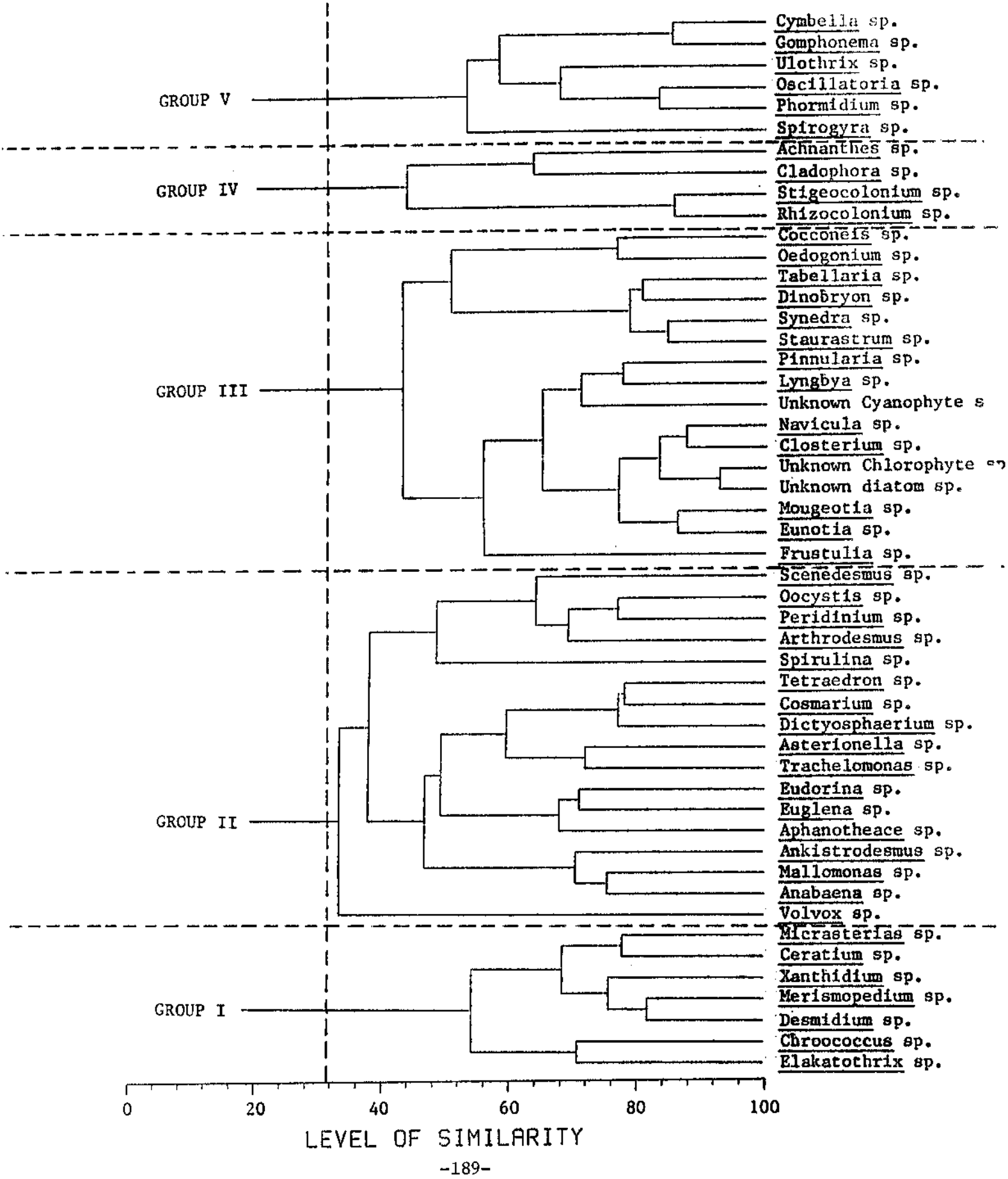
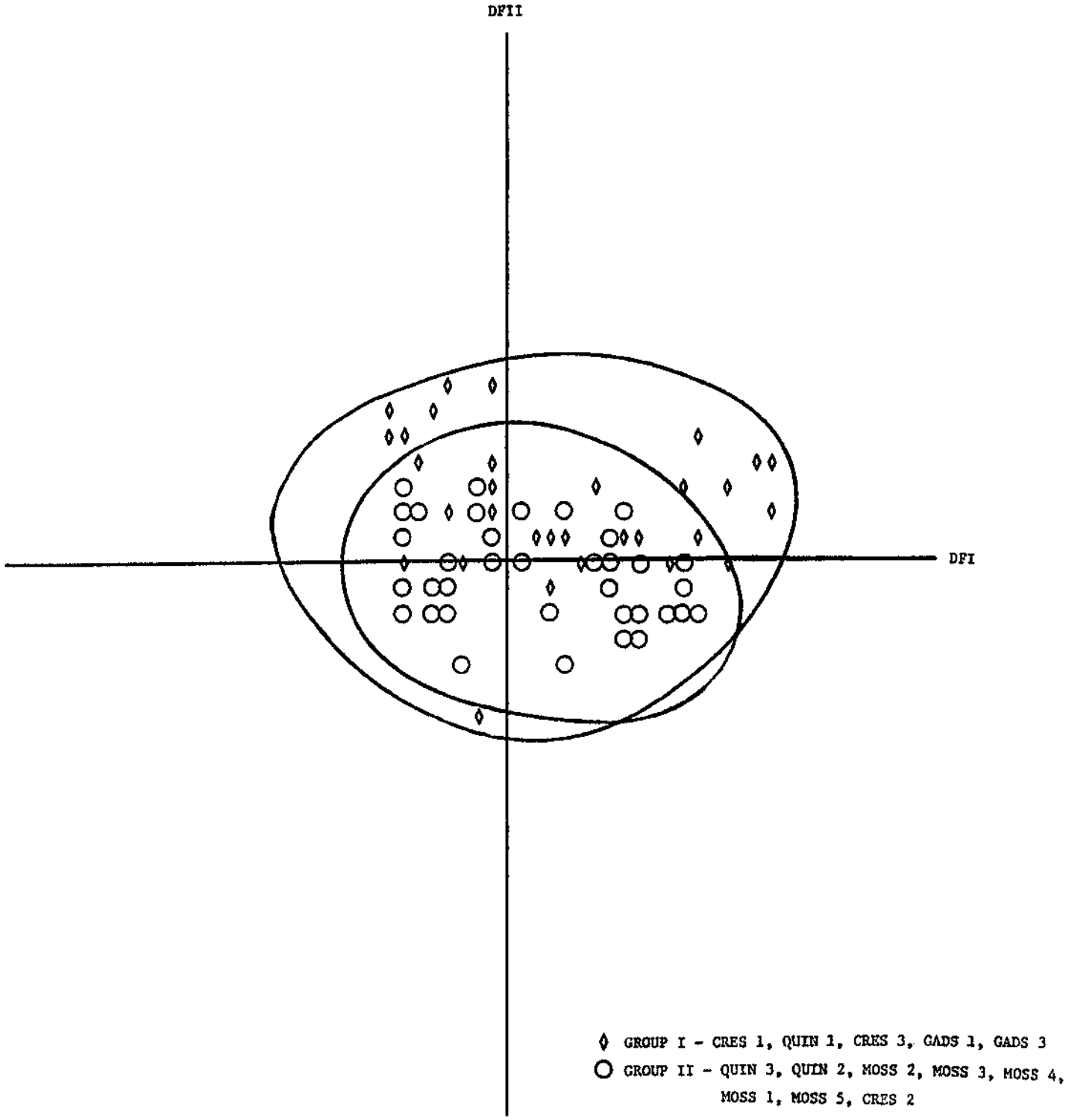


FIGURE 81. Orientation of FREQUENCY phytoplankton groups in discriminant space.



group variance could be explained by Discriminant Function I (DFI); within DFI the most important variable was NO_2+NO_3. The explained variance is increased to 91.49% with the addition of Discriminant Function II (DFII). The parameter contributing the most in DFII was pH.

Figure 81 illustrates the distribution of the station groups in discriminant space. The stations in Group I (CRES 1, CRES 3, GADS 1, GADS 3, QUIN 1) appear to be clustered fairly tightly, and lie within the range set by the Group II stations (CRES 2, MOSS 1, MOSS 2, MOSS 3, MOSS 4, MOSS 5, QUIN 2, QUIN 3). Group II is more scattered and a few stations, such as QUIN 1 and GADS 3, are more widely separated along the DFI axis (NO_2+NO_3) and stand apart from the main group. Mean NO_2+NO_3 levels were .29 mg/ml and .06 mg/ml for QUIN 1 and GADS 3, respectively. With the exception of station CRES 1, a reasonable amount of separation was apparent along DFII (pH).

MASS Sites

A total of 90 genera were identified at the MASS sites over the sampling period: 14 cyanophytes, 45 chlorophytes, 24 chrysophytes (19 bacillariophytes), 3 euglenophytes, 3 pyrrhophytes, and 1 rhodophyte (Table 48).

The five sites from which phytoplankton samples were collected at both upstream and pond stations were Kever (B1, B2), Lett (G1, G2), Whittle (H1, H2), Scott (I1, I2), and McCormick (L1, L2). Additionally, phytoplankton chlorophyll a was measured at all stations, including outfalls. From 3 to 5 samples were collected at any site, depending on the intermittence of the upstream and/or outfall stations. As was the case for periphyton, the small number of samples made it difficult to discern trends with confidence.

Among the sites where upstreams and ponds can be compared, no consistent trend was identified in terms of total number of taxa, mean number of taxa, or $\bar{d}$. A substantial increase in algal abundance was observed at all five of these sites; percent increase from upstream to pond ranged from 189% (I) to 4100% (B). Chlorophyll a increased significantly as well, and percent change ranged from 95% (H) to 3950% (B).

Although the abundances of the different algal divisions did not always vary in the same way from upstream to pond, the changes in relative proportions were fairly consistent. The mean percentage of cyanophytes was always lower in the pond, by as much as 99% (Table 46). While the average proportion of chlorophytes was not always higher in the ponds, the changes did not vary as widely as those for the other divisions. Additionally, the absolute number of chlorophytes was always greater in the ponds (Table 45). At all but the Whittle site (H), the number and proportion of chrysophytes (excluding diatoms) increased substantially, at least 1.5 fold. This was likely due to the abundance of Dinobryon sp., a

TABLE 45. Temperature, number of taxa, Shannon-Weaver diversity indices, and abundance for upstream and pond stations at all MASS sites. Numbers in parentheses are minimum and maximum values for the sample period.

	A2	B1	B2	C2	D2	E2	F2	G1	G2
$\bar{x}$ Temp (°C) (range)	21.5 (7.5-29.0)	17.6 (12.0-21.0)	19.7 (8.4-25.9)	20.7 (8.0-27.8)	19.5 (8.0-26.6)	19.4 (7.6-26.8)	16.7 (7.3-23.9)	20.2 (11.2-29.5)	21.9 (9.6-28.4)
Total # taxa	25	23	25	45	44	29	42	31	44
$\bar{x}$ #taxa (range)	10.4 (6-15)	7.4 (5-9)	11.0 (4-15)	21.2 (15-26)	18.6 (11-23)	11.2 (4-18)	17.2 (11-20)	15.3 (11-19)	17.4 (9-33)
$\bar{x}$ $\bar{d}$ (range)	1.7 (0.6-2.7)	2.5 (2.0-2.8)	2.5 (0.5-3.1)	3.4 (2.7-3.9)	3.3 (2.5-3.7)	1.5 (0.6-3.7)	3.2 (2.4-3.9)	3.1 (2.4-4.0)	2.5 (2.2-3.0)
pooled $\bar{d}$	1.7	4.0	1.3	4.4	4.4	1.7	3.4	3.9	3.2
$\bar{x}$ abundance (#/ml) (range)	31.5 (3.6-121.4)	0.6 (0.2-1.0)	25.2 (0.04-109.9)	40.3 (16.1-73.7)	5.6 (2.7-12.5)	29.0 (2.4-57.3)	5.9 (1.2-19.0)	4.9 (3.7-6.8)	21.6 (5.1-32.4)
# Cyanophyta	0	0.06	0.03	14.0	0.7	10.2	0.1	0.4	0.6
# Chlorophyta	4.4	0.2	1.2	13.8	1.5	0.8	1.4	1.4	3.5
# Chrysophyta	22.8	0.04	20.6	2.5	1.1	2.1	3.3	1.6	14.7
# Bacillariophyta	1.6	0.2	1.9	7.5	1.3	0.5	0.8	1.5	2.5
# Pyrrhophyta	2.7	0.1	0.3	2.5	1.0	15.4	0.4	0.1	0.3

Table 45. Cont.

	H1	H2	I1	I2	J2	K2	L1	L2	M2
$\bar{x}$ Temp (°C) (range)	16.9 (10.0-21.0)	19.5 (8.6-26.3)	15.0 (8.0-21.0)	20.6 (8.0-26.0)	20.3 (8.2-26.8)	18.6 (8.8-25.5)	19.0 (9.5-26.0)	19.3 (8.4-26.3)	19.5 (8.8-26.3)
Total # taxa	18	28	37	32	36	40	23	31	35
$\bar{x}$ #taxa (range)	7.6 (5-11)	9.8 (3-16)	13.8 (7-18)	13.2 (7-18)	12.6 (1-22)	13.6 (10-18)	10.7 (8-14)	10.4 (7-15)	13.0 (12-15)
$\bar{x}$ $\bar{d}$ (range)	2.0 (0.7-2.9)	1.5 (0.1-2.9)	2.3 (1.7-3.0)	2.6 (2.2-3.4)	1.9 (0-3.0)	2.6 (1.2-3.7)	2.5 (2.2-2.6)	2.1 (0.6-3.0)	2.1 (1.1-2.9)
pooled $\bar{d}$	2.5	0.9	3.2	3.5	3.3	3.9	3.5	1.9	2.9
$\bar{x}$ abundance (#/ml) (range)	11.1 (1.9-25.1)	74.5 (3.3-229.9)	4.5 (0.4-8.8)	13.0 (5.8-30.8)	11.8 (2.7-20.4)	5.6 (1.5-8.9)	1.6 (0.8-2.1)	12.7 (1.7-37.2)	10.0 (1.9-19.9)
# Cyanophyta	5.1	0.1	0.1	0.3	0.3	2.0	0.5	0.03	1.1
# Chlorophyta	1.2	2.4	1.6	7.9	2.3	1.3	0.3	2.5	3.2
# Chrysophyta	2.6	2.4	0.05	0.5	4.8	0.4	0.3	9.6	0.1
# Bacillariophyta	1.8	1.3	1.2	1.8	3.5	0.7	0.4	0.6	5.1
# Pyrrhophyta	0.3	65.1	1.5	2.5	0.9	1.3	0.1	0.02	0.6

TABLE 46. Numbers of periphyton taxa identified and average percent composition of selected major algal divisions, MASS Sites, January to August 1985.

No. of Taxa	A2	B1	B2	C2	D2	E2	F2	G1	G2
Cyanophyta	0	3	1	11	7	2	5	5	6
Chlorophyta	9	8	13	17	15	14	20	13	20
Chrysophyta	3	2	2	2	4	3	2	4	3
Bacillariophyta	9	8	7	9	13	5	10	6	11
Euglenophyta	2	0	1	3	3	3	3	2	3
Pyrrhophyta	2	2	1	2	2	2	2	1	1
Rhodophyta	0	0	0	1	0	0	0	0	0
% Composition									
Cyanophyta (range)	0 (0-2.6)	16.9 (0-50.0)	0.2 (15.6-58.3)	34.2 (15.6-58.2)	11.9 (1.4-36.5)	34.3 (0-92.0)	6.3 (0-21.4)	8.3 (1.9-12.0)	2.3 (0-5.0)
Chlorophyta (range)	15.3 (2.0-25.3)	36.6 (17.2-66.7)	26.8 (2.6-62.0)	36.8 (14.4-61.2)	23.4 (16.4-35.6)	5.8 (1.4-19.4)	30.2 (15.2-56.7)	30.4 (19.6-36.7)	15.3 ((2.7-2.8)
Chrysophyta (range)	40.5 (6.9-83.7)	7.7 (0-24.1)	33.0 (7.0-92.2)	3.8 (0-15.6)	25.5 (6.9-62.3)	9.7 (1.4-20.9)	31.2 (1.7-66.7)	26.2 (8.7-60.8)	67.0 (57.3-81.3)
Bacillariophyta (range)	9.5 (2.7-19.0)	22.6 (11.1-36.7)	17.3 (0-57.0)	5.7 (3.8-8.6)	15.2 (0-40.0)	7.7 (0-32.8)	27.1 (5.0-43.0)	32.6 (15.7-43.5)	13.5 (8.2-18.8)
Pyrrhophyta (range)	34.7 (0-73.6)	16.1 (0-42.9)	22.5 (5.2-37.1)	19.1 (12.8-32.8)	24.0 (8.2-42.5)	42.4 (4.8-87.4)	5.2 (3.8-7.5)	2.6 (2.0-3.6)	1.9 (0-3.7)

TABLE 46. Cont.

No. of Taxa	H1	H2	I1	I2	J2	K2	L1	L2	M2
Cyanophyta	3	3	5	4	5	8	4	2	6
Chlorophyta	6	11	12	13	15	18	7	13	16
Chrysophyta	1	2	3	2	2	2	1	4	2
Bacillariophyta	5	8	12	7	9	8	9	8	8
Euglenophyta	1	2	3	3	2	1	1	3	1
Pyrrhophyta	2	2	2	3	3	3	1	1	2
Rhodophyta	0	0	0	0	0	0	0	0	0
% Composition									
Cyanophyta (range)	20.6 (0-89.6)	0.6 (0-1.3)	8.3 (0-23.5)	1.5 (0-3.4)	1.8 (0-5.0)	23.5 (0-81.5)	27.1 (4.3-62.8)	1.5 (0-5.5)	11.1 (0-43.8)
Chlorophyta (range)	21.7 (1.6-53.6)	25.4 (0-75.3)	31.2 (6.9-83.3)	47.1 (8.3-91.7)	24.2 (0-77.0)	29.4 (7.7-75.9)	17.9 (10.6-21.7)	25.6 (0.5-53.7)	42.2 (4.1-84.8)
Chrysophyta (range)	17.9 (0-82.3)	16.3 (0-67.6)	1.2 (0-2.9)	5.9 (0-18.8)	30.1 (0-72.5)	13.6 (0-55.1)	17.5 (1.1-47.8)	58.0 (9.3-90.7)	0.9 (0-1.7)
Bacillariophyta (range)	31.4 (8.8-63.8)	9.2 (0.5-21.8)	39.5 (13.5-59.1)	14.9 (7.1-23.3)	38.5 (2.5-100)	12.5 (0.7-26.7)	27.7 (21.3-35.7)	13.8 (0-29.6)	39.5 (1.9-88.0)
Pyrrhophyta (range)	8.4 (0-21.4)	49.5 (3.8-98.9)	19.8 (0.9-63.3)	30.6 (0-61.5)	5.4 (0-20.0)	21.0 (1.9-42.9)	9.8 (0-25.0)	1.1 (0-5.6)	6.2 (0-21.5)

Table 47. Means and ranges of free-water chlorophyll *a*, MASS Stations.

STATION	Chlorophyll *a* (ug/l) mean	(range)
A2	19.1	(12.9-24.5)
A3	9.5	(0-27.9)
B1	0.6	(0-1.3)
B2	24.3	(10.3-41.4)
B3	12.3	(3.1-29.5)
C1	9.4	(1.2-29.5)
C2	98.8	(65.7-155.4)
C3	55.7	(1.2-162.1)
D2	8.8	(1.1-20.1)
D3	10.4	(0.7-26.5)
E2	9.0	(2.6-12.9)
E3	9.1	(2.8-24.4)
F2	13.1	(3.7-23.0)
F3	33.4	(6.9-71.9)
G1	1.7	(1.1-2.8)
G2	9.9	(1.7-18.9)
G3	14.8	(1.2-53.4)
H1	8.3	(0.6-29.0)
H2	16.2	(5.6-34.0)
H3	15.8	(4.6-30.1)
I1	0.9	(0-1.8)
I2	93.8	(21.3-170.1)
I3	75.3	(9.2-205.4)
J1	2.2	(0.8-6.0)
J2	18.1	(15.2-21.9)
J3	15.9	(9.6-21.3)
K1	2.2	(0.9-5.3)
K2	28.0	(6.0-38.8)
K3	20.3	(6.5-34.4)
L1	3.3	(0-10.2)
L2	10.9	(7.0-15.7)
L3	8.9	(4.5-12.9)
M1	0.3	(0-0.6)
M2	25.3	(11.4-41.0)
M3	28.9	(13.9-41.5)

TABLE 48. Algae identified and number of occurrences at all MASS sites, November 1984 to August 1985.

	Number of Occurrences																	
	A2	B1	B2	C2	D2	E2	F2	G1	G2	H1	H2	I1	I2	J2	K2	L1	L2	M2
CYANOPHYTA																		
Anabaena sp.	-	-	-	4	1	-	2	1	2	-	1	2	1	-	2	-	-	4
Aphanocapsa sp.	-	-	1	3	1	1	1	1	2	-	1	1	-	2	-	-	1	-
Aphanotheca sp.	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Chroococcus sp.	-	-	-	3	1	-	-	-	-	1	-	-	-	-	-	-	1	1
Coelosphaerium sp.	-	-	-	-	1	-	-	-	1	-	-	-	-	-	1	-	-	-
Dactylococcopsis sp.	-	-	-	2	-	-	1	-	-	-	-	-	1	-	-	1	-	2
Gloeocaspa sp	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Gomphosphaeria sp.	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lyngbya sp.	-	2	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-
Merismopedium sp.	-	-	-	4	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Microcystis sp.	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Oscillatoria sp.	-	-	-	3	1	3	2	2	3	1	-	2	1	1	2	1	-	1
Phormidium sp.	-	1	-	1	1	-	-	1	-	2	-	2	1	1	1	1	-	1
Spirulina sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Unknown Cyanophyte sp.	-	1	-	1	2	-	1	2	1	-	-	-	-	1	1	1	-	1
CHLOROPHYTA																		
Ankistrodesmus sp.	1	-	-	2	3	-	-	-	-	-	1	1	2	-	1	-	2	1
Arthrodesmus sp.	-	-	-	1	1	-	1	-	2	-	-	1	1	2	-	-	3	1
Bambusina sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	1	1	-	-	-
Botryococcus sp.	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bulbochaete sp.	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Chlamydomonas sp.	1	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-
Cryptomonas sp.	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladophora sp.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Closterium sp.	4	-	1	-	3	2	3	1	2	1	4	-	3	1	2	2	2	1
Coelastrum sp.	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-	-	-
Cosmarium sp.	-	-	-	-	1	-	1	-	1	-	-	-	1	-	-	-	-	3
Crucigenia sp.	-	-	-	5	-	-	-	-	1	-	-	-	-	2	1	-	-	-

TABLE 48. Cont.

	Number of Occurrences																	
	A2	B1	B2	C2	D2	E2	F2	G1	G2	H1	H2	I1	I2	J2	K2	L1	L2	M2
Desmidium sp.	-	1	1	-	2	1	-	-	2	-	-	-	-	2	1	1	1	1
Dictyosphaerium sp.	-	-	1	1	-	-	2	-	2	-	1	2	-	-	-	-	-	3
Elakatothrix sp.	1	-	-	-	2	-	-	-	1	-	1	-	-	1	1	-	2	1
Euastrum sp.	-	-	1	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-
Eudorima sp.	-	-	-	2	-	2	-	-	1	2	3	1	2	-	-	-	-	-
Gloeocystis sp.	-	-	-	2	-	2	1	-	1	-	-	-	-	-	1	-	1	2
Gonatozygon sp.	-	-	-	-	3	1	1	1	-	-	-	1	-	2	1	-	-	-
Hyalotheca sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Kirchneriella sp.	-	-	-	3	-	-	-	1	1	-	-	-	-	-	-	1	-	1
Micrasterias sp.	-	-	1	1	-	-	4	1	2	-	-	1	-	2	5	-	-	-
Mougeotia sp.	1	3	1	-	-	1	3	2	3	4	1	3	1	1	4	2	1	1
Netrium sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Oedogonium sp.	-	-	-	-	1	-	-	1	-	-	1	-	-	-	1	-	1	-
Onychonema sp.	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Oocystis sp.	-	-	1	-	2	-	1	-	1	1	2	2	-	2	-	-	2	2
Pandorina sp.	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Pediastrum sp.	4	1	-	5	1	2	2	-	1	-	-	-	2	2	-	-	-	-
Pleodorina sp.	1	-	1	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
Pleurotaenium	-	-	-	-	-	2	1	-	-	-	-	-	-	1	-	-	-	-
Quadrigula sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Rhizocolonium sp.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scenedesmus sp.	2	-	-	5	4	1	2	1	1	-	-	2	4	2	2	-	-	4
Schroedaria sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Selenastrum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Sorastrum sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Spirogyra sp.	-	1	2	-	-	-	-	-	-	-	1	-	3	-	1	1	-	-
Spondylosium sp.	-	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-	-	-
Staurastrum sp.	3	3	3	4	5	4	2	1	1	-	3	-	4	3	3	2	4	4
Stigeocolonium sp.	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Tetraedron sp.	-	-	-	1	-	2	2	-	3	-	-	-	-	1	-	-	1	1
Ulothrix sp.	-	-	1	1	1	-	-	2	-	-	1	1	-	-	-	-	-	-
Volvox sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Xanthidium sp.	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown Chlorophyte sp.	-	2	3	5	2	1	5	2	4	-	-	1	2	-	2	1	1	2

TABLE 48. Cont.

	Number of Occurrences																	
	A2	B1	B2	C2	D2	E2	F2	G1	G2	H1	H2	I1	I2	J2	K2	L1	L2	M2
CHRYSOPHYTA																		
Centritractus sp.	-	-	-	-	1	1	-	1	-	-	-	1	-	-	-	-	-	-
Dinobryon sp.	5	1	5	3	5	4	4	2	5	2	3	1	1	3	3	3	4	4
Mallomonas sp.	4	2	3	2	5	5	3	3	4	-	1	-	3	2	2	-	3	-
Synura sp.	1	-	-	-	2	-	-	1	3	-	-	1	-	-	-	-	1	1
Uroglenopsis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Bacillariophyta																		
Achnanthes sp.	1	-	-	-	1	-	1	-	-	-	-	1	-	2	-	1	1	1
Asterionella sp.	-	1	5	-	2	-	3	-	4	4	3	2	4	3	1	-	1	-
Cocconeis sp.	-	2	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Cyclotella sp.	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Cymbella sp.	-	-	-	1	-	-	-	-	-	-	-	1	-	-	1	1	1	-
Eunotia sp.	-	4	5	2	2	-	3	3	3	3	2	3	1	-	-	3	1	1
Frustulia sp.	-	-	3	-	1	-	-	-	-	-	-	2	-	-	-	1	2	-
Gomphonema sp.	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	1	-
Gyrosigma sp.	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-
Melosira sp.	1	1	-	3	3	-	-	-	2	-	-	1	-	3	2	-	-	-
Navicula sp.	-	-	-	1	2	-	1	-	-	-	1	1	-	-	-	-	-	1
Neidium sp.	2	1	-	-	-	-	1	-	1	-	1	-	-	-	-	-	-	-
Nitzschia sp.	-	-	-	2	-	1	1	-	-	-	-	1	2	-	-	-	-	1
Pinnularia sp.	2	1	4	1	4	-	3	1	3	3	1	1	1	1	2	1	-	1
Rhizosolenia sp.	1	-	-	-	2	2	-	-	1	-	-	-	-	1	-	-	-	-
Stauroneis sp.	-	-	-	-	2	1	-	1	1	-	-	-	-	-	-	1	-	-
Surirella sp.	1	-	1	2	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Synedra sp.	3	-	3	4	3	1	4	2	2	-	2	4	3	2	2	1	2	5
Tabellaria sp.	2	1	-	-	2	-	-	-	1	4	1	-	2	1	3	1	-	1
Unknown Diatom sp.	4	2	3	3	5	1	3	3	4	5	3	2	3	1	4	2	3	4

TABLE 48. Cont.

	Number of Occurrences																	
	A2	B1	B2	C2	D2	E2	F2	G1	G2	H1	H2	I1	I2	J2	K2	L1	L2	M2
EUGLENOPHYTA																		
Euglena sp.	2	-	1	3	2	3	3	1	2	1	3	1	3	3	-	-	3	1
Phacus sp.	-	-	-	2	2	2	3	-	2	-	1	1	4	1	1	1	2	-
Trachelomonas sp.	1	-	-	3	1	1	2	1	1	-	-	1	1	-	-	-	1	-
PYRRHOPHYTA																		
Ceratium sp.	1	-	-	5	3	5	4	3	4	2	4	2	3	2	2	2	-	1
Gymnodium sp.	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-
Peridinium sp.	3	3	3	3	2	2	1	-	-	-	1	2	2	2	2	-	1	3
Unknown Pyrrhophyte sp.	-	1	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
RHODOPHYTA																		
Batrachospermum sp.	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

widespread chrysophyte. This alga was more abundant at the pond stations of both the FREQUENCY and MASS sites. Finally, the relative proportion of diatoms was reduced from upstream to pond at each of these sites; the changes ranged from 24% to 74% (Table 46).

A list of average chlorophyll a values for all MASS stations, along with their ranges over the sampling period is presented in Table 47. The sample measurements varied widely, as sampling was begun in winter and ended in late summer in anticipation of minimum and maximum production periods. In all cases, a substantial increase from upstream to pond was observed; this trend is consistent with that of abundance. Biomass levels at the outfall stations were either very similar to or lower than those measured at the ponds.

Cluster/Discriminant Analyses

Normal cluster analysis of phytoplankton species composition and abundance data indicated the presence of two station groupings (Figure 82). Group I consists of the three upstream stations B1, H1, and L1. Group II contains 15 stations, all of the ponds and the upstream stations G1 and I1.

Inverse cluster analysis resulted in the separation of six groupings (Figure 83). Group I contains two cyanophytes and one chlorophyte. These algae were collected in greatest abundance from J2 and primarily C2. Group II, consisting of only one chlorophyte, Chlamydomonas sp., was found almost exclusively at A2. Group III is made up of the chlorophyte, Spirogyra sp., and the diatom Frustulia sp., which was collected from most stations though not in great abundance. Group IV was represented by four chlorophytes, one diatom, and one chrysophyte. They were found primarily at pond stations, though none of the ponds were common to all of the genera. These were not found in great abundance. Group V was the largest (28 genera) and was represented by six major divisions. Among these genera were those collected in greatest abundance over the sampling period, as well as those found in low density. Although many were collected from most stations, all were clearly more abundant at the pond stations. It is interesting to note that all representatives of the euglenophytes were contained in this group. Group VI, consisting of ten genera, appeared to represent those taxa which were found in the least abundance. As was observed with the other groups, density was greatest at the pond stations, and there was no clear association of taxa according to station.

As was observed in the cluster analyses of periphyton data, normal and inverse analyses were based primarily on algae collected from the pond stations. Since there were eight more pond stations than upstreams, and algal abundance was so much higher in the ponds, the upstream stations are poorly represented. This, and the small number of samples could partially explain the lack of clear species-station associations.

FIGURE 82. **Station cluster of MASS phytoplankton taxa.**

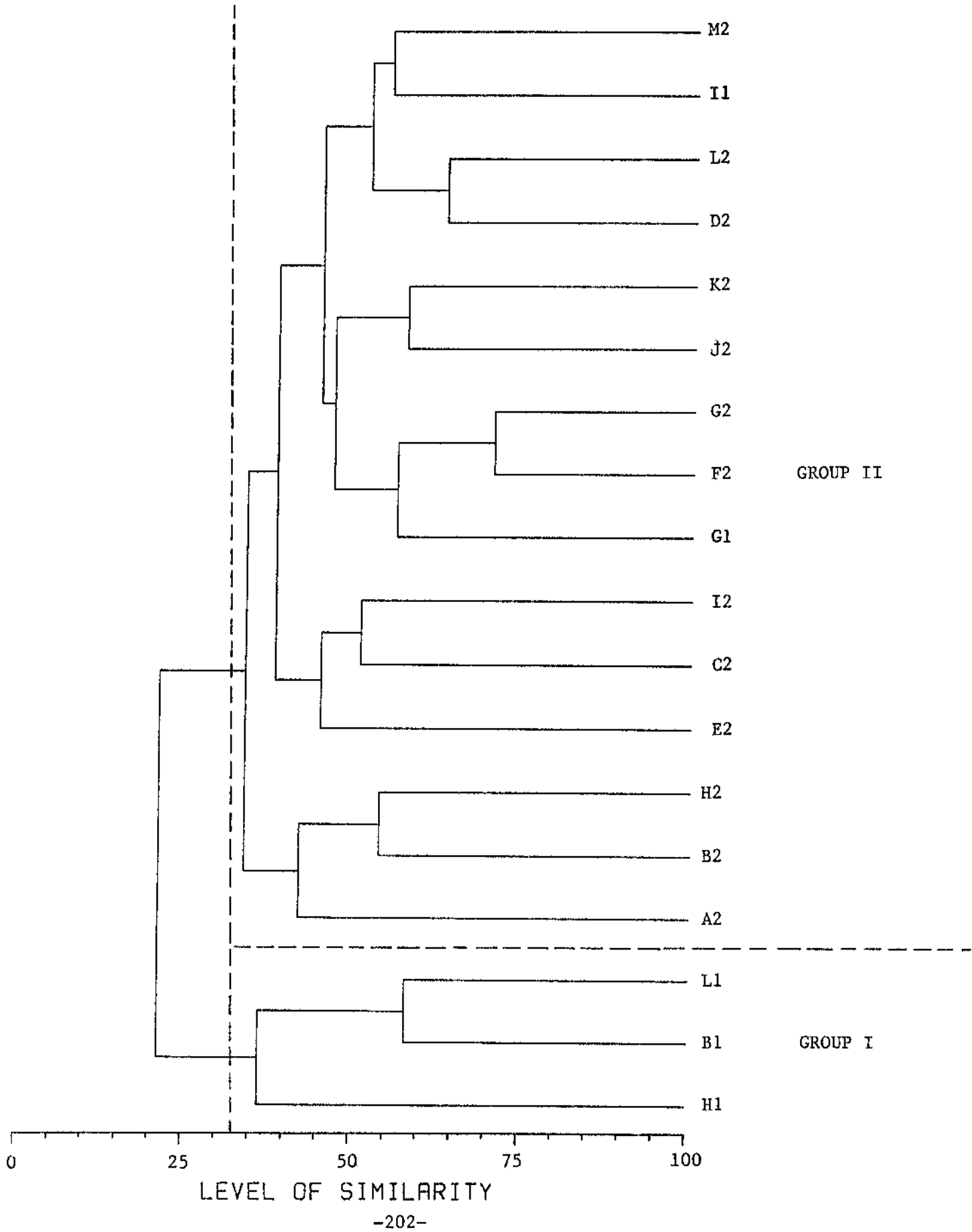


FIGURE 83. Species cluster of MASS phytoplankton taxa.

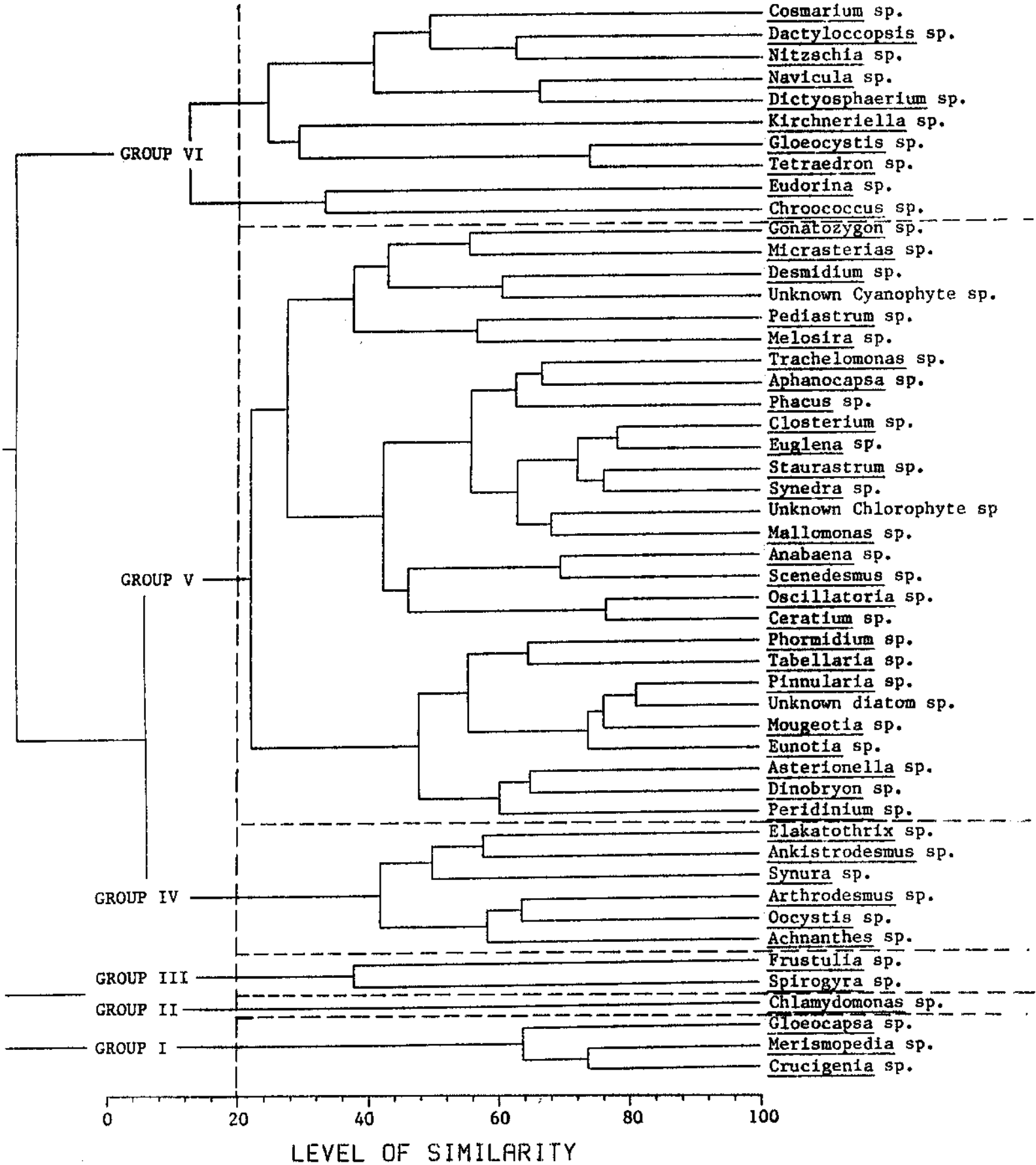
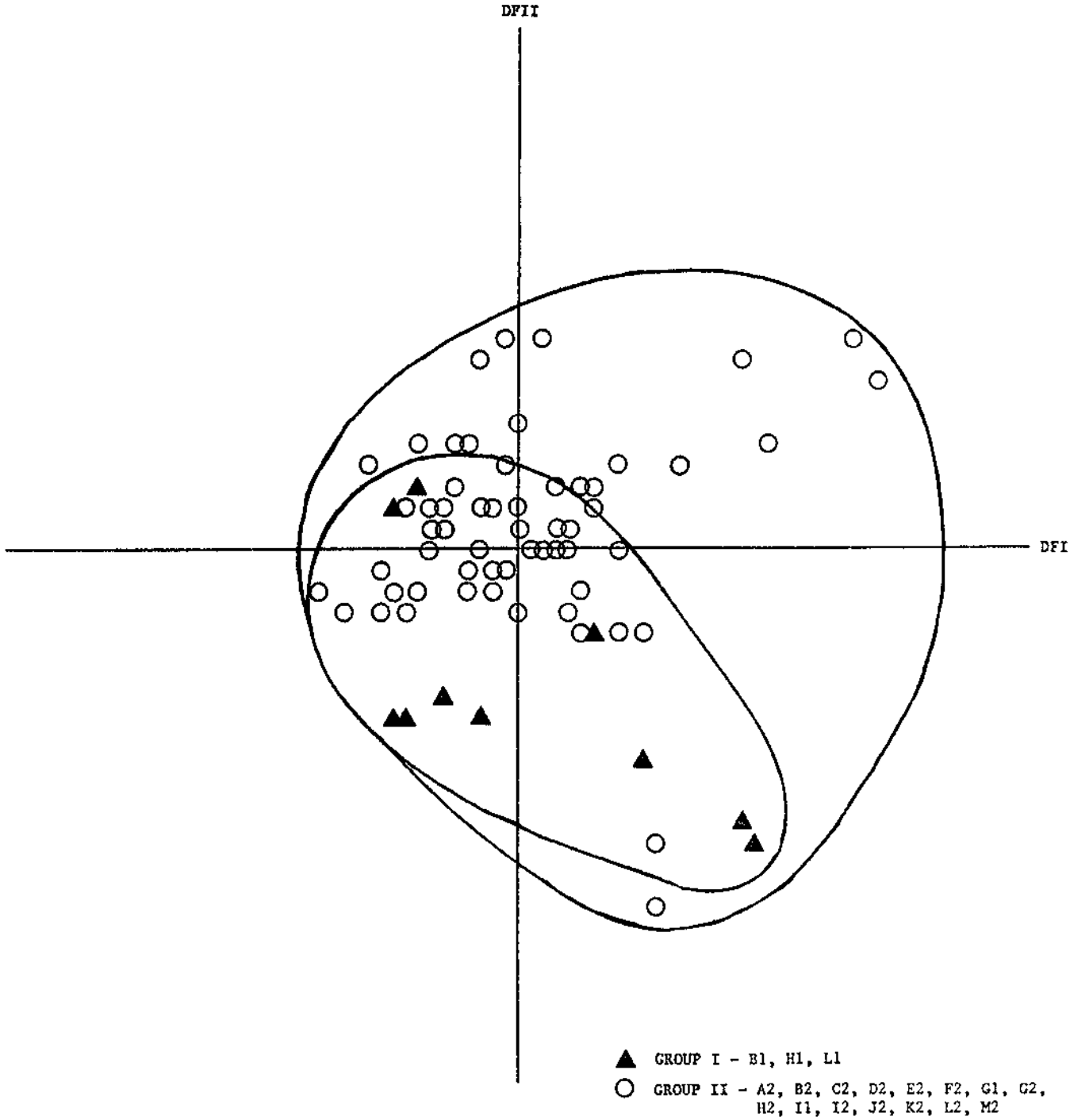


FIGURE 84. Orientation of MASS phytoplankton groups in discriminant space.



Multiple discriminant analysis was performed on phytoplankton data using the same parameters as for the FREQUENCY data (average column temperature, pH, NO_2+NO_3, dissolved phosphorus, and total suspended solids). Results indicated that 40.28% of the among group variance can be explained by Discriminant Function I (DFI); temperature and pH were the most important variables. The addition of Discriminant Function II (DFII) brings the explained variance to 75.64%. The variable which contributed the most to DFII was NO_2+NO_3.

Figure 84 illustrates the distribution of the station groups in discriminant space. A fair amount of separation exists between the two groups along DFII (NO_2+NO_3). The inclusion of Station H1 in Group I extends the range so that it overlaps with Group II. Group I appears to lie completely within the range of DFI (pH, temperature).

Again, it is likely that station group separations would be more distinct had more samples been collected and more data have been available for analysis.

CONCLUSIONS

1. Total number of taxa increased from upstream to pond, and from upstream to outfall at FREQUENCY and MASS stations.

2. Mean number of taxa either increased or was relatively unchanged from upstream to pond, and from upstream to outfall at both FREQUENCY and MASS stations.

3. Algal abundance increased from upstream to pond at all sites (FREQUENCY and MASS), and from upstream to outfall at the QUIN, CRES and MOSS sites.

4. Diversity indices remained relatively stable at all sites, except for QUIN, where a decrease was observed from upstream to pond and from upstream to outfall. At the MASS sites, $\bar{d}$ either decreased or remained the same from upstream to pond.

5. The proportion of chlorophytes increased from upstream to pond and from upstream to outfall at the QUIN and MOSS sites, while a slight decrease was observed at the CRES and GADS sites. Percent chrysophytes was substantially increased at all MASS sites, and at all FREQUENCY sites except for GADS. The diatom fraction was reduced from upstream to pond and from upstream to outfall at all sites (FREQUENCY and MASS). No consistent trend was apparent for changes in the proportion of cyanophytes at the FREQUENCY sites, however, percent cyanophytes decreased from upstream to pond at the MASS sites.

6. Chlorophyll *a* increased dramatically from upstream to pond and from upstream to outfall at all sites (FREQUENCY and MASS). Monthly variation of chlorophyll *a* and algal abundance was not well-correlated.

7. Normal cluster analysis indicated that generally, pond stations cluster together, and stream (influent or effluent) stations group closely. Additionally, some stations from the same site will cluster together regardless of the type of habitat.

8. Inverse cluster analysis indicated that the distribution of many algal genera was related to the site location or the type of habitat.

9. Multiple discriminant analysis indicated that most of the among group variation in both FREQUENCY and MASS stations was based on NO_2+NO_3 and pH, although temperature was also a discriminating function at the MASS stations.

The phytoplankton community was altered in response to the impoundment of streams in this study. Algal abundance and biomass increased from upstream to pond and from upstream to outfall. Total number of taxa increased, and mean number of taxa either increased or remained relatively unchanged following impoundment. At most sites, diversity indices were similar from upstream to pond and from upstream to outfall; at the QUIN site a decrease in $\bar{d}$ was observed. The character of the phytoplankton community in pond stations was different from that of stream stations. The proportion of chlorophytes was greater at both pond and outfall stations, and that of diatoms was greater at upstream stations. At all sites except GADS, percent chrysophytes was substantially increased. Multivariate analysis indicated that the distribution of phytoplankton was related to the site location or type of habitat (pond or stream). Although the majority of the observed changes in phytoplankton were less dramatic than those of periphyton, both algal communities were altered in a similar way.

The increase in abundance in the newly-formed reservoir is typical; reduction of the rate of flow allows the plankton to proliferate before being swept away (Baxter 1977). Artificial lakes are often relatively eutrophic at the beginning, and blooms of blue-green algae are common (Matheny 1976). This response was observed at the QUIN site following pond-fill. Generally, the environmental perturbation of impoundment results in a substantial alteration in the phytoplankton community. Although the initial population change is typical of a eutrophic response, the new algal population may stabilize. Generally, the phytoplankton is enhanced, as a still, lentic environment is more conducive to this algal community than a flowing system.

BACTERIA

INTRODUCTION

Bacteria are ubiquitous in nature. Historically, the role of these organisms in freshwater ecology has been reviewed usually only in terms of trophodynamics (Silvey and Wyatt 1971) or in terms of a pollution burden (U.S. EPA 1978).

Since impoundments are generally created for aesthetic and recreational purposes (waterfront property) or for an agricultural water supply, the concerns for public health and water quality are appropriate. To date the impact on the microbial community of impounding a natural stream has not been studied.

The purpose of this portion of the study was:

(1) to determine the bacteriological characteristics of the stream and its associated impoundment using selected water quality indicators; and,

(2) to investigate the association between the bacterial indicators and the other parameters measured.

METHODS AND MATERIALS

Water samples were taken in 6 oz. screw-cap, sterile glass bottles and kept on ice until processing. Samples were taken from a small boat using the full arm sweep method. Ideally, samples were taken from a depth of two feet, but in some streams and shallows the top few inches had to be taken. Occasionally a few stations were dry and samples were not collected. All samples were collected in duplicate. Samples were processed within 24 hours of collection following Standard Methods for Water and Wastes (15 ed., APHA 1980) and Microbiological Methods for Monitoring the Environment (U.S. EPA 1978). Membrane filter analysis was used for total coliform, fecal coliform, and fecal streptococci determinations. The pour plate method was used for the standard plate count determinations.

Millipore® filter apparatus and either Millipore® HC type or Gelman® GN6 membrane filters were used throughout this study. Filters, after evacuation of the sample aliquots, were incubated on three types of media: M-Endo (Difco®) to enumerate total coliforms, M-FC Broth (Difco®) with 1% rosalic acid to enumerate fecal coliforms, and KF-Streptococcus Agar (Difco®) to enumerate fecal streptococci. All media were made according to the manufacturer's directions. Filters were incubated at either 35.0 $\pm$ 0.5°C for total coliform (24 hours) and fecal streptococci (48 hours) determinations or 44.5 $\pm$ 0.2°C for fecal coliform determinations (24 hours). Colonies were counted manually and recorded.

The pour plate method was used for the determination of the total aerobic bacteria. Aliquots of sample (1.0 and 0.1 ml) were introduced into 15X100 mm petri dishes. Molten standard plate count agar (Difco®) was added, approximately mixed with sample and allowed to solidify. Plates were incubated at 35.0 ± 0.5°C for 24 hours. Colonies were counted using a Fisher® electric colony counter.

RESULTS AND DISCUSSION

Figure 85 shows the relationship of the four bacteriological parameters studied. Of these, only the total and fecal coliform bacteria are used in the evaluation of water quality by regulatory agencies (Table 49; FAC 17-3). Although fecal streptococcus bacteria are not one of the bacterial parameters recognized in FAC 17-3, the identification of this organism is used to assess the difference between human-associated and agriculturally-associated pollution via the use of a fecal coliform-fecal streptococci (FC:FS) ratio. In general, ratios of 4.0 or greater indicate highly significant human-associated pollution whereas ratios of less than 1.0 indicate pollution from agricultural sources (Geldreich and Kenner 1969). Caution has been noted, however, against the strict interpretation of the ratio to define point sources (U.S. EPA 1978). In this project we used the ratio data as indications of potential sources of pollution found within each study area.

Total aerobic plate counts, referred to as standard plate counts (SPC), were used to determine the total bacterial burden to the impounded system. This burden is considered the most conservative representative of bacterial influence since the other groups are subpopulations. Although these bacteria grow over a wide range of temperatures, those growing at 35°C are considered to be of sanitary significance (U.S. EPA 1977).

Total coliform bacteria are used to identify environmental sources of pollution, for example, rainfall/runoff sources or tidal influences (U.S. EPA 1978). Fecal coliform determinations are used to determine sources of pollution and public health impacts directly related to fecal discharges from warm-blooded animals including, of course, man (U.S. EPA 1978).

Statistical comparisons using the Student's t-test (2 tail) were done to investigate trends within each area. Spearman's Rank Correlation was done on all FREQUENCY data to investigate the relationship between bacterial densities and selected physical-chemical parameters.

FIGURE 85. Schematic showing the four bacterial groups studied. Arrows indicate subpopulations based on growth and morphological characteristics.

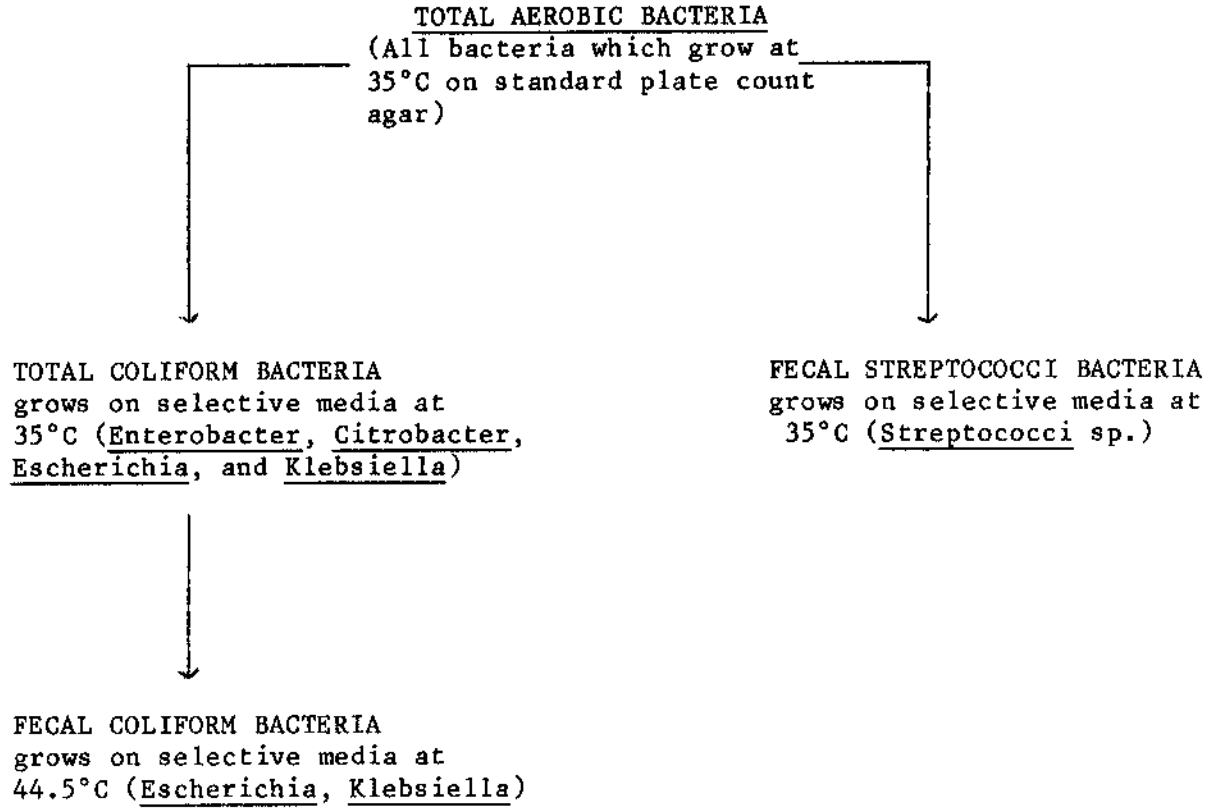


TABLE 49. FAC 17-3.121 Criteria: Class III Waters
Recreation-Propagation and Management of Fish and Wildlife-
Surface Waters

(5) Bacteriologial Quality - fecal coliform bacteria shall not exceed a monthly average of 200 per 100 ml of sample, nor exceed 400 per 100 ml of sample, nor in 10 percent of the samples, nor exceed 800 per 100 ml on any one day, nor exceed a total coliform bacteria count of 1,000 per 100 ml as a monthly average, nor exceed 1,000 per 100 ml in more than 20 percent of the samples examined during any month, nor exceed 2,400 per 100 ml at any time. Monthly averages shall not be expressed as geometric means based on a minimum of 10 samples taken over a 20 day period. Either MPN or MF counts may be utilized.

FREQUENCY Sites

CRES Site

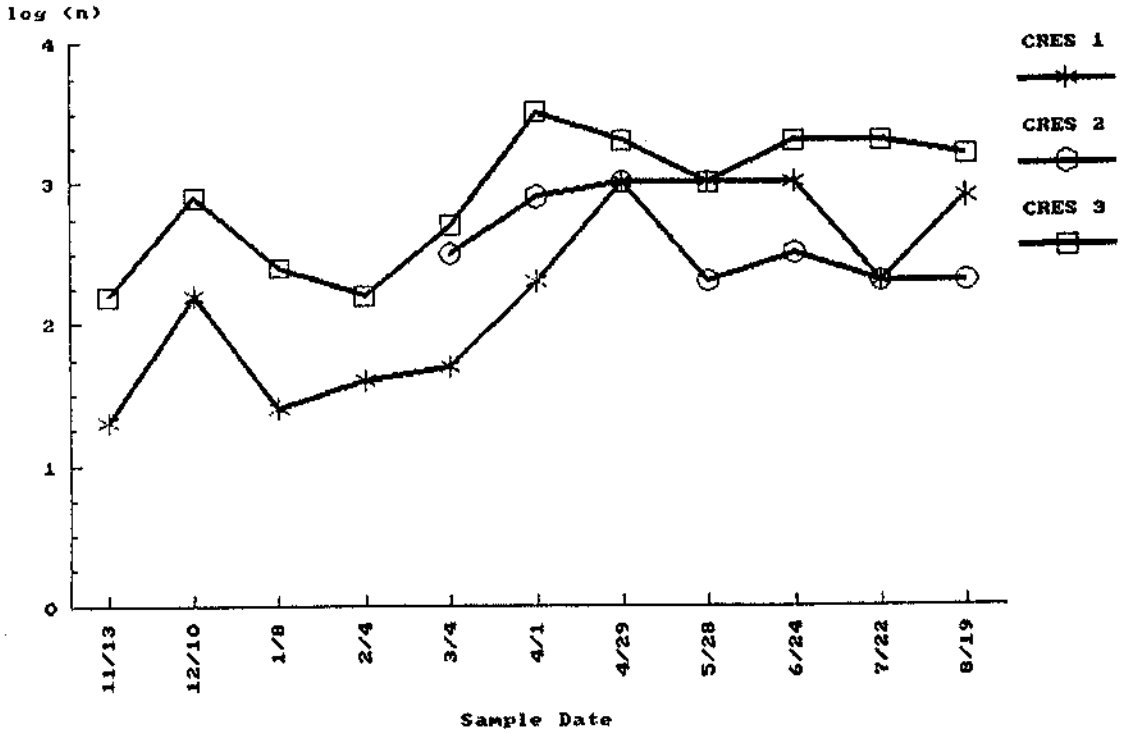
Field observations of this area indicate little influence from residential or agricultural activities. However, construction of a large residential development was just beginning during the study period. Data for each of the four bacterial groups by station are shown in Figures 86 and 87. These data indicate that the bacterial densities were generally lower at CRES 2 than at the CRES 1 or CRES 3 sites. No statistical differences were noted, however, for fecal coliform densities at any of the stations (Table 50), although total coliform densities differed significantly between CRES 1 and CRES 3 and between CRES 2 and CRES 3. Fecal streptococci densities were significantly different between CRES 1 and CRES 2 and between CRES 2 and CRES 3 but not between CRES 1 and CRES 3. SPC were significantly different only between CRES 1 and CRES 3. It appears that bacterial densities in the CRES pond were generally reduced below input concentrations. This may be attributable to dilution (the pond volume > stream volume), or settling of particulates, which serve as bacterial substrates, to the bottom of the pond. The return of bacterial densities to inflow concentrations at CRES 3 (the downstream station) suggests (a) that bacteria are being re-introduced into the system or (b) that the reduced volume of water at the outfall results in a concentration of bacteria. The CRES pond is known to have a bottom discharge which means that the pond overflows or is hydraulically pumped out from the bottom first. Bacterially enriched sediments may be resuspended and entrained in the pump-out water resulting in the higher densities at the downstream station. At the discharge point to the downstream station flow was often minimal, thus, higher densities are not an unexpected result.

For these stations fecal coliform to fecal streptococci (FC:FS) ratios of less than 1.5 (Table 51) suggest a natural background condition. At CRES 2 the ratio in August was approximately 3.0, quite different from all previous data. The fecal coliform density on that date was the highest recovered during the survey of the CRES stations; however, no source was identified.

QUIN Site

This site is a spring-fed system emptying into a stabilized impoundment which originally served as an agricultural pond. The bottom outflow from the pond empties into a continuation of the natural wooded stream. The pond is stocked with game fish. Field observations indicate that a house serviced by a septic tank was in the vicinity of QUIN 1. A pond and cattle were observed approximately one mile north of QUIN 1.

FIGURE 86. Densities of bacteriological groups by sampling date, CRES stations.
Standard Plate Count



Total Coliforms

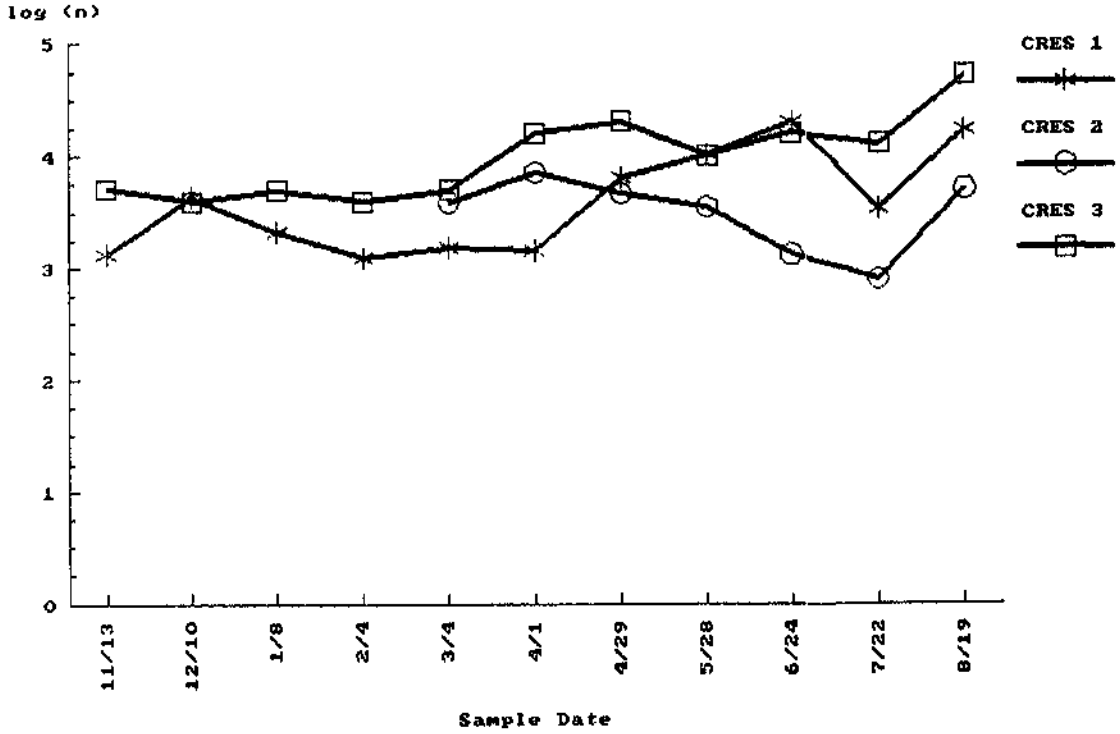
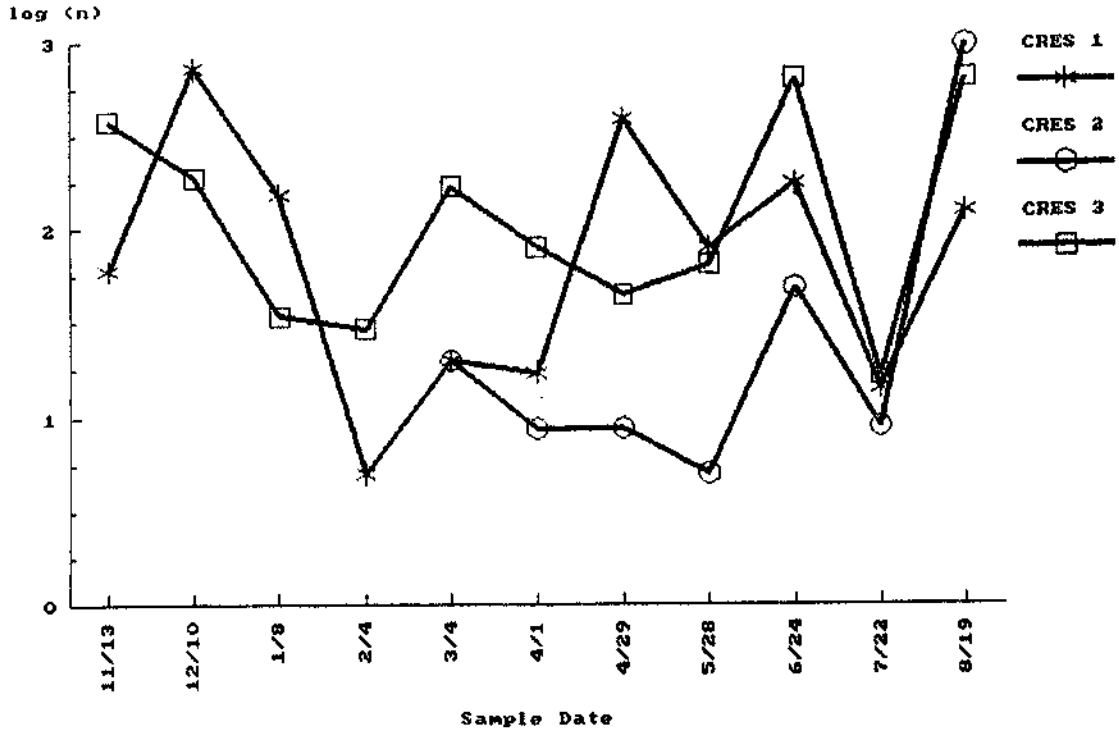


FIGURE 87. Densities of bacteriological groups by sampling date, CRES stations.
Fecal Coliforms



Fecal Streptococci

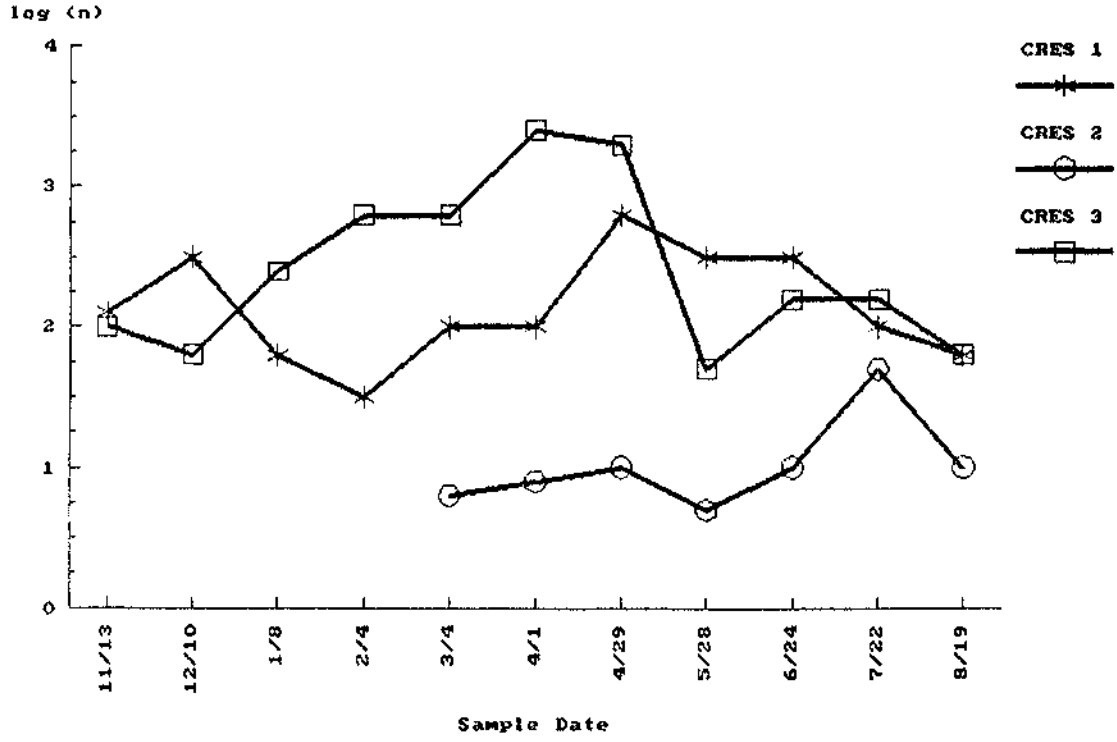


TABLE 50. P values ($p<.05$) for Student's t tests for station pairs for each of the four bacterial groups.

STATION COMPARISON	FC	TC	FS	SPC
QUIN 1 - QUIN 2	.0000	NS	.0028	NS
QUIN 1 - QUIN 3	.0025	NS	.0000	NS
CRES 1 - CRES 2	NS	NS	.0000	NS
CRES 1 - CRES 3	NS	.026	NS	.018
CRES 2 - CRES 3	NS	.0099	.0000	NS
MOSS 1 - MOSS 2	.0008	NS	.0000	NS
MOSS 1 - MOSS 3	.0054	.0019	.0000	NS
MOSS 1 - MOSS 4	.021	.0000	NS	NS
MOSS 1 - MOSS 5	NS	NS	.013	NS
MOSS 2 - MOSS 3	NS	.015	NS	NS
MOSS 2 - MOSS 5	.0000	NS	.0000	NS
MOSS 3 - MOSS 4	NS	NS	NS	NS
MOSS 3 - MOSS 5	.0007	NS	.0000	NS
GADS 1 - GADS 3	NS	NS	NS	NS

FC - fecal coliform
TC - total coliform
FS - fecal streptococci
SPC - standard plant count bacteria

TABLE 51. Fecal coliform to fecal streptococci ratios by station and date.

DATE	QUIN 1	QUIN 2	QUIN 3	CRES 1	CRES 2	CRES 3
11/13/85	0.60	---	0.06	0.86	---	1.27
12/10/85	1.36	---	1.27	1.16	---	1.29
1/8/86	0.85	0.56	0.65	1.21	---	0.63
2/4/86	0.86	0.20	0.81	0.48	---	0.53
3/4/86	0.89	0.42	0.63	0.66	1.62	0.80
4/1/86	0.75	0.32	0.43	0.61	1.00	0.57
4/29/86	1.00	0.70	1.96	0.94	0.94	0.50
5/28/86	1.00	1.00	1.00	.077	1.00	1.07
6/24/86	1.11	1.52	2.10	0.91	1.69	1.27
7/22/86	0.59	1.00	0.75	0.58	0.58	0.56
8/18/86	0.88	0.93	1.88	1.14	2.98	1.52

DATE	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5	GADS 1	GADS 3
11/13/85	1.04	0.00	0.00	0.04	1.00	---	---
12/10/85	1.06	2.45	4.76	1.09	1.08	0.91	0.53
1/8/86	1.03	1.89	0.82	1.26	1.04	0.45	0.83
2/4/86	1.03	0.66	1.59	1.31	1.05	0.73	0.42
3/4/86	1.17	1.00	1.33	1.69	1.28	0.79	1.01
4/1/86	1.11	.085	1.00	0.63	1.04	0.29	0.58
4/29/86	0.84	1.00	1.22	0.50	0.60	0.55	0.96
5/28/86	0.94	1.20	1.22	---	0.76	0.22	0.81
6/24/86	0.94	4.04	2.69	1.47	0.79	0.77	0.87
7/22/86	0.86	0.85	2.45	---	0.91	0.77	0.73
8/18/86	1.18	2.21	2.05	---	1.21	1.22	0.84

Concentrations of total coliform bacteria and SPC bacteria indicate a fairly consistant and high level of bacteria being introduced at QUIN 1 and maintained throughout the system (QUIN 2 and QUIN 3). No significant differences between the upstream and pond (QUIN 1-QUIN 2) or the upstream and downstream (QUIN 1-QUIN 3) concentration of either total coliform bacteria or total aerobic plate counts were noted.

For fecal coliform densities, concentrations at QUIN 2 were consistently lower than either upstream (QUIN 1) or downstream (QUIN 3). A similar but less striking trend was noted for fecal streptococci. Downstream (QUIN 3) concentrations approximated those recovered from the pond (QUIN 2). Both fecal coliform and fecal streptococci concentrations were significantly different for upstream vs. pond (QUIN 1-QUIN 2) and for upstream vs. downstream (QUIN 1-QUIN 3). Thus, it appears that fecal coliform bacteria are being reintroduced into this system below QUIN 2. It is reasonable to speculate that the bottom discharge in close association with the highly bacterially enriched bottom sediments, may, as at the CRES site, be picking up resuspended bottom sediment with its associated bacteria in the discharge water.

GADS Site

Only two locations were sampled at this site - upstream (GADS 1) and downstream (GADS 3). Tree clearing in the pond area occurred in November. Pond construction formally began in late June but the site was not impounded during the course of this study.

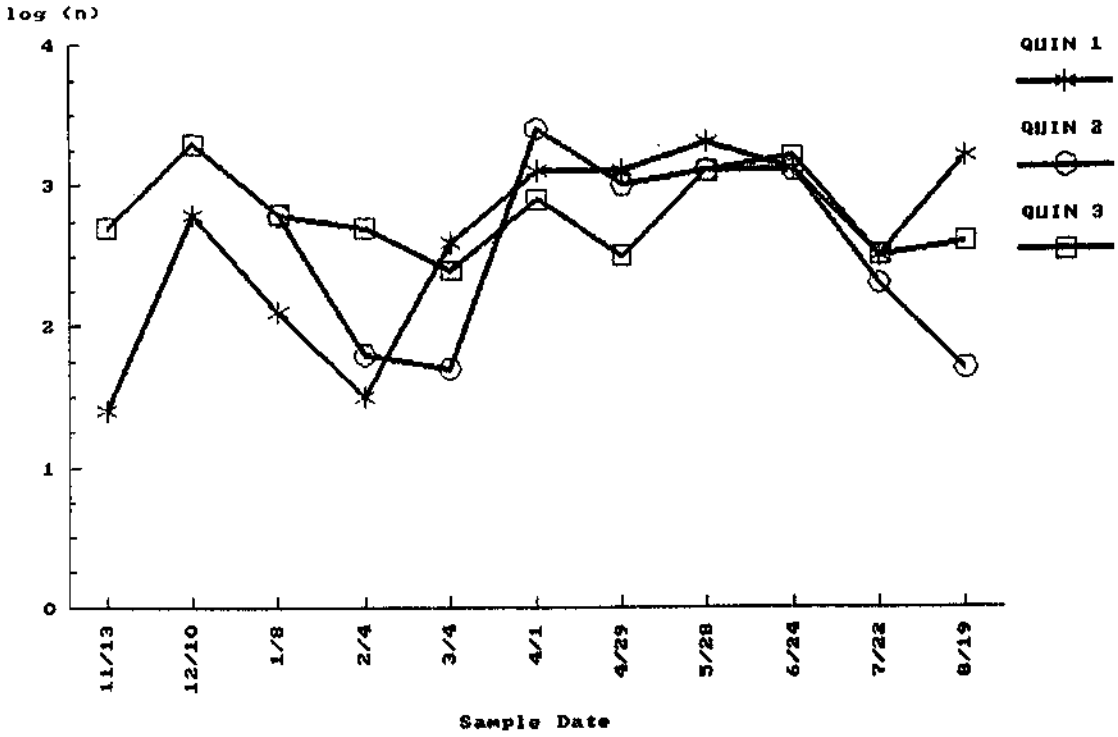
It is interesting to note that although no statistically significant differences were noted between GADS 1 and GADS 3 for any of the four groups of bacteria identified, a reversal of trends occurred after March 4 when concentrations of all bacteria at GADS 3 became consistently higher than at GADS 1 (Figures 90 and 91). This trend may be associated with the increased sediment disturbance as a result of the pond construction.

MOSS Site

The MOSS location was the most complex of the four areas studied. As noted in the description of this area (Table 1, Figure 5), the upstream (MOSS 1) empties into the first of two ponds (MOSS 2), overflows to the second pond (MOSS 3) and discharges to the downstream station (MOSS 4). Station MOSS 5, designated as a control station, was located on an adjacent stream, independent of the MOSS 1-MOSS 4 system. Field observations of this area noted that both ponds were potentially influenced by a few cattle and by septic tank leachates from the nearby residential community.

Data for each of the four bacterial groups are shown in Figures 92 and 93. From the data, fecal coliform densities were significantly reduced between MOSS 1 and MOSS 2 and remained that way through MOSS 3 and 4. Two peaks in the fecal coliform density were noted, on 10 December and on 24 June. Coliform densities for these dates, reviewed as FC:FS ratios,

FIGURE 88. Densities of bacteriological groups
by sampling date, QUIN stations.
Standard Plate Count



Total Coliforms

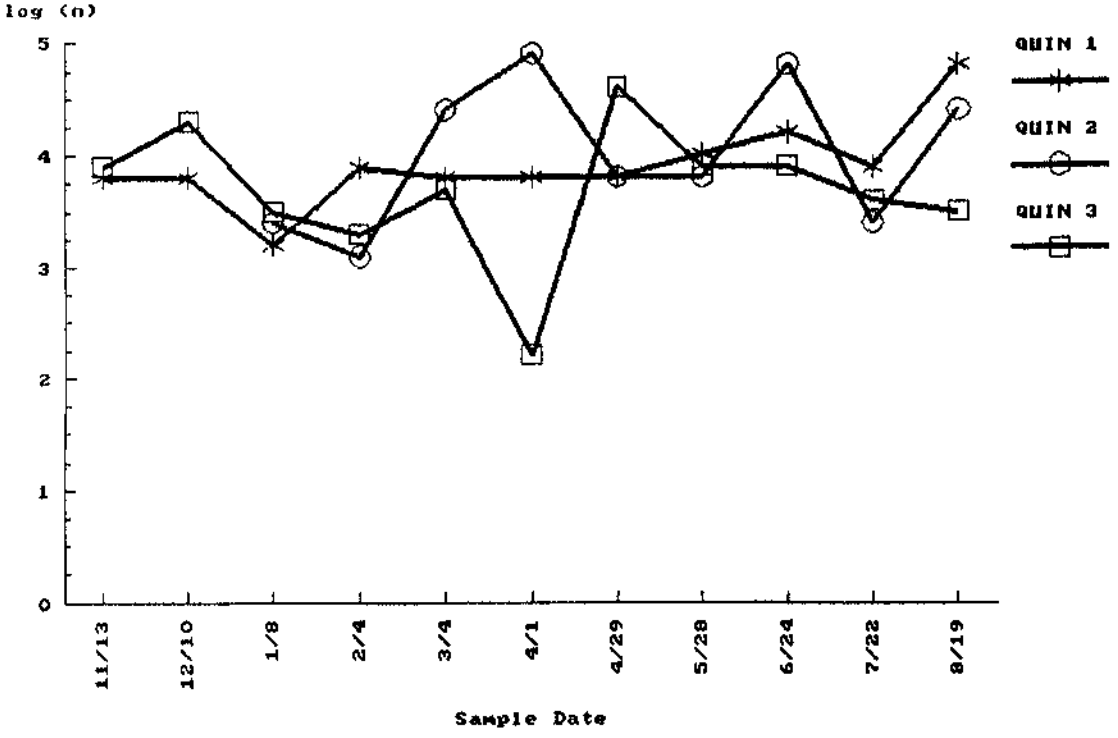
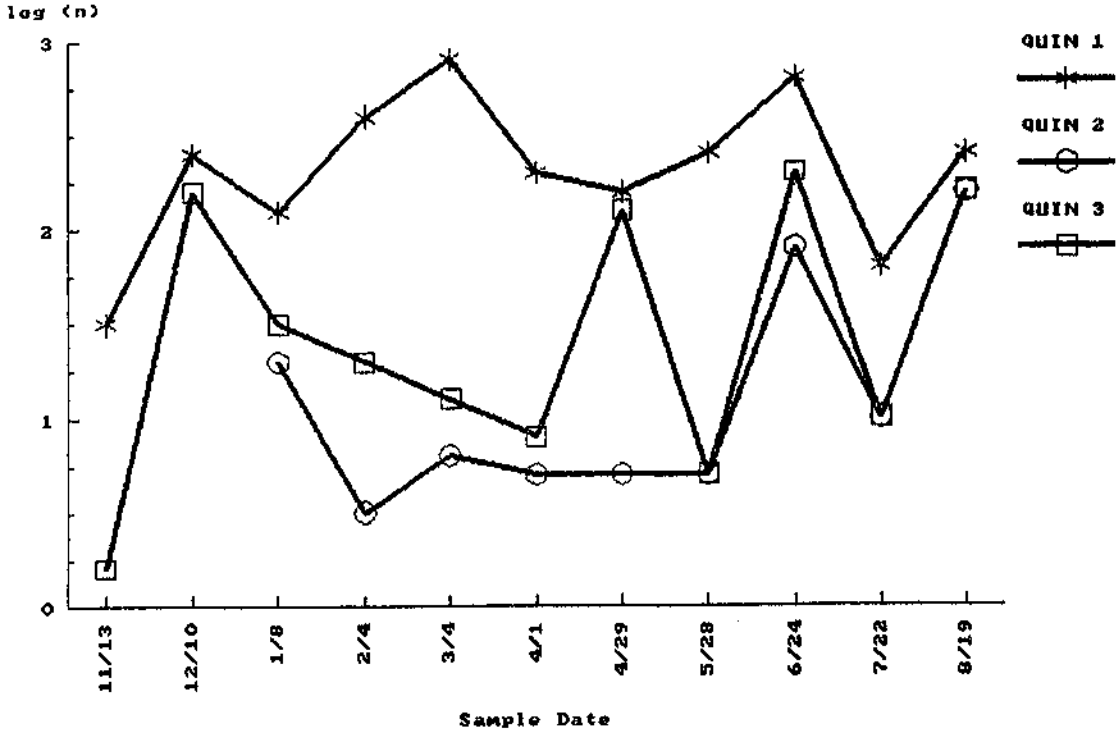


FIGURE 89. Densities of bacteriological groups by sampling date, QUIN stations.
Fecal Coliforms



Fecal Streptococci

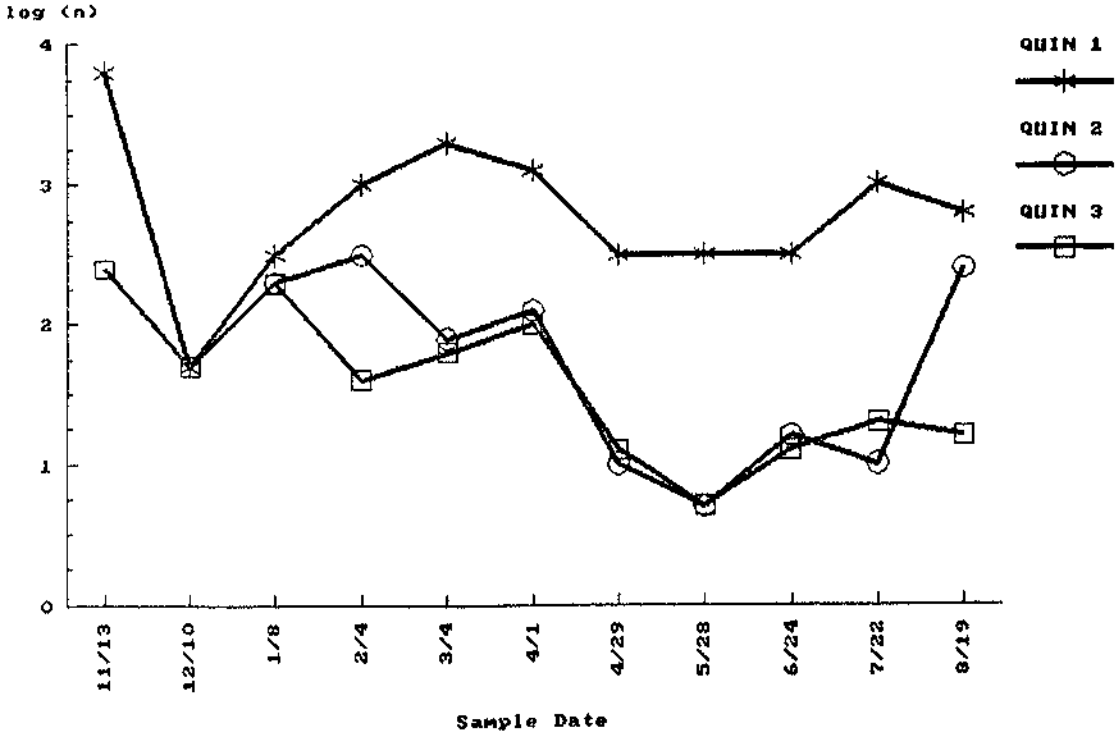
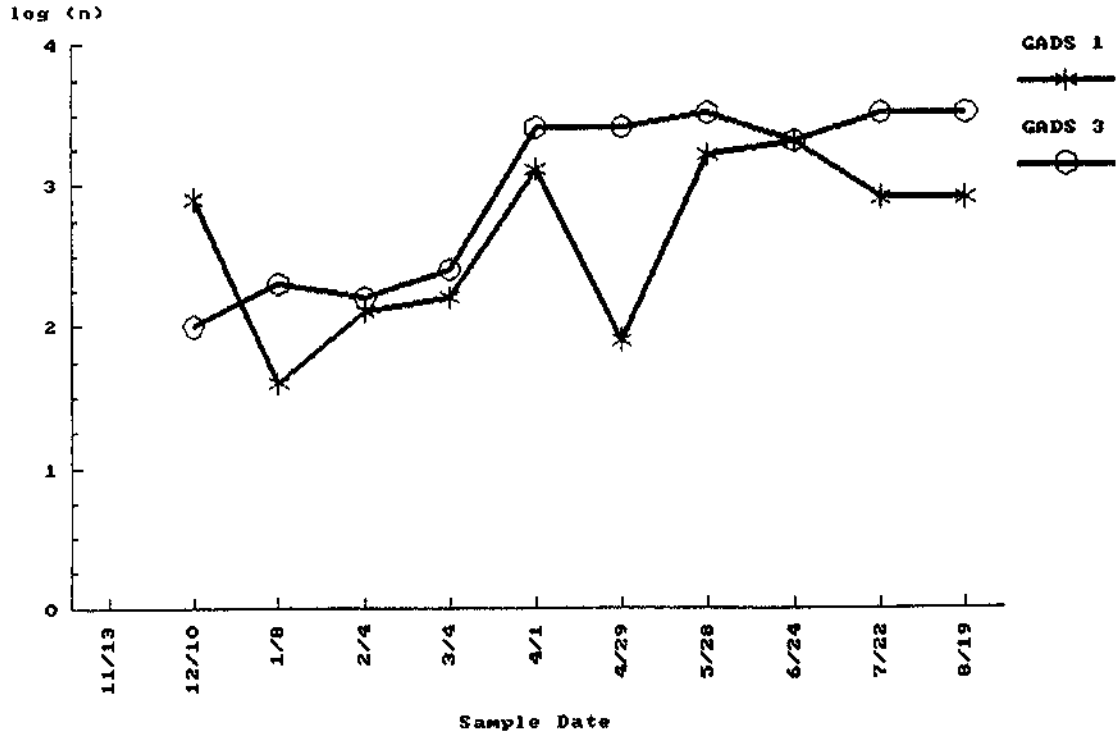


FIGURE 90. Densities of bacteriological groups
by sampling date, GADS stations.
Standard Plate Count



Total Coliforms

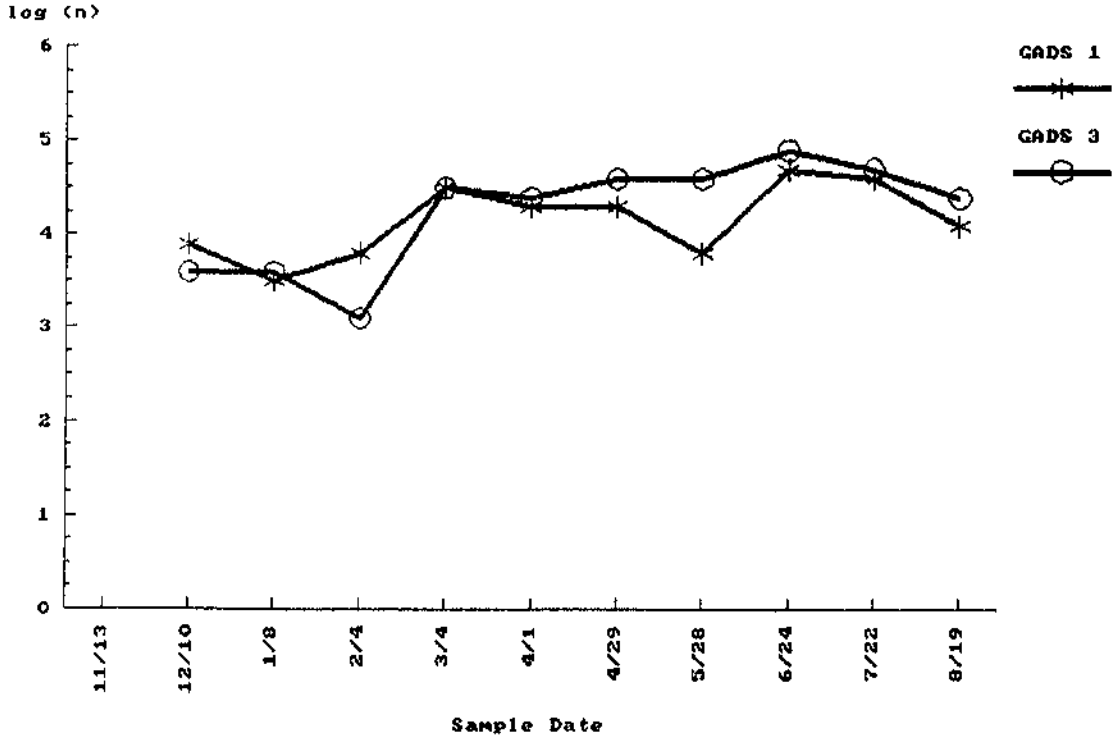
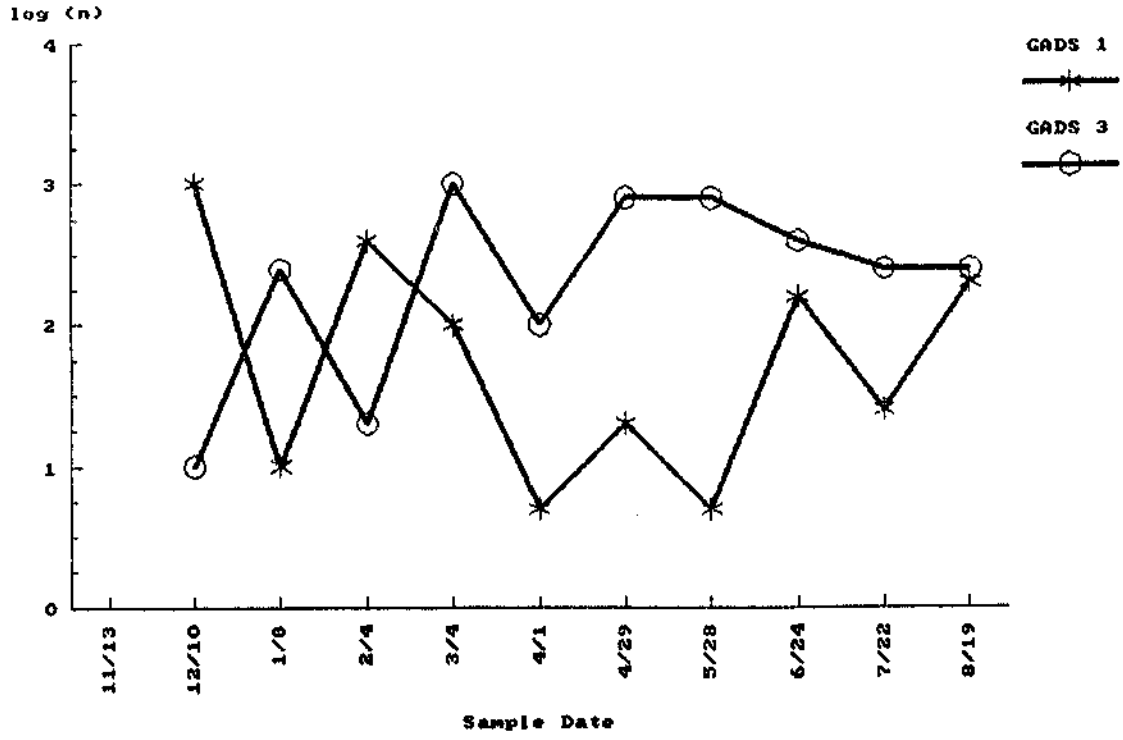


FIGURE 91. Densities of bacteriological groups by sampling date, GADS stations.
Fecal Coliforms



Fecal Streptococci

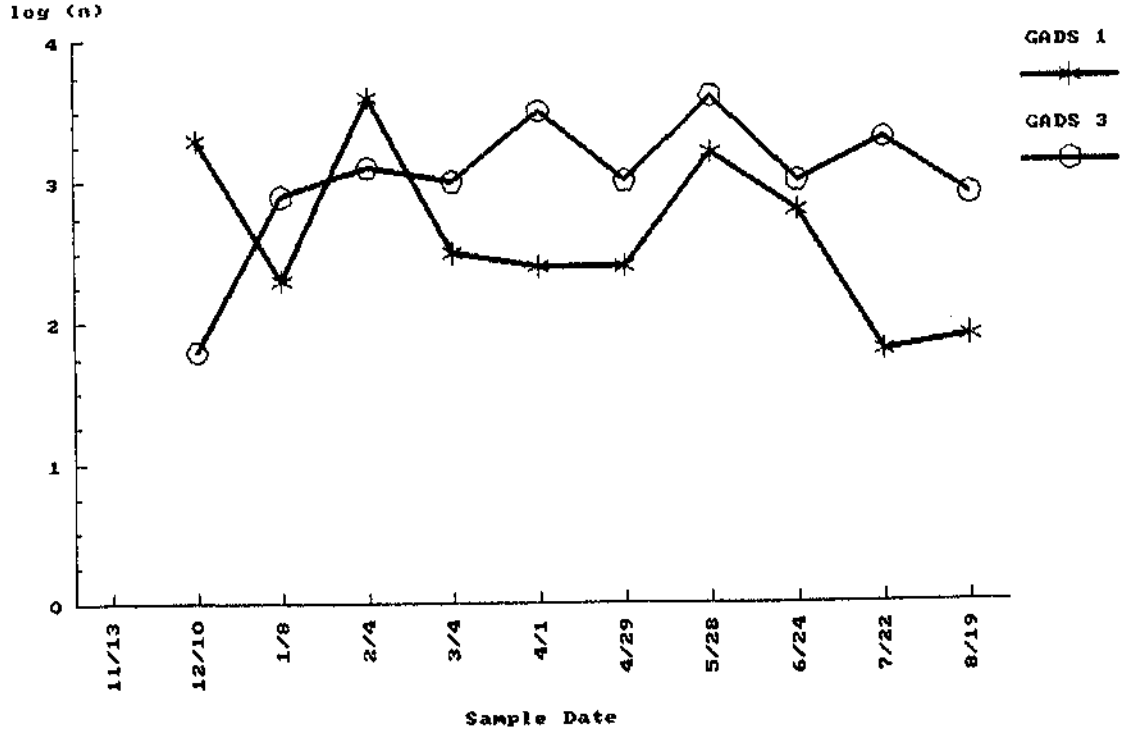
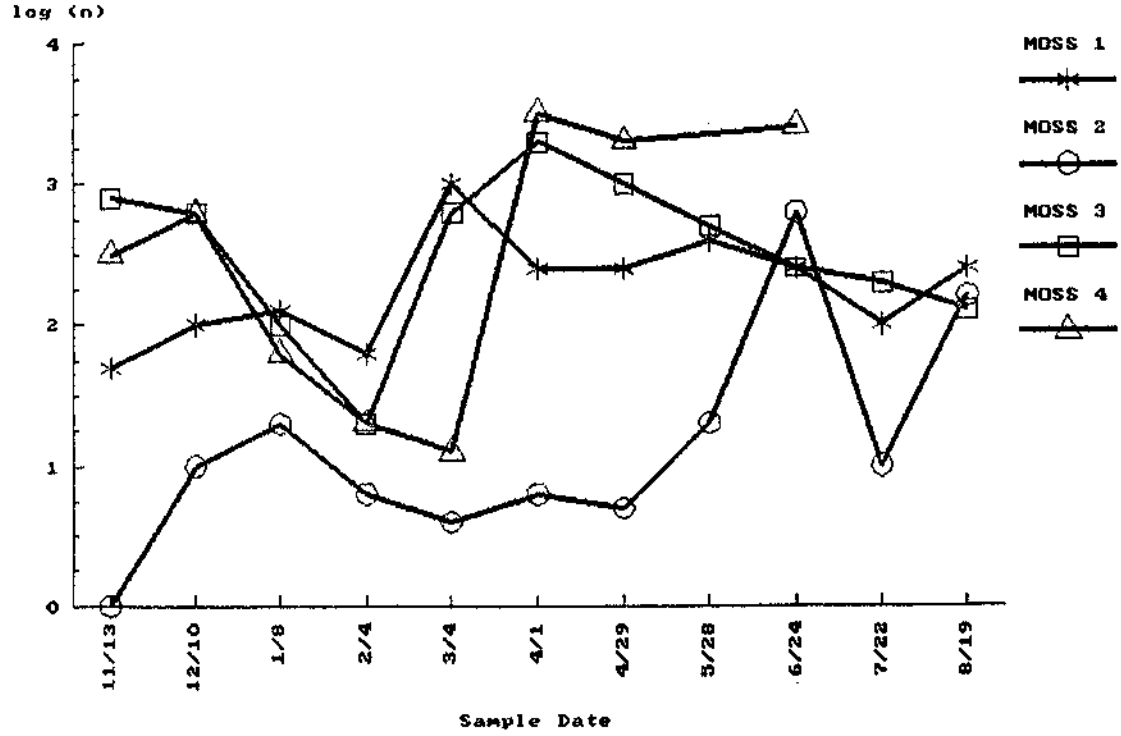


FIGURE 92. Densities of bacteriological groups
by sampling date, MOSS stations.
Standard Plate Count



Total Coliforms

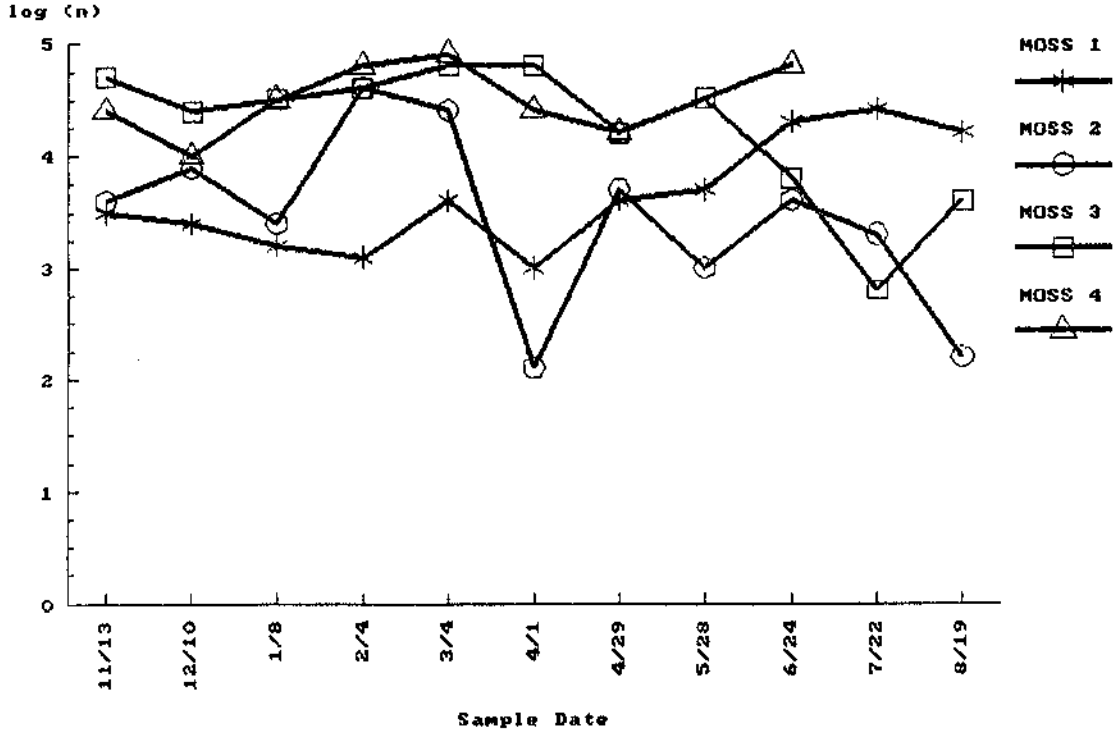
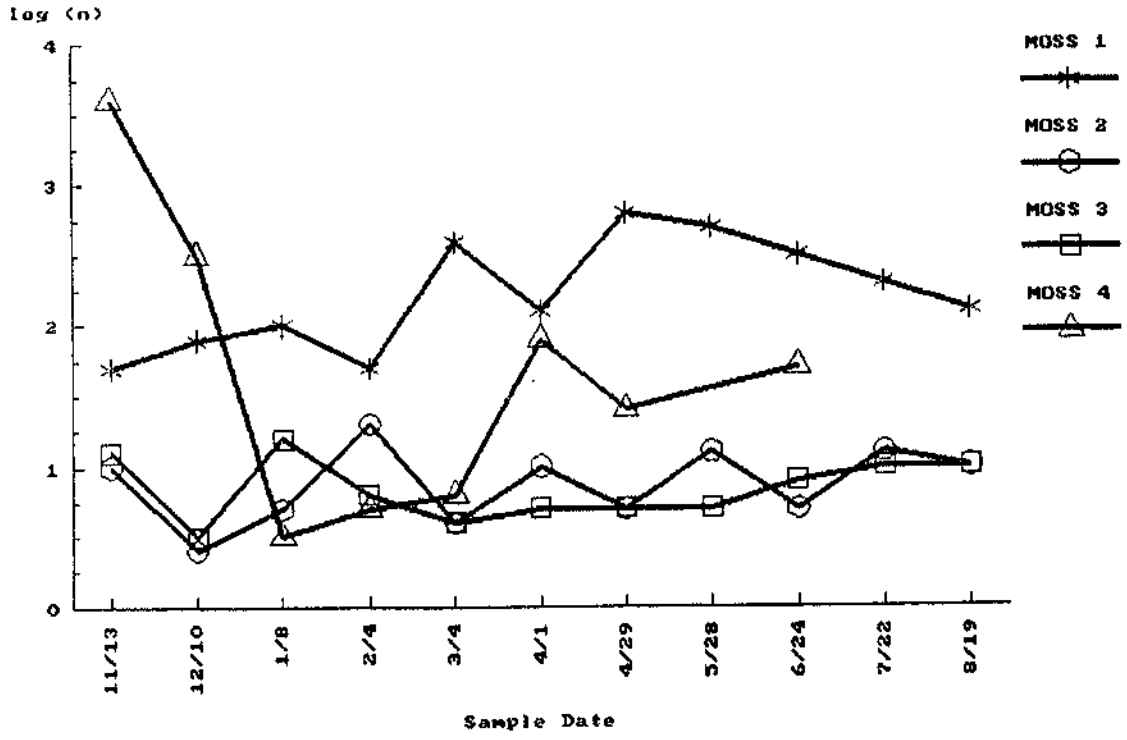
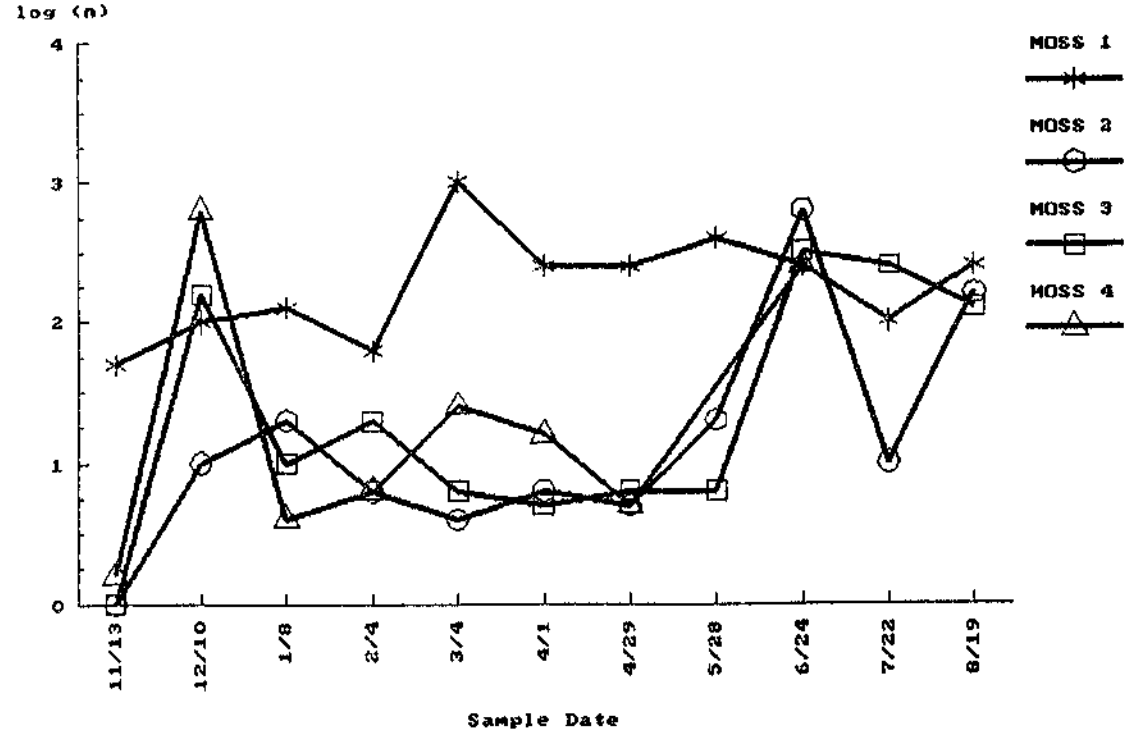


FIGURE 93. Densities of bacteriological groups by sampling date, MOSS stations.
Fecal Streptococci



Fecal Coliforms



appear to reflect a human associated discharge, i.e. a ratio greater than 4.0. It is interesting to note that on 10 December the primary impact was observed at MOSS 3, the second pond, although at MOSS 2 the FC:FS ratio was also slightly elevated. On 24 June the primary impact was to MOSS 2, the first pond, with a secondary impact noted at MOSS 3. The source of the fecal coliform bacteria was not identified in either of these cases. With the exceptions cited above, the ponds appear to reduce the densities of fecal coliform. Downstream (MOSS 4) densities appear consistent with those identified in the two ponds (MOSS 2 and MOSS 3).

Data for total coliform densities suggest that MOSS 1 is not the major contributor of these bacteria to the ponds. Densities of total coliforms were greater at MOSS 2 than at MOSS 1 but less than at MOSS 3 which suggests that local runoff to the ponds, particularly to MOSS 3, introduce significant numbers of total coliform bacteria (Table 50). These organisms appear to be predominantly soil associated (see fecal coliform discussion). Station MOSS 4 reflects the carry over of total coliform densities from the pond (MOSS 3).

In general, trends in the fecal streptococci data were similar to those of the fecal coliform data. The greatest fecal streptococci densities were noted at MOSS 1, and reduced in both MOSS 2 and MOSS 3. At MOSS 4 densities were similar to those in the ponds with the exception of samples taken in November and December. Fecal coliform-fecal streptococci ratios (FC:FS) suggest the influence of domestic animals directly to or in close proximity to MOSS 4. This, however, was not confirmed by field observers on the days of sampling.

Trends in the standard plate count (SPC) were similar for all the stations. It appears that the total bacterial input as measured by the SPC is consistent throughout this system and the variation of densities over time are related to environmental factors affecting the system, such as rainfall and runoff.

Data for station MOSS 5, chosen as a control, was consistent with MOSS 1. Based on the geographical descriptions of MOSS 1 and MOSS 5, this was not unexpected. The only significant difference between MOSS 1 and MOSS 5 (Table 50), was in the fecal streptococci densities. This appears to reflect the impact of the predominant historical (agricultural) use on the MOSS 1-MOSS 4 system.

MASS Sites

In addition to the FREQUENCY stations, thirteen areas (thirty-five stations) were sampled. Since only four months of data are available, no statistical analyses were done on these data above. They were incorporated into a composite data set for an evaluation of trends, of water quality violations, and of the association with selected physical-chemical parameters.

Composite Data

An investigation of the overall trends was conducted after the data were normalized by the frequency of sampling. Specifically, each station was adjusted by the number of sampling points available resulting in an average density per sampling. Thus bias as a result of different numbers of samples among FREQUENCY and MASS stations was eliminated.

Upstream bacterial densities for all four groups were greater than both pond and downstream (Table 52). The bacterial densities in ponds, as an average, were the lowest reported values. The downstream values were less than upstream densities but greater than those of the pond. From this observation, (Table 53) ponds appear to be reducing upstream bacterial densities, particularly fecal coliform and fecal streptococci bacteria. The increase in bacterial densities from the pond to downstream waters suggests a low level re-introduction of total and fecal coliform bacteria and total aerobic bacteria and a high level re-introduction of fecal streptococci bacteria. One might argue that the elevated downstream densities reflect indigenous populations from the downstream station rather than contributions of the pond's discharge. This argument could not be dismissed since one might reasonably expect upstream and downstream densities to be similar, in the absence of a pond structure. However, from the data in Table 53, it appears that downstream densities were lower than upstream. Thus ponds may serve to decrease bacterial densities below upstream values and the increase of bacteria noted in downstream waters, regardless of source, is still lower than the original upstream densities.

Water quality violations of the bacteriological parameters listed in FAC 17-3 were also investigated (Table 54). From a review of these data, the frequency of violation appears to be similar for, a) each of the sampling locations and b) by individual criterion. This information suggests that although ponds appear to reduce bacterial densities this reduction does not significantly reduce the number of water quality violations.

Recent evidence has shown that recoverable bacterial densities are affected by a variety of environmental factors (Faust et al. 1975) and that sedimentation of clay, silt, and organic particulate matter results in high levels of bacteria removed from the water column to the sediments (Burton 1985). For this reason, Pearson's correlation coefficients were determined among the four bacterial parameters and other selected environmental parameters (Table 55). Conductivity was found to be strongly correlated with the occurrence of all four groups of bacteria. Since these bacteria are known to survive in freshwater this was not an unexpected result.

Based on the trends noted at individual stations, turbidity and/or total suspended solids were anticipated to be highly correlated to coliform bacterial recoveries. This, surprisingly, was not confirmed.

TABLE 52. Mean bacterial densities (log) on composite data normalized by frequency of collection for upstream, pond, and downstream locations.

	FC	TC	FS	SPC
Upstream	2.1305	3.8650	2.1345	2.6782
Pond	1.5899	3.5566	1.1978	2.4202
Downstream	1.6149	3.6755	1.7304	2.6033

TABLE 53. Percent of change between locations for each bacterial group.

	FC	TC	FS	SPC
Upstream to Pond	-25.37	-7.98	-43.88	-9.63
Pond to Downstream	+1.57	+3.34	+44.45	+7.57
Upstream to Downstream	-24.20	-4.90	-18.93	-2.79

TABLE 54. Percent frequency of violation of bacteriological water quality standards.

	TC		FC		
	2400	1100	800	400	200
Upstream	75	87	14	20	42
Pond	71	75	8	20	32
Downstream	68	75	14	22	30

TABLE 55. Pearson correlation coefficients for bacterial parameters and selected physical parameters. (Each correlation record contains the following information: the correlation, the number of cases in parentheses, and the significance as p = .)

	STA	DATE	FC	TC	FS	SPC	TURB	TSS	PH	COND
STA	1.0000 (143) P= .001	.0000 (143) P= .500	.1269 (132) P= .073	.2463 (132) P= .002	.1658 (132) P= .029	.0299 (132) P= .367	.0696 (132) P= .214	.0136 (132) P= .438	.3213 (132) P= .001	.4261 (132) P= .001
DATE		1.0000 (143) P= .001	.0422 (132) P= .315	.0554 (132) P= .264	.0050 (132) P= .477	.1444 (132) P= .049	.2183 (132) P= .006	.0339 (132) P= .350	-.1385 (132) P= .057	.1382 (132) P= .057
FC			1.0000 (132) P= .001	.0637 (132) P= .234	.4773 (132) P= .001	.1544 (132) P= .039	-.1011 (132) P= .124	-.0444 (132) P= .307	-.0576 (132) P= .256	.2053 (132) P= .009
TC				1.0000 (132) P= .001	.1028 (132) P= .120	.3405 (132) P= .001	.0747 (132) P= .197	.1021 (132) P= .122	.2684 (132) P= .001	.2438 (132) P= .002
FS					1.0000 (132) P= .001	.2466 (132) P= .002	.1226 (132) P= .081	.0623 (132) P= .239	.1517 (132) P= .041	.3691 (132) P= .001
SPC						1.0000 (132) P= .001	.2897 (132) P= .001	.1983 (132) P= .011	.0399 (132) P= .325	.2848 (132) P= .001
TURB							1.0000 (132) P= .001	.6588 (132) P= .001	.1403 (132) P= .054	.2992 (132) P= .001
TSS								1.0000 (132) P= .001	.1100 (132) P= .105	.1776 (132) P= .021
PH									1.0000 (132) P= .001	.4932 (132) P= .001
COND										1.0000 (132) P= .001

Heterotrophic bacteria, measured as SPC, were, however, strongly correlated with both turbidity and total suspended solids. Thus it appears that the general bacterial burden to the impoundment system can be correlated to turbidity and to a lesser degree total suspended solids. The introduction of selected groups, i.e., the coliforms, appears to be from sources other than runoff or local influences, i.e. leachates.

SUMMARY

Conclusions regarding this portion of the study are limited. It is apparent that the geographical charactistics and local differences in the type of impoundment affect the recovery of the various bacteria studied. The occurrence and fate of the bacteria depends upon the sources to the system and the characteristics of the pond's structure.

However, the following summary observations are offered:

1. Local factors, i.e, geographical area sources, greatly affect the occurrence and recovery of the four bacterial groups studied at an individual location.

2. Ponds based on (composite data) appear to reduce all four groups of bacteria below upstream densities. Subsequent downstream densities, although lower than upstream densities, are slightly elevated above pond densities.

3. When compared to upstream densities ponds appear to reduce bacteria associated with fecal pollution.

4. Although ponds appear to reduce bacteria associated with fecal pollution, the frequency of water quality violations remains unchanged.

ZOOPLANKTON

INTRODUCTION

Investigation of zooplankton community structure and seasonal succession can provide useful information on trophic state, water quality, and on the cycling of dissolved organic matter, phosphorus and other nutrients (Gannon and Stemberger 1978, Sprules 1977). Zooplankton grazing on epilimnetic bacteria have been shown to account for as much as 60% of daily bacterial productivity, and as much as 10% of the annual bacterial productivity (Pedros-Alio and Brock 1983). This, combined with the importance of heterotrophic bacteria in the cycling of dissolved organic matter (Spittler and Gubusch 1979), makes zooplankton grazing on bacteria an important link in the conversion of dissolved organic matter into higher forms.

Zooplankton are also important consumers of phytoplankton. In some instances, it has been shown that larger populations of large-bodied cladocerans can reduce the quantity of chlorophyll a (chl a) independently of changes in total phosphorus (TP). While this effect is not generally considered to be of sufficient magnitude to result in a change in trophic state, it can bias regression analysis of chl a on TP, a relationship which is the basis of current eutrophication modeling (Pace 1984). Predation on zooplankton by fishes and other zooplankton (notably Cyclops spp.) leads to seasonal succession of resistant prey species. This, in turn, can influence the population structure of phytoplankton (Stemberger and Evans 1984).

Zooplankton may also be used as indicators of water quality (Patalas 1972). Gannon and Stemberger (1978) showed the correlation between zooplankton community structure and trophic state in mesotrophic lakes, with particular emphasis on the ratio of calanoid copepods (e.g., Diaptomus) to other groups. Zooplankters are larger and easier to identify than phytoplankton, and appear to respond more quickly to environmental changes than fishes.

The present study involved the sampling of ponds of differing degree of eutrophy, but with many similarities in geography, hydrology, morphometry, water chemistry, and utilization practices. Thus, the effects of trophic state on zooplankton community structure and seasonal succession can be compared.

METHODS AND MATERIALS

Samples from impoundments were collected by vertical hauls from just above the bottom to the surface, using a conical plankton net of 11.25 cm diameter, 56.25 cm length, and 80 u mesh size (Wildco #40-B10). Samples from streams flowing into ponds were collected by pouring a measured volume (20 l) of water from the stream through the net. Separate samples were taken for macrozooplankton (copepods and cladocerans) and rotifers.

Macrozooplankton samples were preserved in a sucrose-formalin solution (Haney and Hall 1973). Rotifers were anesthetized with carbonated water (5% of total sample volume added 10 minutes prior to sample preservation with sucrose-formalin solution (R. Bienert, personal communication).

Macrozooplankton were identified under a dissecting microscope using a plexiglass counting wheel (Ward 1955), and under a compound microscope using specimens mounted on slides with CMC mounting media. Macrozooplankton were identified to species, where possible, using references listed in the Literature Cited. When available, a total of at least 100 macrozooplankton were identified. Samples were split using the bubbling pipet method of McCallum (1979). Samples from some streams with extremely depauperate fauna had less than 100 macrozooplankters in the entire volume sampled. In these instances, the entire sample was examined and all macrozooplankton counted and identified.

Rotifers were identified under an inverted binocular microscope (Wild M-40) using an Ütermöhl cell, into which a measured amount of sample was placed. The contents of the cell were allowed to settle for 5 minutes, the entire area of the cell was examined, and all rotifers counted and identified to genus. A total of 100 or more rotifers was identified where possible, except in the depauperate stream samples, where the total number of rotifers in 6 ml of concentrated sample was counted and identified. Rotifers were identified using references listed in the Literature Cited.

RESULTS AND DISCUSSION

Diversity

Shannon-Weaver diversity index values ($\bar{d}$) were calculated for zooplankton at all pond stations and selected stream stations, and comparisons of pond to pond values, pond vs. stream values, influent stream to control stream and change in diversity index ($\Delta\bar{d}$) were performed. Results of these comparisons show that the number of taxa generally increases when a stream is impounded, but due to the frequent predominance of one or a few taxa, the value for $\bar{d}$ does not increase correspondingly or may even decrease. The values for $\bar{d}$ over the course of this project ranged from 0.5 (Station B1) to 3.6 (Station G1) among the MASS sampling stations, and from 0 (CRES 1 and MOSS 1) to 3.7 (MOSS 1) at the FREQUENCY sites. Average $\bar{d}$'s, along with ranges over the sampling period, are given in Table 56 for FREQUENCY and Table 57 for MASS stations.

It is difficult to determine the effect of impoundment on diversity and abundance from $\bar{d}$ due to natural shifts and fluctuations in zooplankton populations. Seasonal succession in zooplankton plays a greater role in determining annual diversity and abundance levels than it does for benthic macroinvertebrates due to the increased effects of temperature on

TABLE 56. Zooplankton abundance, number of taxa, and Shannon-Weaver diversity index for FREQUENCY stations.

	#/LITER	RANGE #/l	MEAN # TAXA	RANGE #TAXA	MEAN $\bar{d}$	RANGE $\bar{d}$	POOLED $\bar{d}$
QUIN 1	3.33	0.25-5.47	7.18	3-13	2.183	.971-3.085	4.171
QUIN 2	1147.60	47.63-6359.68	15.33	12-22	2.538	1.097-3.396	3.822
QUIN 3	117.84	0.60-799.47	11.46	7-16	2.150	.966-2.648	3.731
CRES 1	3.74	0.45-26.35	6.91	1-13	1.708	0-2.948	3.597
CRES 2	238.06	0.64-597.44	10.57	3-15	2.113	1.320-3.015	3.327
CRES 3	1.72	0.20-5.95	6.33	3-15	1.853	.987-3.320	3.866
MOSS 1	28.13	0.25-113.90	11.46	1-28	2.102	0-3.718	4.331
MOSS 2	1187.8	81.55-9230.77	16.64	14-21	2.821	1.787-3.530	3.905
MOSS 3	2076.7	49.40-12133.70	14.82	9-20	2.511	1.387-3.238	3.824
MOSS 4	222.18	4.150-1239.60	15.75	8-25	2.750	2.007-3.716	4.053
MOSS 5	6.54	0.55-15.55	12.0	4-20	2.635	1.397-3.575	4.100
GADS 1	19.39	2.57-85.31	11.90	9-15	2.533	2.037-3.324	3.687
GADS 3	13.99	.500-106.52	7.80	2-15	2.078	.190-3.230	3.900

populations (Moore 1980a), and also because the life cycle of zooplankters is much shorter than that of benthic macroinvertebrates. This results in a less stable population structure over time, and may particularly bias $\bar{d}$ values as a result of short-term proliferation of a few taxa.

There is also a problem with comparing data of streams to that of ponds, due to their fundamental differences as habitats. Flowing water habitats tend to be shallow and predominated by marginal area, while lakes and ponds are often deeper and are characterized by open water. These differences favor the occurrence of larger numbers of zooplankton in ponds, even though there may not be a corresponding increase in the number of taxa encountered (Ruttner 1953, Hynes 1970).

Finally, zooplankton (and phytoplankton, as well) frequently have considerable variation in their horizontal distribution, i.e., patchiness (Wetzel 1975). This patchiness most frequently results from wind (George and Edward 1976), but may also be influenced by vertical migration patterns and the internal seiche of the body of water (Kamykowski 1978). This patchiness may result in large sampling errors both from the mean population on the sampling date, and from month to month. Non-randomness of distribution of benthic macroinvertebrates does occur, but presents less of a problem, because, being substrate-oriented, they are minimally affected by the two primary forces controlling zooplankton distribution (wind and internal seiche).

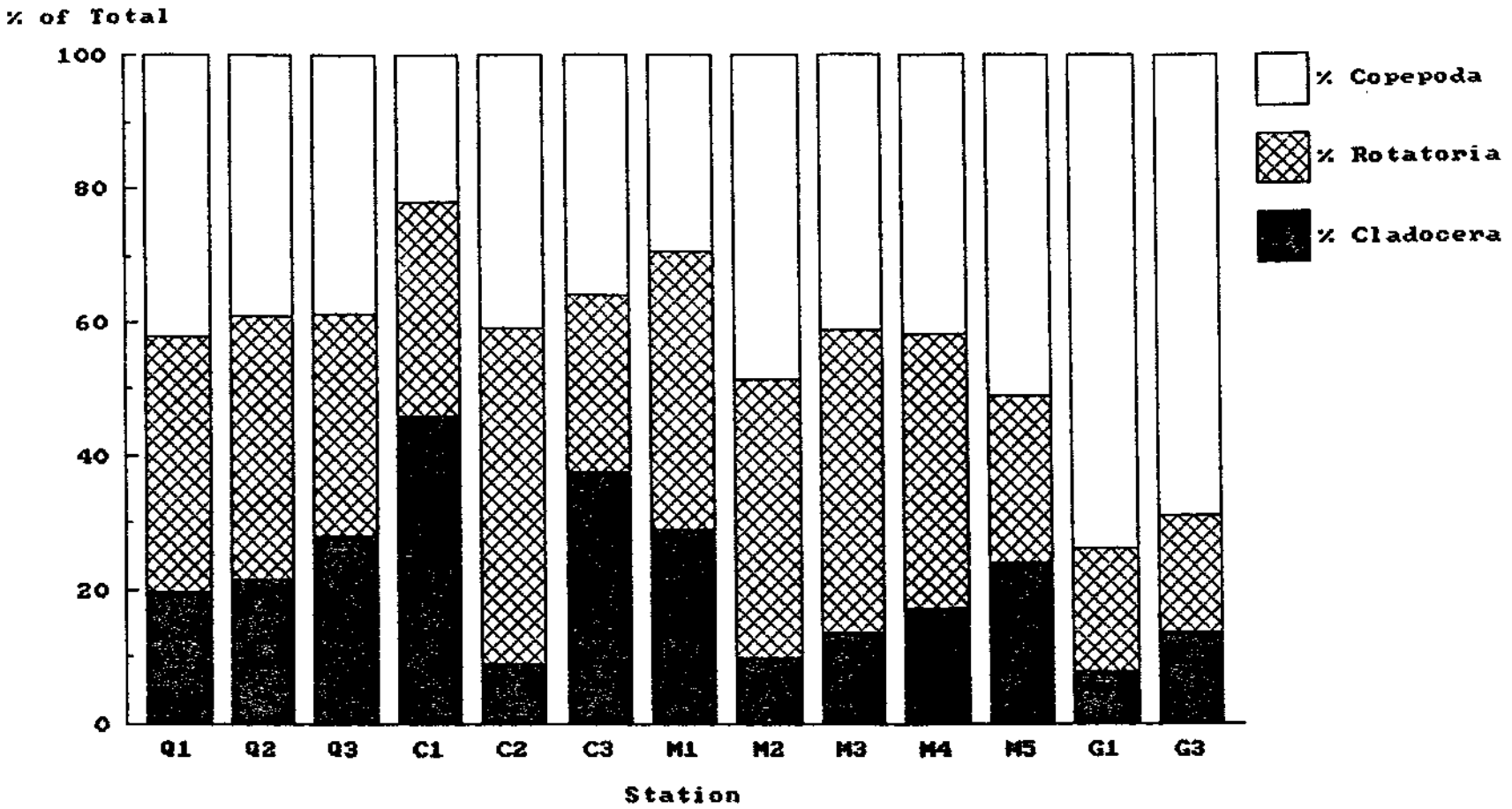
Community Structure-FREQUENCY Stations

Comparison of population data (mean number of organisms/liter, mean number of taxa, and pooled $\bar{d}$) for the thirteen FREQUENCY stations showed that all values for all three parameters increased from influent stream to pond, and then decreased from pond to effluent stream (with the exception of a small increase in $\bar{d}$ from the MOSS 3 pond to the MOSS 4 effluent stream) (Table 56). The values recorded for the effluent streams were generally higher than those seen in the influent streams. This may be an artifact of the proximity of some effluent stream stations to the pond's outfall. This proximity might not allow the zooplankton assemblage to change as a result of the change from pond to stream habitat (Hynes 1970).

Comparison of data charting percent composition by group (Cladocera, Rotatoria, Copepoda) for the FREQUENCY stations (all dates combined) reveal that Cladocera always made up a greater percentage of the assemblage in the influent stream samples than in the pond samples (Figure 94). This can probably be explained by the preference of many cladocerans (particularly chydorids) for littoral, vegetated habitats over open water (T. Crisman, University of Florida, personal communication).

Overall percent composition data for copepods and rotifers shows greater stability between streams and impoundments. Rotifer abundance was quite consistent within each station group, with the exception of the effluent stream at the CRES group of stations. There was a sharp drop in

FIGURE 94. Percent composition of major zooplankton groups, FREQUENCY stations.



rotifer abundance, from 47% of total zooplankton to 19% between CRES 2 (pond) and CRES 3 (effluent stream). This may be explained by the fact that for the first four months of the survey, the stream at the CRES site had not been impounded, and during the entire course of this study there was a great deal of disruption of both the stream course itself and the watershed due to construction activity. Finally, low water levels and delta formation from sedimentation dramatically altered the stream bed at CRES 3, to such an extent that biological samples could not be obtained the last two months of the the survey. Thus, for six out of eleven sampling dates, it was not possible to take samples from both stations simultaneously. Copepod abundance data was also consistent within each station group, again with the exception of the CRES group of stations (Table 56).

Relative nutrient concentrations may also provide an explanation for some of the changes in diversity and abundance. Increases in the values of TKN, TP, and chl a at effluent streams over the levels found in the influent streams were observed at all but one site (Tables 6-9; Tables 33, 36, 39, and 42). It has been shown that nutrient enrichment of a body of water leads to an increase in the zooplankton population, but it is unclear how much of the increases seen in these ponds can be attributed to nutrient enrichment, and how much might be explained by external factors such as temperature or habitat differences (O'Brien and DeNoyelles 1974, Moore 1980a, 1980b, Ruttner 1953).

Community Structure - MASS Stations

Comparison of population data (mean number of organisms per liter, mean number of taxa, and pooled $\bar{d}$) for the eighteen MASS sampling stations indicated that the mean number of organisms/liter increased from influent stream to pond at each of the five sampling groups for which both stream and pond samples were taken (Table 57). In three of five cases the mean number of taxa increased from stream to pond (Figure 95), and in two of five instances the pooled $\bar{d}$ value rose from stream to pond. These results differ somewhat from those seen in the FREQUENCY sampling group of stations, in which values for all three parameters generally rose from influent stream to pond.

Percent composition data (Table 58) for the MASS stations show results similar to those obtained from the FREQUENCY data set, i.e., a decrease in the percentage of the population composed of cladocerans in ponds relative to streams. Percent composition data for copepods and rotifers, as was the case in the FREQUENCY stations, do not show any clear trends.

TABLE 57. Zooplankton abundance, number of taxa, and Shannon-Weaver diversity index for MASS stations.

	#/LITER	RANGE #/1	MEAN # TAXA	RANGE #TAXA	MEAN $\bar{d}$	RANGE $\bar{d}$	POOLED $\bar{d}$
A2	545.01	229.65-683.17	13.40	11-19	2.418	1.548-3.119	3.344
B1	12.80	0.45- 40.58	8.40	2-12	1.770	.503-3.036	2.824
B2	698.20	316.72-966.88	14.80	14-16	2.796	2.325-3.342	3.401
C2	1675.51	373.94-2930.41	14.40	12-18	2.735	2.467-2.894	3.748
D2	385.46	56.87- 821.88	13.20	11-15	2.561	2.087-3.257	3.837
E2	384.79	162.90-1008.52	14.20	10-17	3.336	1.713-3.704	3.544
F2	174.55	53.08-435.30	14.80	11-19	2.760	2.591-2.898	3.307
G1	11.96	9.50-20.26	15.00	9-18	3.062	2.194-3.581	4.143
G2	457.48	215.55-781.94	13.60	7-18	2.233	1.024-3.090	3.713
H1	58.70	7.60-179.81	14.80	12-19	2.982	2.353-3.272	3.719
H2	440.46	110.79-799.42	11.60	9-14	2.368	1.960-2.570	3.193
I1	21.40	5.13-41.62	10.25	8-13	2.278	1.042-3.086	3.736
I2	2938.30	134.63-6370.45	15.40	12-18	1.569	1.014-3.086	3.029
J2	502.43	57.68-1283.35	14.60	8-20	2.662	1.781-3.571	3.837
K2	651.45	15.93-1695.33	13.80	12-16	1.989	.044-2.966	3.177
L1	12.91	0.10-30.08	11.25	2-15	2.377	1.000-3.275	3.610
L2	314.12	137.99-654.57	13.00	12-14	2.837	2.662-3.106	3.439
M2	641.31	14.09-2083.87	12.40	9-14	2.095	1.378-2.716	3.082

FIGURE 95. Numbers of zooplankton taxa, MASS Stations.

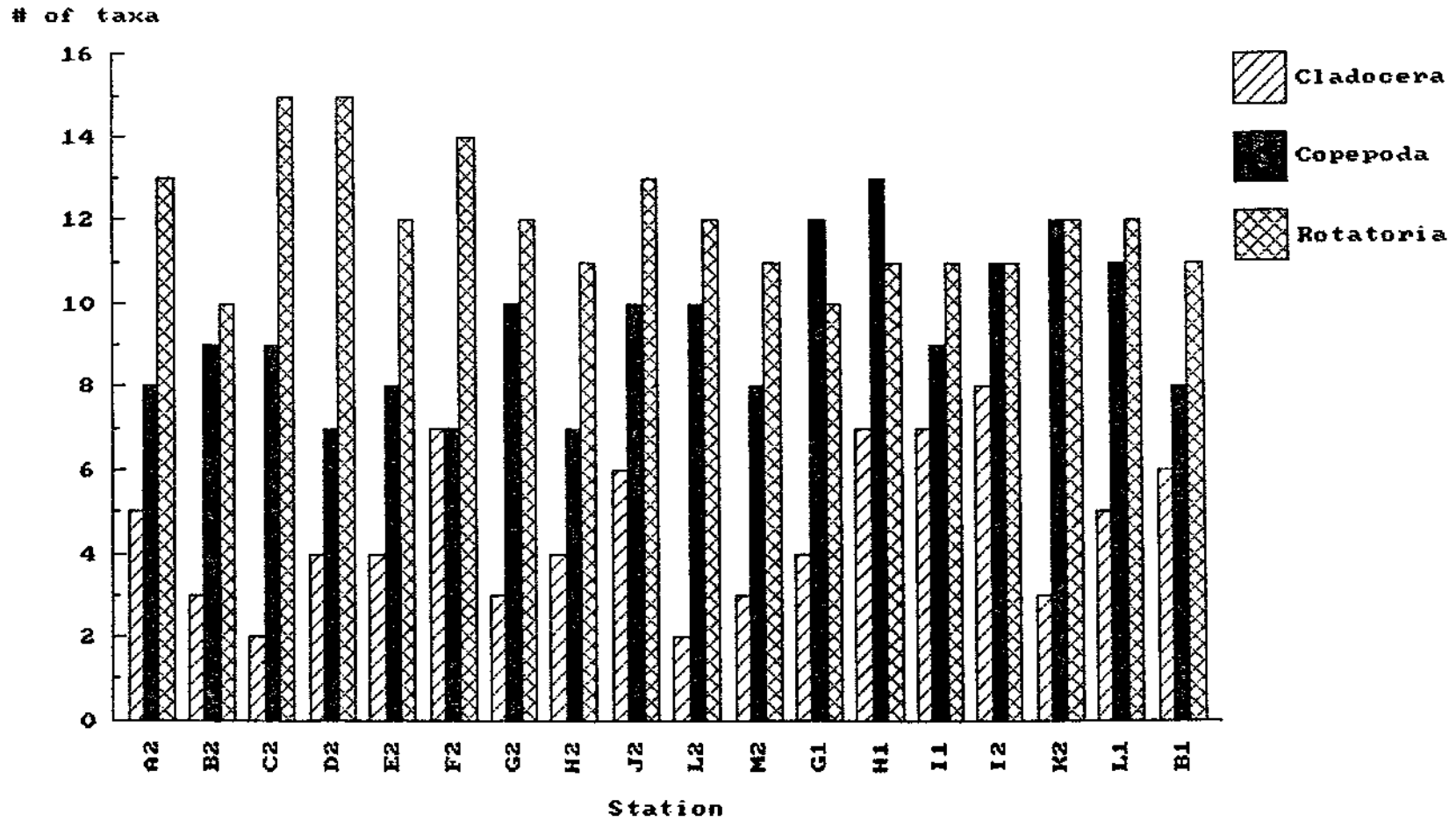


TABLE 58. Percent composition by group for MASS station zooplankton samples and percent composition by group for station clusters.

	CLADOCERA	COPEPODA	ROTATORIA
A2	19	31	50
B2	14	41	45
C2	8	35	58
D2	15	27	58
E2	17	33	50
F2	25	25	50
G2	12	40	48
H2	18	32	50
J2	21	34	45
L2	8	42	50
M2	14	36	50
Group I	16	34	50
G1	15	46	38
H1	22	41	38
I1	26	33	41
I2	27	37	37
K2	11	44	44
L1	18	39	43
Group II	20	40	40
B1	24	32	44

Normal Cluster Analysis-FREQUENCY Sites

The thirteen sampling stations (11 sampling dates) in the FREQUENCY sampling protocol were mapped for degree of similarity using the top fifty zooplankton species as a comparator. The values obtained grouped into three clusters at a degree of similarity of .475 (Figure 96). Group I was composed of the three QUIN stations, the two GADS stations and the pond station at the CRES site. Group II was composed of the MOSS stream stations (influent, effluent and control), and the two CRES stream stations. Group III consisted of the two MOSS pond stations.

These groupings show the strong effect that habitat and geography have on faunal associations. Of the six stations in Group I, four are streams (the ponds at QUIN and CRES finish out the group). Group II is composed entirely of five stream stations. Group III consists of the two ponds at the MOSS site.

At first examination, the pond at CRES seems out of place in Group I. Comparison of co-occurrence data for zooplankton both by species and by group (Tables 59 and 60) support the inclusion of the CRES 2 pond with the other CRES stations. Its inclusion with the QUIN and GADS stations can probably be explained by the fact that, for the first four months of the study the CRES pond was not filled, and during the entire course of the study the basin and watershed were subjected to dramatic disruptions from construction activities. These disruptions resulted in greatly increased sedimentation and suspended material in the pond. These two factors (decreased number of samples taken and disruption due to construction) led to a decrease in the species richness and total number of organisms found at the CRES 2 station.

Group III, composed solely of the two MOSS pond stations is radically different from all the other stations. This difference may be explained by the fact that these are stable, undisturbed systems with minimal detrimental impact from the influent stream or surrounding watershed. Additionally, these are the two largest ponds surveyed in this study and favor more limnetic species. For example, chydorid Cladocera, associated with littoral, vegetated habitats, (T. Crisman, University of Florida, personal communication), were only found in one pond sample during the entire course of the study (Alonella exisa in MOSS 3). The details of zooplankton occurrance at the MOSS stations are presented in Table 60. It shows a reduction of Cladocera at both MOSS ponds relative to the influent, effluent and control stream.

Inverse Cluster Analysis - FREQUENCY Sites

A dendrogram of the results of an inverse cluster analysis of the top 50 zooplankton taxa (Figure 97) revealed the presence of six major groups. Group I consisted only of cladoceran species common in streams (e.g. Chydorus). Not surprisingly then, this group was found almost exclusively at both upstream and downstream stations at all our sites. Group II was made up primarily of rotifers that were, with few exceptions, found only at pond stations. Group III consisted of a single copepod, Cyclops

FIGURE 96. Station cluster of FREQUENCY zooplankton taxa.

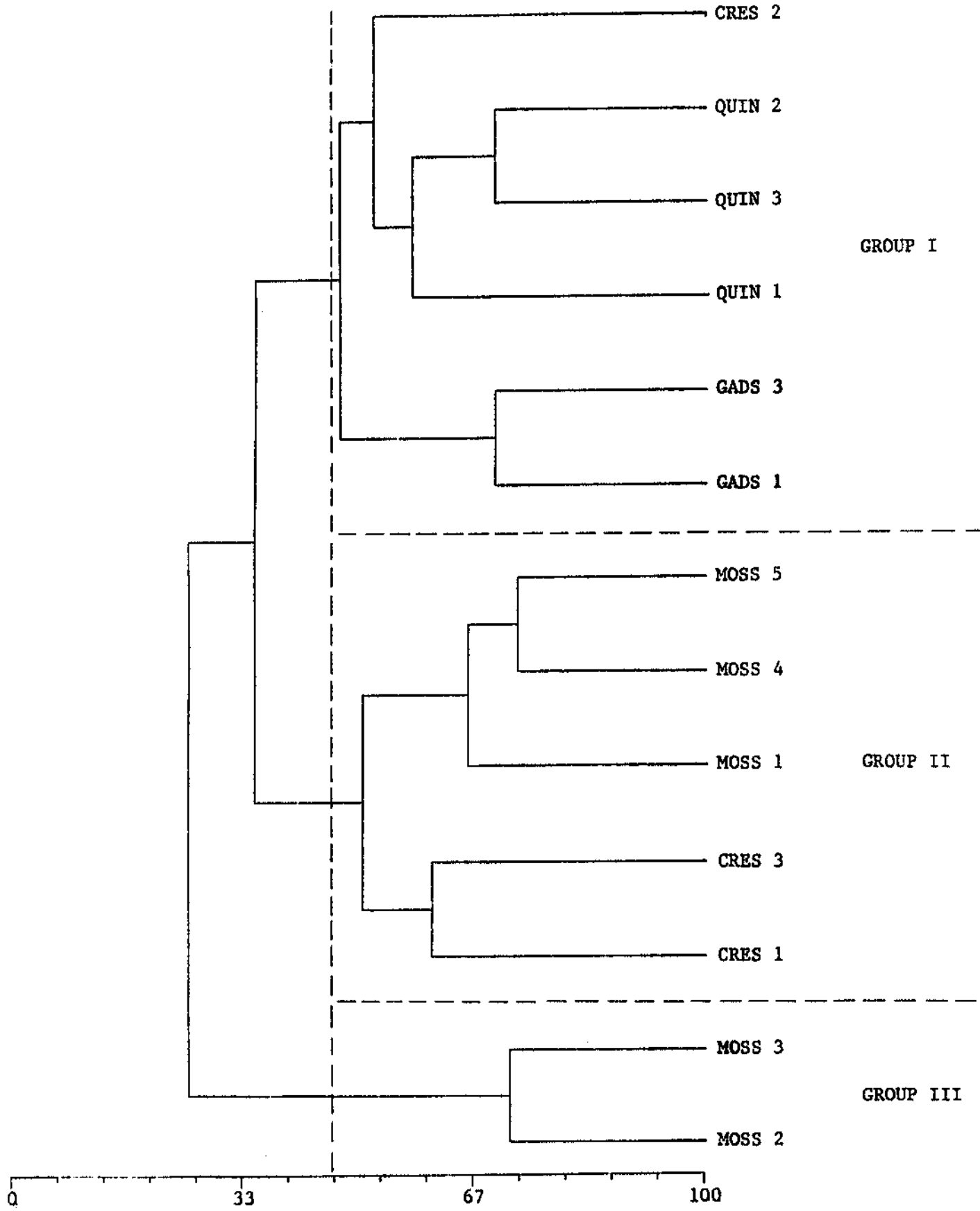


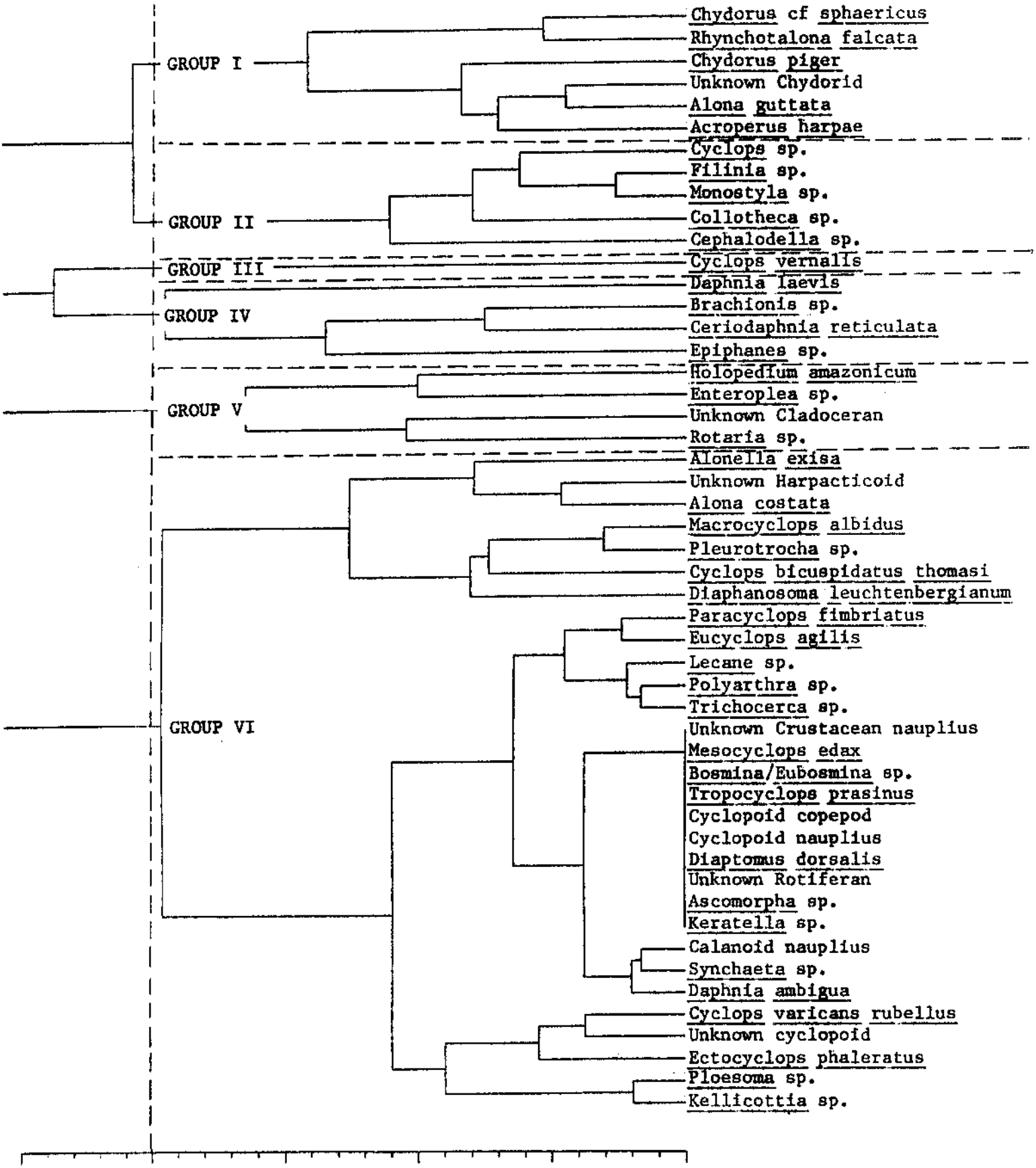
TABLE 59. Co-Occurrence table (absolute), CRES 2 vs CRES 1, 3, and QUIN 1, 2, 3

CRES 2 spp.	CRES 1	CRES 3	QUIN 1	QUIN 2	QUIN 3
Acroperus harpae (1)	8 (1)	5 (1)	------	------	------
Alona costata (1)	4 (1)	------	------	------	------
Alona guttata (2)	3 (2)	2 (2)	------	1 (2)	1 (2)
Bosmina/Eubosmina sp.	3 (6)	2 (6)	7 (6)	7 (6)	7 (6)
Ceriodaphnia reticulata	------	------	1 (2)	4 (2)	3 (2)
Daphnia ambigua (1)	1 (1)	2 (1)	4 (1)	6 (1)	4 (1)
Diaphanosoma leuchtenbergianum (3)	1 (3)	------	------	------	1 (3)
Simocephalus serrulatus(2)	------	------	------	3 (1)	------
Calanoid nauplius (2)	------	1 (2)	2 (2)	7 (2)	5 (2)
Cyclopoid copepod (6)	5 (6)	6 (6)	5 (6)	9 (6)	10 (6)
Cyclops bicuspidatus (1)	------	------	------	1 (1)	------
Cyclopoid nauplius (6)	5 (6)	4 (6)	7 (6)	9 (6)	8 (6)
Diaptomus dorsalis (3)	1 (3)	1 (3)	3 (3)	2 (3)	2 (3)
Eucyclops agilis (6)	2 (6)	------	------	4 (6)	4 (6)
Unknown Harpacticoid (1)	5 (1)	2 (1)	4 (1)	------	------
Macrocyclops albidus (1)	1 (1)	------	------	2 (1)	------
Mesocyclops edax (3)	2 (3)	1 (3)	3 (3)	5 (3)	5 (3)
Paracyclops fimbriatus (1)	3 (1)	1 (1)	------	1 (1)	2 (1)
Tropocyclops prasinus (4)	2 (4)	1 (4)	1 (4)	3 (4)	2 (4)
Unknown Crustacean nauplius	1 (2)	1 (2)	2 (2)	4 (2)	4 (2)
Ascomorpha sp. (3)	3 (3)	5 (3)	4 (3)	7 (3)	5 (3)
Keratella sp. (4)	2 (4)	1 (4)	2 (4)	6 (4)	7 (4)
Pleurotrocha sp. (1)	2 (1)	------	2 (1)	4 (1)	------
Polyarthra sp. (4)	------	------	3 (4)	8 (4)	4 (4)
Synchaeta sp. (3)	------	2 (3)	3 (3)	3 (3)	4 (3)
Trichocerca sp. (3)	1 (3)	------	5 (3)	6 (3)	8 (3)
∅ Found in CRES 2 but not in other	6	9	9	4	6
∅ Not found in CRES 2	8	8	7	14	11

TABLE 60. Composition by Group

	CLADOCERANS	COPEPODS	ROTIFERS
CRES 1	12	12	7
CRES 2	9	11	7
CRES 3	8	12	6
QUIN 1	3	10	12
QUIN 2	8	14	16
QUIN 3	6	12	14
GADS 1	5	16	11
GADS 3	6	14	8
MOSS 1	13	14	16
MOSS 2	5	15	16
MOSS 3	5	12	19
MOSS 4	13	12	12
MOSS 5	12	13	14

FIGURE 97. Species cluster of FREQUENCY zooplankton taxa.



vernalis that was found only once or twice during the study. Why this particular species should be a separate group is unclear, although it was found almost exclusively at upstream stations at several sites. Group IV was represented by a variety of taxa with a wide range of abundances, though some were quite site specific. Group V consisted of two rotifers and two cladocerans that were found exclusively at the MOSS stations 1, 2, and 3. Group VI, the largest group, comprised zooplankton taxa that were found virtually everywhere in a wide range of abundances. Many of the zooplankton that were identified during this study were taxa that have frequently been associated with eutrophic conditions (e.g. Branchionus, Lecane and Diaptomus). That such indicator organisms were found at one time or another in virtually every pond we studied suggests that such ponds may pass quickly through the normal trophic stages noted for comparable size lakes.

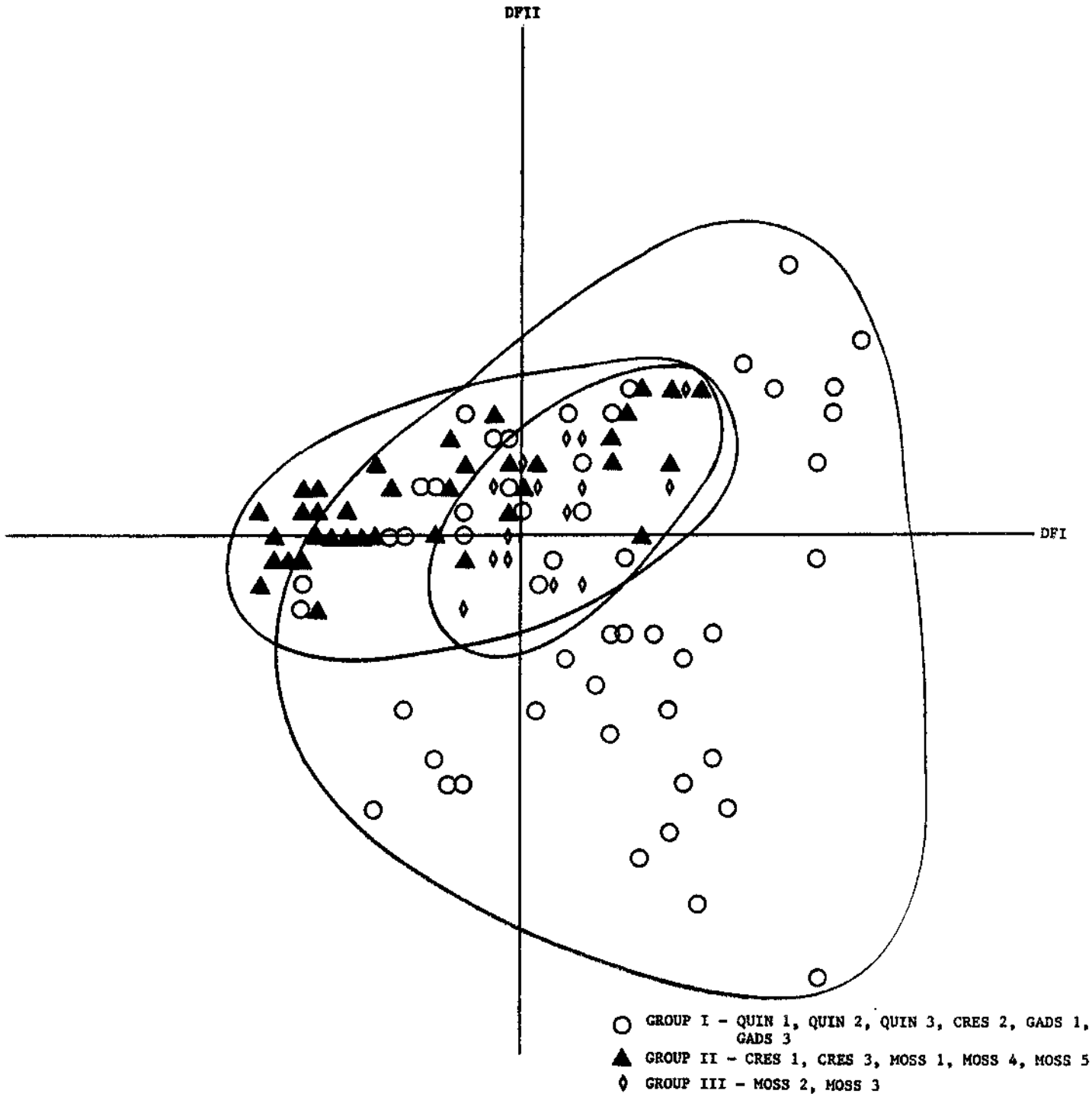
Discriminant Analysis - FREQUENCY Sites

A discriminant analysis scatter plot (Figure 98) of the thirteen FREQUENCY stations showed a high degree of overlap between the three station clusters derived by cluster analysis. The principal components accounting for the variance observed between stations were pH (discriminant function I = 54.8% of observed variance) and a combination of dissolved oxygen and temperature (discriminant function II = 30.5% of observed variance). Group I contained six of the thirteen stations and occupied the greatest area. Group II contained another five stations which grouped much more closely together. However, most of this cluster fell within the discriminant space occupied by Group I. Group III, which contained the two MOSS ponds, also grouped tightly, but was entirely contained within the discriminant space occupied by Group I, and largely within Group II as well.

The fact that pH and temperature were the most significant of the physical, chemical, and nutrient-based factors accounting for between group variance is consistant with prior investigators' findings. The effect of pH on zooplankton assemblages has been well documented. Janicki and DeCosta (1979) showed that in Canadian lakes, lower pH values led to simplified population structure, with dominance by Bosmina. Roff and Kwiatkowski (1977) also examined acid lakes in Canada and expressed similar findings, with species diversity declining sharply below a pH of 5.3. They found rotifers to be the most strongly affected group, with all zooplankton groups showing a reduction in both diversity and abundance.

Temperature has also been identified as a major controlling force in lake zooplankton cycles. Moore (1980a and 1980b) found temperature, not food availability, competition, or predation, to be the controlling factor regulating zooplankton community structure. Janicki and DeCosta (1977) expressed similar findings for Bosmina longirostris, with seasonal age structure shifts a secondary factor in the zooplankton community.

FIGURE 98. Orientation of FREQUENCY zooplankton groups in discriminant space.



The fact that none of the nutrient or prey-based parameters showed a high degree of influence on zooplankton community structure is not surprising. O'Brien and DeNoyelles (1974) found a positive correlation between nutrient levels and zooplankton density in experimental impoundments, but also noted that the increase of zooplankton density with nutrient enrichment was quite variable, and made it impossible to predict zooplankton levels from nutrient data alone.

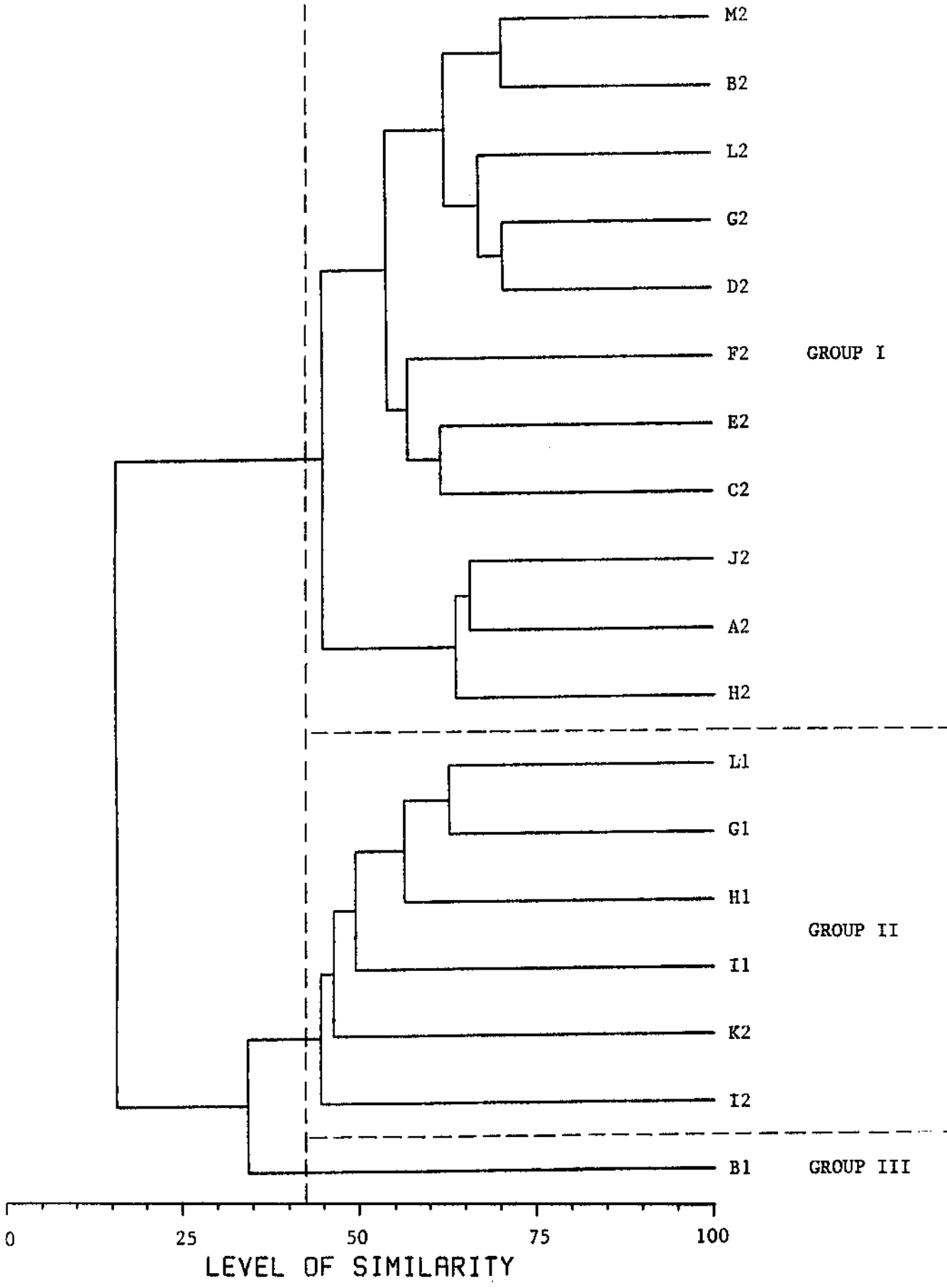
Normal Cluster Analysis-MASS Sites

The eighteen MASS sampling stations at which zooplankton samples were taken were also mapped for degree of similarity using the top fifty zooplankton species as a comparator (Figure 99). As with the cluster analysis of FREQUENCY sites, the stations formed three clusters, separated at a level of similarity of .445. Group I consisted of eleven of the thirteen pond stations. Group II consisted of five of the six influent stream stations and the remaining two pond stations (I2 and K2). Group III consisted of the one remaining influent stream station (B1).

These clusters show even more strongly the effect that habitat-related factors have on faunal associations. All 11 of the stations in Group I are impoundments, and four of the six stations in Group III are influent streams. The two ponds included in Group II were grouped there on the basis of the breakdown of percent composition of zooplankton by group, rather than as a result of the ponds having chemical or physical attributes more resembling those of stream stations (Figure 99; Table 58). The fauna at these two pond stations showed a higher percentage of copepods and a lower percentage of rotifers than the average for the ponds in Group I. The station at pond I2 also supported a much higher percentage of cladocerans than was the average for stations in Group I. All these characteristics (elevated Cladocera and Copepoda and reduced Rotatoria) were consistent with the population breakdown of the other stations in Group II.

Station B1, which was an influent stream, did not group with either Group I or Group II. This station showed an unusual population composition (elevated Cladocera, lowered Copepoda, and elevated Rotatoria). The high percentage of Cladocerans seen is consistent with results from the other stream stations. The elevated percentage of rotifers is intermediate between the values seen for the impoundments of Group I and the streams of Group II. This may be explained by the fact that the zooplankton fauna of station B1 was extremely depauperate, and consistently yielded among the lowest population densities recorded. Thus, the elevated percentage of rotifers may be at least partially an artifact of low population density.

FIGURE 99. Station cluster of MASS zooplankton taxa.



Inverse Cluster Analysis - MASS Sites

A dendrogram of the results of an inverse analysis of the top 50 zooplankton taxa (Figure 100) indicated the presence of eight major groupings at a very low level of similarity. This lack of similarity may likely be attributed to the relatively small data base and thus the results should be viewed with some degree of caution.

Two rare cladocerans that were found only at the J1 and L1 sites comprised Group I. Group II consisted of three taxa that were most numerous at the I2 site. The rotifer Euchlonis sp., found nearly exclusively at I2, was the dominant organism in this group. Group III was dominated by a variety of organisms that were found primarily at the upstream stations of the study sites. Cladoceran species were the dominant organisms of Group IV, and, with one exception, were found only at pond stations. Group V was composed of two taxa, although only one, the rotifer Epiphanes sp., was found in abundance and only at C2. Group VI consisted of two taxa that were, with one exception, found only at H1. The taxa of Group VII were virtually all rotifers that were found in greatest abundance at the pond stations and in far fewer numbers at a few upstream sites. Finally the members of Group VIII were the most ubiquitous and, generally, among the most numerous of all the zooplankton taxa identified during this study.

As with many of the taxa identified from the FREQUENCY sites, a number of taxa identified at the MASS sites are indicative of eutrophic conditions. This would suggest that the MASS ponds, as do the FREQUENCY ponds, experience accelerated eutrophic conditions peculiar to this type of water body.

Discriminant Analysis-MASS Sites

A scatterplot (Figure 101) of the eighteen MASS stations at which biological samples were taken showed greater separation between the three station clusters than was seen for the FREQUENCY stations. The principal components accounting for the variance observed between stations were a combination of total phosphorus and chlorophyll a (discriminant function I = 47.3% of the observed variance) and a combination of temperature and pH (discriminant function II = 23.6% of observed variance). Together, these two factors accounted for 70.9% of the observed variance. Group I contained eleven stations (all ponds) and occupied by far the largest discriminant space. Group II, which contained six stations (four influent stream and ponds I2 and K2), cluster much more tightly than Group I and was slightly separated from Group I along the temperature and pH axis. Group III contained only one station (the influent stream of station group B) and was separated from Group I and II along the temperature and pH axis.

FIGURE 100. Species cluster of MASS zooplankton taxa.

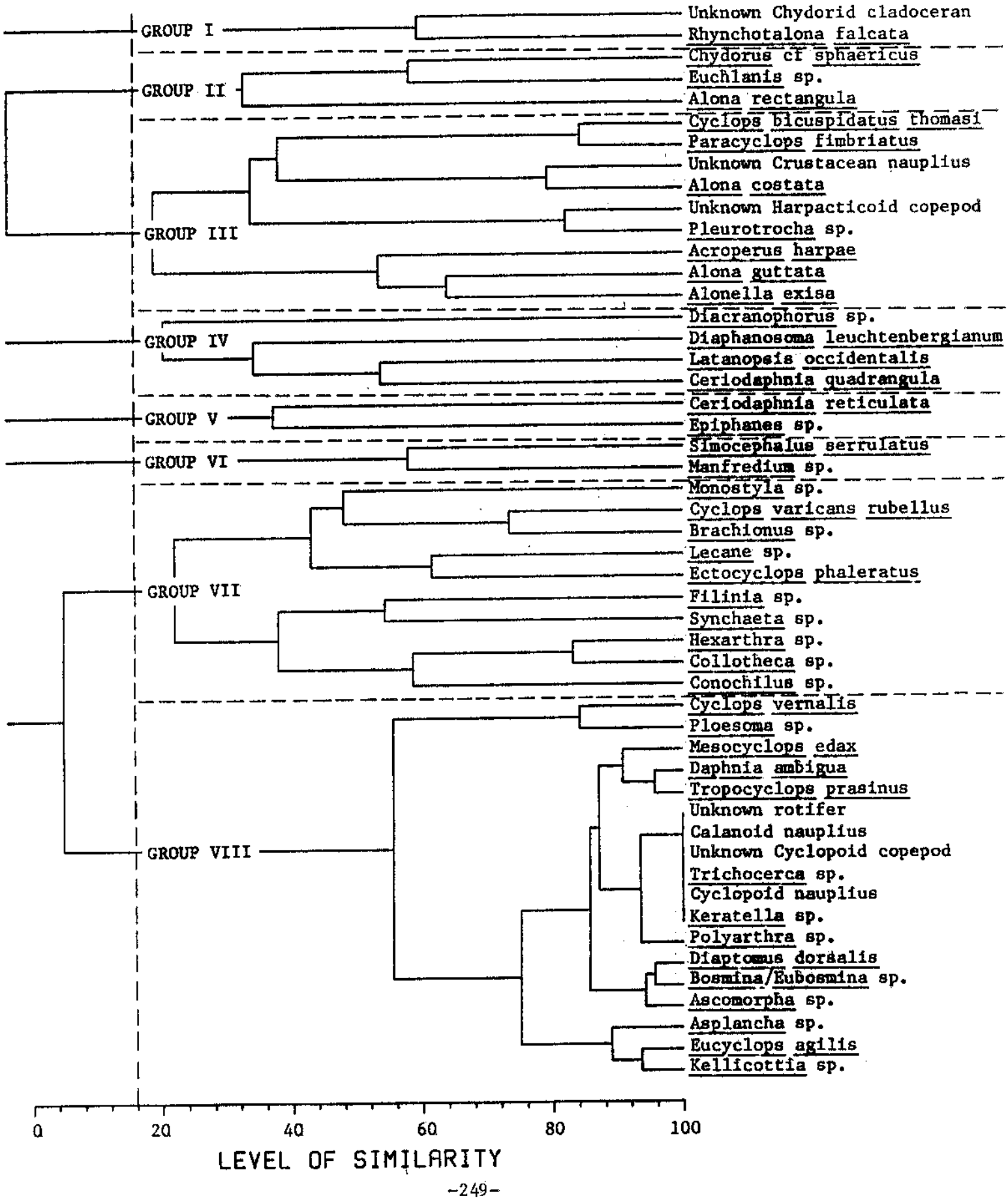
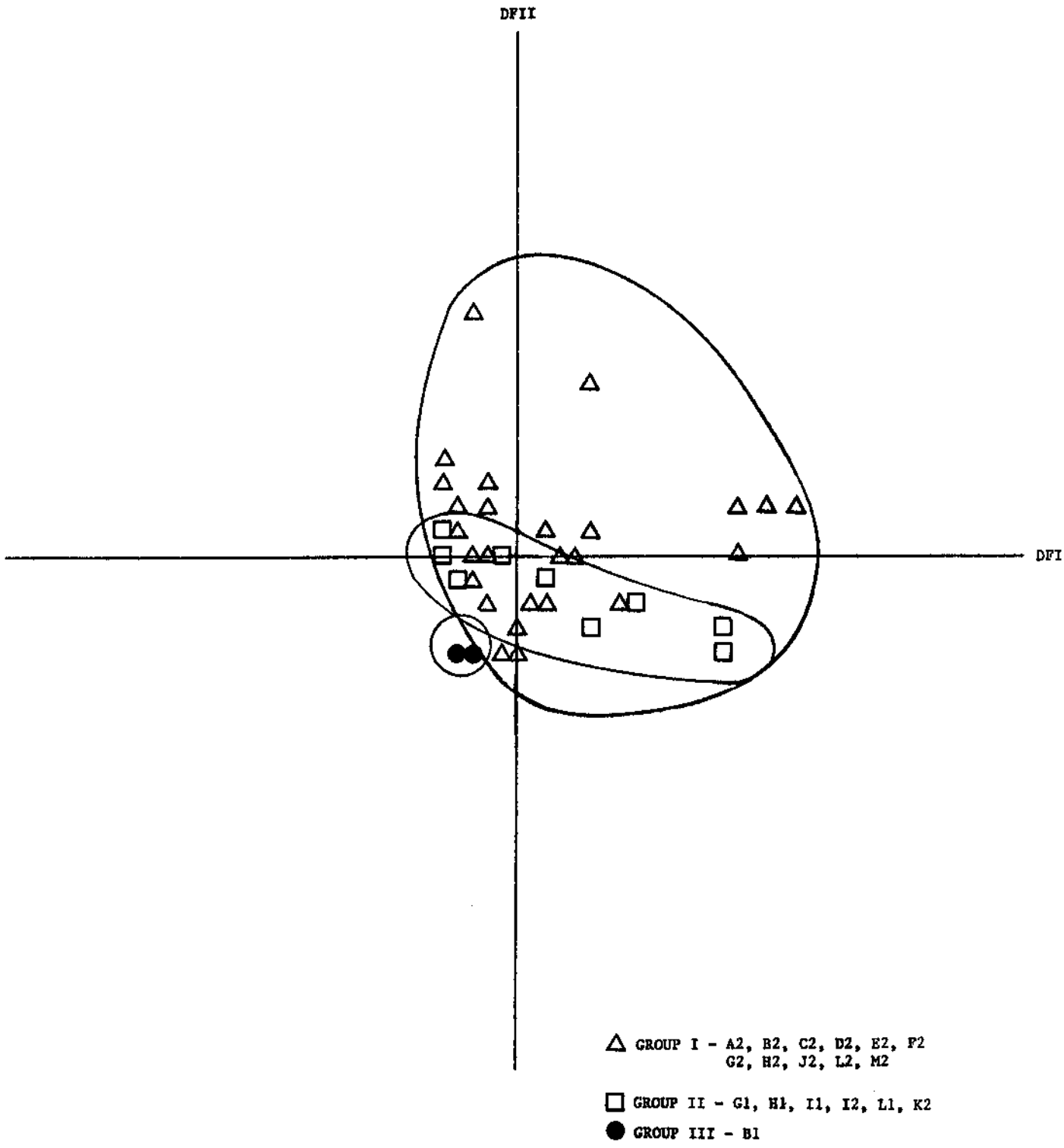


FIGURE 101. Orientation of MASS zooplankton groups in discriminant space.



The results of discriminant analysis of the MASS group of stations are quite different from those for the FREQUENCY stations. While temperature and pH still play a role in explaining the observed variance (23.6%), the dominant parameters separating the station clusters are nutrient-based (chl a and TP). Examination of specific levels of chlorophyll a, total phosphorus, pH and temperature at the eighteen stations shows good separation between streams and ponds in most cases (Tables 14, 15, and 47).

Influent stream stations had much lower chlorophyll a levels, and slightly lower temperature and pH levels than were recorded for pond stations. The inclusion of two impoundment stations (I2 and K2) in Group II (which otherwise was composed entirely of influent stream stations) is not well explained by discriminant analysis. Both ponds showed chlorophyll a levels consistent with results obtained from other ponds. Temperature and pH values were also more similar to values recorded from impoundments than from influent stream stations.

Station B1, which was the lone station in the third cluster, had chlorophyll a levels, pH values and temperature consistent with results seen in the other influent streams. Like the two pond stations in Group II, separation from the other physically similar stations is not well explained by discriminant analysis.

In summary, discriminant analysis of the MASS stations showed that for the most part, the separation of stations into clusters based on population structure can be explained by physical and chemical factors. More frequent sampling and a lengthier study period would likely result in improved delineation of stream and impoundment stations.

SUMMARY

1. The data from our study suggested that the number of zooplankton taxa may increase in an impoundment when compared with the upstream community. However, the diversity ($\bar{d}$) may not show a concurrent increase since one or two organisms may be dominant.

2. The mean number of taxa, the mean number of organisms, and pooled diversity ($\bar{d}$) generally increased from the influent stream to the pond. However, these measurements showed a decrease in the effluent streams.

3. Community composition data indicated that, of the three major groups of zooplankton, the Cladocera were more dominant in the influent streams, while the Rotifera and Copepoda remained relatively constant from upstream to the ponds.

4. A weakly developed trend was observed in which an increase in diversity and abundance from upstream to ponds paralleled a similar increase in nutrient and chlorophyll *a* concentrations.

5. Normal and inverse cluster analysis of both the FREQUENCY and MASS sites indicated that station clusters were formed based primarily on habitat preference rather than other environmental factors.

TABLE 61. Zooplankton taxa identified and number of occurrences, QUIN site, November 1984 to August 1985.

	Number of Occurrences		
	QUIN 1	QUIN 2	QUIN 3
CLADOCERA			
Alona guttata	-	1	1
Bosmina/Eubosmina sp.	7	7	7
Ceriodaphnia reticulata	1	4	3
Chydorus piger	-	1	-
Daphnia ambigua	4	6	4
Daphnia laevis	-	1	-
Diaphanosoma leuchtenbergianum	-	-	1
Simocephalus serrulatus	-	3	-
Unknown Chydorid	-	1	1
COPEPODA			
Calanoid nauplius	2	7	5
Cyclopoid copepod	5	9	10
Cyclops bicuspidatus thomasi	-	1	-
Cyclopoid nauplius	7	9	8
Cyclops sp. A	-	1	-
Unknown Cyclopoid	2	3	3
Cyclops varicans rubellus	2	2	4
Cyclops vernalis	1	-	1
Diaptomus dorsalis	3	2	2
Ectocyclops phaleratus	-	1	3
Eucyclops agilis	-	4	4
Unknown Harpacticoid	4	-	-
Macrocyclops albidus	-	2	-
Mesocyclops edax	3	5	5
Paracyclops fimbriatus	-	1	2
Tropocyclops prasinus	1	3	2
CRUSTACEA			
Unknown Crustacean nauplius	4	4	4
ROTATORIA			
Ascomorpha sp.	4	7	6
Brachionus sp.	1	1	3
Ephalodella sp.	-	1	1

TABLE 61. Cont.

Epiphanes sp.	-	1	-
Euchlanis sp.	-	-	1
Filinia sp.	-	2	1
Kellicottia sp.	1	3	3
Keratella sp.	2	6	7
Lecane sp.	4	3	5
Monostyla sp.	-	2	2
Philodina sp.	1	-	-
Platyias sp.	-	1	-
Pleurotrocha sp.	2	4	-
Ploesoma sp.	1	5	4
Polyarthra sp.	3	8	4
Synchaeta sp.	3	3	4
Trichocerca sp.	5	6	8
Unknown Rotifer	6	7	7

TABLE 62. Zooplankton taxa identified and number of occurrences, CRES site, November 1984 to August 1985.

	Number of Occurrences		
	CRES 1	CRES 2	CRES 3
CLADOCERA			
Acroperus harpae	8	1	5
Alonella acutirostris	1	-	-
Alona costata	4	1	-
Alonella exisa	4	-	1
Alona guttata	3	2	2
Alona karua	-	-	1
Alona quadrangularis	1	-	-
Bosmina/Eubosmina sp.	3	6	2
Ceriodaphnia reticulata	-	2	-
Chydorus piger	-	-	1
Daphnia ambigua	1	1	2
Diaphnanosoma leuchtenbergianum	1	3	-
Pleuroxus hamulatus	1	-	-
Rhynchotalona falcata	1	-	-
Simocephalus serrulatus	-	1	-
Unknown Chydorid	-	1	4
Unknown Cladoceran	1	-	-
COPEPODA			
Calanoid nauplius	-	2	1
Cyclopoid copepod	5	6	6
Cyclops bicuspidatus thomasi	-	1	-
Cyclopoid nauplius	5	6	4
Unknown Cyclopoid	1	-	1
Cyclops varicans rubellus	2	-	1
Diaptomus dorsalis	1	3	1
Ectocyclops phaleratus	1	-	2
Eucyclops agilis	2	6	-
Eucyclops prionophorus	-	-	1
Unknown Harpacticoid	5	1	2
Macrocyclops albidus	1	1	-
Mesocyclops edax	2	3	1
Paracyclops fimbriatus	3	1	1
Tropocyclops prasinus	2	4	1

TABLE 62. Cont.

CRUSTACEA			
Unknown Crustacean nauplius	1	2	2
ROTATORIA			
Ascomorpha sp.	3	3	5
Kellicottia sp.	2	4	1
Keratella sp.	-	-	1
Lecane sp.	2	-	-
Pleurotrocha sp.	2	1	-
Ploesoma sp.	-	-	1
Polyarthra sp.	-	4	-
Synchaeta sp.	-	3	2
Trichocerca sp.	1	3	-
Unknown Rotifer	6	2	5

TABLE 63. Zooplankton taxa identified and number of occurrences, MOSS site, November 1984 to August 1985.

	Number of Occurrences				
	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
CLADOCERA					
Acroperus harpae	3	-	-	2	1
Alona costata	4	-	-	1	1
Alonella exisa	3	-	1	1	-
Alona guttata	6	-	-	2	4
Alona rustica	1	-	-	-	-
Bosmina/Eubosmina sp.	5	11	8	7	7
Camptocercus rectirostris	-	-	-	1	-
Chydorus hybridus	-	-	-	-	1
Chydorus piger	3	-	-	1	2
Chydorus cf. sphaericus	1	-	-	1	1
Daphnia ambigua	4	8	8	6	7
Daphnanosoma leuchtenbergianum	1	8	6	2	2
Holopedium amazonicum	-	1	-	-	-
Ilyocryptus spinifer	-	-	-	1	-
Rhynchotalona falcata	3	-	-	2	2
Simocephalus serrulatus	1	-	-	-	-
Unknown Chydorid	2	-	-	2	1
Unknown Cladoceran	-	1	1	-	2
COPEPODA					
Calanoid nauplius	5	11	11	7	7
Cyclopoid copepod	7	11	8	6	10
Cyclops bicuspidatus thomasi	1	3	1	2	-
Cyclopoid nauplius	7	11	11	7	8
Cyclops sp. A	-	1	1	1	1
Cyclops sp. B	-	1	-	-	-
Unknown Cyclopoid	-	3	2	3	3
Cyclops varicans rubellus	4	2	1	-	-
Cyclops vernalis	1	-	-	-	-
Diaptomus dorsalis	4	10	10	6	6
Ectocyclops phaleratus	2	2	-	-	2
Eucyclops agilis	1	6	6	3	4
Unknown Harpacticoid	3	-	-	2	2
Macrocyclops albidus	1	1	1	-	2
Mesocyclops edax	2	4	1	2	3
Paracyclops fimbriatus	2	1	-	2	1
Tropocyclops prasinus	4	10	8	3	6

TABLE 63. Cont.

CRUSTACEA					
Unknown Crustacean nauplius	4	2	2	1	2
ROTATORIA					
Ascomorpha sp.	4	8	9	5	5
Asplancha sp.	1	1	1	-	-
Brachionus sp.	-	-	1	-	-
Ephalodella sp.	2	-	1	-	1
Collotheca sp.	2	5	6	3	2
Enteroplea sp.	1	1	-	-	-
Epiphanes sp.	-	-	1	-	-
Filinia sp.	-	3	1	2	2
Gastropus sp.	-	-	1	-	-
Kellicottia sp.	4	10	5	4	5
Keratella sp.	6	11	9	7	8
Lecane sp.	3	2	1	4	2
Monostyla sp.	1	3	3	2	1
Pleurotrocha sp.	1	1	1	-	2
Ploesoma sp.	1	3	5	4	2
Polyarthra sp.	2	6	4	3	1
Rotaria sp.	-	1	1	-	-
Synchaeta sp.	2	5	8	6	1
Trichocerca sp.	2	7	8	6	5
Trichotria sp.	2	-	-	-	-
Unknown Rotifer	7	9	11	6	7

TABLE 64. Zooplankton taxa identified and number of occurrences, GADS site, November 1984 to August 1985.

	Number of Occurrences	
	GADS 1	GADS 3
CLADOCERA		
Alona costata	2	3
Alonella exisa	2	1
Alona guttata	-	2
Alona rustica	1	-
Bosmina/Eubosmina sp.	3	2
Ceriodaphnia reticulata	-	1
Daphnia ambigua	1	-
Diaphanosoma leuchtenbergianum	-	2
COPEPODA		
Calanoid nauplius	4	2
Cyclopoid copepod	10	7
Cyclops bicuspidatus thomasi	3	3
Cyclopoid nauplius	10	8
Cyclops sp. A	1	-
Unknown Cyclopoid	3	1
Cyclops varicans rubellus	1	4
Cyclops vernalis	2	-
Diaptomus dorsalis	2	1
Ectocyclops phaleratus	2	2
Eucyclops agilis	5	3
Unknown Harpacticoid	5	4
Macrocyclops albidus	3	2
Mesocyclops edax	5	4
Paracyclops fimbriatus	6	2
Tropocyclops prasinus	9	3
CRUSTACEA		
Unknown Crustacean nauplius	6	6
ROTATORIA		
Ascomorpha sp.	5	1
Brachionus sp.	3	2
Epiphanes sp.	-	1
Kellicottia sp.	2	-

TABLE 64. Cont.

Keratella sp.	1	3
Lecane sp.	1	3
Platyias sp.	1	-
Pleurotrocha sp.	4	-
Polyarthra sp.	1	1
Synchaeta sp.	1	-
Trichocerca sp.	6	1
Unknown Rotifer	8	3

TABLE 65. Zooplankton taxa identified and number of occurrences, MASS stations, January to August 1985.

	Number of Occurrences																	
	A2	B1	B2	C2	D2	E2	F2	G1	G2	H1	H2	I1	I2	J2	K2	L1	L2	M2
CLADOCERA																		
Acroperus harpae	-	-	-	-	-	-	-	1	-	1	-	2	1	-	-	-	-	-
Alona costata	2	-	-	-	-	-	1	1	-	2	-	1	2	-	-	1	-	1
Alonella exisa	1	2	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-
Alona guttata	-	1	-	-	-	-	-	-	1	2	-	1	1	-	-	-	-	-
Alona rectangula	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-
Bosmina/Eubosmina sp.	3	1	5	4	2	4	2	1	4	2	3	1	5	3	5	2	5	-
Ceriodaphnia quadrangula	-	1	-	-	-	2	-	-	-	-	1	-	-	1	-	-	-	-
Ceriodaphnia reticulata	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	1
Chydorus piger	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Chydorus cf. spaericus	-	1	1	-	-	-	1	-	-	-	-	-	2	-	-	-	-	-
Daphnia ambigua	2	-	5	1	3	3	3	2	4	1	3	-	1	5	1	1	5	4
Diaphanosoma leuchtenbergianum	-	-	-	-	1	-	1	-	-	-	-	-	-	4	1	-	-	-
Graptolebris testudinaria	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ilyocryptus spinifer	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Latonopsis occidentalis	-	-	-	-	-	-	2	-	-	-	1	-	-	1	-	-	-	-
Rhynchotalona falcata	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Simocephalus serrulatus	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-
Unknown Chydorid	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-
COPEPODA																		
Calanoid nauplius	4	2	2	2	5	5	2	2	4	4	5	3	5	5	4	1	2	4
Unknown Cyclopoid	1	1	5	5	3	3	5	3	3	3	3	2	5	3	5	2	5	4
Cyclops bicuspidatus thomasi	-	-	-	-	-	-	-	2	-	1	-	-	-	-	1	1	-	-
Cyclopoid nauplius	5	3	5	5	5	5	5	3	5	4	5	3	5	4	5	4	5	5
Cyclops varicans rubellus	2	-	-	1	-	-	-	1	1	3	-	-	2	1	2	1	1	1

TABLE 65. Cont.

	A2	B1	B2	C2	D2	E2	F2	G1	G2	H1	H2	I1	I2	J2	K2	L1	L2	M2
Cyclops vernalis	1	-	1	-	-	1	-	-	2	1	2	1	3	2	3	2	3	4
Diaptomus dorsalis	4	2	3	1	5	5	-	2	4	3	4	1	4	5	2	1	1	-
Ectocyclops phaleratus	-	1	2	1	-	-	1	1	1	1	-	-	2	-	1	-	1	-
Eucyclops agilis	-	-	4	4	3	3	5	2	3	3	-	2	3	1	4	1	3	2
Eucyclops prionophorus	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown Harpacticoid	-	1	-	-	-	-	-	1	-	3	-	-	1	1	-	1	-	-
Macrocyclops albidus	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Mesocyclops edax	1	1	1	1	2	2	2	2	5	1	2	-	3	2	3	-	1	3
Paracyclops fimbriatus	-	-	-	-	-	-	-	1	-	2	-	1	-	-	2	1	-	-
Tropocyclops prasinus	1	-	5	5	4	4	3	2	3	1	1	1	4	1	4	2	5	3
CRUSTACEA																		
Unknown Crustacean nauplius	3	-	-	-	-	-	1	2	1	1	-	2	1	-	1	2	-	-
ROTATORIA																		
Ascomorpha sp.	3	-	4	3	2	3	2	1	3	2	5	1	1	3	1	3	1	-
Asplancha sp.	1	-	2	2	2	4	1	-	3	4	1	1	-	2	1	2	1	4
Brachionus sp.	1	2	-	2	1	-	-	-	-	1	-	-	2	2	2	1	1	-
Collotheca sp.	4	1	-	2	-	1	2	-	1	-	1	1	-	2	1	-	1	1
Conochilus sp.	1	1	-	1	1	2	2	-	1	-	-	-	-	3	-	-	-	-
Dicranophorus sp.	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Epiphanes sp.	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Euchlanis sp.	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Filinia sp.	1	-	-	3	-	1	1	1	-	-	1	-	-	-	1	-	-	-
Hexarthra sp.	4	-	3	3	2	2	2	-	2	-	2	-	-	3	1	-	2	3
Kellicottia sp.	1	-	1	4	5	3	5	3	4	1	-	1	-	1	3	1	4	2
Keratella sp.	5	4	5	5	5	4	4	1	4	3	5	3	5	4	3	3	5	5
Lecane sp.	-	1	-	-	1	-	3	2	1	-	-	1	2	-	-	-	1	1
Manfredium sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Monostyla sp.	-	3	-	2	1	-	-	-	-	4	-	1	-	-	-	1	1	-

TABLE 65. Cont.

	A2	B1	B2	C2	D2	E2	F2	G1	G2	H1	H2	I1	I2	J2	K2	L1	L2	M2
Pleurotrocha sp.	-	-	-	-	1	-	-	1	-	3	-	-	1	1	-	1	-	-
Ploesoma sp.	1	1	2	-	1	-	-	-	1	2	2	1	1	3	3	1	-	1
Polyarthra sp.	4	2	5	5	3	5	5	1	1	4	2	2	4	3	-	2	3	5
Synchaeta sp.	-	-	3	1	1	-	2	1	-	-	1	-	1	-	2	1	-	2
Trichocerca sp.	5	3	5	4	2	5	4	2	4	3	5	2	3	2	4	2	4	4
Unknown Rotifer	5	4	5	4	4	2	5	3	2	5	3	2	4	4	3	2	4	2

ALGAL GROWTH POTENTIAL AND LIMITING NUTRIENT ASSAYS

INTRODUCTION

Increased primary productivity of phytoplankton (algae) has been directly related to increased levels of nutrients, primarily nitrogen and phosphorus (Green et al. 1975, Gerloff and Skoog 1957, Skulburg 1966, Devol et al. 1984). These two nutrients are the primary substances limiting algal growth in natural waters (Green et al. 1975, Miller et al. 1974, Shiroyama et al. 1975). Increased nutrient content, and thus increased productivity in natural waters, has been associated with septic tank leachate, agricultural runoff, irrigation return flow and industrial discharges (Olive and Higgin 1981, Maloney et al. 1972, Skulburg 1966). The algal assay is a method which can be used to determine the effect of added nutrients to a body of water, the nutrient(s) which might be limiting algal growth, and the bioavailability of the nutrient(s) (Maloney et al. 1972, Miller et al. 1978, Green et al. 1975).

In this study algal assays were performed on water samples from streams and impoundments which were utilized for recreation, development, irrigation, stormwater control, homesites, and livestock. The purpose of the algal assay portion of this study was to:

(1) assess the current nutrient status of the water bodies,

(2) determine the nutrient(s) which might be limiting growth in the water bodies, and

(3) determine nutrient availability as measured by algal growth potential.

METHODS AND MATERIALS

Algal assays, following methods described in "The Selenastrum capricornutum Printz Algal Assay Bottle Test" (Miller et al. 1978), were performed on water samples from 13 FREQUENCY stations and 34 MASS stations. Both algal growth potential and limiting nutrient algal assays were performed on the FREQUENCY samples whereas only algal growth potential tests were performed on the MASS samples.

Water samples for the algal assays were collected and handled in accordance with established laboratory procedures (FDER 1985, APHA 1980). Nitrogen, phosphorus, and EDTA (disodium ethylenedinitrilo tetraacetate), a synthetic organic ligand which is added to media or test waters to assure that necessary trace elements are available to support algal growth, were used singularly and in combination as nutrient additions to aid in determining the limiting nutrient(s) of the water samples. In addition to the established test procedures a pH adjusted (to pH 7.5) algal growth potential test was used in samples from the four pond stations of the FREQUENCY group, as an aid in determining the effects of less than optimum pH on the growth of the test algae.

Viability of the test algae and the nutrient spikes was checked by a growth reference series consisting of complete artificial growth media (Miller et al. 1978) and growth media with the various nutrients omitted and then added. Growth response was monitored by cell counts on days 1, 4, 7, 11, and 14 of the test. The cells were counted by an electronic particle counter (Coulter Model ZBI) equipped with a mean cell volume attachment. Dry weight yields were calculated and algal growth curves (mean dry weights vs. time) were plotted for each control and test by the computer programs ALGASSY and ASSYPLOT (Miller et al. 1978).

RESULTS AND DISCUSSION

FREQUENCY Algal Assays

Algal growth potential and limiting nutrient algal assays were performed on samples from 13 sites located in Gadsden, Jackson, and Okaloosa Counties in the North Florida panhandle. At the GADS site the pond was under construction during the sampling period and thus not sampled. The sites were sampled monthly from November 1984 to August 1985. From 7 to 11 samples were taken from any one station; dry sites and the filling of ponds after sampling began accounted for the varying number of samples from site to site.

Algal growth potential (AGP) and limiting nutrient algal assays were successfully completed on a total of 132 samples. AGP was less than 1 mg/l dry weight in 118 samples. AGP in 13 samples ranged from 1-5 mg/l dry weight and in one sample (QUIN site pond station June 1985) an AGP of 13.73 mg/l dry weight was recorded.

The means and ranges of AGP for the FREQUENCY stations are presented in Table 66. Generally, AGP was slightly greater in the pond samples than in the instream or outstream samples. Growth of the test algae in many of the samples was evidently inhibited (i.e. < 0.5 mg/l dry weight) by low pH. Growth inhibition of the test alga, Selenastrum capricornutum, at low pH has been noted earlier (Miller et al. 1978, FDER 1985). Concurrent with the AGP and limiting nutrient tests, pH adjusted (to pH 7.5) AGP tests were conducted on the pond samples. Significant increases in AGP were noted in 26 of the 38 pH adjusted tests (Table 67). The mean increase in AGP of the pH adjusted samples was approximately 450-500%, although the pH adjusted QUIN samples were the only ones to exceed 5.0 mg/l dry weight.

Correlations of the algal growth potential at all sites with some physical-chemical parameters (Table 68) reveal that AGP was significantly correlated ($P=.01$) with chlorophyll-a and total Kjeldahl nitrogen. AGP and total and dissolved phosphate were also significantly correlated ($.02 > P > .01$).

Table 66. Mean, maximum, and minimum algal growth potential of FREQUENCY stations in mg/l dry weight.

Station	Mean	Maximum	Minimum	# of Samples
QUIN 1	0.256	0.505	0.041	11
QUIN 2	2.776	13.731	0.218	9
QUIN 3	0.980	4.080	0.134	11
CRES 1	0.173	0.575	0.020	11
CRES 2	0.417	1.594	0.080	7
CRES 3	0.329	1.007	0.097	11
MOSS 1	0.175	0.351	0.047	11
MOSS 2	0.248	0.434	0.095	11
MOSS 3	0.392	1.181	0.110	11
MOSS 4	0.284	0.604	0.146	8
MOSS 5	0.421	3.017	0.061	11
GADS 1	0.364	1.123	0.097	10
GADS 3	0.319	0.783	0.078	10

Table 67. Algal growth potential of untreated and pH adjusted samples from the FREQUENCY pond stations.

Date	MOSS 2		MOSS 3		QUIN 2		CRES 2	
	Not Adjust	pH Adjust	Not Adjust	pH Adjust	Not Adjust	pH Adjust	Not Adjust	pH Adjust
Nov 84	0.15	1.72	0.11	1.00	----	----	----	----
Dec 85	0.24	1.76	0.35	0.44	----	----	----	----
Jan 85	0.32	0.26	0.44	0.29	1.62	1.25	----	----
Feb 85	0.22	0.16	0.19	0.23	6.26	23.75	----	----
Mar 85	0.12	0.27	0.28	0.45	1.55	0.65	0.11	0.30
Apr 85	0.35	0.52	0.11	0.37	0.22	0.21	0.08	0.42
Apr 85	0.22	1.13	1.02	2.53	0.35	5.2	0.20	3.64
May 85	0.17	2.56	1.18	3.57	0.49	6.25	0.24	4.63
Jun 85	0.43	1.63	0.19	1.02	13.79	5.44	1.59	2.11
Jul 85	0.10	1.66	0.28	3.69	0.30	3.84	0.23	3.24
Aug 85	0.43	0.31	0.16	0.12	0.48	12.96	0.47	0.18

Table 68. Correlations of FREQUENCY pond station AGP vs. chemical parameters.

ALGAL GROWTH POTENTIAL VS.	r	SIGNIFICANCE
Free Water Chlorophyll-a	.253	.01
Total Ammonia	.004	NS
Dissolved Ammonia	.020	NS
Total Kjeldahl Nitrogen (not filtered)	.342	.01
Total Kjeldahl Nitrogen (filtered)	.130	.1 > P > .05
Total Phosphate	.219	.02 > P > .01
Ortho Phosphate	.222	.02 > P > .01
Dissolved Nitrite/Nitrate	-.130	.1 > P > .05
Total Soluble Inorganic Nitrogen	.129	.1 > P > .05
pH	.153	.05 > P > .02

Nutrient concentrations (Table 69), particularly nitrogen, generally increased from instream to pond to outstream with the greatest increase occurring between the instream and the pond. However, changes in phosphorus concentration were more variable and were site dependent.

Results of limiting nutrient assays (Table 70) from all samples show the primary limiting nutrient to be phosphorus (52% of all samples) with nitrogen being limiting in less than 1% of the samples. Co-limitation (N+P) was noted in 27% of the samples, while for 20% a specific limitation was not identified. In 36% of the limiting nutrient assays, low growth ($\leq$ 1.0 mg/l) was evident in all controls and nutrient spiked samples.

Predictions of limiting nutrients based on the chemically analyzed total soluble inorganic nitrogen (TSIN) and orthophosphorus (ortho P) ratios (N:P) were not utilized in this study due to growth inhibition and generally low levels of nutrients but are presented for general information (Table 70). N:P ratios of $<$ 10:1 suggest nitrogen as the limiting nutrient; ratios of 10 to 11:1 suggest co-limitation and ratios $>$ 11:1 suggest phosphorus limitation (Miller et al. 1974, Shiroyama et al. 1975, Miller et al. 1978). Other N:P ratios have been suggested such as N:P $\leq$ 5:1 as N limiting; N:P of 5-10:1 as co-limiting and N:P $>$ 10:1 as P limiting (Chiaudani and Vighi 1976). In our samples, 18 of 69 phosphorus limited samples had a dissolved N:P ratio of $\geq$ 11:1. The remaining 51 phosphorus-limited samples had N:P ratios of $\leq$ 10:1.

Low TSIN: ortho P ratios ($<$ 10:1), in which phosphorus or co-limitation occurs, may indicate that other sources of nitrogen are being utilized by the test alga (Claesson 1980). It may also reflect the relatively low percentages of bioavailable phosphorus either by the generally low concentrations of phosphorus or by pH inhibited growth of the test alga.

Nitrogen and phosphorus bioavailability refers to the quantity of the substance that can be utilized by the test species. The bioavailability of total soluble inorganic nitrogen is calculated by dividing the maximum standing crop of the test species obtained in the phosphorus spiked sample by the nitrogen yield factor (38 $\pm$ 7.6 milligrams algal dry weight per milligram of nitrogen). The bioavailability of orthophosphate is calculated by dividing the maximum standing crop of the test species obtained in the nitrogen spiked samples by the phosphorus yield factor (430 $\pm$ 86 milligrams algal dry weight per milligram of phosphorus (Miller et al. 1978)). Other investigators have determined higher yield factors for phosphorus. Claesson (1978), Toerien et al. (1971), Gerhold and Otto (1976), and Kotai et al. (1978) reported phosphorus yield factors of 640 mg/l, 805 mg/l, 700 mg/l, and 500 mg/l dry weight, respectively. The nitrogen yield factor reported by these investigators is similar (38 mg/l dry weight) except for Kotai et al. (1978) (60 mg/l dry weight). Knowledge of nitrogen and phosphorus bioavailability in a test water can be useful in determining levels of acceptable nutrient loading and can be used in determining whether nutrient removal from a test water would be beneficial.

Table 69. Mean dissolved nutrient concentrations of the FREQUENCY stations in mg/l.

Station	TKN	NH_3	NO_2+NO_3	(TSIN) $NH_3+NO_2+NO_3$	PO_4
QUIN 1	0.131	0.022	0.291	0.313	0.036
QUIN 2	0.520	0.041	0.012	0.053	0.069
QUIN 3	0.636	0.242	0.026	0.268	0.137
CRES 1	0.148	0.016	0.010	0.026	0.022
CRES 2	0.390	0.059	0.094	0.153	0.033
CRES 3	0.479	0.317	0.116	0.433	0.033
MOSS 1	0.179	0.025	0.181	0.206	0.025
MOSS 2	0.339	0.218	0.027	0.245	0.023
MOSS 3	0.352	0.014	0.024	0.038	0.024
MOSS 4	0.237	0.013	0.020	0.033	0.025
MOSS 5	0.164	0.012	0.199	0.211	0.021
GADS 1	0.304	0.088	0.015	0.103	0.053
GADS 3	0.418	0.212	0.061	0.273	0.062

Table 70. FREQUENCY stations limiting nutrients, determined by algal assay and predicted by chemical ratios.

	Nov 84 D / PD	Dec 84 D / PD	Jan 85 D / PD	Feb 85 D / PD	Mar 85 D / PD	Apr 85 D / PD	Apr 85 D / PD	May 85 D / PD	Jun 85 D / PD	Jul 85 D / PD	Aug 85 D / PD
QUIN 1	P 16.5 P	P 12 P	P 12 P	P 11.7 P	P 9 N	P 36 P	P 3.7 N	P 3.3 N	P 5.8 N	P 16 P	P 12.5 P
QUIN 2	X	X	.25 C N	.9 C N	.5 C N	2 P N	.2 P N	1 P N	.9 C N	3 P N	3 P N
QUIN 3	1 ND N	1.3 C N	1.4 C N	2 P N	1 C N	7 C N	.74 C N	2.4 P N	8.3 P N	10 P C	8.5 P N
CRES 1	N* N 2	ND N 1	ND N 1	ND* N 2	P* N 1	C* N 2	ND* N .67	ND* N .5	ND* N .25	C* N 2.5	ND* N 1
CRES 2	X	X	X	X	P* P 17.5	C* P 2.5	ND* N 3.3	ND* N 2.7	ND* N 1.3	ND* N 2.5	ND* N 1
CRES 3	P P 24	P N 2.5	P N 8.3	P P 15.5	P P 18	P P 56	P N 8.8	P P 48	ND* P 13	ND* P 39.5	ND* P 22
MOSS 1	ND* P 11.5	P P 22	ND C 10	P P 18	ND* P 19	P P 18	ND N 4.5	P* N 4.2	P* C 10	ND* N 4	ND* P 11.5
MOSS 2	ND* N 1	C N 3	P N 3	P N 1	P N 3	P N 4	P N 1.3	P* N 4	P N 3.5	ND* N 2.5	ND* N 2
MOSS 3	ND* N .7	C N 3	P N 1	P N 1	P N 1	P N 3	P N 3	C* N 2	C* N 1.3	P N 1	P* N 1
MOSS 4	C N .7	C N 2	C N .7	P N 1	C N .7	C N 3	C N 3	X	P N 1	X	X
MOSS 5	ND* P 23	P N 4.8	P N 5.7	ND* N 9	P P 19	P P 18	P P 25	ND* N 8.3	ND* N 8	ND* C 10	ND* P 12
GADS 1	X	C N 8	P N 2.7	P N 4	C N 1.8	P N 3.5	P N .8	P* N .9	P N 7.5	ND* N 2.6	ND* N 7
GADS 3	X	C N 1.2	P N 2.8	P N 3.8	C N 3.5	P P 25	P N 2.4	C N 2.7	P N 7	P N 6.7	P N 3.8

D = Determined
PD = Predicted
ND = Not Determined
* = Severely inhibited growth

N = Nitrogen limited
P = Phosphorus limited
C = Co-limitation
X = No sample

QUIN Site

Mean AGP increased from QUIN 1 to QUIN 2 and decreased from QUIN 2 to QUIN 3. AGP at QUIN 3 was greater than at QUIN 1 (Table 66). The AGP at QUIN 1 did not exceed 0.55 mg/l dry weight during the study, whereas at QUIN 2 and QUIN 3 AGP exceeded 1.0 mg/l dry weight four times each. The generally poor growth of the test alga in the AGP tests can be attributed to low nutrient levels (especially phosphorus) and to low pH ($\bar{x}$ pH = 5.0) which can inhibit algal growth. However, of the tests in which AGP exceeded 1.0 mg/l dry weight, the QUIN site accounted for over 60% from all sites.

Mean ortho-phosphorus increased from QUIN 1 to QUIN 2 to QUIN 3 as did mean TKN. Phosphorus was determined to be the limiting nutrient in 20 of the 31 QUIN site samples, co-limitation was determined in 9 samples, and one sample was limited by factors other than nitrogen or phosphorus.

Mean bioavailability of nutrients (Table 71) shows that nitrogen was more readily available to the test alga than was phosphorus. The percentage of bioavailable TSIN at QUIN 2 greatly exceeded the chemically analyzed TSIN, suggesting other forms (organic nitrogen compounds) of nitrogen were being made available to the test alga. Phosphorus was less than 9% bioavailable in all but two QUIN site samples. The 24.97% mean bioavailable phosphorus at QUIN 2 can be misleading since the bioavailable phosphorus was less than 9% of the phosphorus concentration in all samples from QUIN 2 except for the February 1985, sample in which the bioavailable phosphorus was 100% of the measured phosphorus concentration. This dramatic increase in bioavailable P at QUIN 2 occurred approximately one month following pond-fill. Such increases in nutrient concentrations upon initial filling are a well known feature of impoundments (Baxter 1977).

The addition of nitrogen and phosphorus together generally elicited a favorable growth response in the test algae. In samples from QUIN 1, the combination spike of nitrogen, phosphorus and EDTA usually resulted in growth of the test alga which exceeded the growth in the nitrogen plus phosphorus spiked tests by more than 10%. This suggests that either trace element regulated growth or toxicity occurred in these test waters.

Growth in all controls and spiked test waters was inhibited in the May and July samples from all three QUIN stations, and in the November 1984 sample from QUIN 3. Growth was more inhibited at QUIN 2 and QUIN 3 than at QUIN 1. This appears to be the result of a combination of pH inhibition and low nutrient concentrations. The lack of growth in the control treatments of the November 1984 sample from QUIN 3, however, cannot be explained by pH or measured nutrients.

Table 71. FREQUENCY stations mean total soluble inorganic nitrogen and the mean percentage bioavailable to the test algae and orthophosphate in milligrams per liter.

Station	Total Soluble Inorganic Nitrogen Mean mg/l	Bioavailable TSIN Mean%	Orthophosphate Mean mg/l	Mean Bioavailable Orthophosphate-%
QUIN 1	0.313	101.3%	0.036	0.8%
QUIN 2	0.053	352.8%	0.069	24.63%
QUIN 3	0.226	50.8%	0.137	7.2%
CRES 1	0.026	11.5%	0.022	0.9%
CRES 2	0.153	3.9%	0.033	0.9%
CRES 3	0.433	36.3%	0.033	1.2%
MOSS 1	0.206	13.1%	0.025	1.2%
MOSS 2	0.245	84.4%	0.023	1.7%
MOSS 3	0.038	192%	0.024	2.1%
MOSS 4	0.033	112%	0.025	2%
MOSS 5	0.211	18.5%	0.021	1.4%
GADS 1	0.103	28.2%	0.053	7.5%
GADS 3	0.273	79.9%	0.063	1.7%

AGP tests conducted on pH adjusted samples from the QUIN 2 station resulted in a significant growth increase in five of nine samples but no increase in four samples (Table 67). The pH was adjusted from acidic to slightly alkaline (pH 7.5) which is approximately mid-range for growth of the test alga (Miller et al. 1978). The mean growth of test algae in the pH adjusted AGP tests suggested greater nutrient bioavailability when pH is within the optimum range for the test species.

In summary, algal growth potential at the QUIN site was dependent upon pH and nutrient levels. The primary limiting nutrient was most often phosphorus, followed by co-limitation of N and P. Inhibition of the test alga by low pH and low nutrient levels resulted in some erratic growth responses in the control and treated test waters. Growth responses to the combined addition of nitrogen and phosphorus indicated a potential for the QUIN site to support greatly increased algal growth if additional nutrients are introduced from natural or man made sources.

CRES Site

AGP (Table 66) was less than 0.6 mg/l dry weight in 93% of samples from the CRES site. The AGP was 1.6 mg/l at CRES 2 in June 1985 and 1.0 mg/l at CRES 3 in May 1985. The growth of the test alga was severely inhibited in nearly all of the controls and treatments of samples from CRES 1. The only growth of a spiked sample which exceeded 1.0 mg/l dry weight occurred with the combined N+P+E addition in December 1984, and January and April 1985. The pH at CRES 1 ranged from 3.7 to 4.9 while the mean pH was 4.1. These pH values are well below the pH favorable for growth of the test species.

By strictly observing the procedures for determining limiting nutrients (Miller et al. 1978), samples from CRES 1 were found to be nitrogen limited once, phosphorus limited once, limited by an unknown nutrient three times and completely inhibited six times. Because of the low pH of the test waters, and the resulting inhibited growth in the controls and treatments, it would be misleading to call nitrogen or phosphorus limiting. The determination of an unknown nutrient limiting the growth of the test alga was noted when the combination N+P+E spike produced the only growth significantly greater than the control. The increase in growth ranged from approximately 1000 to 8000 percent, i.e., when the control was 0.575 mg/l dry weight and the growth in the N+P+E treated sample was 46.85 mg/l dry weight.

Control and treatment samples from CRES 2 were also severely inhibited by low pH. Growth did not exceed 0.5 mg/l dry weight except for the June 1985 AGP, which was 1.594 mg/l dry weight. The pH at CRES 2 ranged from 3.9 to 4.2 with a mean of 4.0. Again, by strict adherence to guidelines for determining limiting nutrients, phosphorus was identified as the primary limiting nutrient on one occasion while co-limitation was noted once. In five samples limiting nutrients could not be determined.

In contrast to the non-pH adjusted samples at CRES 2, algal growth in the pH adjusted samples increased significantly in six of seven tests. The mean growth in the pH adjusted control was 2.075 mg/l dry weight vs. 0.417 mg/l dry weight in the non adjusted samples.

Although the AGP at CRES 3 was similar to that at CRES 1 and CRES 2, the growth in the treated samples was substantially greater at CRES 3 than at CRES 1 or CRES 2. This may be a function of the higher pH noted there (pH range = 4.7 to 6.2, $\bar{x}$ = 5.3). The limiting nutrient was determined to be phosphorus in 8 of 11 samples from CRES 3 with three samples so severely inhibited as to preclude the determination of a limiting nutrient (Table 70).

Practically all values of physical-chemical parameters at CRES 3 increased over those values noted at CRES 1 and CRES 2. The exception was dissolved phosphorus, which did not increase over the concentration found at CRES 2. The increase in pH also parallels the increased bioavailability of TSIN to the test alga. At CRES 1 and CRES 2 less than 12% of TSIN was bioavailable to the test alga, whereas at CRES 3, 36% of mean TSIN was bioavailable (Table 71). When pH was not inhibiting growth in the CRES 3 samples, TSIN bioavailability ranged from 52% to 97%. In the pH adjusted samples from CRES 2, mean TSIN was approximately 50% bioavailable.

Ortho-P was less than 1.3% bioavailable at the CRES site. In the CRES 2 pH adjusted samples, ortho-P was approximately 16% bioavailable vs. less than 1% in the non-adjusted samples. All three CRES stations had such low concentrations of phosphorus that even when pH was not inhibiting, phosphorus was not readily bioavailable to the test alga. As demonstrated in samples from CRES 3, when additional phosphorus (0.1 mg/l) was added to the test waters and pH was not a factor, other nutrients in the water could support a substantial growth of the test algae.

In summary, test algal growth in the samples from CRES 1 and CRES 2 was severely inhibited by low pH. Limiting nutrients were difficult to determine at CRES 1 and CRES 2, although phosphorus was determined to be the primary limiting nutrient at CRES 3. Nutrient bioavailability to the test alga increased with increasing pH. Nutrient concentrations increased from CRES 1 through CRES 3, with phosphorus remaining the same at CRES 2 and CRES 3. These data suggest that nutrient additions to the CRES site may increase algal growth at the site in the future although pH inhibition may somewhat mitigate these effects.

MOSS Site

MOSS 1 and MOSS 5 were located in two separate streams at the MOSS site and, although unconnected, they were very similiar in physical-chemical characteristics (Table 7). AGP, as was observed at the previously discussed stream sites, was also similar at these two stations. The AGP at MOSS 1 and MOSS 5 was less than 1.0 mg/l dry weight with the exception of the June 1985 sample at MOSS 5 (AGP = 3.017 mg/l dry weight).

As the pH of this sample was 4.3, which is much less than the optimum pH for growth of the test alga, and algal growth occurred in no other treatments, it is suspected that the apparent algal growth noted in this sample was the result of contamination in the laboratory.

The mean pH values at the MOSS 1 and MOSS 5 sites were 4.9 and 4.5, respectively, and both had nearly identical concentrations of ortho-P and TSIN. Although the control growth was low in all samples and the pH was less than 5.2, substantial growth occurred in the N+P and the N+P+E treated samples five times each. The mean N+P+E growth was greater than the mean N+P growth for both MOSS 1 and MOSS 5 which suggests that a trace element may have been secondarily limiting (Miller et al. 1978).

Phosphorus was the primary limiting nutrient five times in samples from MOSS 1 and MOSS 5. In samples from MOSS 1, severe inhibition was noted three times and thus a limiting nutrient could not be determined, while an unknown nutrient(s) was limiting three times. In samples from MOSS 5, complete inhibition occurred four times while an unknown nutrient was limiting twice (Table 70).

Five samples from both MOSS 1 and MOSS 5 had ortho-P concentrations of 0.01 mg/l, which is the minimum necessary for growth of the test alga. As was noted at other stations, the combination of low phosphorus concentrations and low pH made phosphorus practically non-bioavailable to the test alga ($\leq$ 1.3%). Mean TSIN bioavailability was 13% at MOSS 1 and 18% at MOSS 5 (Table 71). When the pH was near 5, the bioavailable TSIN increased to 79% and 89% at MOSS 1 and MOSS 5, respectively.

MOSS 2 and MOSS 3 are adjacent and connected by a pipe through an earthen dam. Physical-chemical characteristics were similar at the two stations. TSIN and TKN were slightly higher at MOSS 2 than at MOSS 3, though pH and ortho-P were slightly lower. AGP in samples from MOSS 2 and MOSS 3 was under 0.5 mg/l dry weight, except for the April and May 1985 samples from MOSS 3, which were 1.023 and 1.181 mg/l dry weight, respectively. As in other samples, the combination spikes produced very good growth, but unlike any other sites discussed thus far, growth was less variable when the pH was around 5.0. Inhibition did occur in samples from both MOSS 2 and MOSS 3, with the sample from MOSS 2 being completely inhibited three times and that from MOSS 3 once. Phosphorus was the primary limiting nutrient seven times at both MOSS 2 and MOSS 3, though co-limitation was detected occasionally at each station. The mean TSIN bioavailability was 82.5% at MOSS 2 and 192% at MOSS 3. Bioavailable ortho-P was less than 2.2% at MOSS 2 and MOSS 3 (Table 71). The magnitude of the bioavailability of TSIN at MOSS 3 suggests that other nitrogen sources were possibly being utilized (Claesson 1980).

AGP tests were conducted on pH adjusted samples from MOSS 2 and MOSS 3. AGP increased significantly in 6 of 11 of these samples from MOSS 2, while at MOSS 3 AGP increased significantly five times. In the pH adjusted samples, TSIN became approximately 75% bioavailable at both MOSS 2 and MOSS 3, while phosphorus bioavailability increased to approximately 11%.

AGP at MOSS 4, the outstream, was less than 0.6 mg/l dry weight for all samples. This may reflect the low nutrient concentrations and the low bioavailability of nutrients to the test alga. Additionally, the pH of samples from MOSS 4 was generally just slightly less than optimum. However, growth in combination spike (N+P and N+P+E) tests was good in all samples.

Mean TSIN bioavailability in samples from MOSS 4 was only 28% until the June 1985 sample, in which approximately 590% of the analyzed TSIN was bioavailable. In all samples from MOSS 4, TSIN was less than the minimum amount necessary for the growth of the test alga, though the total nitrogen exceeded the minimum necessary for the test alga. This again shows that other sources of nitrogen may have been utilized by the test algae. Mean bioavailability of ortho-P from MOSS 4 samples was 2%, while phosphorus concentrations ranged from 0.01 to 0.04 mg/l. In two samples, phosphorus was at the minimum concentration (0.01 mg/l) necessary for normal growth.

The pH in samples from MOSS 4 ranged from 5.2 to 6.1 ($\bar{x}$ = 5.4). There was no obvious growth inhibition due to low pH. All of the combination N+P spiked samples grew consistently well. Phosphorus was determined to be the limiting nutrient in two of the eight samples from MOSS 4, while co-limitation of nitrogen and phosphorus was noted in the other samples.

The data suggest that low nutrient concentrations and low pH affected algal growth in samples from the MOSS site more than any other physical-chemical factors. Samples from all of the MOSS stations were capable of supporting algal growth if additional nutrients were added to the water. TSIN was more bioavailable in samples from the MOSS ponds than in samples from the MOSS streams. Ortho-P concentrations were low and did not differ significantly between any of the MOSS sites, while ortho-P bioavailability increased with increased pH in the pond samples.

GADS Site

GADS 3 differed from GADS 1 in several physical-chemical parameters which evidently made GADS 3 a more favorable site for supporting the growth of our test alga. Among these parameters, the mean pH at GADS 3 was 6.0 vs mean pH 5.3 at GADS 1 and mean TSIN of 0.27 mg/l at GADS 3 vs. 0.103 mg/l at GADS 1. The higher pH at GADS 3 was within the optimum range (pH 6-10, Miller et al. 1978) for the test alga and the higher TSIN concentrations made nitrogen more readily available. Although the mean TSIN concentration was slightly less than the reported minimum (0.28 mg/l) necessary for the test alga (Miller et al. 1978), it has been established that Selenastrum can utilize other forms of nitrogen (Claesson 1980). Since the mean total nitrogen concentration was significantly greater than the mean TSIN concentration, our test organisms could have been using additional nitrogen sources. The mean phosphorus concentrations at the two sites differed by less than 0.01 mg/l, with GADS 3 > GADS 1 (0.061 vs. 0.053 mg/l).

AGP in samples from both GADS 1 and GADS 3 was less than 1.0 mg/l dry weight with the exception of the May 1985 sample when AGP at GADS 1 was 1.123 mg/l dry weight.

Severe growth inhibition occurred three times in samples from GADS 1 when the pH was less than 5.0. Slight growth inhibition occurred once at GADS 1 and once at GADS 3. In several samples taken during the summer months, the combination N+P spiked samples grew much better than the combination N+P+E spiked samples from both GADS 1 and GADS 3.

Phosphorus was determined to be the primary limiting nutrient five times at GADS 1 and seven times at GADS 3. Co-limitation was determined twice at GADS 1 and three times at GADS 3. Limiting nutrients could not be determined on two occasions at GADS 1. As at all other FREQUENCY sites, the major factors controlling algal growth at the GADS site appear to be pH and bioavailable phosphorus. Phosphorus was 7.5% bioavailable at GADS 1 and 1.7% bioavailable at GADS 3. TSIN was 28% bioavailable at GADS 1 and 79.9% bioavailable at GADS 3. Growth of the test algae in samples from GADS 1 appeared to be primarily controlled by the low bioavailability of nutrients and occasionally by less than optimum pH. Although the pH at GADS 3 was favorable for the growth of test algae, the low bioavailability of phosphorus evidently precluded growth of alga in the AGP tests. In samples from GADS 3 the addition of phosphorus alone usually resulted in a significant growth response by the test alga.

MASS Algal Assays

A portion of the pond study consisted of algal growth potential assays performed on samples from 13 sites located in Jackson and Gadsden counties. Each site had from two to three stations consisting of an instream, an outstream, a pond or a combination thereof. There were nine instream stations, 13 pond stations, and 13 outstream stations. A maximum of six and a minimum of four samples were taken from any one station for a total of 184 samples from the 13 sites. The samples from the MASS sites were taken in January, February, May, June, July, and August, 1985. In May, 1985 only the pond stations were sampled (Table 72).

A lack of data from individual stations precluded correlations of algal growth potential with individual station physical-chemical parameters. Although the stations were located at 13 different physical sites, correlations were done by assigning all of the sites into the instream, outstream, and pond categories. The results of these correlations of algal growth potential and different physical-chemical parameters are shown in Table 73. These correlations are similiar to those obtained in the FREQUENCY samples. AGP was significantly correlated with chlorophyll-a, total Kjeldahl nitrogen, total ammonia, and total phosphorus in the instream and the pond stations and with chlorophyll-a and total Kjeldahl nitrogen in the outstream stations. AGP did not correlate with nitrite-nitrate at any of the station groups. Means, and ranges of AGP data from the MASS sites are presented in Table 74.

Table 72. MASS sample sites, sample dates, and number of samples.

Stations	Number of samples	Jan 85	Feb 85	May 85	Jun 85	Jul 85	Aug 85
Syrett 2	6	X	X	X	X	X	X
Syrett 3	4	X	X	-	-	X	X
Kever 1	5	X	X	-	X	X	X
Kever 2	6	X	X	X	X	X	X
Kever 1	5	X	X	-	X	X	X
Hopper 1	5	X	X	-	X	X	X
Hopper 2	6	X	X	X	X	X	X
Hopper 3	5	X	X	-	X	X	X
Crawford 2	6	X	X	X	X	X	X
Crawford 3	5	X	X	-	X	X	X
McLendon 2	6	X	X	X	X	X	X
McLendon 3	5	X	X	-	X	X	X
Suber 2	6	X	X	X	X	X	X
Suber 3	5	X	X	-	X	X	X
Lett 1	4	X	X	-	-	X	X
Lett 2	6	X	X	X	X	X	X
Lett 3	4	X	X	-	-	X	X

Table 72. Cont'd.

Stations	Number of samples	Jan 85	Feb 85	May 85	Jun 85	Jul 85	Aug 85
Whittle 1	5	X	X	-	X	X	X
Whittle 2	6	X	X	X	X	X	X
Whittle 3	5	X	X	-	X	X	X
Scott 1	4	X	X	-	-	X	X
Scott 2	6	X	X	X	X	X	X
Scott 3	4	X	X	-	X	X	-
Thompson 1	5	X	X	-	X	X	X
Thompson 2	6	X	X	X	X	X	X
Thompson 3	4	X	X	-	X	X	X
Kingry 1	5	X	X	-	X	X	X
Kingry 2	6	X	X	X	X	X	X
Kingry 3	5	X	X	-	X	X	X
McCormick 1	5	X	X	-	X	X	X
McCormick 2	6	X	X	X	X	X	X
McCormick 3	5	X	X	-	X	X	X
Faircloth 1	5	X	X	-	X	X	X
Faircloth 2	6	X	X	X	X	X	X
Faircloth 3	4	X	X	-	X	X	-

1 = instream
2 = pond
3 = outstream
X = sampled
- = not sampled

Table 73. Correlations of algal growth potential and chemical parameters of combined MASS instream, pond and outstream stations.

ALGAL GROWTH POTENTIAL VS.		r	SIGNIFICANCE
Free Water Chlorophyll-a	1	.251	.1
	2	.855	.01
	3	.321	.01
Total Kjeldahl Nitrogen	1	.448	.01
	2	.543	.01
	3	.250	.05 > P > .02
Total Ammonia	1	.429	.01
	2	.500	.01
	3	.070	NS
Total Phosphate	1	.379	.02
	2	.310	.01
	3	.119	NS
Dissolved Nitrite/Nitrate	1	.021	NS
	2	-.086	NS
	3	-.111	NS
pH	1	.104	NS
	2	.050	NS
	3	-.008	NS

1 = instream
2 = pond
3 = outstream

TABLE 74. MASS stations, mean, maximum and minimum Algal Growth Potential in milligrams per liter.

SITE	INSTREAM			POND			OUTSTREAM		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Syfrett	----	----	----	1.11	4.47	0.16	0.27	0.61	0.13
Kever	0.20	0.35	0.11	1.93	10.46	0.12	3.75	17.14	0.16
Hopper	16.16	30.15	0.64	31.68	65.13	11.41	16.69	47.67	0.21
Crawford	----	----	----	0.18	0.28	0.11	0.52	1.47	0.10
McLendon	----	----	----	0.61	1.17	0.14	5.86	10.37	1.22
Suber	----	----	----	0.746	1.61	0.23	16.93	42.16	0.29
Lett	0.43	0.811	0.26	1.15	4.75	0.14	0.46	1.19	0.10
Whittle	0.77	1.26	0.14	2.27	9.93	0.03	3.82	8.58	0.36
Scott	0.28	0.40	0.18	32.83	111.16	0.30	5.42	18.92	0.62
Thompson	0.27	0.47	0.12	1.08	4.09	0.08	0.22	0.28	0.16
Kingry	2.77	6.95	0.12	0.14	0.23	0.08	0.81	3.19	0.07
McCormick	3.44	16.29	0.13	0.68	3.11	0.06	1.02	4.43	0.10
Faircloth	0.16	0.27	0.06	0.28	0.57	0.12	0.76	1.56	0.19

Syfrett Site (A)

AGP of samples from the Syfrett site was generally less than 1.0 mg/l. The maximum AGP occurred in the January 1985 pond sample. The pH of all but one sample (outstream, January 1985) was in the range (< pH 6) known to be inhibitory to the test alga. The phosphorus concentration (0.01 mg/l) of this sample did not exceed the minimum necessary for growth of the test alga, therefore AGP remained low.

Kever Site (B)

AGP of the Kever site was generally less than 1.0 mg/l dry weight, and increased from instream to pond to outstream. With the exception of the January 1985 pond sample and the February 1985 outstream sample, there were no significant differences in AGP of any of the Kever site samples. The pH of all the Kever site samples was in the range (< pH 6) known to be inhibitory to the test alga. Occasionally Selenastrum will grow quite well when all measured parameters indicate that the algae should not grow. This occurred in the January, 1985, pond sample. The February, 1985, outstream sample also produced a substantial AGP when the measured pH was in the range (< pH 5) considered to be severely inhibitory. However, in this sample, the measured phosphorus concentration (0.19 mg/l) was apparently great enough to overcome the inhibitory effects of the low pH.

Hopper Site (C)

AGP of the Hopper site samples was among the highest recorded from any of the MASS sites. Twelve of 16 Hopper site samples were highly productive (i.e., > 6.0 mg/l dry weight). Mean AGP of the pond station was nearly twice that of the instream and outstream stations, which were similar. The pH of all but one sample from the Hopper site was in the inhibitory range, but apparently inhibition was inconsistent with measured parameters. That is, lower pH's did not necessarily result in lower AGP. AGP of the Hopper site is fairly consistent with increased AGP expected from increased nutrients associated with livestock operations (Filip and Middlebrooks 1975).

Crawford Site (D)

The AGP of all but the July 1985 outstream (1.466 mg/l dry weight) Crawford site samples was less than 1.1 mg/l dry weight. The pH was in the range (< pH 6) known to be inhibitory to Selenastrum in all of the Crawford site samples. Nutrient concentrations were generally low, and on several occasions, phosphorus was at the minimum concentration necessary for growth of the test alga.

McLendon Site (E)

Mean AGP of the outstream station samples was nearly ten times the mean AGP of the pond station samples. The pH of the samples from the McLendon site was in the optimum range for growth of the test algae in all but two samples. Nutrient concentrations appeared to be the controlling factor for AGP in the samples from this site. Phosphorus concentrations were significantly higher in four of five outstream samples as compared to concurrent pond samples. AGP was significantly higher in each of the outstream samples as compared to the pond samples.

Suber Site (F)

AGP of the Suber site was affected by pH and nutrient concentrations. Less than optimum pH (pH < 6.0) and low nutrient concentrations were responsible for the low productivity of the Suber pond samples. The Suber outstream samples for July and August, 1985 were highly productive, and again demonstrated the unpredictable growth that can occur when the pH is less than optimum but nutrient concentrations, particularly phosphorus, are substantial. In this case the June outfall samples had a phosphorus concentration of 0.24 mg/l, a pH of 5.3, and an AGP of 1.29 mg/l dry weight. The July and August outfall sample had phosphorus concentrations of 0.27 and 0.31 mg/l, respectively. The pH's were 5.1 in the July sample and 5.2 in the August sample and the AGP was 40.754 (July) and 42.151 (August) mg/l dry weight. Possible explanations for this unpredictable growth include lack of a nutrient other than N or P, or the presence of a substance in the test water which was toxic to the test species. The AGP values of the first three concurrent pond and outstream station samples were not significantly different, though the July and August samples were significantly different in AGP and nutrient concentrations.

Lett Site (G)

Less than optimum pH (< 6.0) and low nutrient concentrations were the factors which were responsible for the generally low AGP in samples from the Lett site. The pond station had the highest mean AGP. The differences in the mean AGP of the outstream and the instream stations were insignificant.

Whittle Site (H)

Mean AGP increased from the instream station to the pond station to the outstream station. The pH was in the severely inhibitory range (< 5.0) in 10 of 16 samples and in the inhibitory range (pH < 6.0) in all of the samples. As noted at several previous sites, some of the highest AGP values noted were in samples with low pH but fairly high phosphorus concentrations. AGP of three Whittle site samples was quite high (> 6.0 mg/l dry weight). The greatest measured AGP occurred in the May 1985 pond station, but on this date the other stations were not tested and a comparison cannot be made between stations for this month.

Scott Site (I)

The pH was less than optimum (< 6.0) in all samples, and the low AGP yields (< .5 mg/l dry weight) of the samples from the instream station were typical of results obtained in test waters having low pH and low nutrient concentrations. The Scott pond station produced the highest AGP yield of any of the MASS stations. The mean phosphorus concentration of this station was slightly higher than average, but the mean nitrogen concentration was the highest of any of the MASS stations.

The January 1985 outstream sample was highly productive in terms of AGP. The primary importance of the Scott outstream samples are as a comparison to the pond station samples to show how seemingly insignificant differences in pH, phosphorus and nitrogen concentrations can produce vastly different AGP yields. This usually signifies that other factors such as toxicity or a lack of an essential nutrient in these particular samples played an important role in AGP yields.

Thompson Site (J)

The low AGP noted at the Thompson site is probably attributable to generally less than optimum pH (< 6.0) and low nutrient concentrations. Low phosphorus concentrations were probably responsible for low AGP even when the pH was in the optimum range. The June 1985 pond sample was the only one in which the AGP exceeded 1.0 mg/l dry weight. Other than this particular sample, there were basically no significant differences in AGP among the three Thompson site stations.

Kingry Site (K)

AGP results of the Kingry site samples were different from most other MASS sites in that the instream stations had the highest AGP, the outstream station the next highest AGP, and the pond station the lowest AGP. Less than optimum pH and low phosphorus concentrations appear to have been the factors controlling AGP in the Kingry site samples. The AGP of two instream samples and one outstream sample exceeded 1.0 mg/l dry weight. The pH of these samples was less than optimum (< 6.0) and the phosphorus concentrations were such that the AGP of these samples was greater than expected.

McCormick Site (L)

AGP of the McCormick site samples was less than 1.0 mg/l dry weight in all but one sample from each station. The pH was less than optimum (< 6.0) in all but one sample and in that case nutrient concentrations were at or below the minimum concentrations (0.01 mg/l phosphorus and 0.28 mg/l nitrogen) required for growth of the test alga. The maximum AGP from the instream samples and from the outstream samples occurred when phosphorus concentrations were greatest. This did not occur in the pond samples.

Faircloth Site (M)

AGP was < 0.6 mg/l dry weight in all samples from the instream station and the pond station. AGP of the outstream station exceeded 1.0 mg/l dry weight in two samples. These results corresponded with the greatest nutrient concentrations. AGP was less than expected in the only two samples in which pH was not considered to be an inhibitory factor. In one of these two samples, nitrogen was less than the minimum (0.28 mg/l) required for the test alga. In the other sample, the low AGP resulted from a factor other than pH, phosphorus or nitrogen.

SUMMARY

1. Algal growth potential was generally low (< 1.0 mg/l dry weight), except for several stations associated with livestock and recreational use which had substantial AGP.

2. Although pH sometimes inhibited the growth of the test algae, the addition of combined nutrients (N+P or N+P+E) often elicited substantial growth in the test waters.

3. Limiting nutrient tests showed phosphorus to generally be the primary limiting nutrient though nitrogen was most often predicted by chemical ratios to be the primary limiting nutrient.

4. Nitrogen was generally much more bioavailable than phosphorus to the test algae.

5. AGP in 26 of 38 pH adjusted tests increased significantly over that in non pH adjusted samples.

6. Results of algal growth potential tests indicated that productivity increases when a stream is impounded due to the impoundment acting as a nutrient sink.

CONCLUSIONS

Algal growth potential was generally less than 1.0 mg/l dry weight in most samples except for a few from stations associated with livestock and recreational use. The low AGP was probably the result of low phosphorus concentrations or inhibition by low pH ($\leq$5.0). Samples from all stations usually supported substantial growth with combined nitrogen and phosphorus additions. The combined addition of nitrogen, phosphorus and EDTA sometimes supported significantly greater growth than the N+P treatment alone suggesting that a trace element may have been secondarily limiting in some tests.

Complete inhibition of test algal growth occurred in at least one sample from all stations except for GADS 3 and MOSS 4. Inhibition was often related to the pH being less than optimum for the growth of the test alga.

AGP tests were conducted with pH adjusted samples from several pond stations. Of these tests, 26 of 38 exhibited significant increases in algal growth. The concentration of phosphorus was extremely important to the test alga as phosphorus was generally less than 2% bioavailable. This was true even when pH was not inhibiting algal growth. Phosphorus concentrations were usually low and occasionally so low as to preclude growth of the test alga. Nitrogen concentrations were usually sufficient for algal growth though it was noted that Selenastrum may have sometimes utilized nitrogen sources other than TSIN.

The nutrient concentrations noted at the various sites suggest that most nutrients are from natural sources and that, thus far, light development activity at some sites has not had major impacts, but some sites have been severely affected by livestock operations. The growth of algae in the combination treatments does suggest, however, that the sites are capable of supporting substantial algal crops if nutrient levels are significantly increased.

BENTHIC MACROINVERTEBRATES

INTRODUCTION

Aquatic macroinvertebrate communities have been shown to be very sensitive to stress and, therefore, can serve as useful indicators of environmental perturbations resulting from introduced contaminants (Gaufin and Tarzwell 1952, Beck 1954, Hynes 1959, Butcher 1959, U.S. EPA 1973, Bauer et al. 1980). Benthic macroinvertebrates are an integral part of the aquatic food web, and thus the relative health of this community is reflected in the well-being of higher trophic levels such as fish (Tippets and Moyle 1978). The sedentary nature of benthic macroinvertebrates, coupled with the phenomenon of "biological magnification", makes them susceptible to contaminants (e.g., pesticides, radioactive materials, and metals) which may be present in undetectable concentrations, but which can be absorbed over time and produce adverse impacts on the benthic community (U.S. EPA 1973).

A major goal of this project was to determine the effects that stream impoundments have on benthic populations. Florida Administrative Code 17-3.121(7) states that "the Shannon-Weaver diversity index of benthic macroinvertebrates shall not be reduced to less than 75% of established background levels...". The impact of stream impoundment, as it relates to this biological integrity criterion and other parameters involving benthic macroinvertebrate communities, is discussed in this section.

METHODS AND MATERIALS

A modification of the method of Parsons and Tatum (1974) was selected, which consists of mounting 4 Hester-Dendy multiplate samplers (as modified by U.S. EPA 1973) on a concrete block. The concrete blocks were then placed at a depth of approximately 0.5 meters at stream stations and 2-3 meters at pond stations. Each Hester-Dendy sampler has a total surface area of 0.11 m^2. The samplers were incubated for 28 days, which, according to previous studies (Rosenberg and Resh 1982), was adequate to allow macroinvertebrate colonization of the samplers to reach equilibrium. Upon retrieval, the incubated samplers were placed in separate Whirl Pak® bags, partially filled with water from that particular station, and then stored on ice.

In the laboratory, the samplers were dismantled and the plates carefully brushed and washed with tap water over a 0.5 mm mesh sieve. The sieved material was then stored in 70% ethanol, and later, the organisms separated from detritus under a 60X dissecting microscope and placed in fresh 70% ethanol. Organisms were then counted and identified, using either a dissecting or compound microscope, to the lowest possible taxonomic level using the taxonomic references listed in the Literature Cited.

Additionally, three replicate Petite Ponar benthic grab (272 cm^2) samples were taken at selected pond stations. The dredged material was initially sieved in situ through a 30 mesh screen (500 um) and placed in separate polypropylene containers. A 70% ethanol solution was then added (with rose bengal) to preserve these samples. Further processing of the ponar samples followed the procedures for the dismantled Hester-Dendy samples.

Qualitative collections, using a dip net to capture invertebrates at all available micro-habitats within a station, were conducted at certain sites. Approximately 1 1/2 man/hours were spent at each of these selected stations. Animals were collected from under and around logs, roots, snags, aquatic vegetation, sand and muck. The littoral zones of the ponds were extensively sampled with the dip net. Adult odonates were also captured for identification.

Data Analysis

To determine the effects of stream impoundment on macroinvertebrate communities, data from the feeder or "control" stream was compared to the impounded area or "pond" and the downstream or "outfall" for each study site. Several levels of data analysis have been utilized, including, but not limited to, the techniques of Lenat et al. (1979) in their evaluation of pollution impacts on North Carolina streams and rivers. The multivariate techniques of classification and ordination (Bloom et al. 1977, Green and Vascotto 1978, Field et al. 1982) were also used very successfully, along with multiple discriminant analysis (Nie et al. 1975). The following is a description of the application and usefulness of each type of data analysis technique, and their relevance to this study.

Single number summaries include 1) mean abundance or density, 2) total taxa, 3) mean taxa, and 4) Shannon-Weaver diversity index (d). Where applicable, a range of values from minimum to maximum for each parameter has been provided. A reduction (or increase) of these single number summaries between the control stream and the pond, or the control stream and the outfall is useful in interpreting how impoundments affect general trends of the benthic communities. Table 75 provides analytical criteria for evaluating these data in relation to controls. Additionally, three important abiotic parameters have been provided along with these single number summaries, since these were thought to directly relate to changes in the benthos. These are mean bottom temperature, mean bottom dissolved oxygen and percent organic composition of the sediment.

The mean density of individuals belonging to the major taxonomic groups has also been tabulated. These data are somewhat more detailed than the single number summaries in that reduction or elimination of certain sensitive groups of organisms (e.g., Plecoptera, Trichoptera) can be determined. Reduction or elimination of sensitive groups between the control and impacted area may indicate perturbation. Conversely, an increase of known tolerant groups (e.g., certain Oligochaeta) may indicate stress.

Table 75. Analysis criteria for evaluating macroinvertebrate data in relation to controls.

A. Reduction in Density (N) (from Lenat et al. 1979)

1. < 20%: Unstressed

2. 30%-60%: Moderate Stress

3. > 60%: Severe Stress

B. Reduction in Species (or Taxa) Richness (s) (from Lenat et al. 1979)

1. < 20%: Unstressed

2. 20%-50%: Moderate Stress

3. > 50%: Severe Stress

C. Diversity (d) (from Wilhm 1970)

1. > 3: Clean

2. 2-3: Moderate Stress

3. < 2: Severe Stress

D. Diversity (d) (from FAC 17-3.121(7))

1. 25% reduction in d (compared to the control) is a violation.

Species level data can also be utilized to show reduction in occurrence or complete elimination of taxa collected at the control station compared to the pond or outfall stations. The complete elimination of certain species between two stations only several hundred meters apart would suggest a rather sudden alteration in habitat and/or water quality parameter(s) necessary for the species to survive.

A particular organism can be considered "representative" of a station if it occurred in 50% or more of the samples taken from that station. Attention can then be focused on these representative organisms for comparisons between stations. The total number of different taxa occurring in at least 50% of the samples can be used to provide a measure of the "qualitative stability" of a station.

Multivariate techniques (similarity indices and ordination) are standard analytical tools in community ecology (Bloom 1981). Put simply, these methods place either similar sampling stations (Q or normal analysis) or taxa (R or inverse analysis) into groups with similar attributes, and therefore link these groups. Quite often, the geographically closest sampling stations (assuming a continuous aquatic system) will group together. When two control stations (which are 50 km apart) group together, rather than grouping with their respective downstream impact station (which may only be 100 m away), it may suggest some type of environmental perturbation. The clustering of certain species groups (e.g., those restricted to either control streams or ponds) may also help explain apparent differences in the biota sampled from two dissimilar stations.

Finally, discriminant analysis was used to isolate the abiotic factors that exerted the most influence on the benthic community. These results were compared to the results from the species occurrence data to attempt to correlate the environmental parameters responsible for the station clusters.

RESULTS AND DISCUSSION

FREQUENCY Sites

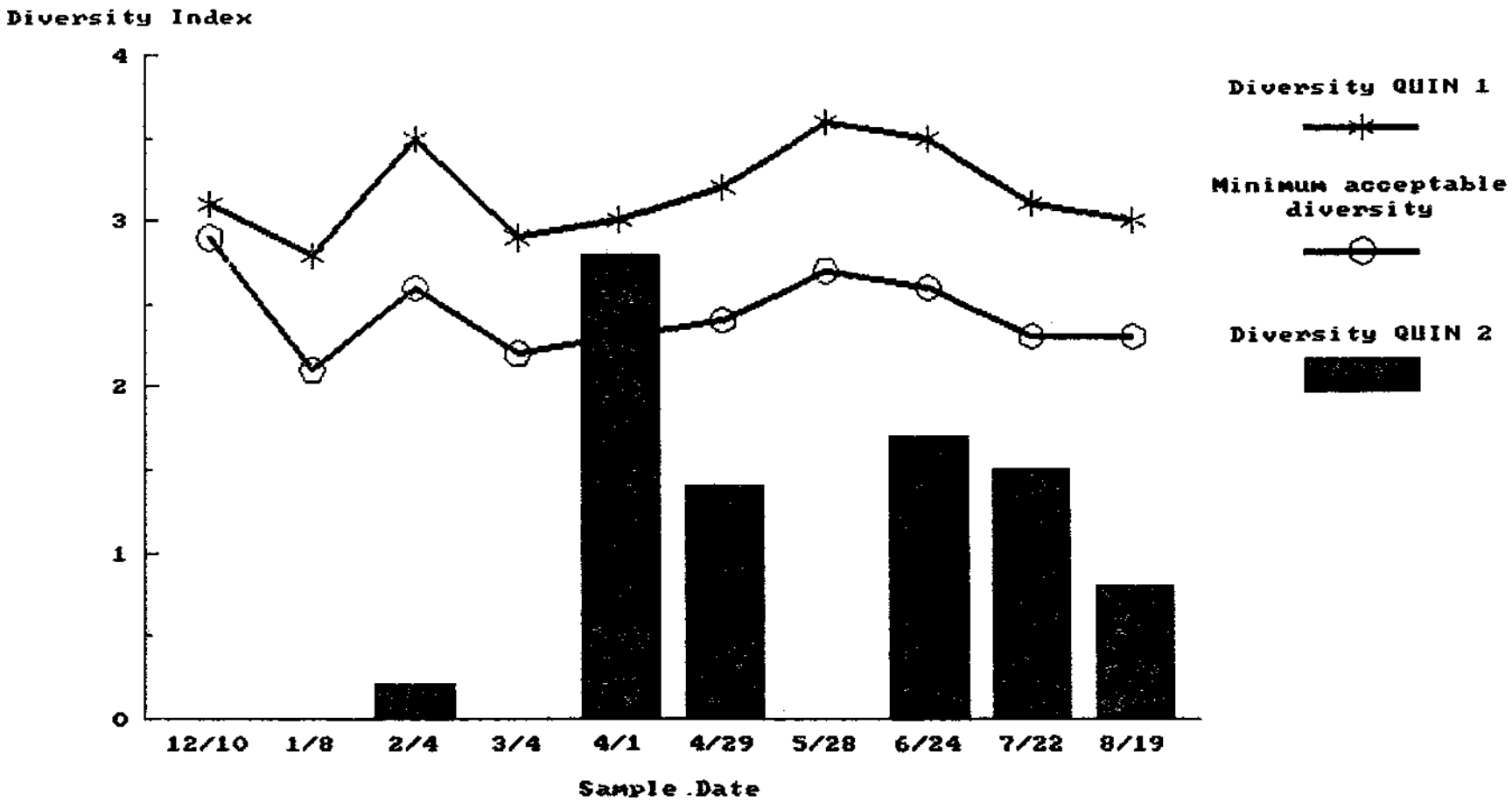
QUIN Site

Single number summaries showed uniform decreases between stations QUIN 1 and QUIN 2 (Table 76). Mean abundance dropped by 92%, total and average taxa declined by 67% and 78%, respectively, while mean d decreased by 55%. This suggests that the benthic population of QUIN 2 was severely stressed (Table 75). The biological integrity criterion (25% reduction in $\bar{d}$) was violated five out of the six times that data were available for QUIN 2 (Figure 102).

TABLE 76. Benthic macroinvertebrate mean abundance, total taxa, mean taxa, mean Shannon-Weaver diversity index, the "pooled" variation of this index, mean bottom temperature, mean bottom dissolved oxygen, % of organic matter in the sediment, and the mean number of individuals in selected taxonomic groups for the QUIN Site, November 1984 to August 1985. Numbers in parentheses are minimum values for the sample period.

	QUIN 1	QUIN 2	QUIN 3
$\bar{x}$ Abundance (ranges)	149.3 (58-377)	11.5 (1-43)	517.6 (40-2452)
Total Taxa	67	22	75
$\bar{x}$ Taxa (ranges)	19.5 (14-25)	4.3 (1-8)	19.8 (7-28)
$\bar{x}$ $\bar{d}$ (ranges)	3.1 (2.9-20.1)	1.4 (0.0-2.8)	2.6 (1.2-3.9)
Pooled $\bar{d}$	3.8	3.2	3.4
$\bar{x}$ Bottom Temperature (°C)	16.0 (5.4-20.1)	16.8 (6.0-25.8)	17.6 (9.0-28.0)
$\bar{x}$ Bottom Dissolved Oxygen (mg/1) (ranges)	7.8 (6.4-11.0)	1.9 (0.2-6.6)	6.7 (4.5-9.2)
Sediment % Organic		1.6%	
$\bar{x}$ Individuals			
Coleoptera	0.4	0.0	0.8
Diptera	111.3	4.5	397
Ephemeroptera	16.7	0.2	0.1
Megaloptera	0.6	0.0	0.0
Odonata	0.3	0.2	0.4
Oligochaeta	0.4	6.5	116.1
Plecoptera	15.1	0.2	0.0
Trichoptera	3.5	0.0	0.0

FIGURE 102. QUIN site biological integrity violations.



Values below minimum acceptable diversity (25% reduction from control) indicate violation.

Depleted dissolved oxygen (D.O.) in the pond ($\bar{x}$ = 1.9 mg/l, minimum = 0.2 mg/l) may very well account for this stress. In fact, beginning in March, 1985, the bottom dissolved oxygen value fell below 1.0 mg/l in the pond and remained there throughout the remainder of the study (Figure 103). It is interesting to note, however, that even with D.O. below 1.0 mg/l on 1 April, 1985, the $\bar{d}$ was surprisingly high for such conditions (2.8).

A comparison of these same parameters for QUIN 1 and QUIN 3 showed increases in mean density and total taxa (71% and 11%, respectively) (Table 76). Mean $\bar{d}$ decreased by 16% while mean taxa remained the same for both stations. Similar increases in density and decreases in $\bar{d}$ downstream of an impoundment have been noted by other investigations (Ward 1974).

Summaries by taxonomic group indicated some notable differences between QUIN 1 and QUIN 2 (Table 76). Groups found in the control stream, including coleopterans, odonates, megalopterans, and trichopterans, were completely eliminated in the pond. The mean abundance of the Diptera, Ephemeroptera and Plecoptera was reduced by 96%, 98%, and 99%, respectively. The oligochaete population, however, increased between QUIN 1 and QUIN 2 by 94%. In fact, oligochaetes were dominant among the highly depauperate fauna at this recently filled impoundment (QUIN 2). Paterson and Fernando (1969) also found oligochaetes to be the first invaders of a new impoundment in Canada. The megalopteran, stonefly and caddisfly populations were eliminated between QUIN 1 and QUIN 3. Mayflies were reduced at the outfall station (compared to the control) by 99%. Aquatic beetles, dipterans, and oligochaetes increased by 50%, 72%, and 100%, respectively. Increased abundance of chironomids and oligochaetes is often associated with elevated organic loading (Hynes 1970).

Several interesting trends appear by comparing numbers of taxa occurring in at least 50% of the samples (Table 77). QUIN 1, QUIN 2 and QUIN 3 had 14, 0, and 13 of such taxa, respectively. The lack of such taxa at the pond station is striking, and may indicate that conditions there (e.g., episodes of severe D.O. depletion) are inhospitable for the development of a stable benthic community. The similarity of the number of frequently occurring taxa at the control and outfall stations, however, is misleading. QUIN 1 and QUIN 3 had five such species in common. These were organisms such as Conchapelopia sp. and Tanytarsus sp. which are sometimes considered indifferent to habitat preference (Beck 1977). The frequently occurring taxa collected at QUIN 1 but not QUIN 3 were generally those inhabiting undisturbed areas such as the mayfly Habrophlebiodes brunneipennis, the stonefly Leuctra sp., and the caddisfly Diplectrona modesta. Taxa which are known to be tolerant of organic enrichment and low D.O., such as Chironomus riparius and Limnodrilus hoffmiesteri, (Beck 1977, Stimpson et al. 1982) occurred frequently at the outfall but not at the control.

FIGURE 103. Dissolved oxygen values for QUIN 1 and QUIN 2.

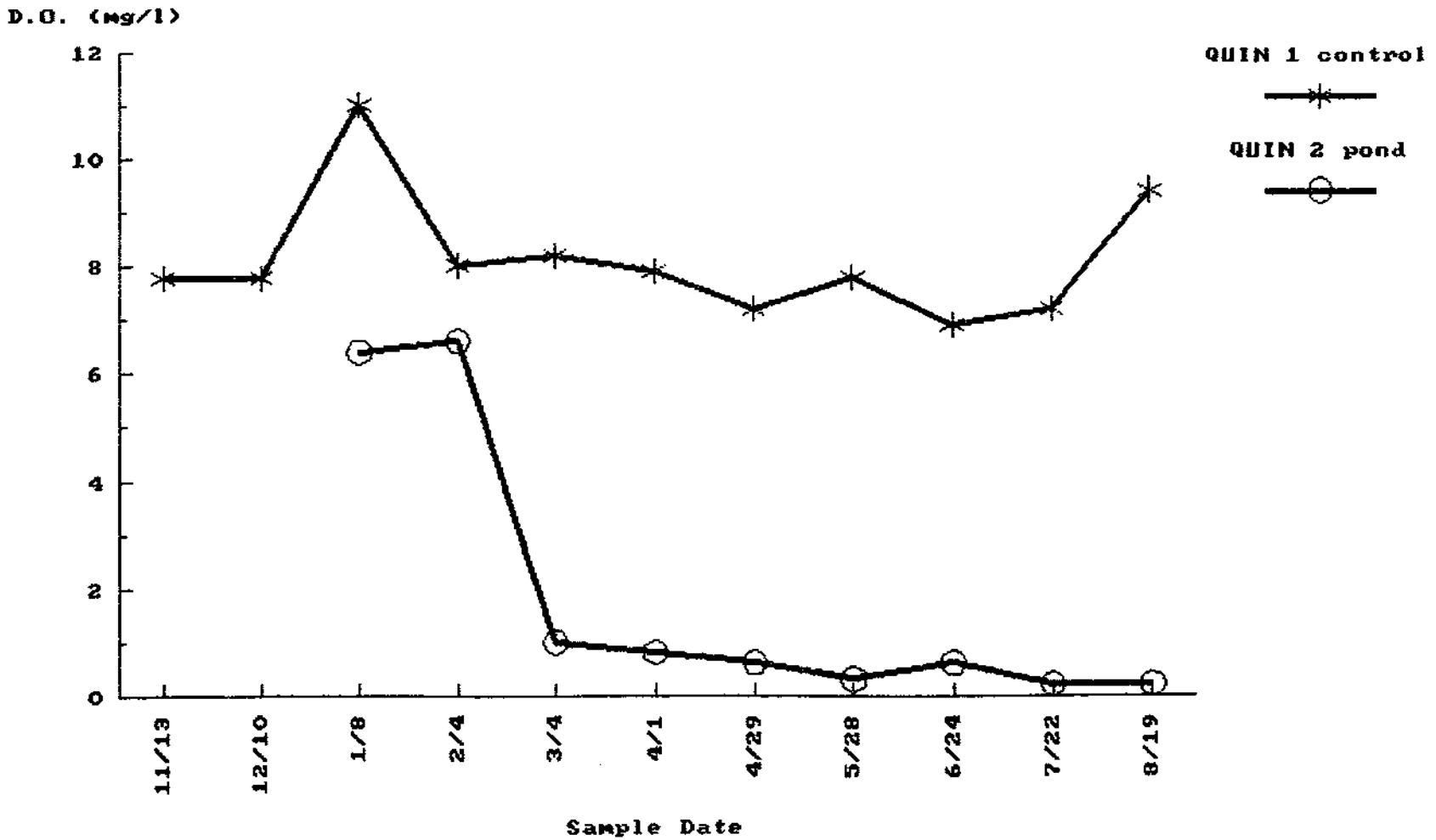


TABLE 77. Taxonomic listing with number of ocurrences for each taxa at each station for the QUIN Site.

NAME	Number of Occurrences (10 max) QUIN 1	QUIN 2	QUIN 3
Atractides sp.	1	0	0
Lycosa sp.	1	0	0
Mideopsis sp.	1	0	0
Torrenticola sp.	1	0	0
Dineutus sp.	0	0	1
Unk. Dytiscidae	1	0	0
Enochurus sp.	0	0	1
Helobata striata	0	0	1
Helochares maculicollis	0	0	1
Hydroporus sp.	0	0	1
Stenelmis crenata	1	0	0
Stenelmis cinuata	1	0	1
Stenelmis sp.	0	0	2
Isotomurus sp.	1	0	3
Ablabesmyia cinctipes	1	0	0
Ablabesmyia mallochi	1	0	1
Ablabesmyis ornata	2	0	1
Ablabesmyia philosphagnos	2	0	1
Ablabesmyia tarella	0	0	2
Bezzia sp.	3	0	4
Bittacomorpha clavipes	0	0	6*
Chaoborus punctipennis	0	3	2
Unk. Chironomidae	3	1	4
Chironomus attenuatus	0	0	5*
Chironomus riparius	0	1	7*
Chironomus sp.	1	0	5*
Chironomus staegeri	0	0	2
Chironomus stigaterus	0	0	2
Conchapelopis sp.	9*	0	9*
Cricotopus bicinctus	2	0	0
Cricotopus sp.	1	0	0
Cryptochironomus fulvus	0	0	6
Dicrotendipes nervosus	1	1	3
Djmabatista pulcher	3	0	0
Endochironomus nigricans	0	0	2
Epoicocladius sp.	2	0	0
Eukiefferiella coerulescens	2	0	0
Eukiefferiella sp.	3	0	0
Glyptotendipes lobiferus	3	1	4
Glyptotendipes meridionalis	0	0	2
Glyptotendipes paripes	0	0	1
Glyptotendipes sp.	0	0	2
Goeldichironomus holoprasinus	0	1	2
Hemerodromia sp.	9*	1	5*
Labrundinia floridana	2	0	0

TABLE 77. Cont.

NAME	Number of Occurrences (10 max) QUIN 1	QUIN 2	QUIN 3
Macropelopis sp.	0	0	4
Microtendipes pedellus	0	1	0
Nanocladius sp.	0	0	1
Nilothauma sp.	1	0	0
Orthocladius sp. A (Dye)	3	0	0
Orthocladius sp.	2	0	0
Parachironomus schneideri	0	0	2
Pentaneura iconspicua	0	0	4
Pericoma sp.	1	0	0
Phaenopsectra obediens	0	0	1
Polypedilum convictum	8*	2	3
Polypedilum fallax	4	0	2
Polypedilum halterale	1	0	7*
Polypedilum illinoense	7*	1	7
Paramerina sp.	0	1	1
Parametriocnemus lundbecki	6*	0	1
Parametriocnemus sp.	3	0	0
Unk. Dipteran pupae	4*	2	10*
Rheocricotopus robackii	2	0	0
Rheocricotopus sp.	1	1	5*
Rheotanytarsus sp.	9*	0	0
Simulium sp.	7*	0	1
Tanytarsus sp.	10*	1	9*
Thienemanniella xena	6*	0	0
Tipula sp.	0	0	1
Tribelos fuscicornus	1	0	1
Tribelos jucundus	0	0	3
Zavrelia sp.	1	0	0
Caenis hilaris	0	0	1
Habrophlebiodes brunneipennis	9*	1	0
Ferrissia hendersoni	1	0	0
Ferrissia sp.	0	1	0
Asellus sp.	0	0	3
Hyalella aztecus	2	0	3
Corydalus cornutus	1	0	0
Nigronia serricornis	3	0	0
Unk. Nematoda	0	0	1
Argia bipunctulata	0	0	1
Argia sp.	0	0	1
Boyeria vinosa	1	0	0
Hetaerina titia	1	0	0
Unk Libellulid	1	0	0
Aulodrilus limnobius	0	1	0
Aulodrilus pigueti	0	0	1
Dero furcata	0	0	1

TABLE 77. Cont.

NAME	Number of Occurrences (10 max) QUIN 1	QUIN 2	QUIN 3
Dero obtusa	0	0	1
Eclipidrilus sp.	0	0	2
Ilyodrilus templetoni	0	0	1
Limnodrilus hoffmeisteri	0	1	5*
Nais communis	0	1	5*
Nais elinguis	0	1	1
Nais pardalis	0	0	3
Nais simplex	1	0	0
Nais variablis	1	0	4
Pristina idrenis	0	0	1
Pristina sp.	0	0	1
Slavina appendiculata	2	0	1
Unk. Tubificidae	0	1	1
Unk. Pelecypod	0	0	1
Unk. Sphaeriid	0	0	3
Acroneuria lycorias	1	0	0
Leuctra sp.	9*	1	0
Perlesta placida	1	0	0
Cheumatopsyche sp.	1	0	1
Diplectrona modesta	5*	0	1
Hydroptila sp.	2	0	0
Lype diversa	3	0	0
Oecetis cinerascens	1	0	0
Polycentropus sp.	5*	0	1
Psilotreta sp.	4	0	0

* indicates organisms found in more than 50% of samples

MOSS Site

Comparing data from MOSS 1 (control stream) and MOSS 2, a distinct pattern appears (Table 78). Mean abundance dropped by 62%, total and mean taxa decreased by 41% and 67% respectively, and average d was reduced by 47%. MOSS 2 was evidently severely stressed (Table 75). The biological integrity criteria was violated 7 times during the study (Figure 104). Once again, low dissolved oxygen was probably a factor responsible for the poor benthic community health at this station ($\bar{x}$ = 4.0 mg/1, minimum = 0.05 mg/1). D.O. values fell below 1.0 mg/1 in May, 1985, and remained even lower throughout the study (Figure 105).

The condition of MOSS 3 can be regarded as slightly improved over MOSS 2, based on single number summaries (Table 78). Average benthic abundance and total taxa at MOSS 3 were virtually identical with the control stream. However, mean taxa and d, were 43% and 29% less. respectively, at MOSS 3 than at MOSS 1. This indicated moderate stress (Table 75). Again, seven violations of the biological integrity criterion occurred at MOSS 3 (Figure 106). These violations appeared to occur independently of dissolved oxygen levels in the pond (Figure 107). In fact, the highest $\bar{d}$ (3.5) for MOSS 3 occurred in June 1984 simultaneously with the lowest D.O. (1.9 mg/1) recorded for that station.

Mean abundance increased by 59% and total taxa by 19% between MOSS 1 and MOSS 4 (outfall station). This increase in abundance and taxa at the outfall was a trend also noted at the QUIN site. Mean number of taxa was not significantly higher (10%) at the outfall. Average diversity was identical ($\bar{d}$ = 3.4) for both stations.

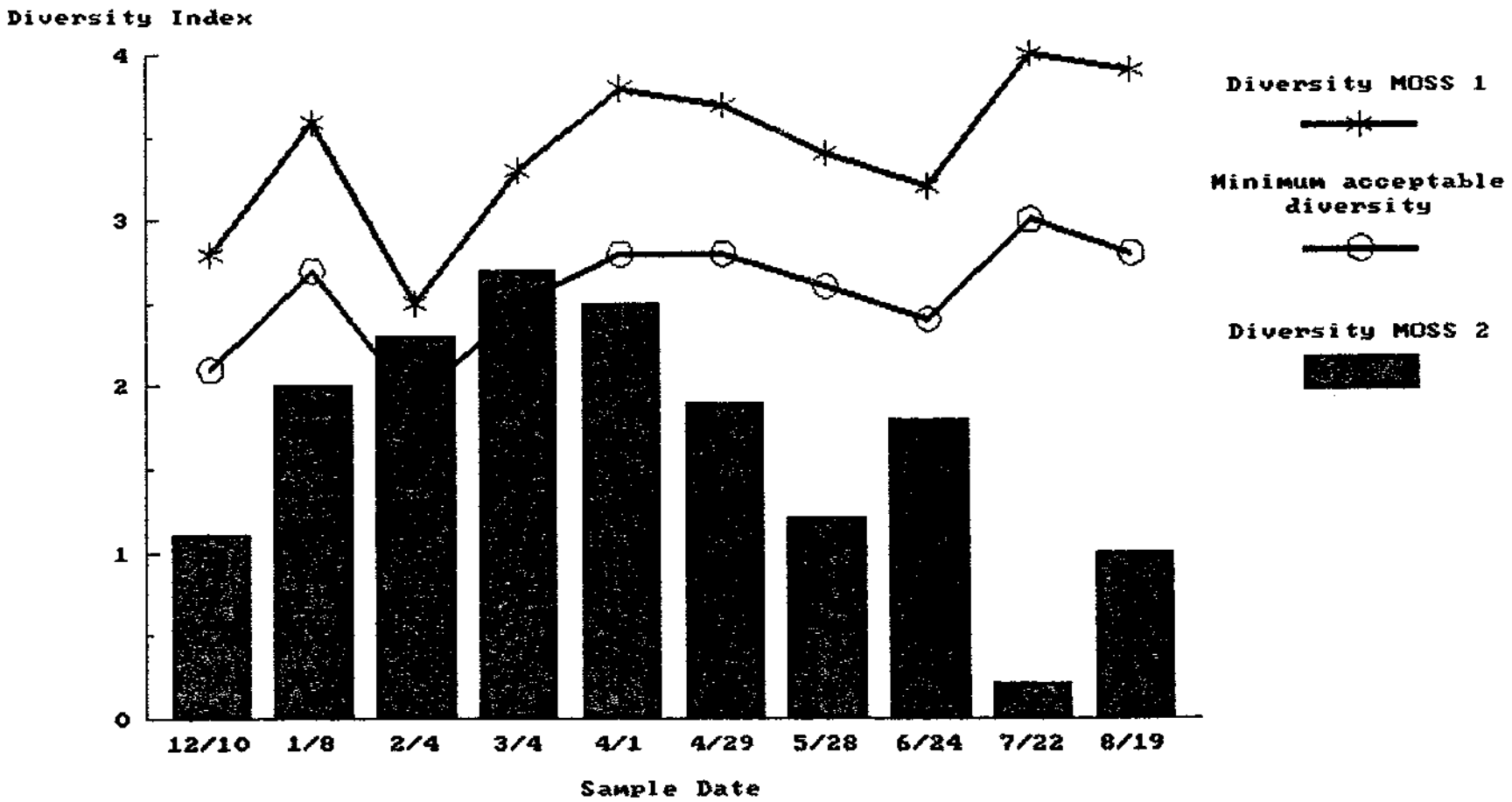
The two parallel control streams, MOSS 1 and MOSS 5, had remarkably similar data for a number of parameters. This was despite major differences in habitat. MOSS 1 is a very slow moving system, rich with submergent and emergent aquatic macrophytes. MOSS 5 has a moderately swift current and no aquatic macrophyte growth, since this site was well shaded by bottomland hardwoods. MOSS 1 had only 17% greater mean abundance and 12% higher d than did MOSS 5. Conversely, 11% more total taxa were present at MOSS 5. The biggest difference in single number summaries between the two stations (though only a moderate one) was in the mean taxa category. MOSS 1 averaged 22% more taxa than did MOSS 5. Based on Table 75, both systems are unstressed. As mentioned previously, these fairly small differences can probably be attributed to the fact that these stations are located in two separate, unconnected aquatic systems with different vegetation and flow regimes.

These parallel controls are useful in interpreting the data. It is apparent that normal background differences in these single number summaries can be up to 20%. This is reflected in the Analysis Criteria for Evaluating Data in Table 75.

TABLE 78. Benthic macroinvertebrate mean abundance, total taxa, mean taxa, mean Shannon-Weaver diversity index, the "pooled" variation of this index, mean bottom temperature, mean bottom dissolved oxygen, % of organic matter in the sediment, and the mean number of individuals in selected taxonomic groups for the MOSS Site, November 1984 to August 1985. Numbers in parentheses are minimum and maximum values for the sample period.

	MOSS 1	MOSS 2	MOSS 3	MOSS 4	MOSS 5
$\bar{x}$ Abundance (ranges)	121.5 (11-235)	46.8 (6-216)	122.3 (9-495)	298.8 (5-1174)	101.0 (26-237)
Total Taxa	59	35	57	73	66
$\bar{x}$ Taxa (ranges)	22.6 (6-36)	7.4 (4-13)	12.9 (3-21)	25.0 (4-45)	17.7 (6-31)
$\bar{x}$ $\bar{d}$ (ranges)	3.4 (2.5-4.0)	1.8 (1.1-2.7)	2.4 (1.2-3.5)	3.4 (2.0-4.2)	3.0 (1.6-3.9)
Pooled $\bar{d}$	4.7	2.2	3.2	4.1	3.9
$\bar{x}$ Bottom Temperature (°C)	16.5 (4.2-24.0)	18.1 (11.0-27.2)	18.7 (10.5-29.0)	17.6 (12.0-28.1)	16.1 (9.0-24.0)
$\bar{x}$ Bottom Dissolved Oxygen (mg/l) (ranges)	8.2 (6.3-10.2)	4.0 (0.05-9.0)	6.1 (1.9-11.0)	8.6 (6.4-10.7)	8.7 (7.2-10.8)
Sediment % Organic		10.1%	5.5%		
$\bar{x}$ Individuals					
Coleoptera	0.2	0.0	0.1	0.5	2.8
Diptera	53.8	34.6	94.2	163.0	51.2
Ephemeroptera	19.2	0.0	3.6	10.5	30.2
Megaloptera	0.0	0.1	0.0	0.0	1.3
Odonata	7.9	0.0	0.1	1.6	3.6
Oligochaeta	18.5	11.0	15.7	61.5	0.5
Plecoptera	0.0	0.0	0.0	0.0	1.3
Trichoptera	3.1	0.6	8.0	5.8	9.8

FIGURE 104. MOSS 2 biological integrity violations.



Values below minimum acceptable diversity (25% reduction from control) indicate violation.

FIGURE 105. Dissolved oxygen values for MOSS 1 and MOSS 2.

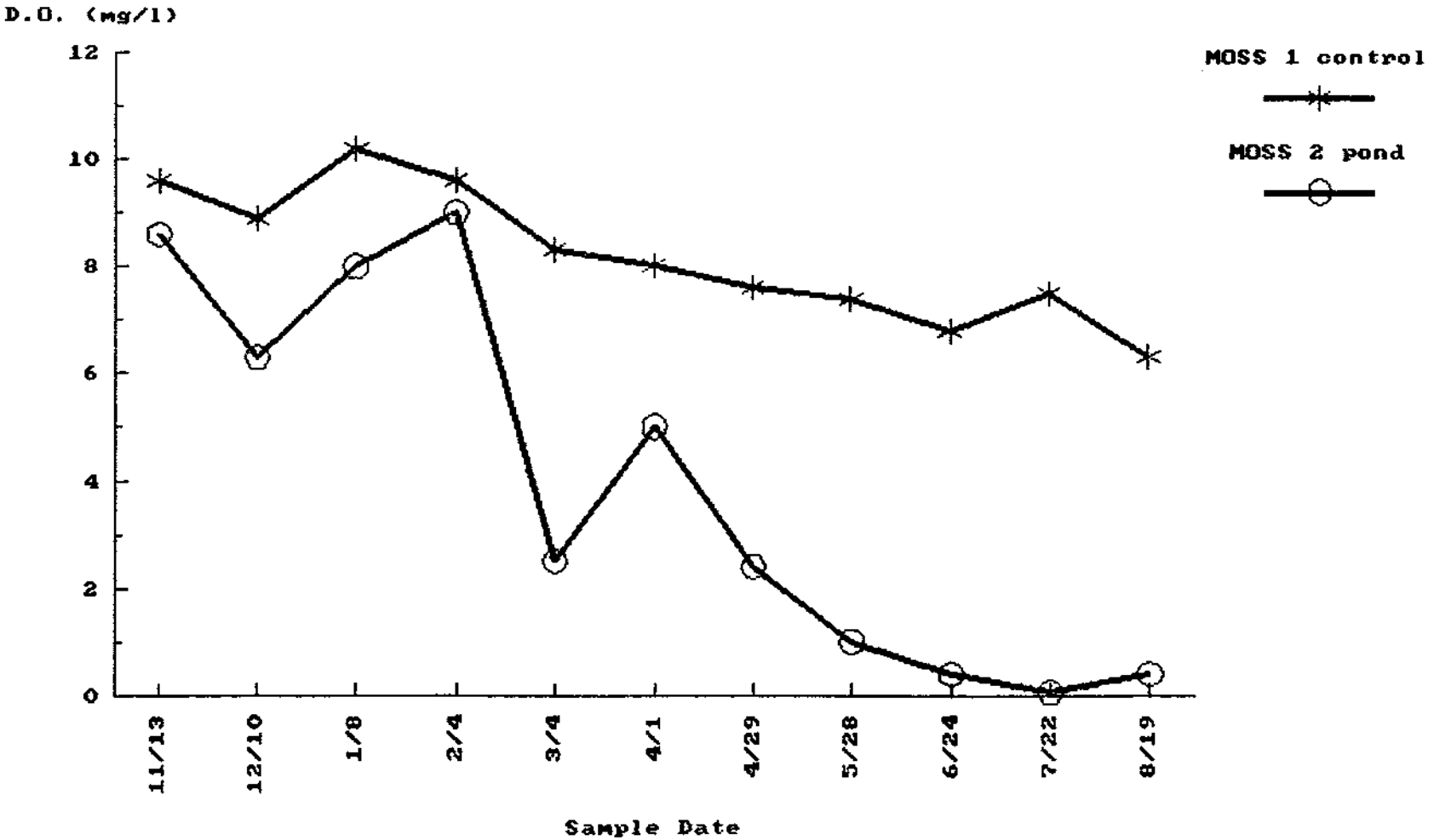
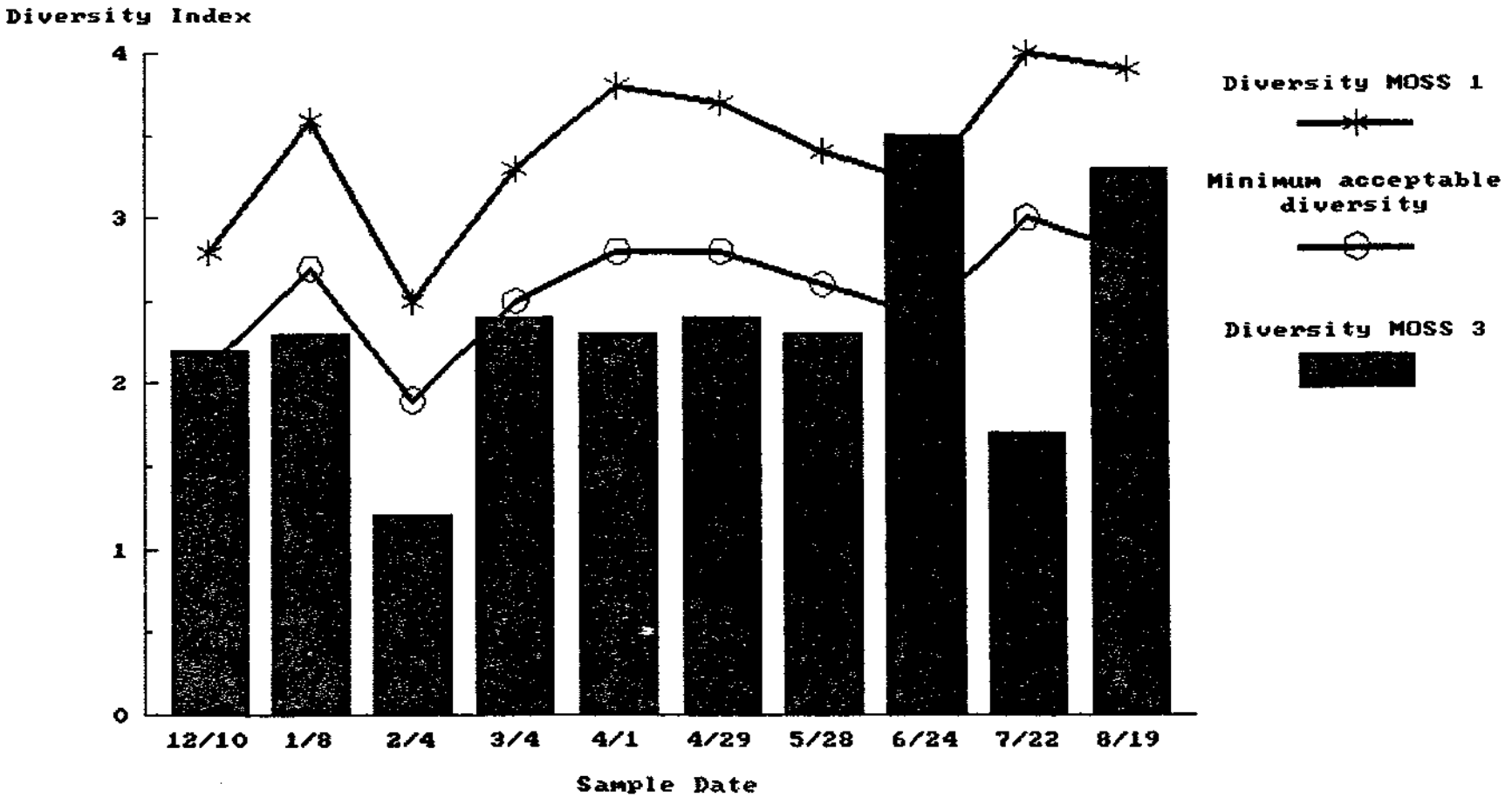
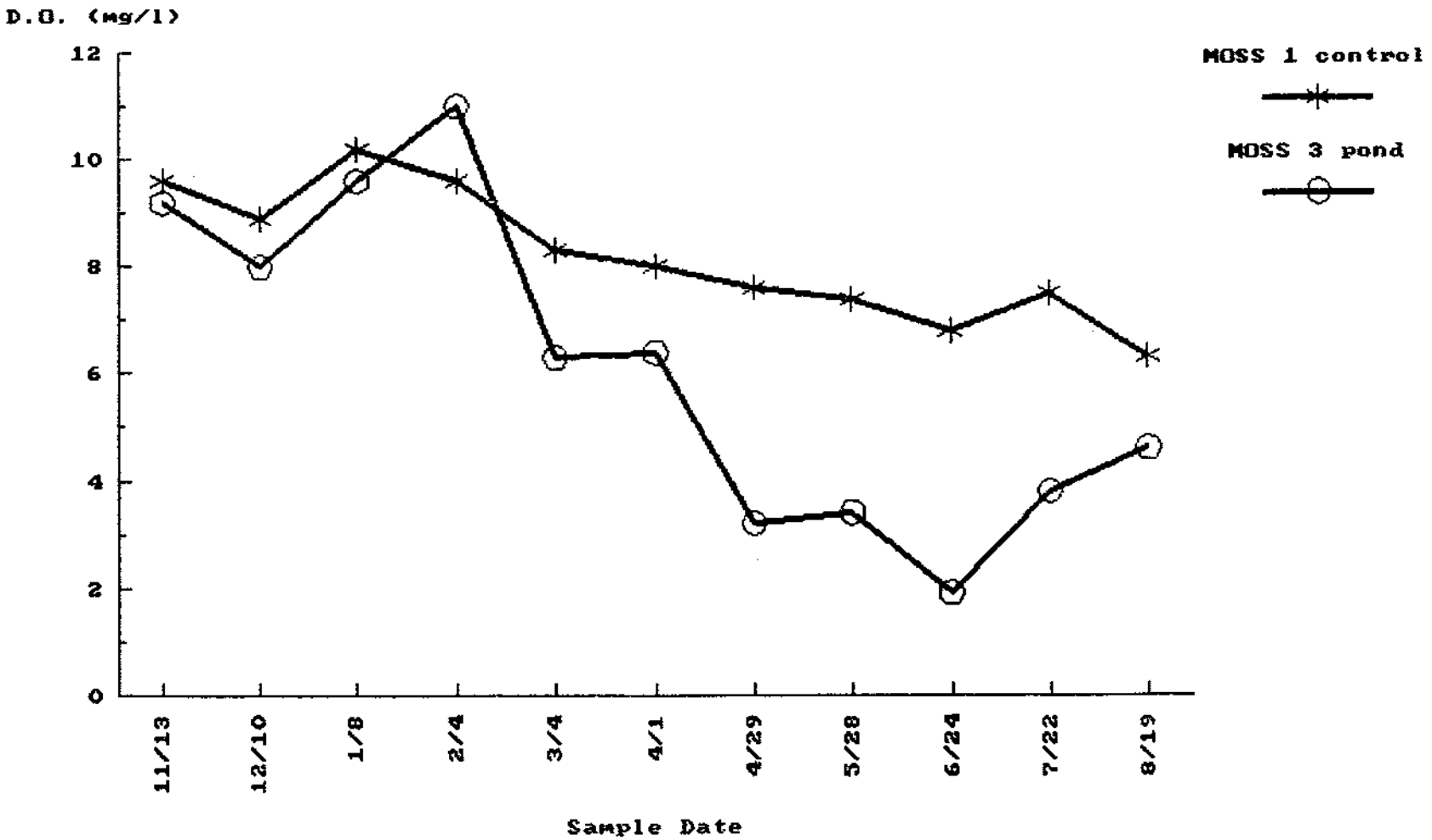


FIGURE 106. MOSS 3 biological integrity violations.



Values below minimum acceptable diversity (25% reduction from control) indicate violation.

FIGURE 107. Dissolved oxygen values for MOSS 1 and MOSS 3.



Coleopterans, ephemeropterans, and odonates were eliminated between MOSS 1 and MOSS 2 (Table 78). Similarly, the mean abundance of the Diptera, Oligochaeta and Trichoptera decreased by 36%, 41%, and 81%, respectively. A lone megalopteran, Sialis sp., appeared once at MOSS 2 but not at the control. These data suggest, therefore, that the benthos of MOSS 2 were stressed.

Taxonomic group summaries indicated that once again MOSS 3 had a healthier benthic community than did MOSS 2 when compared to the control. Mean abundance of beetles, mayflies, odonates and oligochaetes decreased by 50%, 81%, 99%, and 15%, respectively, between MOSS 1 and MOSS 3. Diptera and Trichoptera increased by 43% and 51% at MOSS 3. Although these data still indicate that MOSS 3 was stressed, note that no groups were completely eliminated. The outfall station (MOSS 4) had an increased abundance of beetles, dipterans, oligochetes and caddisflies (60%, 67%, 70%, and 47%, respectively) over the control. Conversely, the mayfly and odonate populations decreased by 45% and 80% between MOSS 1 and MOSS 4. The increased abundance of certain groups at MOSS 4 may be related to enrichment effects at the outfall, or limnetic drift (Corkum et al. 1977, Dudgeon 1983).

The two parallel control stations (MOSS 1 and MOSS 5) had basically the same mean abundance of dipterans. However, MOSS 5 was characterized by increased populations of coleopterans (93%), ephemeropterans (36%), megalopterans (100%), plecopterans (100%), and trichopterans (68%) compared with MOSS 1. Odonates and oligochaetes were numerically higher (54% and 97%, respectively) at MOSS 1 than at MOSS 5. As noted above, habitat differences may account in part for the disparity in taxonomic group abundances between these two stations.

Some rather interesting observations can be made by comparing the two in-series ponds, MOSS 2 and MOSS 3. One would normally assume that the benthic populations found at these two stations would be fairly similar. This would be based on the virtually identical hydrological conditions (i.e., lentic), basin morphometry and habitat (sand-bottomed, macrophyte fringed littoral zone). Dramatic differences, however, are clearly discernable between these two stations. As mentioned previously, single number summaries showed uniform increases between MOSS 2 and MOSS 3. Mean abundance, total taxa, mean taxa, and average $\bar{d}$ were up 62%, 39%, 43%, and 25%, respectively between MOSS 2 and MOSS 3. Similarly, dramatic increases in taxonomic groups occurred as well.

Mean abundance of every group (except oligochaetes and hellgramites) increased by 63% up to 100% between MOSS 2 and MOSS 3. Oligochaetes increased by 30% at MOSS 3 while the single megaloperan found at MOSS 2 pond (none found at MOSS 3) caused the only decrease in group abundance between the two. The cause for this substantial (although not total) improvement between these two ponds is not known, but may be related

to differences in the sediment organic fractions found at these ponds. MOSS 2 had 46% more organic matter in the sediment than did MOSS 3 (see sediment section). Organic enrichment in the sediment has been known to have effects on the composition and density of benthic communities (Hynes 1970). Dissolved oxygen levels may also help explain the observed differences between MOSS 2 and Moss 3 (Figures 105 and 107 and Table 78). Mean D.O. was 2.1 mg/l higher at MOSS 3 and the minimum D.O. (1.9 mg/l) was 1.85 mg/l higher than the minimum D.O. at MOSS 2 (0.05 mg/l). The causes of these differences in dissolved oxygen regimes in the two ponds are not known, but may be related to prevaling wind patterns providing better mixing at MOSS 3.

Numbers of frequently occurring taxa yielded a pattern consistent with that found at the QUIN site (Table 79). MOSS 1 had 15 such taxa compared with 2 at MOSS 2. These organisms at MOSS 1 were well represented by many "sensitive" species such as the odonate, Argia bipunculata, and the mayfly, Stenacron interpunctatum. Nais variablis, a ubiquitous segmented worm, and Glyptotendipes lobiferus, which has been classified as a facultative, anoxyphilous midge (Hiltunan and Klemm 1980, Beck 1977), were the only frequently occurring taxa found at MOSS 2.

As reflected in the previous data presented, the eight taxa which occurred frequently at MOSS 3 again indicated improvement between the two ponds. Although many of these animals at MOSS 3 were facultative mesoxyphiles, (e.g., Ablabesmyia parajanta) (Beck 1977) organisms such as Caenis hilaris and Polycentropus sp. also occurred there in over 50% of the samples.

Four of six frequently occurring organisms found at the outfall station (MOSS 4) were also found directly upstream at MOSS 3. This is not surprising, though it is interesting to note that these organisms at MOSS 4 were all midges (e.g., Tanytarsus) or worms (e.g., Slavina appendiculata).

The two parallel control stations (MOSS 1 and MOSS 5) had only four animals in common which were found in over 50% of the samples. These were sensitive, saprophobic, and rheobiontic taxa such as Stenacron interpunctatum and Microtendipes pedellus (Beck 1977). Additional taxa with similar requirements (e.g., Stenonema smithae and Oecetis inconspicua) brought the number of frequently occurring organisms at MOSS 5 to seven. This number of organisms is in contrast to the other control, which had a total of 15 frequently occurring animals.

In an effort to further compare and contrast biota of the two MOSS in-series pond, Petite Ponar grabs were taken monthly. Single number summaries extracted using this sampling method proved to be consistant with the data obtained via Hester-Dendy multiplate samplers (Table 80).

TABLE 79. Taxonomic listing with the number of occurrences for each taxa at each station for the MOSS Site.

NAME	Number of Occurrences (10 max) Control MOSS 1	Pond MOSS 2	Pond MOSS 3	Outfall MOSS 4	Parallel Control MOSS 5
Hydra sp.	1	0	0	4	0
Ancyronyx variagata	0	0	0	0	2
Berosus sp.	0	0	1	0	0
Dineutus sp.	0	0	0	1	1
UNK. Dytiscidae	0	0	0	0	1
Hydroporus inaequalis	0	0	0	1	0
Hydroporus sp.	0	0	0	0	4
Hyperodes sp.	1	0	0	0	0
Unk. Coleopteran	0	0	0	1	0
Stenelmis crenata	0	0	0	0	3
Isotomurus sp.	0	0	0	0	1
Smynthurinus sp.	0	0	0	1	0
Ablabesmyia americana	0	1	2	0	0
Ablabesmyia annulata	1	0	0	0	0
Ablabesmyia aspera	4	0	1	1	0
Ablabesmyia hauberi	1	0	0	0	0
Ablabesmyis mallochi	0	0	1	2	1
Ablabesmyia ornata	5*	2	3	2	3
Ablabesmyia parajanta	3	2	5*	4	2
Ablabesmyia philosphagnos	3	0	0	0	1
Ablabesmyia sp.	1	0	0	0	0
Ablabesmyia tarellanis	1	0	1	1	0
Atrichopogon sp.	0	1	0	1	0
Bezzia sp.	3	1	2	2	0
Bittacomorpha clavipes	0	1	0	0	0
Unk Chironomidae	6*	0	2	3	3
Chironomus attenuatus	0	0	2	0	0
Chironomus crassicaudatus	0	0	1	0	0
Chironomus riparius	2	3	3	0	0
Chironomus stigmaterus	0	1	0	0	0
Cladotanytarsus sp.	0	0	0	3	0
Conchapelopia sp.	4	1	0	5*	7*
Corynoneura sp. A (Dye)	1	0	0	0	0
Corynoneura sp.	1	0	0	1	1
Corynoneura taris	3	0	0	2	0
Cricotopus bicinctus	0	0	0	1	0
Cricotopus sp.	0	0	0	1	0
Cryptochironomus blarina	0	0	0	0	1
Cryptochironomus fulvus	0	0	1	0	1
Dicrotendipes fumidus	1	0	0	1	0
Dicrotendipes modestus	2	1	1	1	0
Dicrotendipes neomodestus	1	0	1	0	0
Dicrotendipes nervosus	0	2	6*	2	1
Dicrotendipes sp.	0	2	2	1	0
Einfeldia natchitochea	1	0	2	0	0

TABLE 79. Cont.

NAME	Number of Occurrences (10 max) Control MOSS 1	Pond MOSS 2	Pond MOSS 3	Outfall MOSS 4	Parallel Control MOSS 5
Endochironomus nigricans	0	0	1	4	0
Endochironomus sp.	1	0	0	0	0
Geranomyia rostrata	0	0	0	1	0
Glyptotendipes lobiferus	2	8*	8*	5	3
Glyptotendipes meridionalis	0	0	1	0	0
Glyptotendipes paripes	0	0	1	0	0
Harnischia sp.	0	0	1	0	0
Hemerodromia sp.	0	0	1	0	3
Labrundinia floridana	2	0	0	0	0
Labrundinia neopilosella	0	0	1	1	0
Labrundinia virescens	5*	0	1	0	0
Macropelopia sp.	0	1	0	1	0
Microtendipes pedellus	7*	0	0	3	7*
Nanocladius sp.	1	1	0	3	0
Nilothauma sp.	1	0	4	2	3
Nilotanypus sp.	0	0	0	0	2
Orthocladius annectens	2	0	0	0	0
Orthocladius sp.	0	1	0	1	0
Parachironomus hiralatus	0	2	2	0	1
Parachironomus schneideri	0	2	4	2	0
Parachironomus sp.	0	0	1	1	1
Pentaneura inconspicua	0	0	0	0	1
Phaenopsectra obediens	1	0	0	0	1
Paralauterborniella nigrohalteralis	0	0	0	1	0
Polypedilum convictum	0	0	0	1	3
Polypedilum fallax	3	0	0	1	3
Polypedilum halterale	0	0	1	0	0
Polypedilum illinoense	3	1	1	4	0
Potthastia sp.	0	0	0	1	0
Parametriocnemus lunbecki	1	0	0	0	1
Parametriocnemus sp.	1	0	0	0	0
Psectrocladius sp.	1	0	0	0	0
Psectrocladium vernalis	0	0	0	1	0
Pseudochironomus fulviventris	0	0	1	1	0
Unk. Dipteran pupae	9*	4	6*	5*	10*
Rheocricotopus robackii	0	0	0	1	1
Rheocricotopus sp.	0	0	0	2	2
Rheotanytarsus sp.	2	1	2	3	4
Tanytarsus sp.	9*	4	7*	5*	10*
Thienemanniella xena	0	0	0	0	1
Tribelos fuscicornus	6*	1	2	0	1
Tribelos jucundis	5*	0	0	0	0
Trissocladius sp.	3	0	0*	1	1
Zavrelimyia sp.	1	0	0	0	0
Caenis hilaris	4	0	6*	4	0

TABLE 79. Cont.

NAME	Number of Occurrences (10 max) Control MOSS 1	Pond MOSS 2	Pond MOSS 3	Outfall MOSS 4	Parallel Control MOSS 5
Eurylophella sp.	1	0	0	1	1
Eurylophella temporalis	4	0	0	0	2
Habrophlebia vibrans	0	0	0	0	2
Hexagenia sp.	0	0	1	0	0
Leptophlebia intermedia	2	0	0	0	3
Paraleptophlebia sp.	2	0	0	0	0
Paraleptophlebia volitans	0	0	0	0	1
Stenonema exiguum	1	0	0	0	1
Stenonema smithae	3	0	1	1	10*
Stenacron interpunctatum	9*	0	0	0	9*
Ferrissia hendersoni	5*	0	0	0	0
Ferrissia sp.	5*	0	0	0	2
Gyraulus sp.	0	0	1	0	0
Laevapex sp.	1	0	0	0	0
Batracobdella phalera	2	1	0	0	0
Placobdella ornata	3	0	0	0	0
Eoparargyractis sp.	0	0	0	2	0
Asellus sp.	4	0	0	0	0
Nigronia serricornis	0	0	0	0	4
Sialis sp.	0	1	0	0	0
Unk. Nematoda	1	0	1	0	0
Argia bipunctulata	9*	0	0	3	3
Argia sp.	5*	0	0	1	4
Argia tibialis	1	0	0	0	1
Calyopteryx maculata	0	0	0	0	1
Enallagma doubledayi	1	0	0	0	0
Enallagma signatum	0	0	0	1	0
Enallagma sp.	4	0	0	0	0
Epicordulia princeps regina	0	0	1	0	0
Erythemis simplicicollis	1	0	0	0	0
Hetaerina titia	0	0	0	0	1
Ischnura posita	1	0	0	0	1
Unk. Libellulid	1	0	0	0	0
Chaetogaster diaphanus	0	0	0	2	0
Dero obtusa	3	0	2	0	0
Haemonais waldvogeli	0	1	1	0	0
Ilyodrilus templetoni	0	1	2	3	0
Limnodrilus hoffmeisteri	0	0	1	0	0
Nais barbata	0	0	0	3	0
Nais communis	1	2	1	4	0
Nais pardalis	1	0	0	0	0
Nais elinguis	1	0	0	0	0
Nais simplex	1	0	0	1	0
Nais variablis	5*	8*	7*	5*	0
Pristina osborni	0	1	0	1	0

TABLE 79. Cont.

NAME	Number of Occurrences (10 max) Control MOSS 1	Pond MOSS 2	Pond MOSS 3	Outfall MOSS 4	Parallel Control MOSS 5
Slavina appendiculta	10*	1	1	5*	4
Unk. Naididae	0	0	0	2	0
Dugesia sp.	0	0	0	2	0
Dugesia tigrina	0	2	1	2	0
Leuctra sp.	0	0	0	0	1
Perlesta placida	0	0	0	0	4
Perlinella drymo	0	0	0	0	1
Anisocentropus pyraliodes	1	0	0	0	4
Chimarra sp.	0	0	0	0	2
Cyrnellus fraternus	3	0	4	2	2
Diplectrona modesta	0	0	0	0	1
Hydropsyche decalda	0	0	0	1	0
Hydroptila sp.	0	0	0	2	0
Lype diversa	1	0	0	0	0
Neureclipsis sp.	0	0	1	0	2
Nyctiophalax sp.	2	0	0	0	3
Oecetis cinerascens	3	0	0	0	4
Oecetis inconspicua	2	2	3	2	8*
Oecetis sp.	2	0	0	0	2
Orthotrichia sp.	0	0	3	2	0
Oxyethira sp.	4	2	1	1	0
Polycentropus sp.	2	1	7*	2	1
Unk. Tricopteran pupae	0	0	0	0	1

* indicates organisms found in more than 50% samples

TABLE 80. Benthic macroinvertebrate mean abundance, total taxa, mean taxa, mean Shannon-Weaver diversity index, the "pooled" variation of this index, mean bottom temperature, mean bottom dissolved oxygen, % of organic matter in the sediment, and the mean number of individuals in selected taxonomic groups for the MOSS ponar samples, November 1984 to August 1985. Numbers in parentheses are minimum and maximum for the sample period.

	MOSS 2P	MOSS 3P
$\bar{x}$ Abundance (ranges)	240.2 (69-448)	248.9 (49-449)
Total Taxa	22	38
$\bar{x}$ Taxa (ranges)	6.9 (5-10)	11.7 (5-23)
$\bar{x}$ $\bar{d}$ (ranges)	1.5 (1.0-2.1)	2.3 (1.3-3.1)
Pooled $\bar{d}$	1.8	2.6
$\bar{x}$ Bottom Temperature (°C)	18.1 (11.0-27.2)	18.7 (10.5-29.0)
$\bar{x}$ Bottom Dissolved Oxygen (mg/l) (ranges)	4.0 (0.05-9.0)	6.1 (1.9-11.0)
Sediment % Organic	10.1%	5.5%
$\bar{x}$ Individuals		
Coleoptera	0.0	0.0
Diptera	149.9	236.5
Ephemeroptera	0.0	0.4
Megaloptera	0.0	0.0
Odonata	0.0	0.1
Oligochaeta	90.1	9.1
Plecoptera	0.0	0.0
Trichoptera	0.1	0.2

TABLE 81. Taxonomic listing with the number of occurrences for each taxa at each station for the MOSS ponar samples

NAME	Number of Occurrences (10 max) Pond MOSS 2P	Pond MOSS 3P
Ablabesmyia aspera	1	0
Ablabesmyia ornata	0	1
Ablabesmyia parajanta	0	2
Abalbesmyia tarella	0	1
Bezzia sp.	0	5*
Chaoborus punctipennis	10*	10*
Unk. Chironomidae	0	1
Chironomus attenuatus	3	6*
Chironomus riparius	2	5*
Chironomus sp.	1	2
Conchapelopia sp.	1	1
Cryptochironomus fulvus	1	1
Djmabatista pulcher	0	1
Einfeldia natchitochea	6*	10*
Glypotendipes lobiferus	1	4
Glyptotendipes sp.	0	1
Harnischia sp.	8*	8*
Microtendipes pedellus	0	2
Microtendipes sp.	0	1
Nanocladius sp.	1	0
Nilothauma sp.	0	1
Polypedilum halterale	0	4
Polypedilum illinoense	1	0
Procladius bellus	10*	10*
Procladius sp.	1	0
Unk. Dipteran pupae	4	7*
Rheotanytarsus sp.	0	2
Tanytarsus sp.	3	9*
Tanypus clavatus	1	1
Tribelos fuscicornus	0	1
Caenis hilaris	0	1
Hexagenia munda elegans	0	1
Hexagenia sp.	0	2
Gyraulus sp.	0	1
Unk. Nematoda	1	3
Somatochlora sp.	0	1
Dero obtusa	0	1
Haemonais waldvogel	0	2
Limnodrilus hoffmeisteri	10*	0
Nais elinguis	0	1
Nais variablis	1	4
Unk. Naididae	0	2
Cyrnellus fraternus	0	1
Oecetis inconspicua	1	0

* indicates organisms found in more than 50% of samples

Although MOSS 3 exhibited a negligible increase in mean abundance (3%), increases in total taxa (42%), average taxa (41%), and mean $\overline{d}$ (32%) were notably higher at MOSS 3 than MOSS 2. Members of the Ephemeroptera and Odonata were represented at MOSS 3 (ponar samples) but were not present at MOSS 2. Mean abundance of the Diptera and Trichoptera rose 37% and 100% respectively, between MOSS 2 and MOSS 3. In contrast, 90% more oligochaetes were collected at MOSS 2.

The number of taxa collected in more than 50% of the samples went from five at MOSS 2 to nine at MOSS 3 (four taxa in common). Tolerant, limnobiontic organisms such as Chaoborus punctipennis and Procladius bellus were found at both stations (Table 81). It is interesting to note, however, that Limnodrilus hoffmeisteri was present in every MOSS 2 ponar sample but was never collected at MOSS 3. On the other hand, Bezzia sp., which was collected in half of the MOSS 3 ponar samples was not found at MOSS 2. Since the trend of improvement between these stations is reflected by both sampling methods, it appears to be genuine. Possible explanations for the differences in the benthic communities between these two stations sampled by ponar grabs are the same as those discussed above for the multiplate samplers.

CRES Site

The benthic macroinvertebrate community at the CRES site followed similar longitudinal trends exhibited by the benthos of the QUIN and MOSS sites. Specifically, uniform decreases of single number summaries occurred between the control (CRES 1) and the pond (CRES 2) (Table 82). The 73% decrease in mean abundance and the 67% decrease of total taxa at CRES 2 is suggestive of severe stress (Table 75). This conclusion is reinforced by the 65% drop in average taxa and the 61% decline in mean $\overline{d}$ from the control to the pond.

The biological integrity criterion was violated in 75% of the samples collected at CRES 2 (Figure 108). Severe dissolved oxygen depletion also occurred at this pond (Figure 109), and was probably a major factor affecting the benthic community.

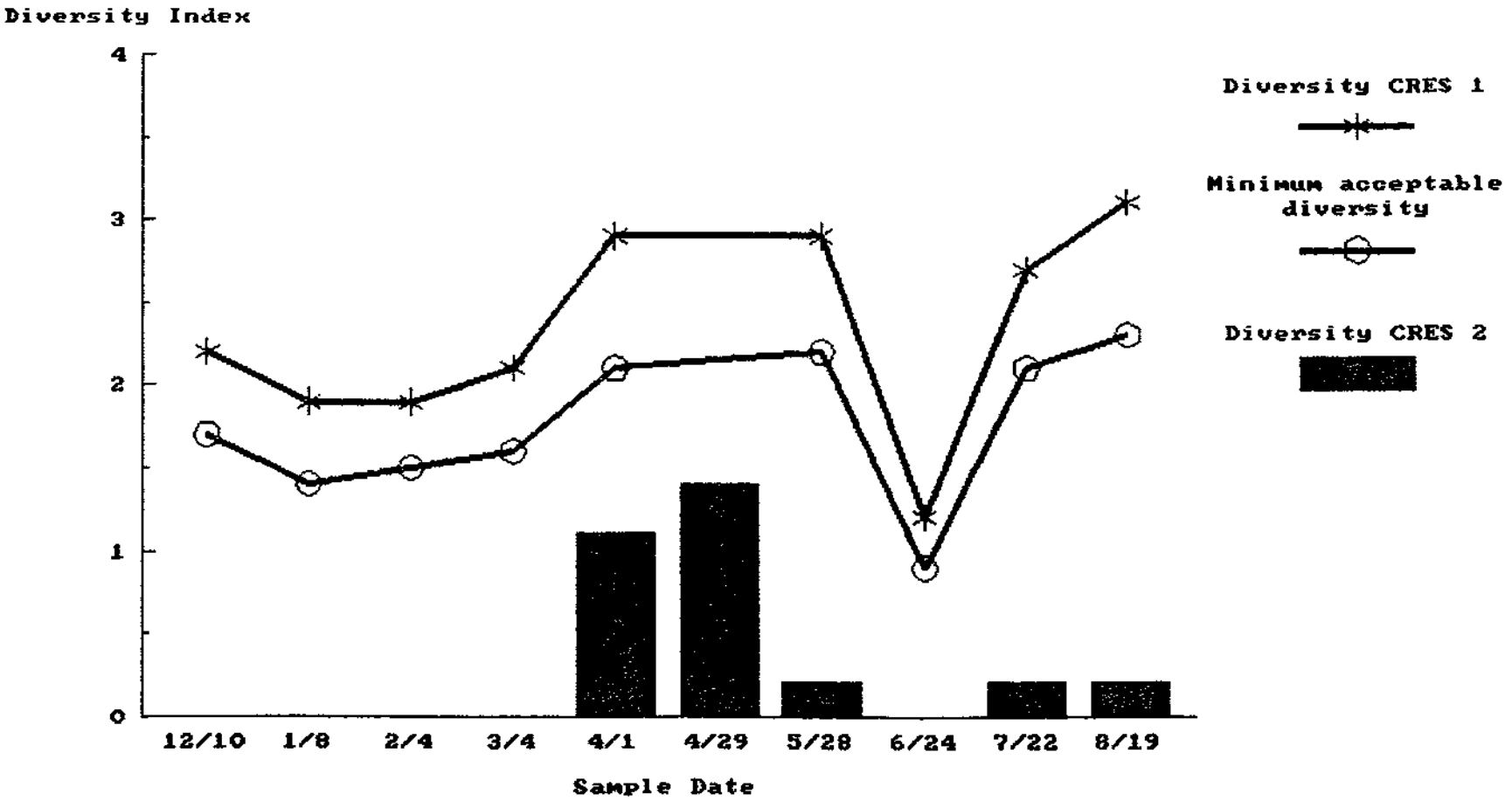
As at the other sites, the outfall station (CRES 3) exhibited increases in mean abundance (up 63%) and total taxa (up 47%) from the control (CRES 1). While $\overline{d}$ remained about the same between CRES 1 and CRES 3 (up 12%), mean taxa rose 48%.

Mayflies, the most numerous group at the control stream, were not found in the pond. Odonates and stoneflies, also present at CRES 1, were eliminated at CRES 2. Midge and caddisfly populations were reduced by 27% and 88%, respectively, from the control to the pond. Note however, that there were 97% more megalopterans in the pond than the control.

TABLE 82. Benthic macroinvertebrate mean abundance, total taxa, mean taxa, mean Shannon-Weaver diversity index, the "pooled" variation of this index, mean bottom temperature, mean bottom dissolved oxygen, % of organic matter in the sediment, and the mean number of individuals in selected taxonomic groups for the CRES Site, November 1984 to August 1985. Numbers in parentheses are minimum and maximum values for the sample period.

	CRES 1	CRES 2	CRES 3
$\bar{x}$ Abundance (ranges)	57.4 (11-95)	15.5 (6-31)	154.3 (33-448)
Total Taxa	42	14	79
$\bar{x}$ Taxa (ranges)	10.9 (4-18)	3.8 (4-10)	19.0 (11-28)
$\bar{x}$ $\bar{d}$ (ranges)	2.3 (1.1-3.1)	0.9 (0.0-2.6)	2.6 (1.0-3.7)
Pooled $\bar{d}$	3.3	3.6	2.9
$\bar{x}$ Bottom Temperature (°C)	15.0 (8.5-22.0)	18.3 (14.0-22.0)	16.0 (8.0-26.0)
$\bar{x}$ Bottom Dissolved Oxygen (mg/l) (ranges)	8.5 (7.0-10.6)	1.5 (0.2-7.4)	8.5 (5.4-10.6)
Sediment % Organic		8.1%	
$\bar{x}$ Individuals			
Coleoptera	0.3	0.8	1.6
Diptera	14.4	10.5	137.5
Ephemeroptera	3.5	0.0	2.0
Megaloptera	0.1	3.3	6.3
Odonata	0.7	0.0	1.5
Oligochaeta	0.3	0.3	2.9
Plecoptera	3.7	0.0	0.0
Trichoptera	2.4	0.3	1.3

FIGURE 108. CRES site biological integrity violations.



Values below minimum acceptable diversity (25% reduction from control) indicate violation.

FIGURE 109. Dissolved oxygen values for CRES 1 and CRES 2.

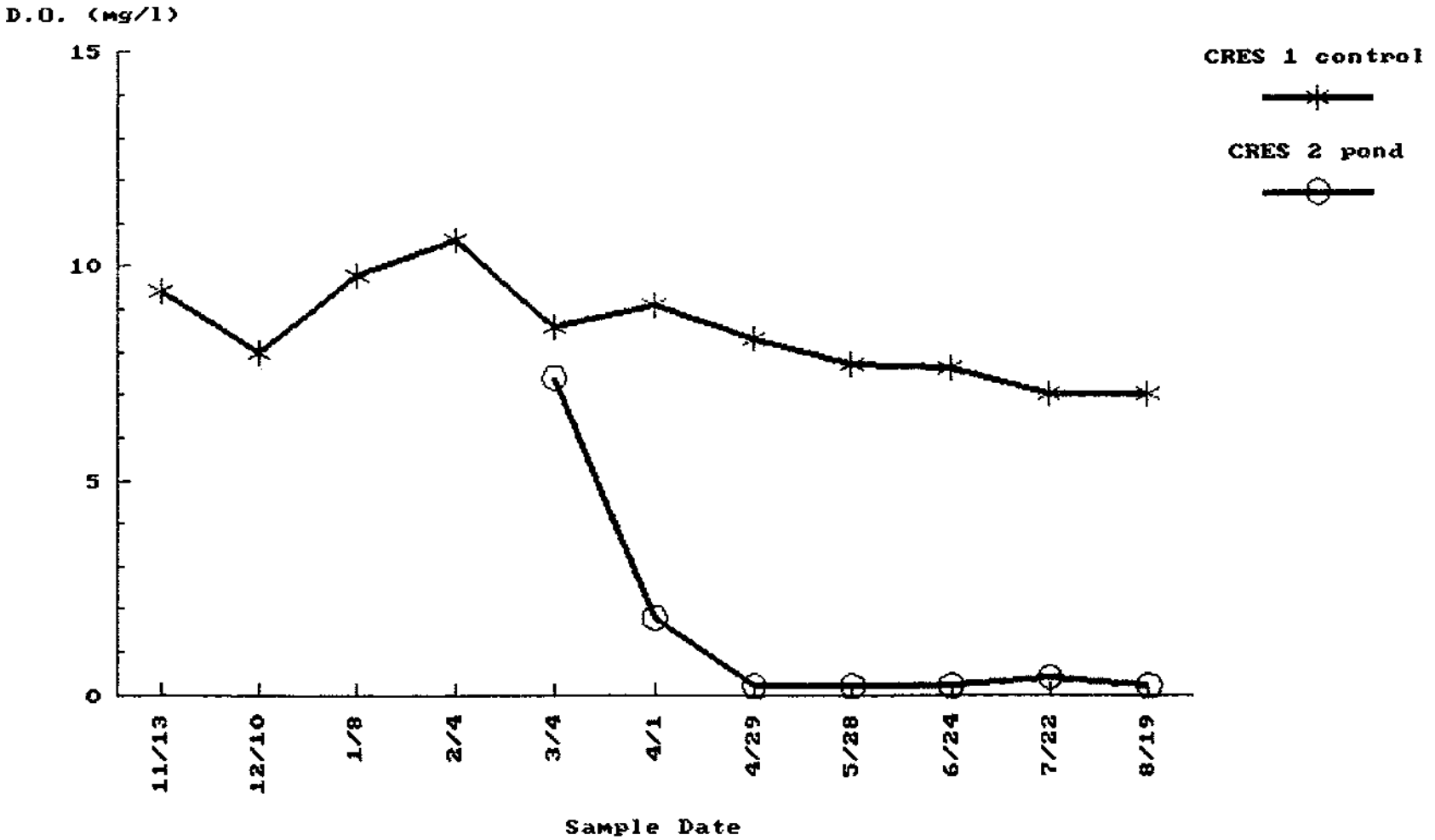


TABLE 83. Taxonomic listing with the number of occurrences for each taxa each station for the CRES Site.

NAME	Number of Occurrences (10 max)		
	CRES 1	CRES 2	CRES 3
Hydrodroma sp.	1	0	2
Hygrobates sp.	1	0	1
Lycosa sp.	1	0	0
Dineutus sp.	2	1	1
Dubiraphia bivittata	0	0	1
Dubiraphia sp.	0	0	1
Gyrinus sp.	0	0	1
Helocombus bifidus	0	0	1
Hydroporus sp.	0	1	2
Microcylleopus pusillus	0	0	1
Stenelmis sp.	0	0	1
Ablabesmyia annulata	0	0	2
Ablabesmyia cinctipes	0	0	1
Ablabesmyia hauberi	0	0	1
Ablabesmyia mallochi	0	0	1
Ablabesmyia ornata	0	0	3
Ablabesmyis parajanta	0	0	4
Ablabesmyia philosphagnos	0	0	3
Ablabesmyia tarella	0	0	3
Bezzia sp.	0	0	4
Chaoborus punctipennis	0	1	0
Unk. Chironomidae	0	0	2
Chironomus attenuatus	0	0	2
Chironomus riparius	1	2*	4
Chironomus sp.	0	1	1
Conchapelopia sp.	7*	1	8*
Corynoneura sp.	1	0	0
Cryptochironomus fulvus	0	0	2
Cryptochironomus sp.	0	0	1
Djmabatista pulcher	0	0	1
Glyptotendipes lobiferus	1	0	0
Hemerodromia sp.	1	0	1
Heterotrissocladius sp.	0	0	1
Labrundinia floridana	3	0	2
Labrundinia virescens	0	0	1
Macropelopia sp.	0	0	1
Microtendipes pedellus	3	1	0
Nilothauma sp.	1	0	0
Orthocladius annectens	0	0	1
Pentaneura inconspicua	0	0	1
Phaenopsectra obediens	0	0	1
Parakiefferiella sp.	1	0	0
Polypedilum convictum	4	0	5*
Polypedilum fallax	0	0	5*
Polypedilum halterale	0	0	1

TABLE 83. Cont.

NAME	Number of Occurrences (10 max)		
	CRES 1	CRES 2	CRES 3
Polypedilum illinoense	1	0	0
Paramerina anomala	1	0	0
Procladius bellus	0	0	1
Unk. Dipteran pupae	4	1	6*
Rheocricotopus sp.	1	0	0
Rheotanytarsus sp.	2	0	4
Simulium sp.	1	0	0
Stenochironomus sp.	0	0	1
Tanytarsus sp.	8*	1	8*
Thienemanniela xena	0	0	1
Tribelos fuscicornus	0	0	3
Tribelos jucundis	0	0	3
Caenis hilaris	0	0	2
Eurylophella temporalis	8*	0	2
Habrophlebia vibrans	0	0	1
Stenonema smithae	7*	0	2
Stenacron interpunctatum	8*	0	0
Ferrissia hendersoni	1	1	0
Batracobdella phalera	0	0	1
Asellus sp.	0	0	1
Hyalella aztecus	1	1	0
Corydalus cornutus	0	0	1
Nigronia serricornis	1	0	2
Sialis mohri	0	0	2
Sialis sp.	0	1	1
Unk Nematoda sp.	0	0	2
Argia bipunctulata	1	0	0
Argia sp.	2	0	1
Dromogomphus armatus	0	0	1
Hylogomphus geminatus	0	0	1
Neurocordulia alabamensis	0	0	1
Eclipidrilus sp.	0	0	2
Haemonais waldvogeli	0	0	1
Nais barbata	1	0	1
Nais communis	0	0	2
Nais pardalis	0	0	1
Nais simplex	1	0	0
Nais variablis	0	0	4
Pristina sp.	0	0	2
Slavina appendiculata	1	1	2
Specaria josinae	0	0	2
Unk. Naididae sp.	0	0	1
Unk. Pelecypod sp.	0	0	1
Leuctra sp.	4	0	0

TABLE 83. Cont.

NAME	Number of Occurrences (10 max)		
	CRES 1	CRES 2	CRES 3
Perlesta placida	5*	0	0
Chimarra sp.	4	0	0
Diplectrona modesta	1	0	0
Lepidostoma sp.	1	0	0
Nyctiophalax sp.	0	0	1
Oecetis cinerascens	1	1	2
Oecetis inconspicua	2	0	2
Oecetis sp.	0	0	1
Oxyethira sp.	0	0	1
Polycentropus sp.	1	0	0
Unk. Tricopteran pupae	0	0	1

* indicates organisms found in more than 50% of samples

Dipteran and oligochaete populations increased dramatically at CRES 3, the mean number of individuals in both groups being 90% greater there than at CRES 1. Odonates (53%) and hellgramites (98%) were also more numerous at CRES 3, 53% and 98% respectively. However, ephemeropterans were significantly reduced (94%) at the outfall, as were trichopterans (46%) and plecopterans (complete elimination).

Patterns in the numbers of frequently occurring species at the CRES site were once again very consistent with those of the other sites discussed (Table 83). Sufficient occurrences of sensitive organisms such as the stonefly Perlesta placida, and the mayfly, Eurylophella temporalis, brought the numbers of frequently occurring species at CRES 1 up to six. Chironomus riparius, a known anoxyphile often found in eutrophic waters (Beck 1977), was the only animals occurring frequently at CRES 2. Such taxa (five total) at the outfall station (CRES 3) included organisms such as Conchapelopis sp. and Tanytarsus sp.. These "indifferent" invertebrates have been discussed previously.

GADS Site

Results from the GADS site are unusual, in that GADS 1 appears to be disturbed and therefore cannot adequately serve as a control station. The headwaters of this sluggish stream exclusively drain agricultural areas, and throughout the study, the stream was coated with several inches of what appeared to be iron/sulfate metabolizing bacteria. Although the pond area (GADS 2) had not yet been filled, comparisons can be made between GADS 1 and GADS 3, located approximately 500 meters apart.

Notable improvements in single number summary data generally occurred between GADS 1 and GADS 3. For example, mean abundance increased 82%, as did total taxa (up 47%) and mean taxa (up 56%) (Table 84). Diversity values ($\bar{d}$) at both stations, however, were indicative of moderate stress (Table 75).

Many taxonomic groups were not represented at GADS 1, including mayflies, odonates, megalopterans, and stoneflies. While dipterans and oligochaetes were fairly abundant at GADS 3, GADS 1 possessed 56% and 98% less of these two groups, respectively. GADS 3 also had higher mean numbers of beetles (96%).

Environmental perturbation at GADS 1 was also evident in terms of taxa occurring in more than 50% of the the samples. Although a few sensitive invertebrates appeared at GADS 1, they occurred so infrequently (less than 10% of the time) that severe stress was indicated at this station (Table 85). Four organisms occurred 50% of the time GADS 3. The presence of these specific animals (e.g. the oligochaete Slavina appendiculata and unknown dipteran pupae) however, did not help improve status of GADS 3 as a moderately stressed system.

TABLE 84. Benthic macroinvertebrate mean abundance, total taxa, mean taxa, mean Shannon-Weaver diversity index, the "pooled" variation of this index, mean bottom temperature, mean bottom dissolved oxygen, % of organic matter in the sediment, and the mean number of individuals in selected taxonomic groups for the GADS Site, November 1984 to August 1985. Numbers in parentheses are minimum and maximum values for the sample period.

	GADS 1	GADS 3
$\bar{x}$ Abundance (ranges)	17.3 (1-55)	94.7 (3-346)
Total Taxa	36	68
$\bar{x}$ Taxa (ranges)	6.5 (1-11)	14.7 (2-24)
$\bar{x}$ $\bar{d}$ (ranges)	2.0 (0.0-3.0)	2.4 (0.5-3.8)
Pooled $\bar{d}$	3.8	3.6
$\bar{x}$ Bottom Temperature (°C)	18.4 (10.6-25.0)	18.7 (10.3-26.5)
$\bar{x}$ Bottom Dissolved Oxygen (mg/l) (ranges)	6.4 (2.4-9.4)	8.2 (6.4-9.6)
Sediment % Organic		
$\bar{x}$ Individuals		
Coleoptera	0.1	2.4
Diptera	15.4	35.3
Ephemeroptera	0.0	2.0
Megaloptera	0.0	0.2
Odonata	0.0	0.3
Oligochaeta	0.9	51.1
Plecoptera	0.0	0.2
Trichoptera	0.4	0.1

TABLE 85. Taxonomic listing with the number of occurrences for each taxa at each station for the GADS Site.

NAME	Number of Occurrences (10 max) GADS 1	GADS 3
Hygrobates sp.	1	0
Hydra sp.	0	1
Ancyronyx variagata	0	4
Dubiraphia quadrinotata	0	2
Ecotopria sp.	0	1
Hydroporus sp.	0	2
Macronychus glabratus	0	2
Microcyllepus pusillus	0	2
Tropisternus sp.	0	1
Isotomurus sp.	1	0
Ablabesmyia annulata	0	1
Ablabesmyia mallochi	1	3
Ablabesmyia ornata	1	5*
Ablabesmyia philosphagnos	0	3
Ablabesmyia tarella	0	3
Bezzia Sp.	1	1
Bittacomorpha clavipes	2	0
Unk. Chironomidae	1	1
Chironomus attenuatus	1	3
Chironomus riparius	3	4
Chironomus sp.	2	4
Chironomus stigmaterus	2	2
Cochapelopia sp.	0	3
Cryptochironomus fulvus	0	1
Dicrotendipes sp.	1	1
Eukiefferiella coerulescens	1	0
Eukiefferiella sp.	0	1
Glyptotendipes lobiferus	1	1
Goeldichironomus holoprasinus	0	1
Hemerodromia sp.	0	1
Microtendipes pedellus	0	2
Nanoclasius sp.	0	1
Pentaneura inconspicua	1	4
Phaenopsectra flavipes	1	0
Phaenopsectra obediens	0	1
Polypedilum convictum	1	0
Polypedilum fallax	0	3
Polypedilum halterale	0	1
Polypedilum illinoense	2	1
Potthastia sp.	1	0
Procladius bellus	4	1
Procladius sp.	1	0
Paratendipes subaequalis	3	0
Unk. Dipteran pupae	2	6*
Rheotanytarsus sp.	0	1

TABLE 85. Cont.

NAME	Number of Occurrences (10 max) GADS 1	GADS 3
Simulium sp.	1	0
Unk. Dipteran	1	0
Tanytarsus sp.	4	6*
Tribelos fuscicornus	1	1
Zavrelimyia sp.	0	1
Eurylophella temporalis	0	3
Habrophlebiodes brunneipennis	0	3
Leptophlebia intermedia	0	2
Stenonema smithae	0	1
Ferrissia hendersoni	1	0
Ferrissia sp.	0	3
Micromenetus dilatus	0	1
Promenetus sp.	0	3
Helobdella triserialis	1	0
Hyalella aztecus	0	1
Nigronia serricornis	0	1
Sialis sp.	0	1
Unk. Nematoda	0	1
Enallagma sp.	0	1
Aulodrilus pigueti	0	1
Haemonais waldvogeli	1	2
Limnodrilus hoffmeisteri	1	4
Nais communis	0	1
Nais variablis	0	1
Paranais sp.	0	1
Slavina appendiculata	0	6*
Specaria josinae	0	1
Tubifex harmani	2	2
Unk. Pelecypod	0	1
Unk. Sphaeriid	0	1
Acroneuria lycorias	0	1
Leuctra sp.	0	1
Hydatophylax sp.	1	0
Polycentropus sp.	1	0
Psilotreta sp.	0	1
Unk. Tricopteran	1	0

* indicates organisms found in more than 50% of samples

MASS Sites

Three of the five MASS sites behaved very similarly to the majority of FREQUENCY sites already discussed, with respect to longitudinal trends of the benthos (Table 86). Uniform and significant declines in single number summaries (approx. 50% or more) between the control and pond stations at the Kever, Whittle and McCormick sites were evident. The ponds at these sites were severely stressed (e.g., $\bar{d} \leq 1.0$). These data suggested that the Lett site pond was only moderately stressed. This result may have been somewhat different however, had more data from the control station there been available. The Scott site control was an intermittent stream, as it dried out on several occasions during the project. The biological data reflect this, and therefore make this station relatively unsuitable as a control. The Scott pond, however, would be considered severely stressed if compared to the Whittle control stream, which is 8 km away and somewhat similar. All of these MASS ponds experienced episodes of dissolved oxygen depletion (< 0.5 mg/l) which may be a factor explaining the reduced quality of the benthic communities.

Species data from all MASS control stations and all MASS pond stations were experimentally combined, and species in more than 50% of the samples determined (Table 87). The combined control stations were represented by eight typical saprophobic, mesoxyphilous species such as Ablabesmyia ornata and Tribelos jucundus. The combined pond stations, with only three such organisms, were represented by well known inhabitants of eutrophic systems, such as the saprophilic Chironomus attenuatus and the anoxyphilous Glyptotendipes lobiferus.

Qualitative Collections

Extensive qualitative sampling of selected sites (MOSS 1, MOSS 2, MOSS 3, MOSS 5, QUIN 1, QUIN 2, and QUIN 3) indicated the presence of many organisms living in the pond littoral zone which were not found using other sampling methods (Tables 88 and 89). It appeared that the littoral zone was a much more hospitable habitat than the rest of the pond, and supported more total benthic taxa and, perhaps, bioamass. In fact, many organisms found in the littoral zone (e.g., the odonate Nehalennia sp.) were those dependent on a dense growth of certain aquatic macrophytes for habitat (Jerrell Daigle, FDER, pers. comm.). Most control streams (i.e., pre-impounded sections of stream) were shaded by a heavy growth of bottomland hardwoods (e.g., sweetbay, red maple, oak, tulip poplar and sweetgum), which limited the growth of aquatic macrophytes. Therefore, the habitat available to these macroinvertebrates was basically limited to snags, leaf packs and sand.

Before pond formation, the area of stream to be impounded was clear cut, destroying the forest in the immediate area. This, of course, increased the amount of sunlight available for the growth of submerged and emergent macrophytes. Aided by the decreased flow regime, macrophyte growth was thus favored, which in turn influenced the types of

TABLE 86. Benthic macroinvertebrate mean abundance, total taxa, mean taxa, mean Shannon-Weaver diversity index, the "pooled" variation of this index, mean bottom temperature, mean bottom dissolved oxygen, and % of organic matter in the sediment for the MASS Sites, November 1984 to August 1985. Numbers in parentheses are minimum and maximum values for the sample period.

	Kever Site		Lett Site		Whittle Site		Scott Site		McCormick Site	
	B1	B2	G1*	G2	H1	H2	I1	I2	L1	L2
$\bar{x}$ Abundance (ranges)	31.5 (11-52)	4.0 (1-9)	78	66.7 (41-97)	373 (51-699)	3.3 (1-7)	15.0 (7-23)	55.0 (53-57)	38.3 (8-67)	1.3 (0-4)
Total Taxa	13	7	15	24	49	6	9	20	19	4
$\bar{x}$ Taxa (ranges)	7.5 (7-8)	2.7 (1-5)	15	11 (8-13)	24.3 (15-33)	2.3 (1-5)	5.0 (3-7)	12.0 (12-12)	9.0 (4-13)	1.3 (0-4)
$\bar{x}$ $\bar{d}$ (ranges)	2.2 (1.5-2.8)	1.0 (0.0-1.9)	3.2	2.5 (2.3-2.8)	2.5 (1.8-3.0)	0.8 (0.0-2.2)	1.6 (1.2-2.1)	2.9 (2.9-3.0)	2.3 (1.9-2.7)	0.7 (0.0-2.0)
Pooled $\bar{d}$	2.1	2.6	3.2	3.4	2.9	2.4	2.6	3.7	3.1	2.0
$\bar{x}$ Bottom Temperature (°C)	17.8 (12-21)	18.8 (7.5-24.2)	20.4 (11.2-29.5)	22.0 (9.0-28.0)	16.7 (10.0-21.0)	18.5 (8.0-25.0)	14.5 (8.0-21.0)	20.8 (8.0-26.0)	19.5 (9.5-26.0)	18.3 (7.0-24.0)
$\bar{x}$ Bottom Dissolved Oxygen (mg/l) (ranges)	8.0 (7.0-8.1)	3.3 (0.4-11.6)	8.4 (7.1-9.7)	3.1 (0.4-10.7)	9.5 (8.0-12.0)	3.3 (0.2-12.5)	7.1 (3.8-10.4)	2.9 (0.2-9.8)	8.0 (4.7-13.2)	3.3 (0.2-11.9)
Sediment % Organic		1.4%		12.9%		1.5%		0.6%		16.8%

* Biological data based on a single sampling.

TABLE 87. Taxonomic listing with the number of occurrences for each taxa at each station for the MASS Site.

NAME	Number of Occurrences	
	Combined Controls (8 total)	Combined Ponds (9 total)
Hygrobates sp.	1	0
Dineutus sp.	1	0
Stenelmis sp.	1	0
Isotomurus sp.	1	0
Ablabesmyia annulata	1	0
Ablabesmyia aspera	0	1
Ablabesmyia mallochi	4*	2
Ablabesmyia ornata	5*	1
Ablabesmyia parajanta	3	0
Ablabesmyia sp.	2	0
Ablabesmyia tarella	3	3
Bezzia sp.	2	0
Chaoborus punctipennis	0	3
Unk. Chironomidae	2	1
Chironomus attenuatus	0	5*
Chironomus riparius	2	2
Chironomus sp.	1	1
Chironomus staegeri	1	1
Chironomus stigmaterus	1	0
Conchapelopia sp.	4*	0
Corynoneura taris	2	0
Cryptochironomus fulvus	1	0
Dicrotendipes modestus	0	1
Dicrotendipes neomodestus	0	1
Dicrotendipes nervosus	0	4
Dicrotendipes sp.	0	1
Einfeldia natchitochea	0	2
Endochironomus nigricans	0	1
Glypotendipes lobiferus	3	6*
Glyptotendipes meridionalis	1	2
Glyptotendipes paripes	1	1
Glyptotendipes sp.	1	0
Goeldichironomus holoprasinus	0	1
Harnischia sp.	0	1
Hemerodromia sp.	1	0
Labrundinia neopilosella	2	0
Labrundinia pedellus	2	0
Nanocladius sp.	1	0
Nilothauma sp.	2	1
Parachironomus schneideri	1	1
Phaenopsectra obediens	1	0
Polypedilum halterale	3	1
Polypedilum illinoense	3	1
Procladius bellus	5*	2

TABLE 87. Cont.

NAME	Number of Occurrences: Combined Controls (8 total)	Number of Occurrences: Combined Ponds (9 total)
Procladius sp.	1	1
Unk. Dipteran pupae	6*	3
Tanytarsus sp.	6*	3
Tribelos fuscicornus	2	0
Tribelos jucundis	4*	0
Caenis hilaris	1	0
Eurylophella temporalis	1	0
Leptophlebia intermedia	1	0
Stenonema exiguum	1	0
Ferrissia hendersoni	2	1
Ferrissia sp.	1	0
Placobdella ornata	1	0
Hyalella aztecus	2	0
Procambarus sp.	1	0
Nigronia serricornis	1	0
Anomalagrion hastatum	1	0
Argia bipunctulata	1	0
Argia sp.	1	0
Enallagma divagans	1	0
Enallagma sp.	0	1
Epicordulia princeps regina	2	0
Erythrodiplax connata minuscula	1	0
Dero furcata	1	0
Dero nivea	1	0
Dero obtusa	3	4
Eclipidrilus sp.	1	0
Haemonais waldvogeli	0	3
Nais communis	0	2
Nais pseydobtusa	1	0
Nais variablis	4*	5*
Pristina idrensis	1	0
Pristina sp.	1	0
Slavina appendiculata	3	0
Unk. Tubificidae	0	1
Unk. Sphaeriid	1	1
Dugesia tigrina	1	1
Leuctra sp.	2	0
Perlesta placida	1	0
Anisocentropus pyraliodes	1	0
Cyrnellus fraternus	1	0
Lype diversa	1	0
Nyctiophalax sp.	0	1
Orthotrichia sp.	2	0
Psilotreta sp.	1	0
Triaenodes tardus	1	0

* indicated organisms found in more than 50% of samples

TABLE 88. Qualitative macroinvertebrate collections (includes dip netting of aquatic forms and adult odonates.)

MOSS 1

Copelatus sp.
Nanocladius sp.
Procladius bellus
Procambarus sp.
Nigronia serricornis
Argia fumipennis atra
Boyeria vinosa
Cordulegaster maculata
Dromogomphus spinosus
Erythemis simplicicollis
Erythodiplax connata minuscula
Libellula auripennis
Progomphus obscurus
Aniocentropus pyraloides
Molanna tryphena

MOSS 2

Ablabesmyia ornata
Ablabesmyia parajanta
Bezzia sp.
Chironomus sp.
Dicrotendipes modestus
Glyptotendipes paripes
Glyptotendipes sp.
Macropelopia sp.
Nanocladius sp.
Callibaetis pretiosus
Planorbella trivolvis
Mesovelia sp.
Ranatra sp.
Anax junius
Anax longipes
Anomalagrion hastatum
Argia bipunctulata
Argia fumipennis atra
Celithemis amanda
Celithemis eponia
Celithemis faciata
Coryphaeschua ingens
Enallagma concisum
Enallagma sp.
Erythemis simplicicollis
Erythrodiplax connata minuscula

TABLE 88. Cont.

Ischnura kellicotti
Ischnura posita
Ischnura ramburii
Libellula auripennis
Nehalennia sp.
Pachydiplax longipennis
Pantala flavescens
Perithemis tenera seminole
Tramea carolina
Tramea lacerata
Hydroptila sp.
Oecetis inconspicua
Polycentropus sp.

MOSS 3

Berosus cf. striatus complex
Berosus sp.
Haliplus cf. triopsis
Hydaticus cf. bimarginatus
Tropisternus sp.
Djmbatista pulcher
Polypedilum halterale
Pseudochironomus fulviventris
Tanytarsus sp.
Caenis sp.
Nigronia serricornis
Anax longipes
Aphylla williamsoni
Argia fumipennis atra
Celithemis amanda
Celithemis bertha
Erythemis simplicicollis
Gomphus cavilaris brimleii
Ischnura ramburi
Perithemis tenera seminole
Progomphus bellei
Oecetis inconspicua
Oxyethira (case only)

MOSS 5

Dineutus discolor
Polypedilym convictum
Procambarus cf. pygmaeus
Nigronia serricornis

TABLE 88. Cont.

Argia tibialis
Boyeria vinosa
Calopteryx maculata
Epicordulia princeps regina
Libellula incesta (one seen)
Progomphus bellei
Stenacron interpunctatum
Stenonema smithae
Acroneuria arenosa
Leuctra sp.
Anisocentropus pyraloides
Molanna tryphena

TABLE 89. Qualitative macroinvertebrate collections (includes dip netting of aquatic forms and adult odonates.)

QUIN 1

Hygrobates sp.
Stenelmis sp.
Bittacomorpha clavipes
Conchapelopia sp.
Hemerodromia sp.
Paratendipes subaequalis
Tanytarsus sp.
Asellus sp.
Procambarus sp.
Sialis sp.
Argia bipunctulata
Argia fumipennis atra
Calopteryx maculata
Cordulegaster cf. maculata
Erythemis simplicicollis
Progomphus bellei
Progomphus obscurus
Musculium sp.
Pisidium sp.
Leuctra sp. (common)
Ceraclea sp. (cases only)
Phylocentropus sp. (larvae and pupae)
Psilotreta sp. (common)
Trianodes sp. (cases only)

QUIN 2

Berosus sp.
Atrichopogon sp.
Dicrotendipes nervosus
Endochironomus nigricans
Parachironomus schneideri
Physella heterostropha pomila
Polypedilum illinoense
Caenis diminuta
Imm. heteroptera
Chauloides rastricornis
Anomalagrio hastatum
Argia sp.
Epicordulia princeps regina (common)
Erythemis simplicicollis
Erythrodiplax connata minusula
Ischnura posita
Ischnura ramburii

TABLE 89. Cont.

Pachydiplax longipennis
Ilyodrilus templetoni
cf. Oecetis sp. (case only)
Orthotrichia sp. (common)

QUIN 3

Copelatus caelatipennsi princeps
Chironomus riparius
Goeldihironomus holoprasinus
Polypedilum illinoense
Calopteryx maculata

invertebrates found in the littoral zone of the ponds. The majority of the pond area, however, was profundal rather than littoral zone, and was subject to episodes of severely depleted dissolved oxygen. Therefore, despite the ability of the littoral zone to support a numerous and diverse benthic population, the far greater benthic profundal area was usually inhospitable to many aquatic organisms.

Multivariate Techniques-FREQUENCY Sites

Normal Analysis

Normal cluster analysis of species composition and abundance data (excluding animals with less than 2 occurrences) indicated the presence of six station groups at the level of 20% similarity (Figure 110). Group 1 consisted of the two MOSS ponds, (MOSS 2, MOSS 3) and the MOSS outfall station (MOSS 4). It was not unexpected that these stations in close geographic proximity within a continuous aquatic system grouped together. Note however, that neither MOSS 1 nor MOSS 5 (the two control streams) were present in this group.

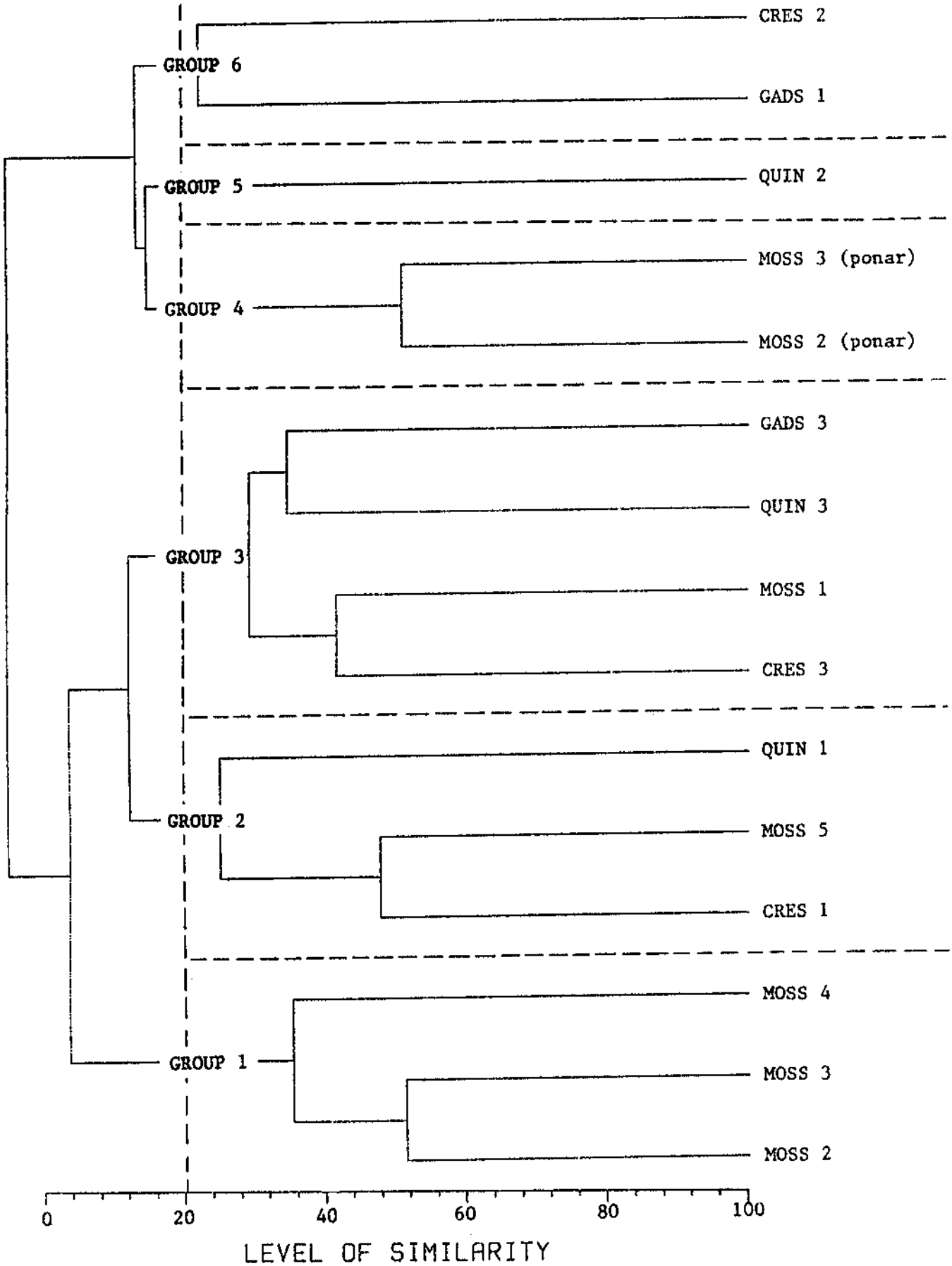
Group 2 contained the various control stations which were located under a hardwood canopy (CRES 1, MOSS 5 and QUIN 1). The fact that these geographically isolated control stations clustered together rather than with their respective downstream pond and outfall stations, suggests that impoundments significantly alter macroinvertebrate community structure from that found in streams from which they were formed.

Group 3 comprised three outfall stations (CRES 3, QUIN 3 and GADS 3) and MOSS 1. It is not surprising that the outfall stations grouped together, as the moderately enriched conditions found downstream of impoundments would probably favor the occurrence of a similar type of detritivore/predator dominated community. The reason MOSS 1 is grouped with this assemblage may be related to the slow current velocity and luxurient growth of benthic macrophytes (and thus large amounts of organic matter) found at this station.

Group 4 was made up of the MOSS 2 and 3 ponar stations. This was almost certainly a function of sampling type and the close proximity of the two ponds.

Group 5, consisting only of the newly formed pond QUIN 2, illustrates that at this particular similarity level, severely stressed systems may not necessarily cluster with other stressed systems. Finally, Group 6 was also composed of a newly formed, stressed pond (CRES 2) and the anomalous, GADS 1 control. This coincides with other observations indicating that GADS 1 is stressed.

FIGURE 110. Normal cluster analysis (FREQUENCY stations) based on the abundance and distribution of the top 160 taxa.



Inverse Analysis

The results of inverse cluster analysis of the top 50 taxa revealed six species groups (Figure 111). The total number of organisms in all six groups was 18,592, which accounted for 92% of all animals collected during the study.

Group A, which represented 40% of the top 50 animals collected, occurred in greatest densities at outfall stations (CRES 3, MOSS 4 and QUIN 3) but was generally ubiquitous. This group was dominated by detrital feeders with widespread distribution, such as the midge, Tanytarsus sp., and the oligochaete, Nais variablis.

The members of Group B (6% of the top 50 organisms) occurred almost exclusively at three control stations, MOSS 1, MOSS 5 and CRES 1. The organisms in this group were indicators of good water quality, such as the mayflies, Stenacron interpunctatum and Stenonema exiguum, and the caddisfly, Oecetis inconspicua.

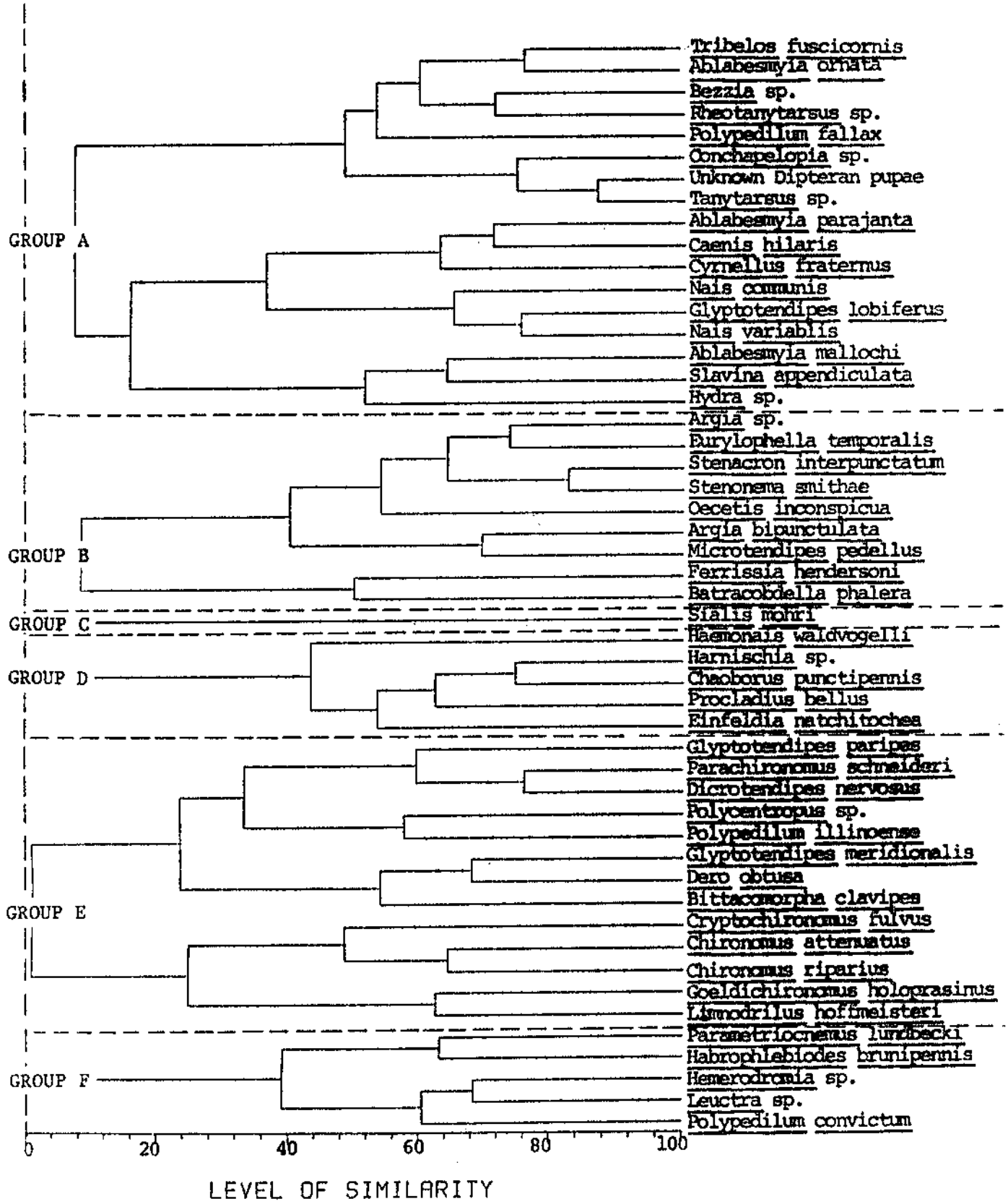
Group C contained a single organism, Sialis mohri, 46 of which occurred on a single sampling at only one outfall station, CRES 3. This group is most likely a sampling anomaly perhaps caused by the hatching of an egg mass.

Of the Group D organisms (20% of the top 50 taxa collected), 95% were found in ponar samples from stations MOSS 2 and MOSS 3. Chaoborus punctipennis, a well known anoxyphile, dominated Group D, followed by Procladius bellus and Harnischia sp., two midges sometimes considered characteristic of water with low dissolved oxygen concentrations (Beck 1977).

Group E (19% of the top 50 taxa) was dominated by the oligochaete Limnodrilus hoffmeisteri. This tubificid worm is frequently the most abundant organism in areas sustaining high degrees of organic enrichment (Stimpson et al. 1982). Other conspicuous members of this group were the dipterans, Polypedilum illinoense and Bittacamorpha clavipes, and the oligochaete, Dero obtusa. These saprophiles occurred mostly at QUIN 3, MOSS 2 ponar samples and GADS 3, indicating the organically enriched conditions noted at certain pond and outfall stations.

Group F, which accounted for 14% of the top 50 organisms collected, could better be described by two sub-groups. The first of these sub-groups contained sensitive organisms which occurred almost exclusively at QUIN 1, the QUIN control stream. These were the stonefly, Leuctra sp., and the mayfly, Habrophlebiodes brunipennis, which together accounted for 12% of the total individuals within Group F. The second sub-group was dominated by Polypedilum convictum, a midge found virtually only at the QUIN outfall station. This chironomid accounted for 76% of all Group F organisms.

FIGURE 111. Inverse cluster analysis (FREQUENCY stations) of the top 50 taxa.



Discriminant Analysis

The results of multiple discriminant analysis indicated that 51% of the among-group variance could be explained by Discriminant Function I (DFI). The most important variables within DFI were pH and temperature. The addition of DFII increased the explained variance an additional 36% to 87%. Dissolved oxygen was the parameter that contributed most to among-group separation in DFII.

The distribution of station groups in discriminant space is evident in Figure 112. Dissolved oxygen seems to play a major role in separating the control stations from the various pond stations. This is consistent with previous discussions on the subject of low D.O. in the ponds having an adverse effect on benthic communities. (See Hynes 1970 for a discussion of dissolved oxygen and benthic animals.)

Separation of the outfall group from both the pond and control group was more a function of pH and temperature. This suggests that the water leaving the pond is generally warmer and less acidic. Increased retention time in a pond subject to the hot Florida sun would account for warmer water downstream of the impoundment (Baxter 1977). Meanwhile, the prolific phytoplankton growth that occurred in the ponds would account for the higher pH values downstream due to the nature of algal metabolism.

Cases where there was overlap between control, pond, or outfall stations in the station clusters simply reflects the complex influences that other biotic and/or abiotic factors (e.g., geologic, hydroglogic) may be having on the biota of the systems. However, considering the distance separating our various sites, as well as the variable vegetation and land-use patterns in the drainage basins, it is clear that the effects of impoundment dominated other factors controlling the biota.

Multivariate Techniques- MASS Sites

Normal Analysis

Normal cluster analysis of species composition and abundance data of the MASS stations also indicated the presence of six station groups at the level of approximately 20% similarity (Figure 113). Groups 1, 2, 4, and 5 consisted of control streams only, while Groups 3 and 6 were made up of pond stations. Although based on only a few samplings, it is interesting that in no case did control streams and ponds from the same location cluster together. This is consistent with the results of cluster analysis performed on the FREQUENCY stations, and indicated again that impoundments can significantly alter macroinvertebrate community structure.

FIGURE 112. Orientation of FREQUENCY upstream, pond, and outfall stations in discriminant space.

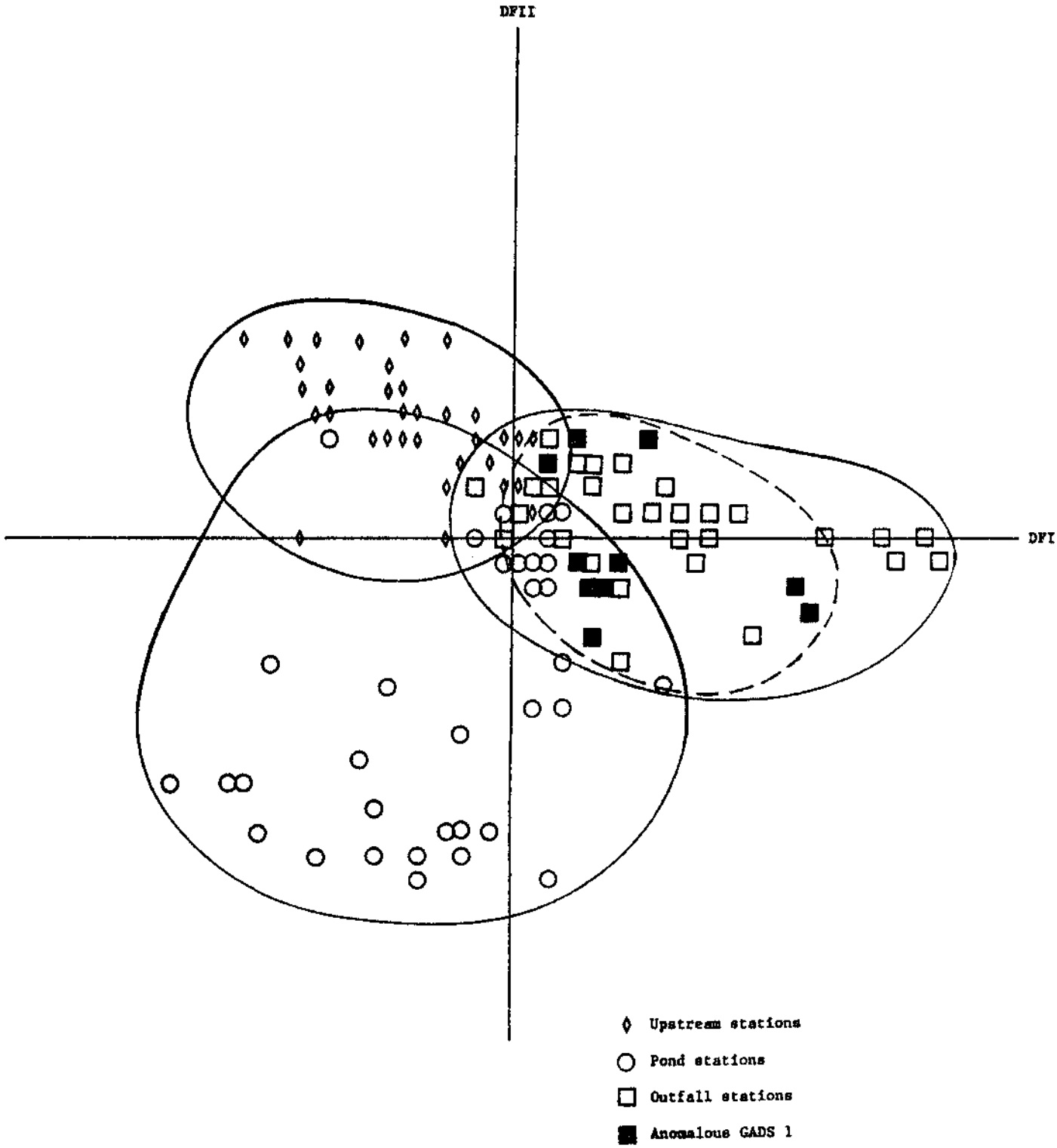
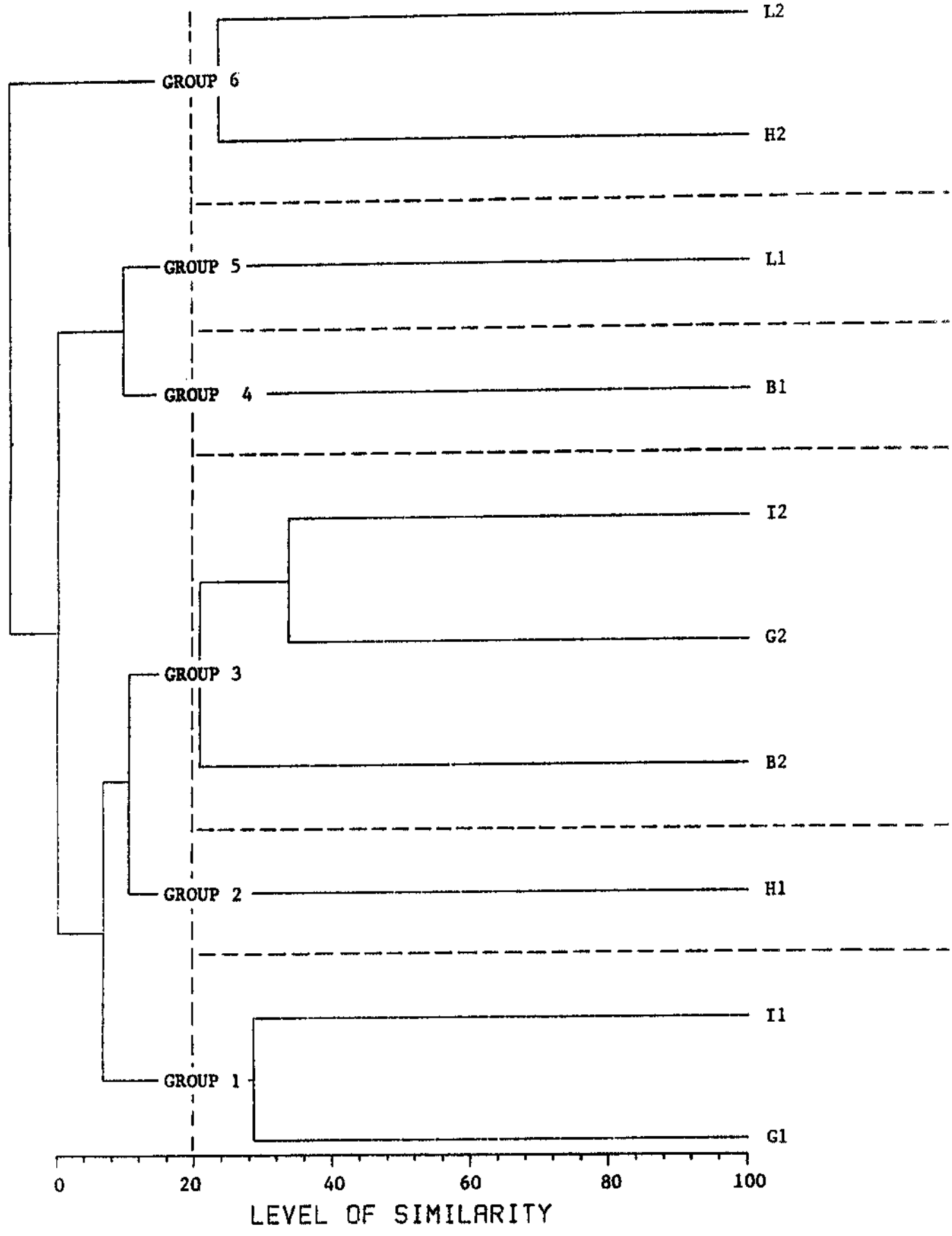


FIGURE 113. **Normal cluster analysis (MASS stations) based on the abundance and distribution of all organisms.**



Inverse Analysis

The results of inverse cluster analysis of the top 50 benthic invertebrate taxa animals collected from the MASS stations reveal the presence of seven species groups (Figure 114). Group A accounted for 7% of the top 50 organisms, and most of these (83%) occurred at the L1 control stream. Only 4% of the top 50 animals made up Group B, and virtually all of these were found at G1 and H1. Good water quality indicators, such as Leptophlebia intermedia and Triaenodes tardus, dominated this group. Group C was another "control stream" group, having as members stations G1, H1 and I1. Group D was yet another "control stream" group with 96% of its two constituents occurring at B1. These were the sensitive stonefly Leuctra sp. and mayfly Stenonema smithae. Group E was composed primarily of worms such as Nais variablis, Dero obtusa and Haemonais waldvogeli. Not surprisingly, 88% of this group occurred at the pond stations G2 and I2. Members of Group F also occurred only at pond stations (G2, H2 and I2). The midge Dicrotendipes nervosus a common inhabitant of eutrophic water (Beck 1977), was typical of this group. Group G was the most abundant group among the MASS stations, accounting for 61% of all top 50 organisms. Ninety six percent of these organisms were found at H1 and were generally mesoxyphilous organisms with widespread distributions such as Glyptotendipes lobiferus and Ablabesmyia parajanta.

Discriminant Analysis

Not surprisingly, multiple discriminant analysis performed on the MASS stations yielded results consistent with those obtained from the analysis conducted on the FREQUENCY stations. Discriminant Function I (DFI), which accounted for 54% of the among-group variance, was again defined primarily by pH. The addition of DFII increased the explained variance an additional 31% to 85%. As was the case with the FREQUENCY stations, dissolved oxygen was the parameter that contributed most to among-group separation for DFII.

The distribution of MASS station groups in discriminant space is also analogous to the distribution of the FREQUENCY control and pond stations (Figures 115). Low dissolved oxygen values in the ponds once again appear to exert a significant influence in separating the control stations from the pond stations.

CONCLUSIONS

All types of data analysis performed on both artificial substrate and ponar sampled macroinvertebrate data clearly indicated that impoundments have a profound and deleterious effect on benthic communities. Significant declines in abundance, species richness and diversity generally occurred between the control (stream) and pond stations. Biological integrity criterion violations were numerous in the ponds. Sensitive groups of organisms (e.g., Ephemeroptera, Trichoptera) were

FIGURE 114. Inverse cluster analysis (MASS stations) of the top 50 taxa.

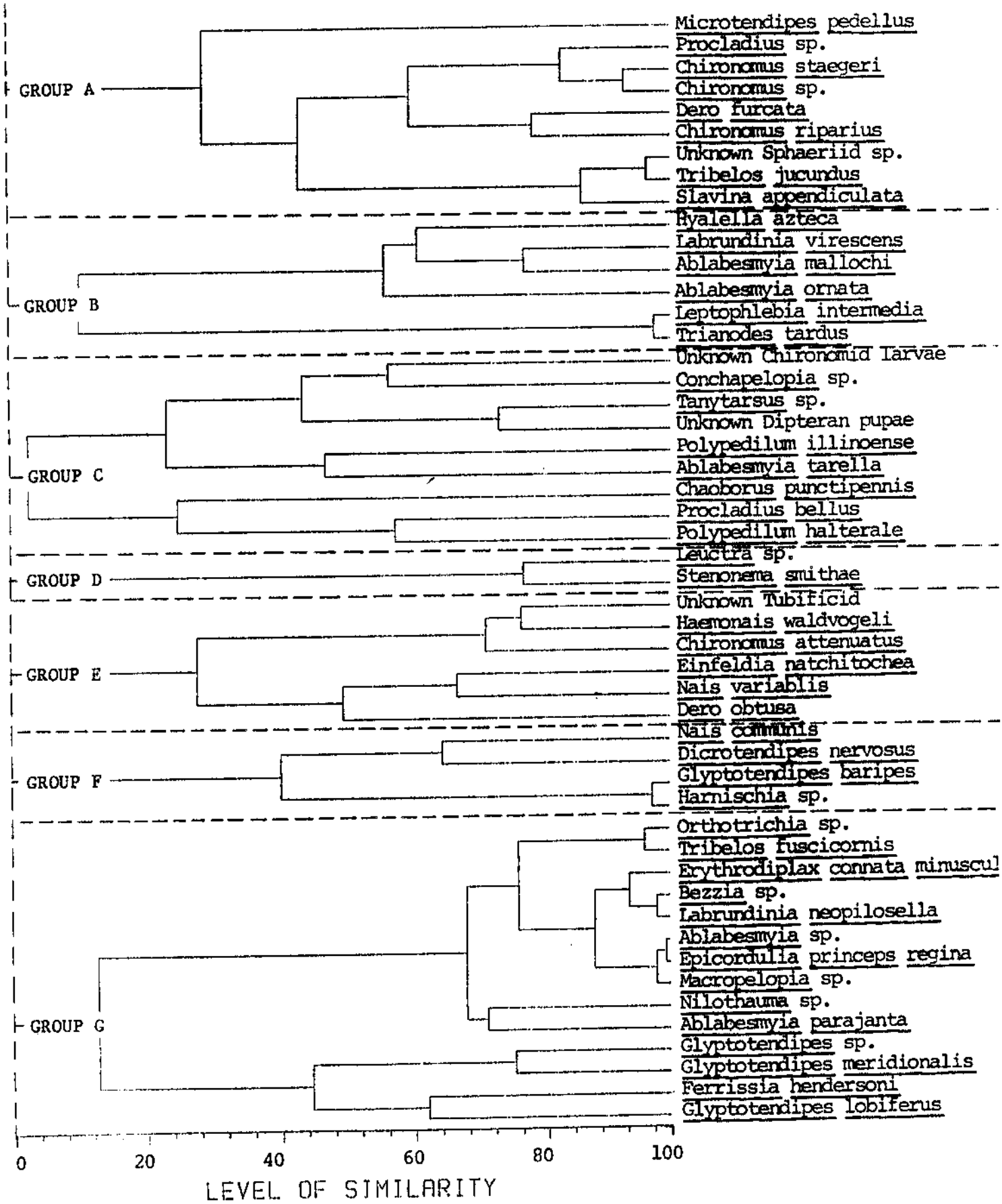
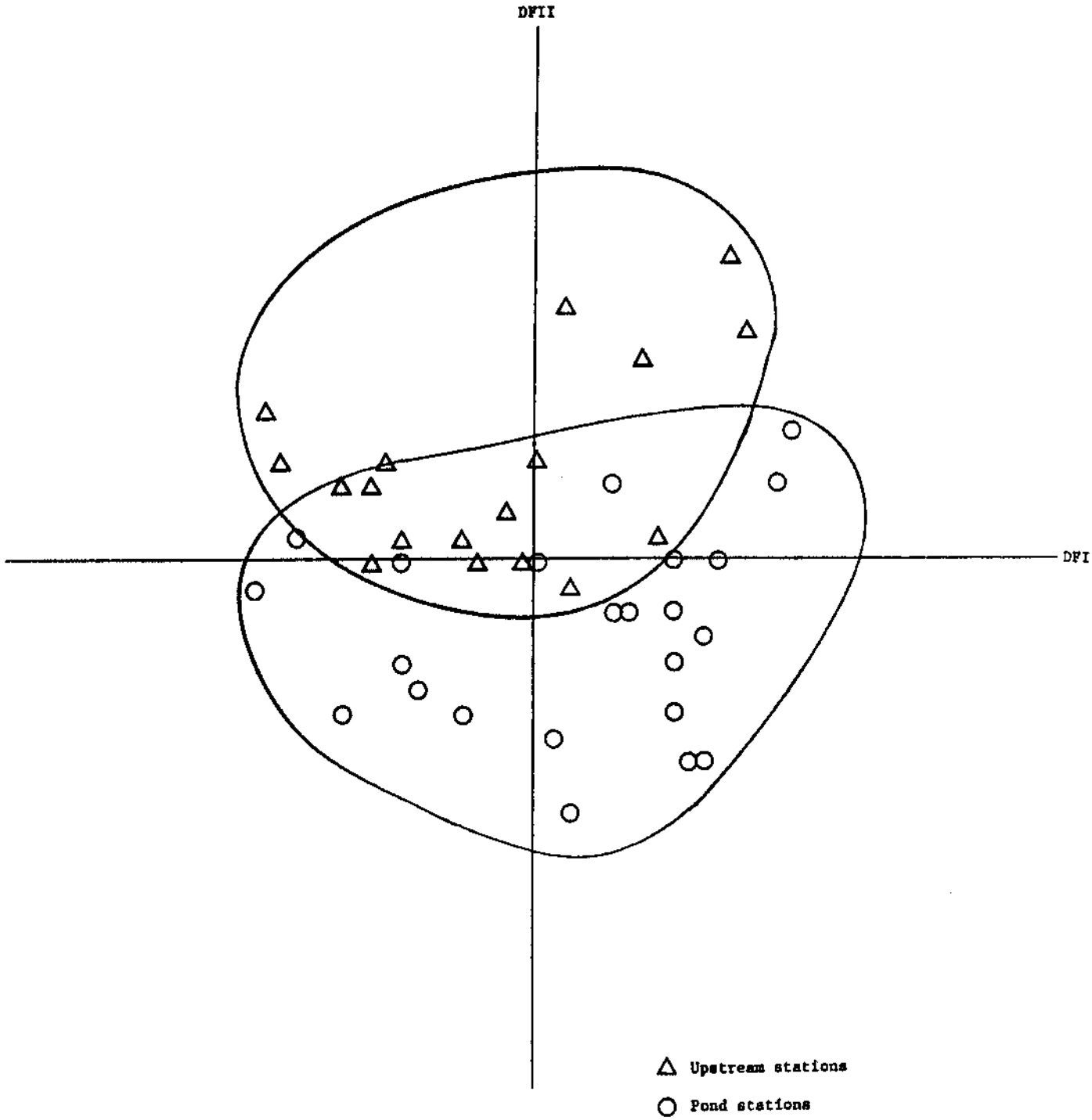


FIGURE 115. Orientation of MASS upstream and pond stations in discriminant space.



repeatedly eliminated as a result of impoundment. Species level data and data on frequently occurring species also indicated dramatic changes in the biota due to impoundment. Multivariate cluster analysis results supported these findings.

Physical-chemical factors responsible for changes in the benthos (as a result of impoundment) were the drastically lowered dissolved oxygen levels and the increases in both temperature and pH. Qualitative benthic sampling in the littoral zone of selected ponds indicated the presence of many organisms there not found in the rest of the pond. Most of these preferred aquatic macrophytes as habitat. However, despite the ability of the littoral zone to support benthic organisms, the far greater benthic profundal area was inhospitable to life.

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