Arkansas Water Resources Center

AN EVALUATION OF THE EFFECTS OF DREDGING WITHIN THE ARKANSAS RIVER NAVIGATION SYSTEM, VOLUME II, The Effects upon the Phytoplankton Associations

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AN EVALUATION OF THE EFFECTS OF DREDGING WITHIN THE ARKANSAS RIVER NAVIGATION SYSTEM

VOLUME II

EFFECTS UPON THE PHYTOPLANKTON ASSOCIATIONS

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INTRODUCTION

Phytoplankton are a major source of primary production in aquatic ecosystems and constitute one of the most important assemblages of the biotic community. These organisms are the basic level of the trophic pyramid upon which other organisms are dependent. The development, maintenance, and environmental influence of phytoplankton in and on the aquatic ecosystem has been a subject of interest and concern for many years. Most of the studies concerning the nature and distribution of phytoplankton have been confined to lacustrine systems. Hutchinson (1967), citing several lake studies, summarized various aspects of the physical and chemical factors associated with phytoplankton. These studies have limited application to riverine systems.

Studies of river phytoplankton, or potamoplankton as referred to by many workers, have been very limited due to the complexity of the lotic environment. Features associated with river systems, such as water movements and wide fluctuations in water volume and turbidities, can have pronounced effects on the structure and the stability of the phytoplankton community. Several of these characteristic features and their consequent influence on river algae have been reviewed by Blum (1956), Greenburg (1964), and Hynes (1970). In addition to the influences that natural, unhampered river systems impose on phytoplankton, the effects of impoundments and more recently the effects of dredging activities on phytoplankton, have become major concerns.

In previous studies one of the main emphases of river systems has been the effects of impoundments on the phytoplankton community. Many rivers, including the Arkansas River, are regulated through various impoundments which are reservoir-dam systems used mainly for flood control or lock-dam systems used for navigational purposes. Various rivers have been studied to assess the ecological impact of impoundments on phytoplankton. Among these rivers studied were: Nile River (Brook and Rzoska, 1954); Shenango River (Hartman and Himes, 1961); rivers of North Carolina (Whitford and Schumacher, 1963); Montreal River (Cushing, 1964); and the Ohio River (Hartman, 1965). There seems to be general agreement that impoundments, by way of reducing the flow rates, increasing the depth, reducing turbidity, and increasing the concentration of available nutrients, favor the development and reproduction of phytoplankton. These impounded areas create lacustrine conditions which result in the development of typical lake plankters (Cole, 1975).

During the last few years, more attention has been directed toward the environmental impact of dredging on phytoplankton. Since the major waterways are used for navigational purposes, dredging activities are of frequent occurrence. The actual impact of dredging on phytoplankton at the dredging and disposal sites has not been clearly determined. Previous studies, cited in a literature review by Lee and Plumb (1974), have been concerned mainly with the effects of turbidity and the possible release of nutrients

and toxic chemicals from the dredged materials on phytoplankton. Even though the influence of suspended material on phytoplankton can be detrimental (Hollis, et al. 1964 and Plumb 1973), it is still questionable whether increased turbidity is an objectionable condition resulting from dredging activities (Harrison and Chisholm, 1974).

Dredging activities on the Arkansas River have not previously been analyzed in terms of effects on the biota of the river. For this project the major divisions of the biotic trophic pyramid were studied. This report focuses on the primary trophic level, the phytoplankton, of the Arkansas River. Since phytoplankton are principle food sources for many aquatic organisms, and thus can directly influence their quality and quantity, the fate of the phytoplankton during and after dredging is an important aspect that needs careful consideration.

A limited number of prior studies addressed to the water quality of the Arkansas River plankton were based on diatom abundances and distribution. Williams (1964) analyzed the trophic level of the Arkansas River according to the frequency of the four most abundant diatom species. His study was confined to three collecting points: Pendleton Ferry, Arkansas; Ponca City, Oklahoma; and Coolidge, Kansas. He concluded that Ponca City along the Arkansas River had the least diversity and, therefore, was the most enriched of the sites studied. Pendleton Ferry similarily had a "high

trophic index". Ponca City is approximately 250 miles upstream from the study area. Williams associated these high indices with restrictively elevated chloride concentrations. The occurrence of the four most abundant diatom species of the Arkansas River, as well as for the other major rivers of the United States, is listed in a guide for water quality studies by Weber (1971).

Low levels of primary production were reported for Lake Dardanelle (Palko, 1974), a main stem lake of the Arkansas River which is included in the present study reach. Since the results of this study were based on the chlorophyll analysis of plankton net samples only, the production level could actually be greater than the study indicated. The net collection technique retains mostly the larger organisms, and most of the highly productive nanoplankters are lost. Although this impoundment is within the total study area it was not sampled since no dredging activities are planned within the lake limits?

The 240 mile study reach covered in this report has not previously been studied for phytoplankton occurrence and distribution. In order to adequately assess the dredging effects on the phytoplankton of the Arkansas River, this baseline study of the phytoplankton was conducted. Major taxa and species of the Arkansas River were identified from river mile 283 to river mile 45. The spatial and temporal distribution of phytoplankton throughout the study reach is reported. Phytoplankton determinations were based

on an annual survey with samples collected seasonally. A qualitative study conducted on the July samples and a quanitative study conducted on October, January and April samples were used for the phytoplankton analyses. The influence of turbidity on the phytoplankton abundance and distribution is discussed. Structural changes in the transitory nature of the phytoplankton community in terms of major taxonomic transitions throughout the study reach are examined.

The latter part of this report focuses on the environmental impact of dredging on the phytoplankton population of the Arkansas River. Sites at three of the thirteen stations in the study reach were dredged during the July and January sampling periods of this project. The results of these dredging activities are examined. A review of past dredging studies is also given.

MATERIALS AND METHODS

Samples for phytoplankton analyses were collected at thirteen stations with several sites per station at regions along the Arkansas River (See Vol. I). Figure 1 shows the location of each station both along the study reach and in profile. At each site within the particular station, samples collected by the U. S. Corps of Engineers (Little Rock District), were taken with a pump (described in the materials and methods for zooplankton) during July and October, and with a 3.1 liter Kemmerer (Model #1230) during January and April. Surface and mid-depth samples were collected in order to detect differences in the vertical distribution patterns of the phytoplankton. The samples were preserved in 125 ml amber glass bottles previously filled with 2 ml of M^3 fixative (Meyer, 1971). This fixative retains the cytological integrity of the algae, aids in the settling of the algae in the counting chamber, and facilitates identification and enumeration.

During July an abbreviated sampling period was conducted in which Stations 1 through 8 were sampled. A qualitative study of these samples was made to determine the major taxa, genera, and species present in the Arkansas River. The diatoms which comprised the majority of the phytoplankton in these samples were identified to species according to the preparation and mounting procedures outlined by Patrick (1966). Aliquots from the river samples were

Figure 1 - Sampling Stations located along the study reach and in profile.

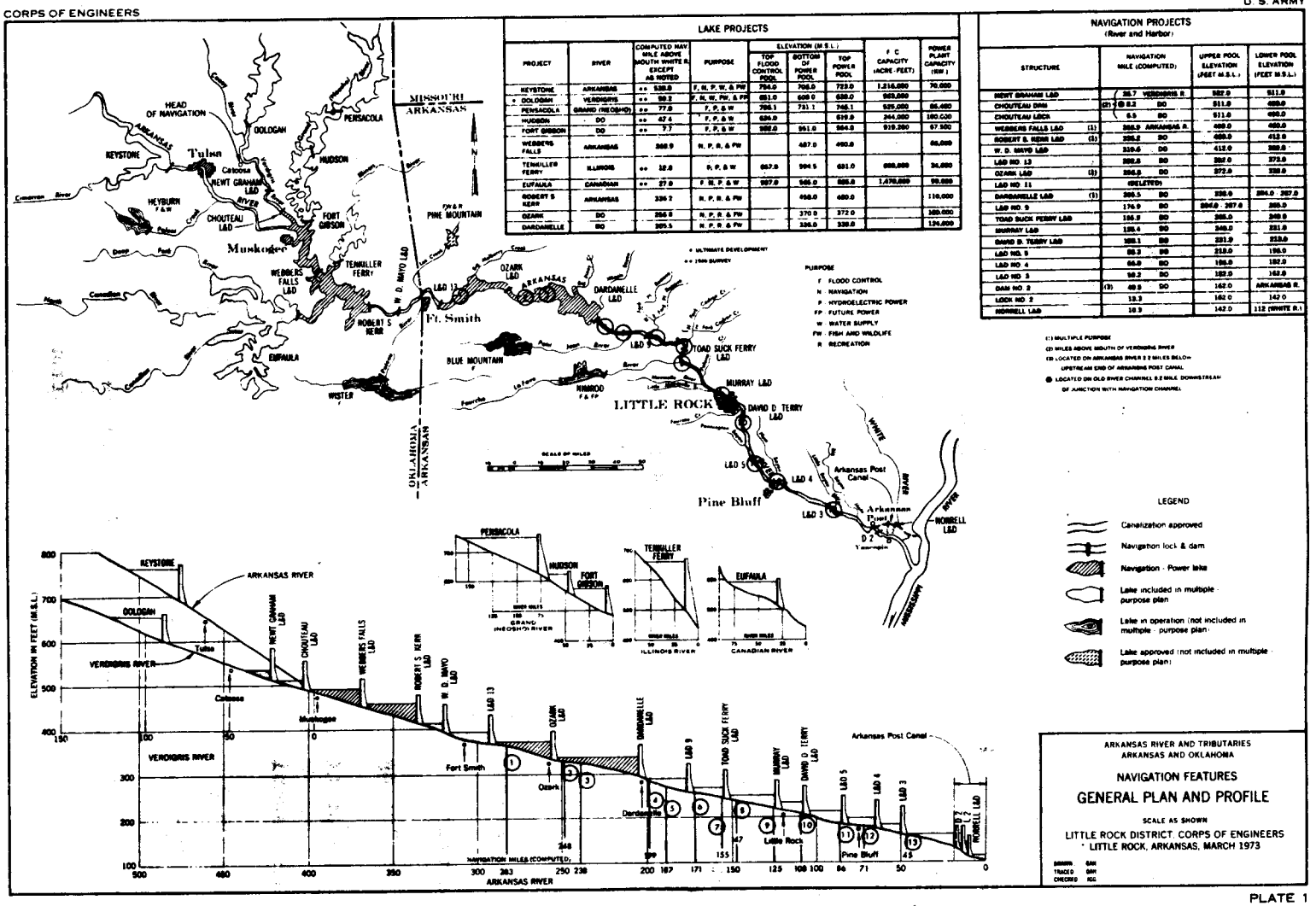


PLATE 1

treated with a potassium dichromate-sulfuric acid cleaning solution which removed the organic matter from the samples, leaving the silicious frustules of the diatoms with their fine wall markings easily discernible. After several washings with distilled water, the supernatant was decanted. The remaining residue was mounted with Hydrax on microscope slides. The prepared slides were observed with a Zeiss Photoscope II containing phase-contrast and Nomarski interference contrast optics. The species list prepared from this qualitative study was used in the construction of data sheets for the enumeration of the phytoplankton from the other three sampling periods. In order to determine an adequate enumeration method, the July samples were also examined by microscope observations to determine the degree of siltation in comparison to the abundance of algae.

The fixed samples collected during October, January, and April were prepared for enumeration according to the sedimentation technique of Utermohl (1958). Through preliminary experimentation (July samples) with 5, 10, 25, 50, and 100 ml settling chambers, the 5 ml chamber was determined to provide the greatest efficiency for the identification and enumeration of the phytoplankton. Larger volume settling chambers were not satisfactory due to the high silt content of the river samples which obscured the organisms.

After resuspending the fixed samples, an aliquot from each river sample was poured into the 5 ml settling chambers. A period of 6 to 8 hours was allowed for the resuspended organisms to settle.

The phytoplankton occurring in a transect through the diameter of the chamber were enumerated with the Wild Inverted Microscope at a magnification of 300x (20x objective, 10x oculars and 1.5x tube factor). Only the phytoplankters considered viable at the time of collection were enumerated. All the organisms were identified to species were possible. The raw data obtained by this study were converted to cells per liter by a conversion factor of 7917.3. The seasonal and biographical aspects of the phytoplankton were analyzed from calculations of the mean number of cells per liter for station or site. The scope of this project required the data for the phytoplankton to be reported in cells per liter instead of organisms per liter due to the inadequency of relating colonial organisms, which can be composed of several individual cells such as *Microcystis*, to single-celled organisms such as *Chlamydomonas*.

Following the enumeration of the phytoplankton, the turbidity of each river sample was analyzed. Turbidity, which is considered a significant parameter in this particular study, was determined by an Analytical Nephelometer (Model #2424). To insure the resuspension of the settled particulate material, each sample was sonicated in a Bransonic 12 sonicator. A yellow filter was used in this analysis to eliminate color interference. The turbidity was measured in NTU's (Nephelometric Turbidity Units) to the greatest whole number. The turbidity data are reported in Volume I of this study.

RESULTS

INTRODUCTION

Phytoplankton consisting of 243 species were observed from the thirteen sampling stations covering approximately 240 river miles (RM) of the Arkansas River through an annual cycle. The stations and sites have previously been described in the general introduction to this report (see Volume I).

Collections taken during July from the first eight of the thirteen sampling stations provided a basis for determining the major taxa present in the river. Identification of questionable species, especially diatoms, was facilitated by this study. Uncommon organisms were photographed for permanent record. Several species previously not recorded for the state of Arkansas were identified. These new records will be included in the Arkansas algal flora listings (refer to Meyer, 1969 and Meyer, et al., 1970).

The October, January, and April samples were used for the enumeration of the phytoplankton. The data and results are based on the enumeration of 189,648 cells for these sampling periods. Phytoplankton genera and species observed in this study are listed in Table 1. All organisms were identified to the generic level. Those species that could not be associated with descriptions given in the literature were assigned numbers, e.g., *Chlamydomonas* sp. 1.

The phytoplankton was composed of eight major taxa (blue-greens, green flagellates, coccoid greens, diatoms, cryptomonads,

TABLE 1

INVENTORY OF PHYTOPLANKTON FROM THE ARKANSAS RIVER

Chlorophyceae
- Volvocales
  - *Carteria* sp.
  - *Chlamydomonas* sp. 1
  - *C.* sp. 2
  - *C.* sp. 3
  - *Chlorogonium* sp.
  - *Chloromonas* sp.
  - *Dysmorphococcus variabilis*
  - *Eudorina* sp.
  - *Gloeomonas* sp.
  - *Gonium sociale*
  - *G.* sp.
  - *Pandorina charkowiensis*
  - *P. morum*
  - *Pedinomonas* sp.
  - *Phacotus* sp.
  - *Ptermonas* sp.
  - *Sphaerellopis* sp.
- Tetrasporales
  - *Asterococcus* sp.
  - *Gloeocystis ampla*
  - *G. gigas*
  - *G. vesiculosa*
  - *Sphaerocystis shroeteri*
- Chlorococcales
  - *Actinastrum hantzschii*
  - *Ankistrodesmus convolutus*
  - *A. falcatus*
  - *Chlorella* sp.
  - *Chodatella longiseta*
  - *C. genevensis*
  - *Closteriopsis* sp.
  - *Coccoid green* sp.
  - *Coelastrum microporum*
  - *C. reticulatum*
  - *C. scabrum*
  - *C.* sp.
  - *Crucigenia crucifera*
  - *C. irregularis*
  - *C. quadrata*
  - *C. rectangularis*
  - *C. tetrapedia*
  - *Dictyosphaerium erenbergianum*
  - *D. pulchellum*
  - *D.* sp.
  - *Dispora crucigenioides*
  - *Elakatothrix viridis*
  - *Euastropsis Richteri*
  - *Franceia Droescheri*
  - *Gloeoactinium limneticum*
  - *Golenkinia radiata*
  - *Kirchneriella lunaris*
  - *K. obesa*
  - *K. subsolitaria*
  - *Lagerheimia subsalsa*
  - *Micractinium pusillum*
  - *Nephrocytium agardhianum*
  - *Oocystis borgei*
  - *O. lacustris*
  - *O. marsonii*
  - *O. parva*
  - *O. pusilla*
  - *O. solitaria*
  - *O. subsolitaria*
  - *O.* sp.
  - *Pachycladon umbrinus*
  - *Pediastrum duplex*
  - *P. simplex*
  - *P. tetras*
  - *P. tetras* v. *tetraedron*
  - *Planktosphaeria* sp.
  - *Quadrigula chodatii*
  - *Q. closteriodes*
  - *Scenedesmus abundans*
  - *S. acuminatus*
  - *S. arcuatus*
  - *S. bijuga*
  - *S. denticulatus*
  - *S. dimorphus*
  - *S. hystrix*
  - *S. quadracauda*
  - *S. obliqus*
  - *Schroederia setigera*
  - *Tetraedron minimum*
  - *T. regulare*
  - *Tetrastrum heteracanthum*
  - *Trochiscia reticularis*
  - *Westella botryoides*

TABLE 1 (CONT.)

Conjugatophyceae
  Zygnemtales
    Arthrodesmus sp.
    Closterium sp.
    Desmidium sp.
    Euastrum sp.
Euglenophyceae
  Euglenales
    Euglena Allorgei
    E. pisciformis
    E. variablis
    E. sp.
    Lepocinclis ovum
    Phacus brevicaudus
    P. caudatus
    P. longicaudata
    P. sp.
    Strombomonas verrucosa
    S. sp.
    Trachelomonas scabra
    T. volvocina
Chrysophyceae
  Chrysomonadales
    Chromulina sp.
    Chrysococcus bisetus
    C. cordiformis
    C. minutus
    C. rufescens
    C. puntaformis
    C. triporus
    C. sp.
    Chrysophaeria parvula
    Dinobryon barvaricum
    D. divergens
    D. sertularis
    Hymenomonas sp.
    Kephryion cylindrica
    K. mastigophorum
    K. rubi-claustri
    K. sp.
    Mallomonas akrokomos
    M. caudata
    M. coronata
    M. pseudocoronata
    M. sp.
    Ochromonas sp.
    Pseudokephyrion sp.
    Stichogloea sp.
    Synura petersenii
    S. uvella
    S. sp.
Pyrrhophyceae
  Ceratiales
    Ceratium sp.
  Gymnodiniales
    Gymnodinium fuscum
    G. sp.
  Peridiniales
    Glenodinium Steinii
    Peridinium inconspicum
    P. sp.
Cryptomonadophyceae
  Cryptomonadales
    Chilomonas sp.
    Chroomonas acuta
    C. sp.
    Cryptomonas erosa
    C. marsonii
    C. ovata
Xanthophyceae
  Heterococcales
    Centritractus belonophorus
Bacillariophyceae
  Centrales
    Coscinodiscus lacustris
    C. Rothii
    Cyclotella atomus
    C. chaetoceras
    C. glomerata
    C. kutzingiana
    C. meneghiniana
    C. michiganiana
    C. ocellata
    C. stelligera
    Melosira ambigua
    M. distans
    M. granulata
    M. islandica
    M. varians
    Microsolenia sp.
    Rhizosolenia sp.
    Stephanodiscus astrea
    S. dubius
    S. invisitatus
    S. tenuis
    S. sp.

TABLE 1 (CONT.)

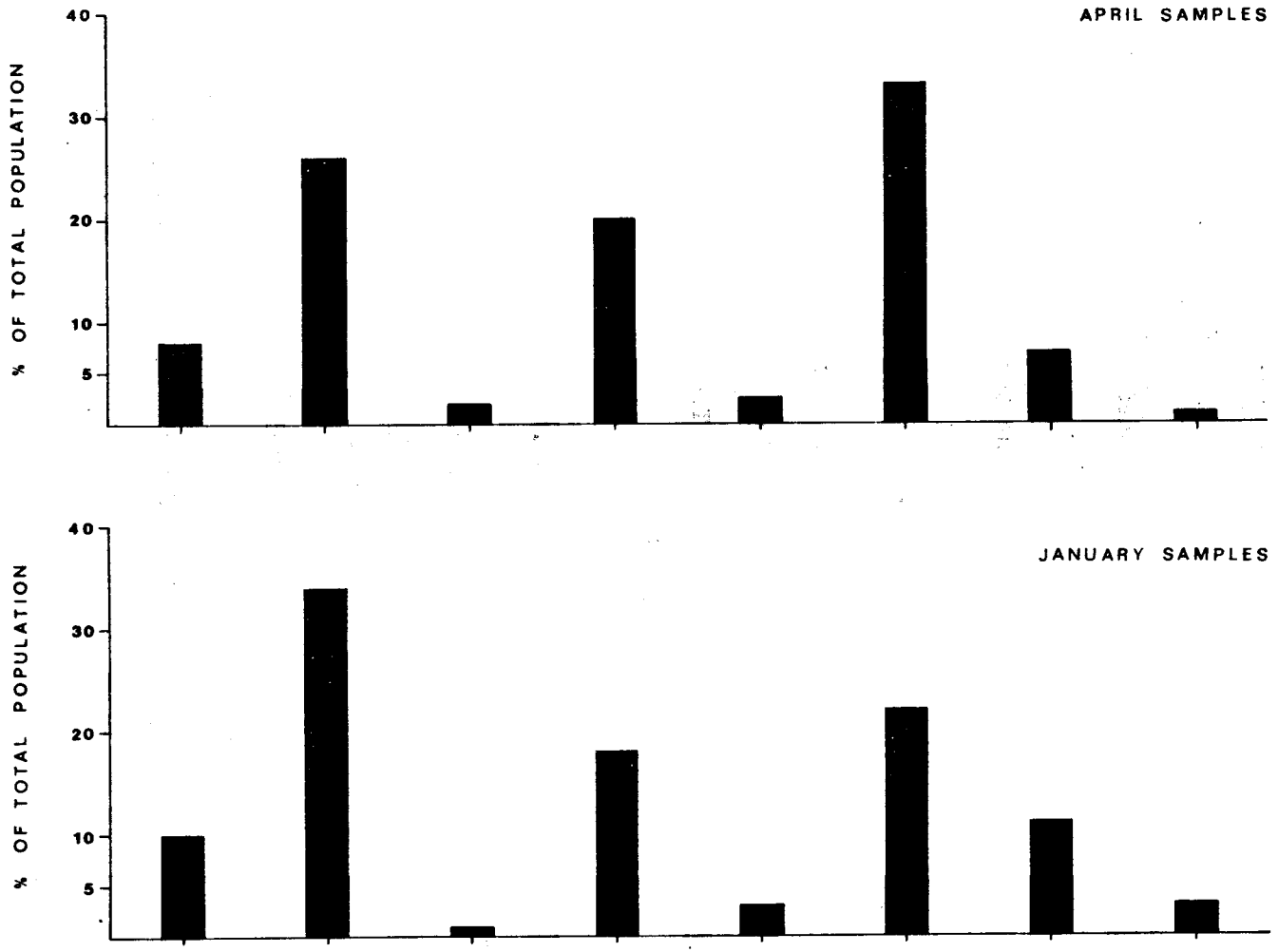
Pennales
Achnanthes linearis
A. linearis v. *curta*
A. minutissima
Amphiprora sp.
Amphora sp.
Asterionella formosa
Carpartogramma crucicula
Cymbella affinis
C. tumida
Diploneis sp.
Epithemia turgida
Frustulia sp.
Gomphonema constrictum
G. constrictum v. *capitata*
G. olivaceum
Gyrosigma sp.
Meridion sp.
Navicula auriculata
N. canalis
N. capitata
N. capitata v. *hungarica*
N. cryptocephala
N. cryptocephala v. *exilis*
N. cryptocephala v. *veneta*
N. exigua
N. luzonensis
N. mutica
N. sabinana
N. ventralis v. *chilensis*
N. veridula
N. zanoi
Nitzschia acicularis
N. amphibia
N. baccata
N. dissipata
N. filiformis
N. fonticola
N. luzonensis
N. palea
N. paradoxa
N. sigma
Pinnularia sp.
Pleurosigma delicatulum
Surirella angustata
S. brightwelli
S. ovalis
S. ovata
S. sp.
Synedra actinastroides
S. acus
S. fasciculata
S. ulna
S. sp.
Cyanophyceae
Chroococcales
Aphanothece microspora
A. nidulans
A. saxicola
Chroococcus pallidus
C. turgidus
Dactylococcopsis rhaphidioides
Gloeocapsa sp.
Gomphosphaeria aponia
G. lacustris
Holopedia sp.
Merismopedia elegans
M. glauca
M. sp.
Microcystis aeroginosa
M. flos-aquae
M. incerta
M. marginata
Rhabdoderma lineare
Romeria lepoliensis
Oscillatoriales
Anabaena sp.
Aphanizomenon sp.
Lyngbya sp.
Oscillatoria sp. 1
Oscillatoria sp. 2
O. limosa

dinoflagellates, euglenoids, and golden browns). The importance of these taxa within the phytoplankton community can be determined by calculating the proportion each taxon contributes. This relative abundance value (% composition) for each major taxon collected during the three sampling periods is shown in Figure 2 and Table 2. Five of the eight taxa (green flagellates, coccoid greens, blue-greens, diatoms and cryptomonads) constitute greater than 95% of the total phytoplankton population throughout this study. Depending on the collection period, the euglenoids, golden browns, and dinoflagellates constitute 0 to 3% of the phytoplankton, and were considered insignificant contributors. They, therefore, are only included when they occur above 5% composition level.

The composition of the phytoplankton during each sampling period is shown in Table 2. The blue-greens constituted the major portion (76%) of the total cell numbers during October. The coccoid greens and diatoms, each forming less than 10% of the total cell numbers, were the other major groups making a significant, but slight contribution during that particular period. In January percentage increases occurred in all the taxa except the blue-greens which decreased significantly. The coccoid greens formed the greatest percentage (35%) with the diatoms (22%) and blue-greens (18%) being of secondary importance. The percentage of cryptomonads (11%) in the phytoplankton reached its height during the January sampling period. In April the diatoms (33%) formed the largest

FIGURE 2

RELATIVE ABUNDANCE OF THE TOTAL PHYTOPLANKTON BY TAXON



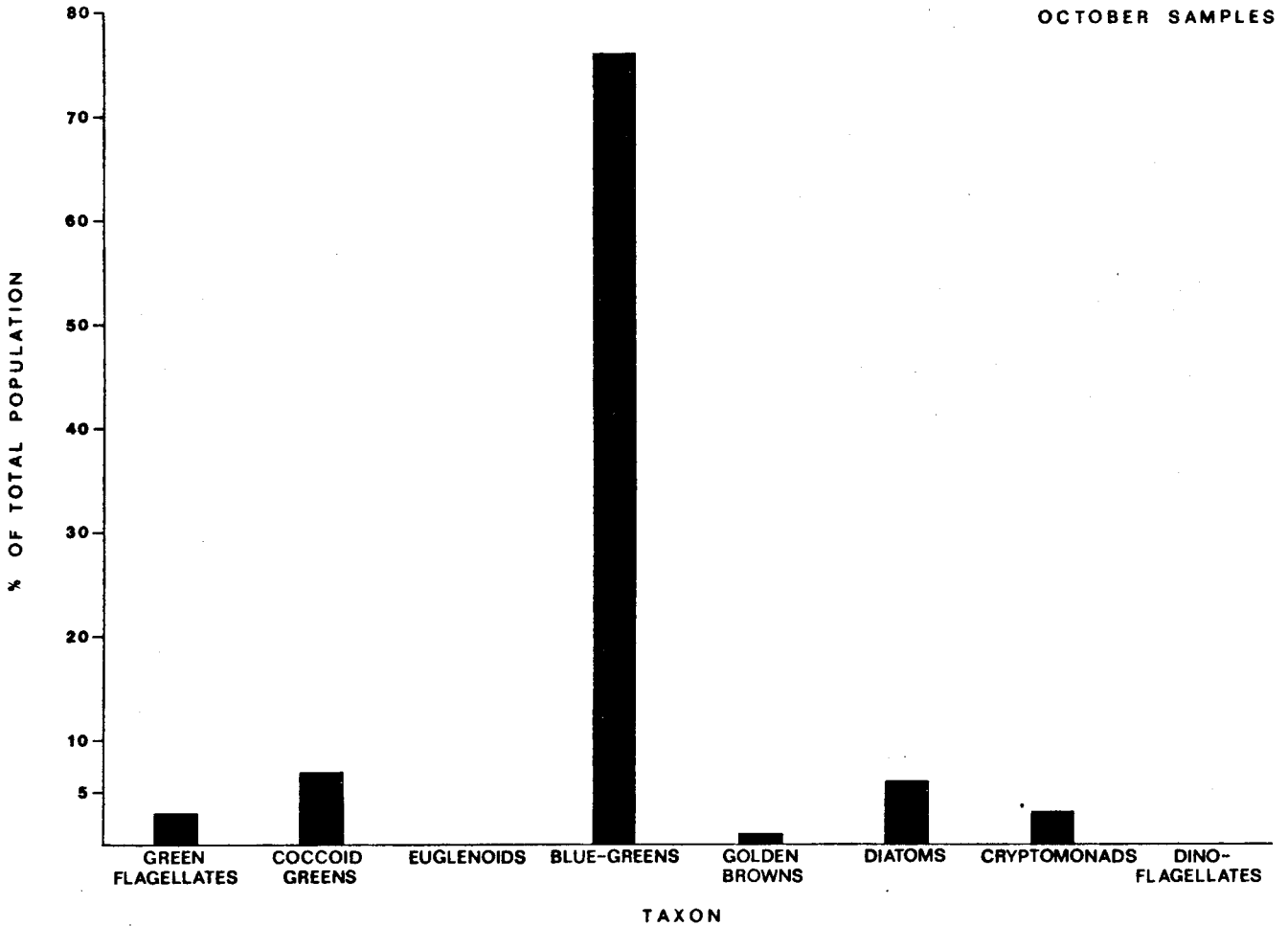

OCTOBER SAMPLES
% OF TOTAL POPULATION
80
70
60
50
40
30
20
10
5
GREEN FLAGELLATES
COCCOID GREENS
EUGLENOIDS
BLUE-GREENS
GOLDEN BROWNS
DIATOMS
CRYPTOMONADS
DINO-FLAGELLATES
TAXON

TABLE 2

PERCENT COMPOSITION OF TOTAL POPULATION BY TAXON

TAXON	OCTOBER	JANUARY	APRIL
GREEN FLAGELLATES	4	10	8
COCCOID GREENS	8	34	26
EUGLENOIDS	0	1	2
BLUE-GREENS	76	18	20
GOLDEN BROWNS	1	3	2
DIATOMS	7	22	33
CRYTOMONADS	3	11	7
DINOFLAGELLATES	0	3	1

percentage of the cell numbers with the coccoid greens (26%) and blue-greens (20%) being of secondary importance.

The mean number of cells per liter by station for each taxon indicates the size of the standing crop of phytoplankton at the time of collection. The data were clustered into means per station since the variation between depths and sites within each station was generally not significant. The abundances of the standing crop for each sampling period are given in Table 3. The abundance of phytoplankton generally increased from upstream to downstream, with fluctuations in the total cell numbers occurring along the study reach (Fig. 3). Accompanying the increase in the number of cells, the diversity of the species composition generally increased downstream. Thus diversity and abundance tended to vary directly, but the application of diversity importance must be applied with caution. The application of mathematical analysis to diversity is of questionable value (Peet, 1975), particularly when applied to river systems. Because of the serious problems associated with the development of an usuable method of diversity assessment, we have not determined indices.

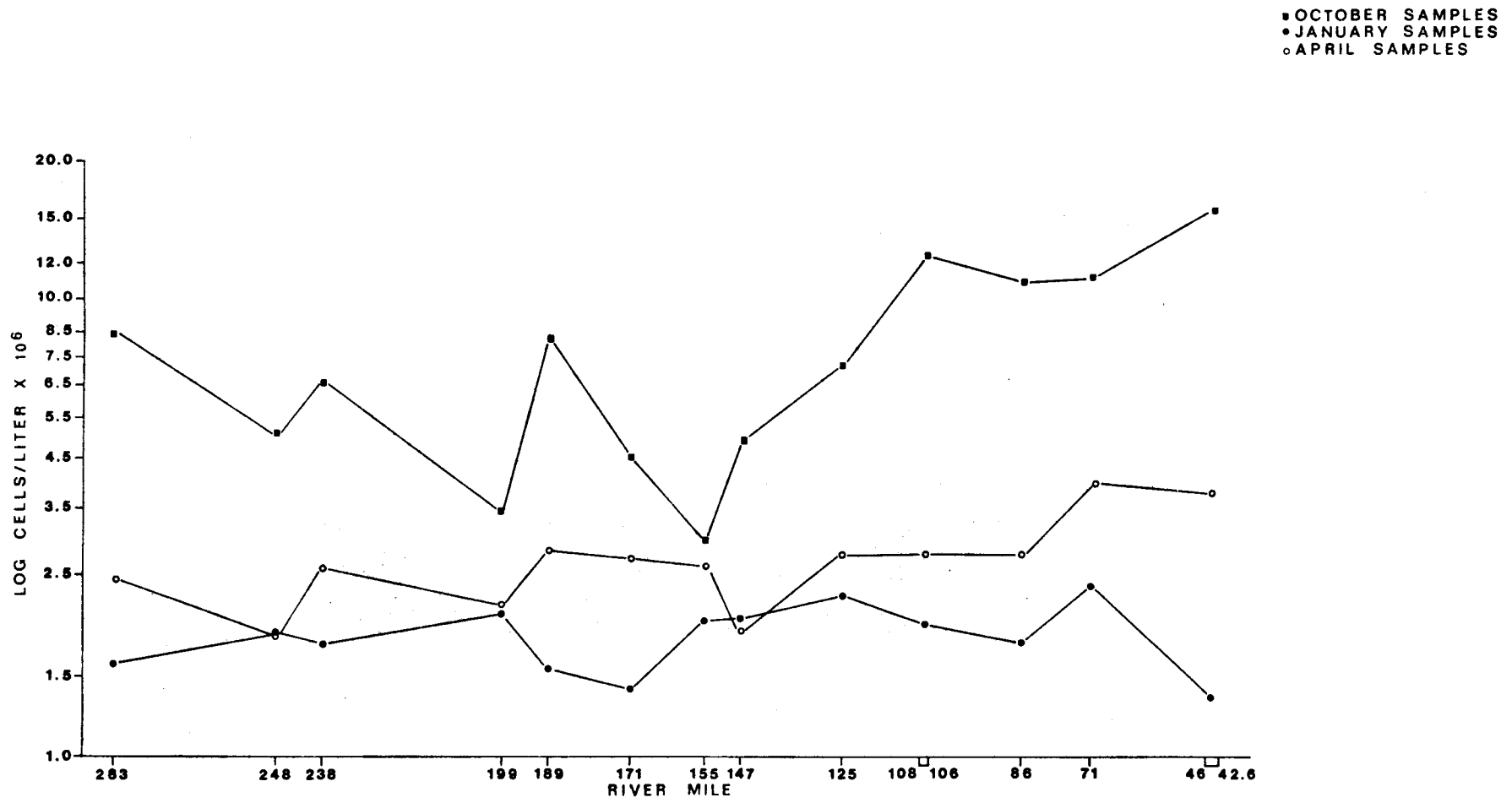
TABLE 3

MEAN NUMBER OF CELLS PER LITER AT EACH RIVER MILE

RIVER MILE	OCTOBER	JANUARY	APRIL
283	8,463,593	1,594,346	2,441,497
248	4,964,147	1,857,596	1,831,865
238	6,666,367	1,753,682	2,557,287
199	3,419,284	2,059,487	2,125,795
189	8,350,772	1,551,791	2,833,403
171	4,562,344	1,395,424	2,717,613
155	2,942,266	1,975,366	2,617,657
147	4,924,560	2,005,716	1,896,193
125	7,165,156	2,252,472	2,754,230
108	12,402,450	1,943,697	2,767,756
86	10,930,822	1,781,392	2,770,065
71	11,018,902	2,361,331	4,031,885
45	15,673,175	1,358,608	3,763,884

FIGURE 3

ACTUAL ABUNDANCE OF COMBINED
SAMPLES AT EACH STATION BY RIVER MILE



TEMPORAL AND SPATIAL DISTRIBUTION OF MAJOR TAXA

Examination of the data revealed that October had the greatest phytoplankton cell numbers with the mean number of 7.8×10^6 cells per liter (c/l) for the entire reach. The blue-greens, mainly *Microcystis incerta* along with *Merismopedia* spp. and *Oscillatoria* spp., were responsible for this great abundance. The lowest abundance for the three sampling periods was recorded for the winter samples (January) with a mean number of 1.83×10^6 c/l. Although the major taxa decreased in abundance during the winter season, these low numbers were attributed to a 95% decrease in the blue-greens. The euglenoids and dinoflagellates increased slightly, but were insignificant in their contribution to the total cell numbers. The abundance of the spring phytoplankton (April) resulted from greater than a 100% increase in the diatoms along with lesser increases in the other taxa excluding cryptomonads and dinoflagellates.

Examination of the data (Table 4) summarized from Table 3 reveals the degree of stability of the total phytoplankton community along the entire study reach during each period of collection. The phytoplankton showed the greatest range and instability during the October sample with the total number of cells deviating approximately 49% from the mean. This autumnal community contained ca. 7.8×10^6 mean c/l with a range from 2.9 to 15.7×10^6 c/l. The January cell numbers with a 16.7% deviation from the mean of

TABLE 4

DATA SUMMARY

NUMBER OF CELLS PER LITER BY COLLECTION PERIOD

COLLECTION PERIOD	MINIMUM	MAXIMUM	DIFFERENCE	MEAN	% STD. DEV.
October	2,942,266	15,613,175	12,730,909	7,806,449	48.9%
January	1,358,608	2,361,331	1,002,725	1,837,762	16.7%
April	1,831,865	4,031,885	1,200,020	2,700,702	23.3%

1.8 x 10^6 c/l and a range of 1.3 to 2.4 x 10^6 c/l, was the most stable of the three populations. When compared with October and January samples, the total cell numbers during April showed a slightly lesser degree of stability throughout the study reach than January but greater stability than October. The spring collections contained a mean of 2.7 x 10^6 c/l with a 23.3% deviation and a range of 1.8 to 4.0 x 10^6 c/l. The observed variances from season to season are probably associated with cyclical physico-chemical parameters.

Turbidity readings (NTU's - Nephelometric Turbidity Units) and temperature data for each sampling period are shown in Figures 16 and 17 of Volume I and listed in the Appendix of Volume I. Samples taken during the October period possibly refect the influence of turbidity on the phytoplankton (Figure 3). The high turbidities are attributed to the flooding during October which caused the resuspension of organic and inorganic material. The most dramatic decreases in phytoplankton abundance (between RM 238 and RM 125) may be due to increased turbidities within this same zone of reference. Because of the short generation of the phytoplankton, the nutrients available from runoff and resuspended sediments, and the relatively long duration of the flood it would be anticipated that the phytoplankton population would recover from the effects of dilution. The most probable cause of decreased abundances is the attenuation of light input due to increased turbidity.

Upstream and downstream from this high turbidity zone, increases in the phytoplankton population occurred. Except during periods of high turbidity, adequate light and temperature provided favorable conditions for phytoplankton growth. The large number of cells at RM 45 could possibly be due to increases in nutrients from the Mud Lake Bend area (Figure 15, Volume I).

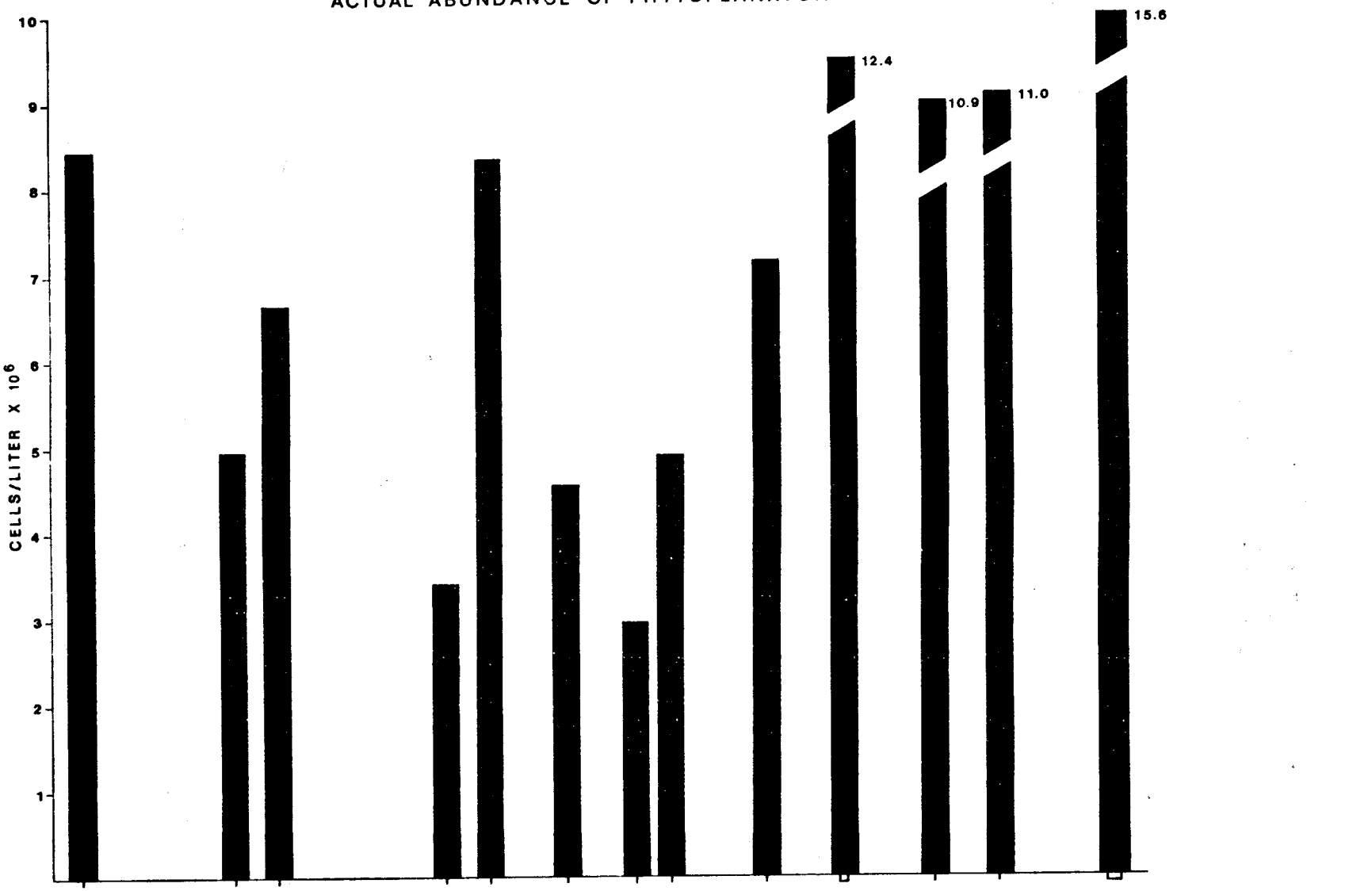
With the onset of winter the decrease in temperature and reduction of illumination contributed to the decreased abundance. The turbidity of the river during January was low (approximately 15 NTU's) and relatively stable downstream except for an increase at RM 45. This increase in turbidity was associated with a reduction in phytoplankton abundance at RM 45.

During April increased illumination and warmer temperatures provided for an increase in the number of cells in the phytoplankton community. The turbidity remained at approximately 11 NTU's throughout the study reach, thus permitting greater efficiency in the utilization of light in the growth, reproduction and photosynthetic processes of the phytoplankton during this sampling period.

The seasonal and biogeographical distributions of the phytoplankton during each sampling period are illustrated according to actual abundance (mean number of c/l) and relative abundance (percent composition of cell numbers for each taxon) in Figures 4, 5, and 6. In order to assess the size and taxonomic structure of the phytoplankton standing crop, the actual and relative abundance

Figure 4

ACTUAL ABUNDANCE OF PHYTOPLANKTON BY RIVER MILE



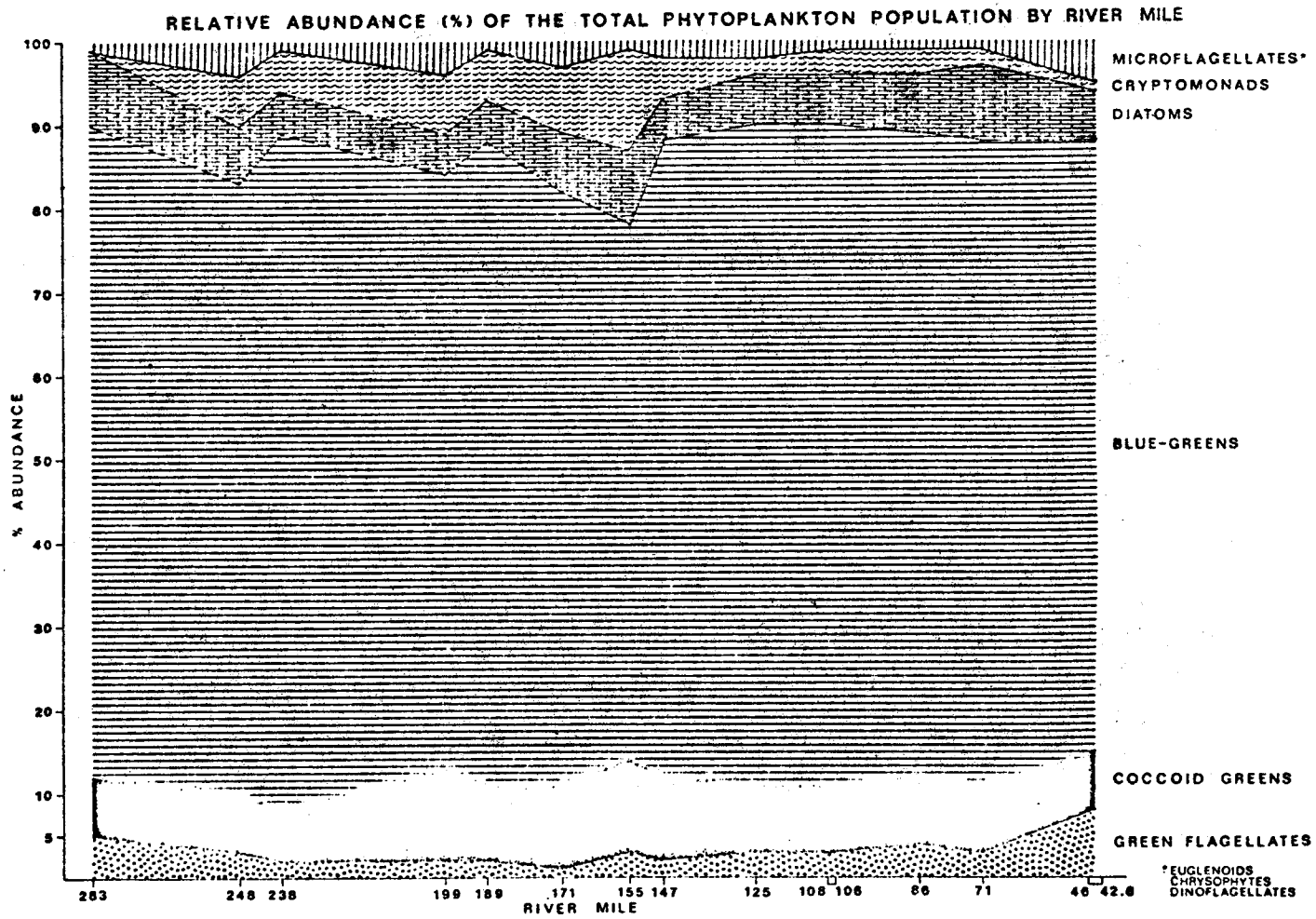
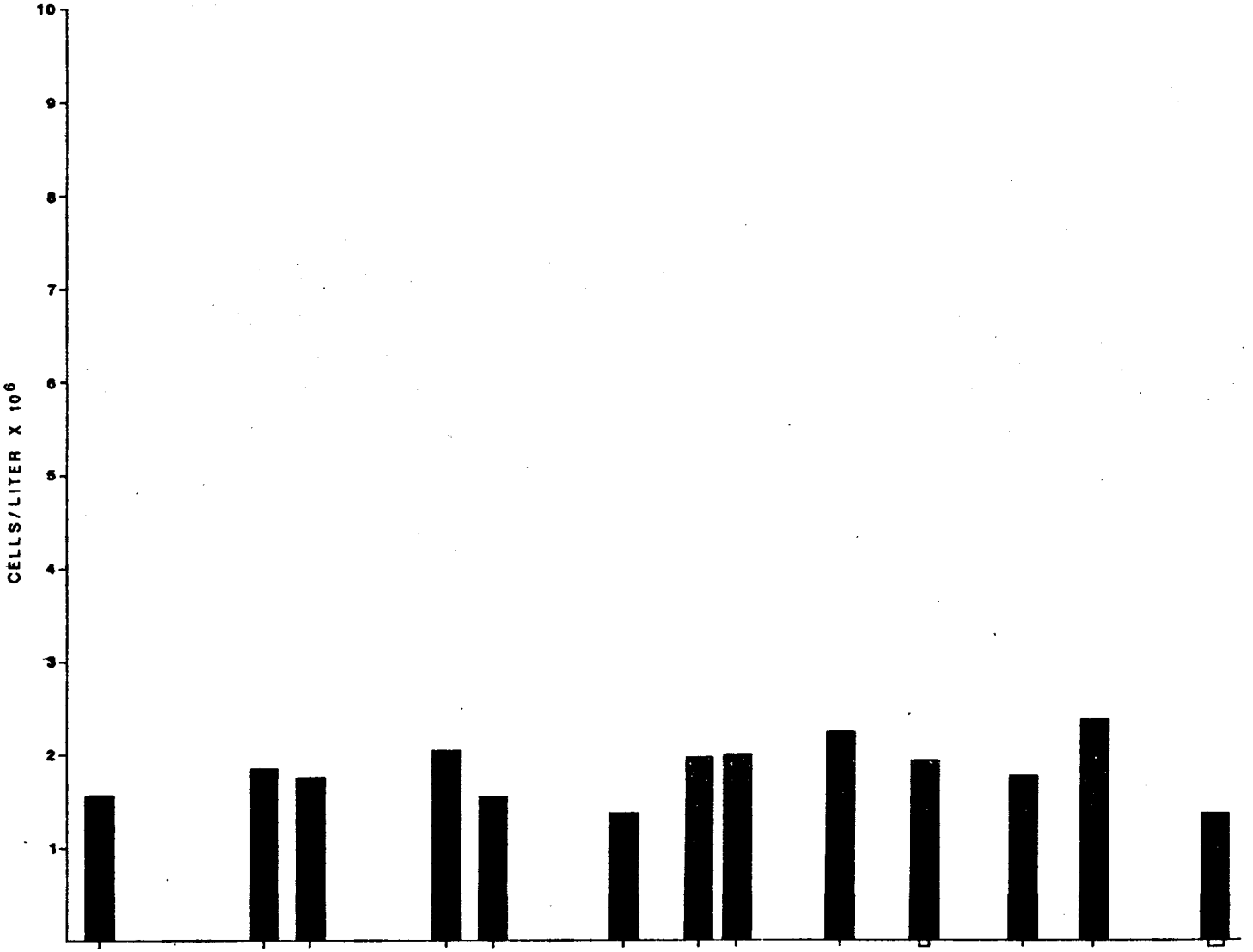

RELATIVE ABUNDANCE (%) OF THE TOTAL PHYTOPLANKTON POPULATION BY RIVER MILE
% ABUNDANCE
100
90
80
70
60
50
40
30
20
10
5
MICROFLAGELLATES*
CRYPTOMONADS
DIATOMS
BLUE-GREENS
COCCOID GREENS
GREEN FLAGELLATES
*EUGLENOIDS
CHRYSOPHYTES
DINOFLAGELLATES
283
248 238
199 189
171
155 147
125
108 106
86
71
46 42.8
RIVER MILE

Figure 5

ACTUAL ABUNDANCE OF PHYTOPLANKTON BY RIVER MILE JANUARY SAMPLES



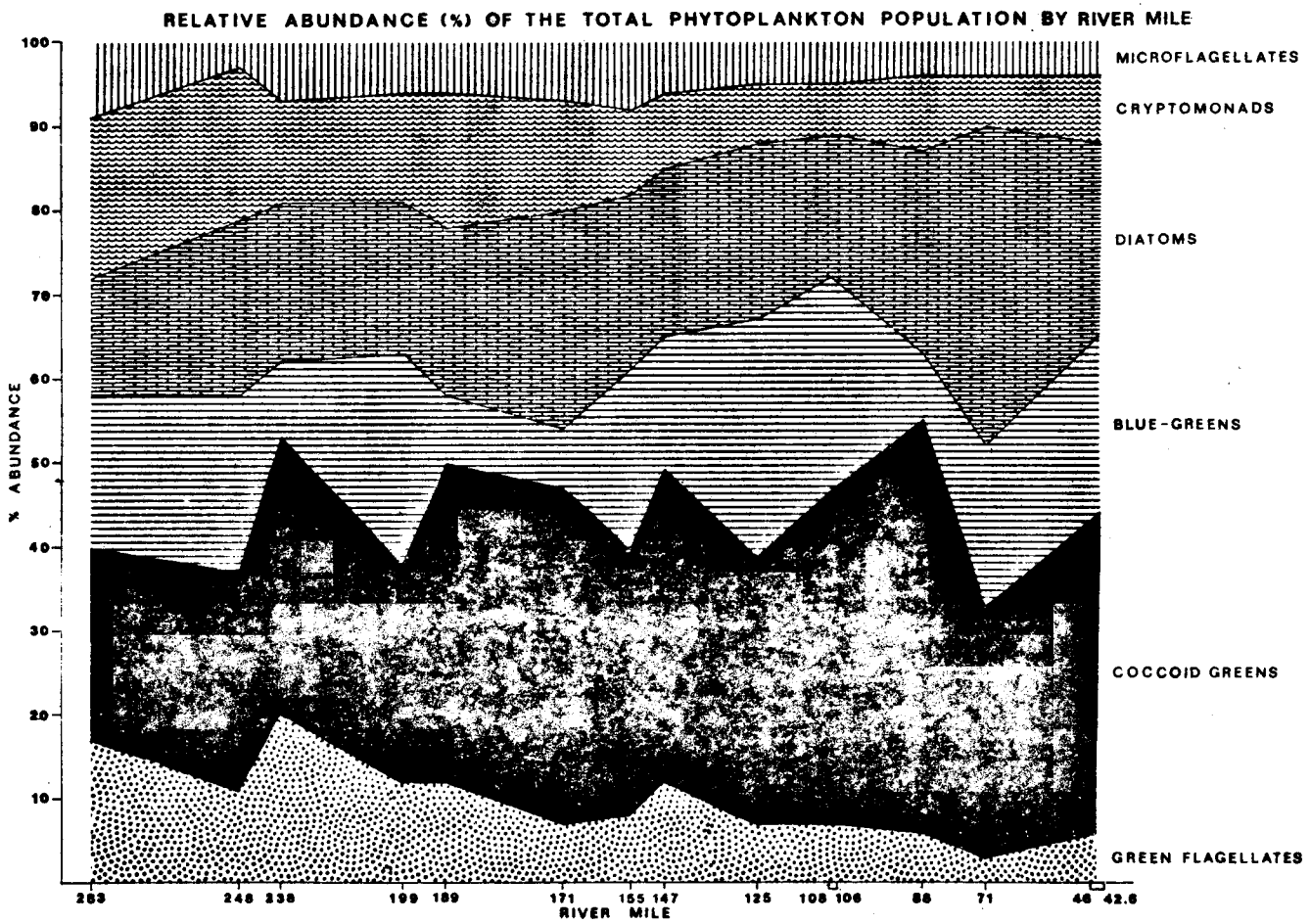
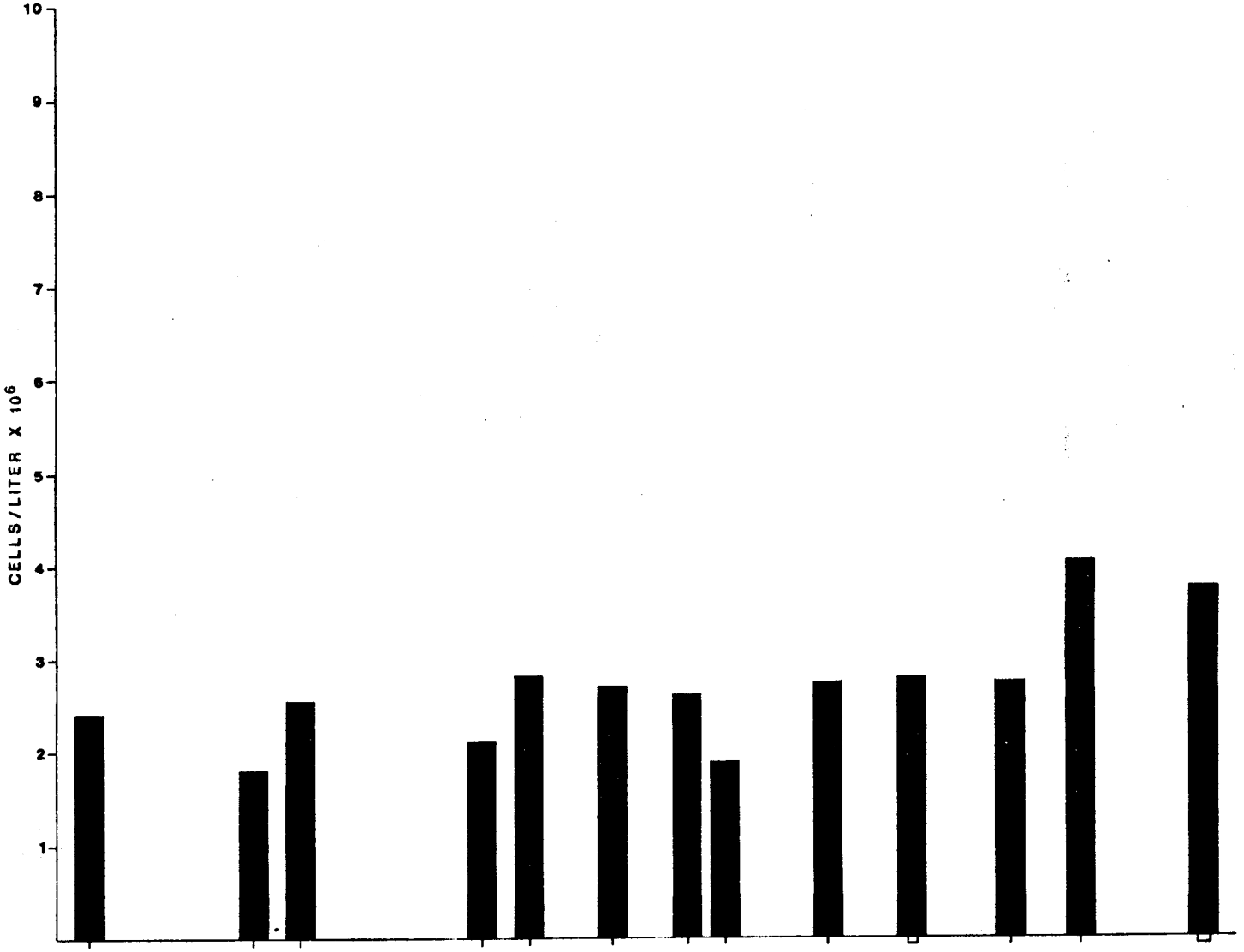
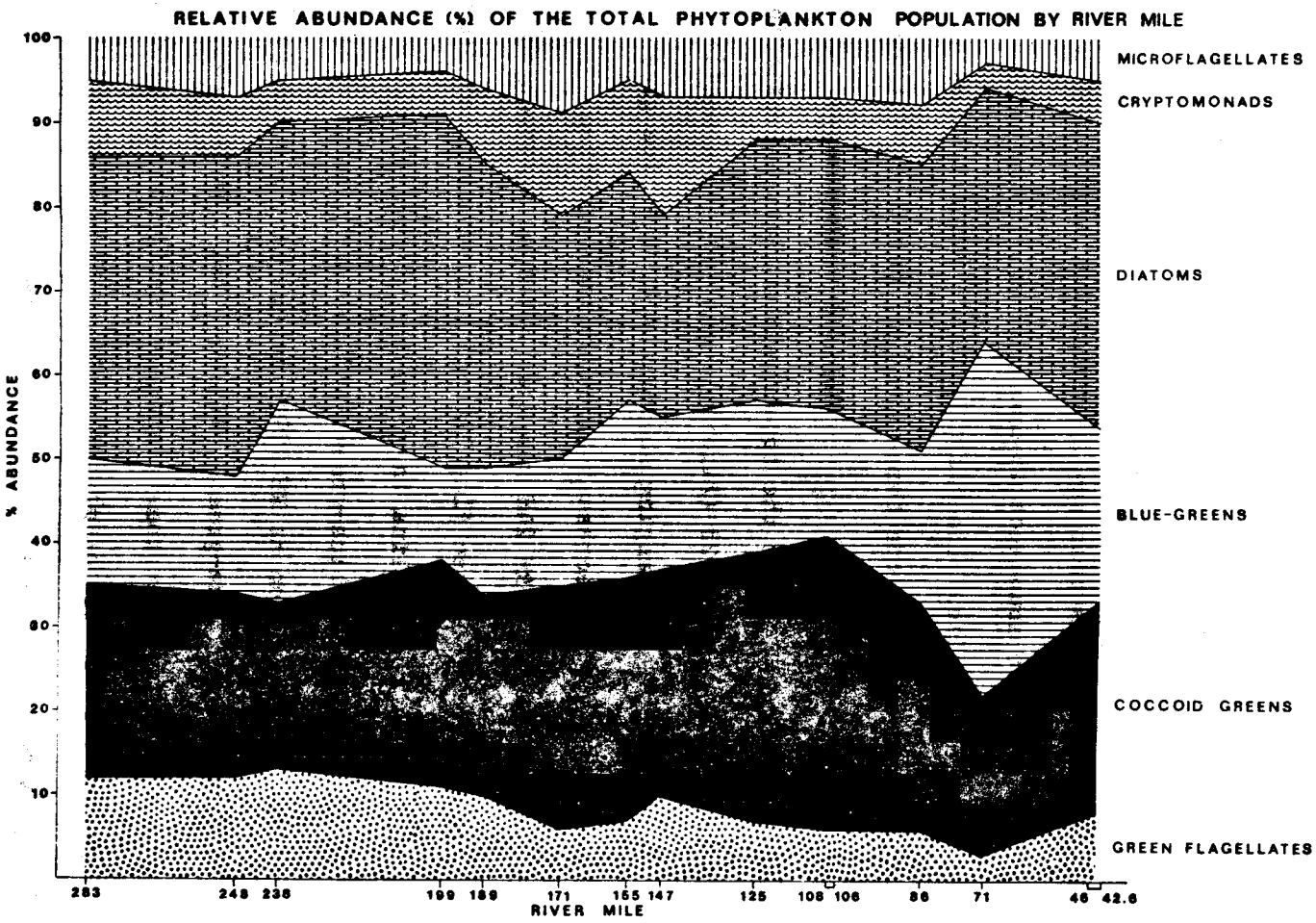

RELATIVE ABUNDANCE (%) OF THE TOTAL PHYTOPLANKTON POPULATION BY RIVER MILE
% ABUNDANCE
100
90
80
70
60
50
40
30
20
10
MICROFLAGELLATES
CRYPTOMONADS
DIATOMS
BLUE-GREENS
COCCOID GREENS
GREEN FLAGELLATES
263
248 238
199 189
171
155 147
125
108 106
88
71
46 42.6
RIVER MILE

Figure 6

ACTUAL ABUNDANCE OF PHYTOPLANKTON BY RIVER MILE

APRIL SAMPLES




RELATIVE ABUNDANCE (%) OF THE TOTAL PHYTOPLANKTON POPULATION BY RIVER MILE
% ABUNDANCE
100
90
80
70
60
50
40
30
20
10
MICROFLAGELLATES
CRYPTOMONADS
DIATOMS
BLUE-GREENS
COCCOID GREENS
GREEN FLAGELLATES
283
248
238
199
189
171
155
147
125
108
106
86
71
46
42.6
RIVER MILE

data (Table 3, and Appendix Tables 1 and 2) of the total cell numbers from each sampling period were analyzed concurrently. The relative abundance graphs depict the structure of the phytoplankton community as being dynamic with shifts occurring in the percent composition of the phytoplankton both in the temporal and spatial distributions. Comparison of the actual and relative abundances of the total cell numbers shows that the importance of each taxon as indicated by its relative abundance is independent of the changes in the total number of cells. The distributional pattern of each major taxon by river mile for the three sampling periods is illustrated in Figures 7, 8, and 9.

A noticeable fluctuation in the total cell numbers occurred in October between RM 283 and RM 125 (Figures 3 and 4). This oscillating pattern reflected the changing abundances of the blue-green assemblage, although slight decreases in other taxa occurred (Figure 7). The decrease at RM 248 was attributed to a reduction in four of the major taxa (green flagellates, blue-greens, coccoid greens, and diatoms). The decline in green flagellates at RM 238 was offset by an increase in blue-greens and coccoid greens. The reduction of the phytoplankton at RM 199 resulted from a decrease in the green flagellates, blue-greens, diatoms, and cryptomonads. This station exhibited greater than average variation between collecting sites. The abundance of phytoplankton varied by a factor of two with a range from a minimun of 2.3×10^6 c/l at site four

Figure 7

ACTUAL ABUNDANCE OF EACH TAXON BY RIVER MILE

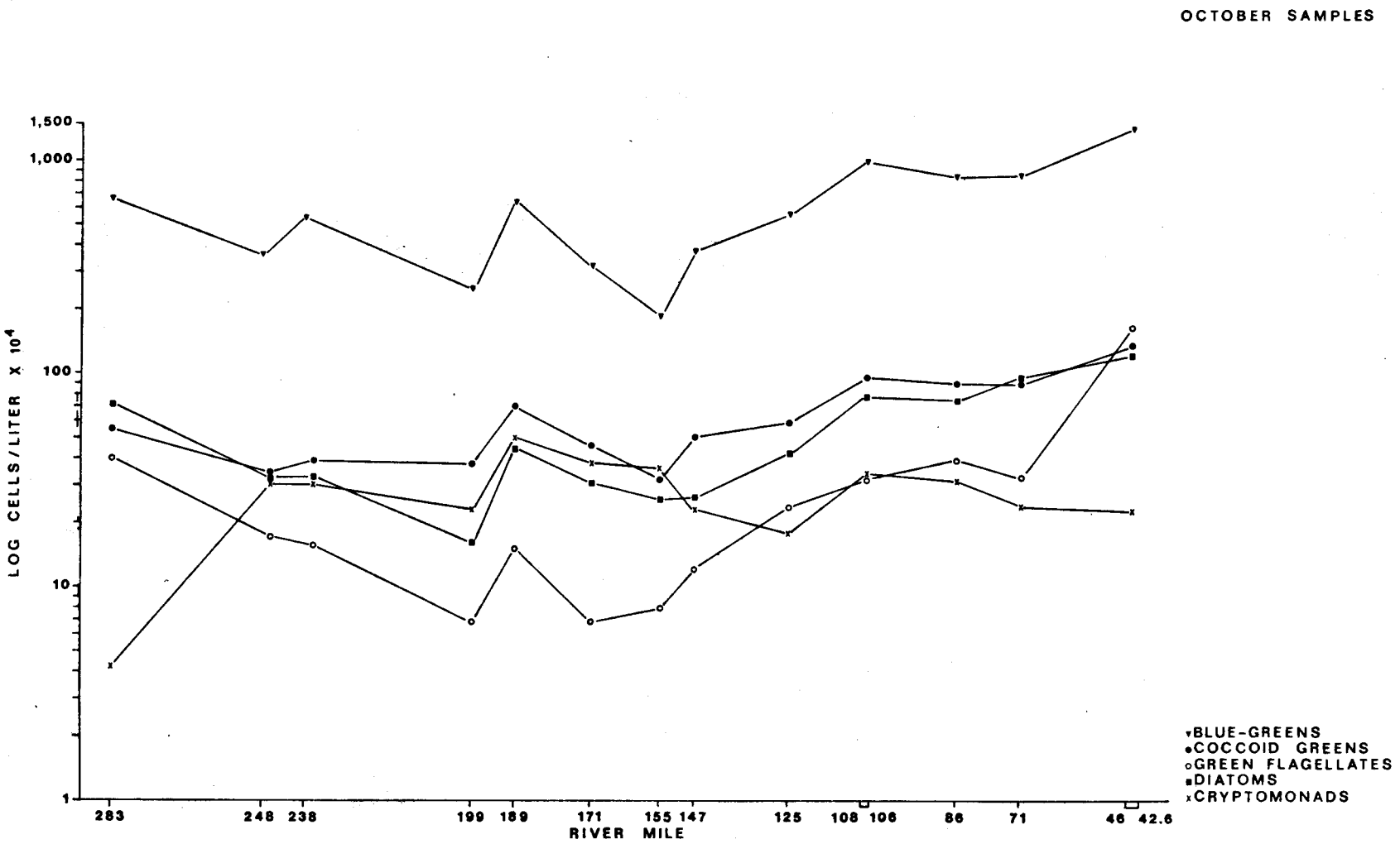


Figure 8

ACTUAL ABUNDANCE OF EACH TAXON BY RIVER MILE

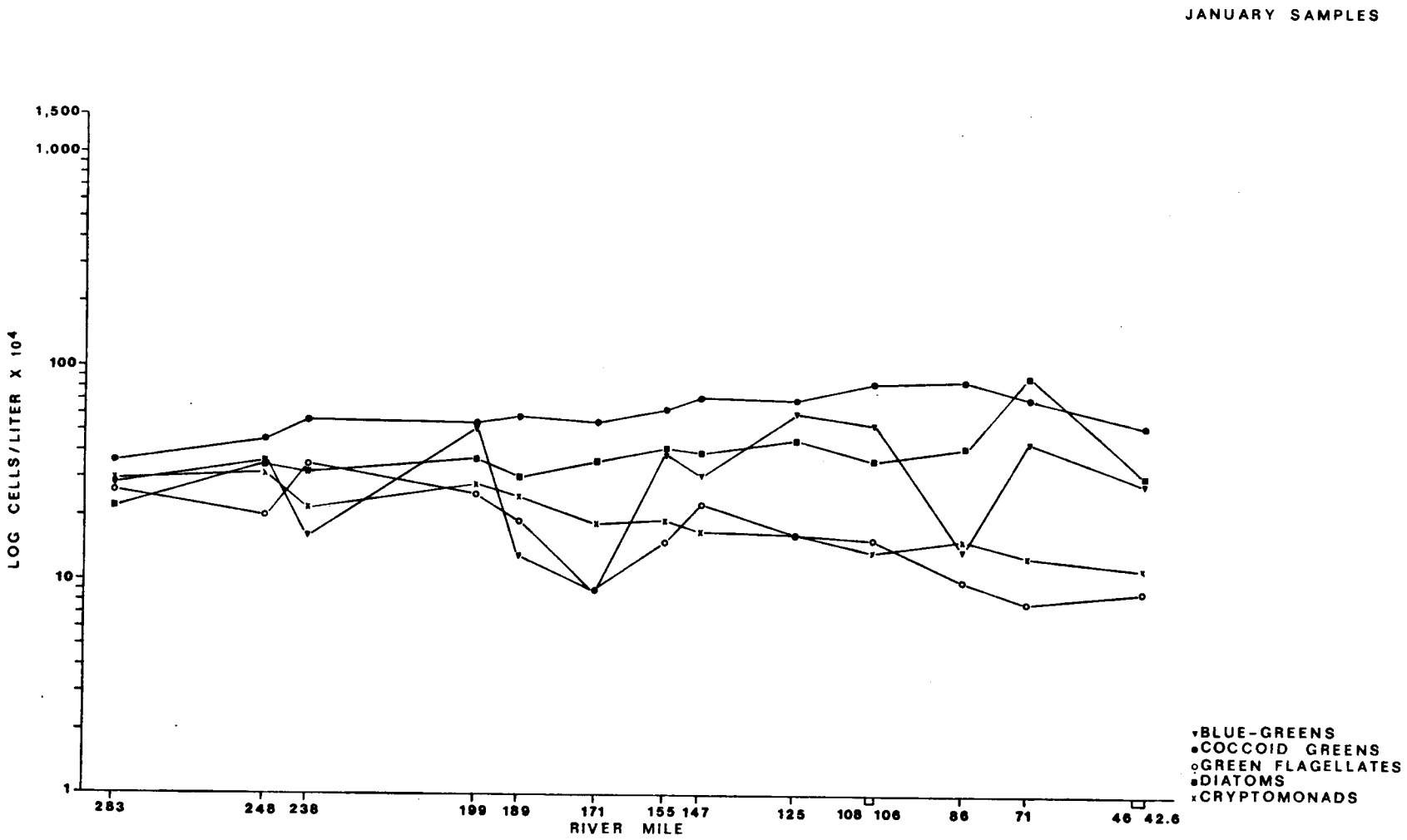
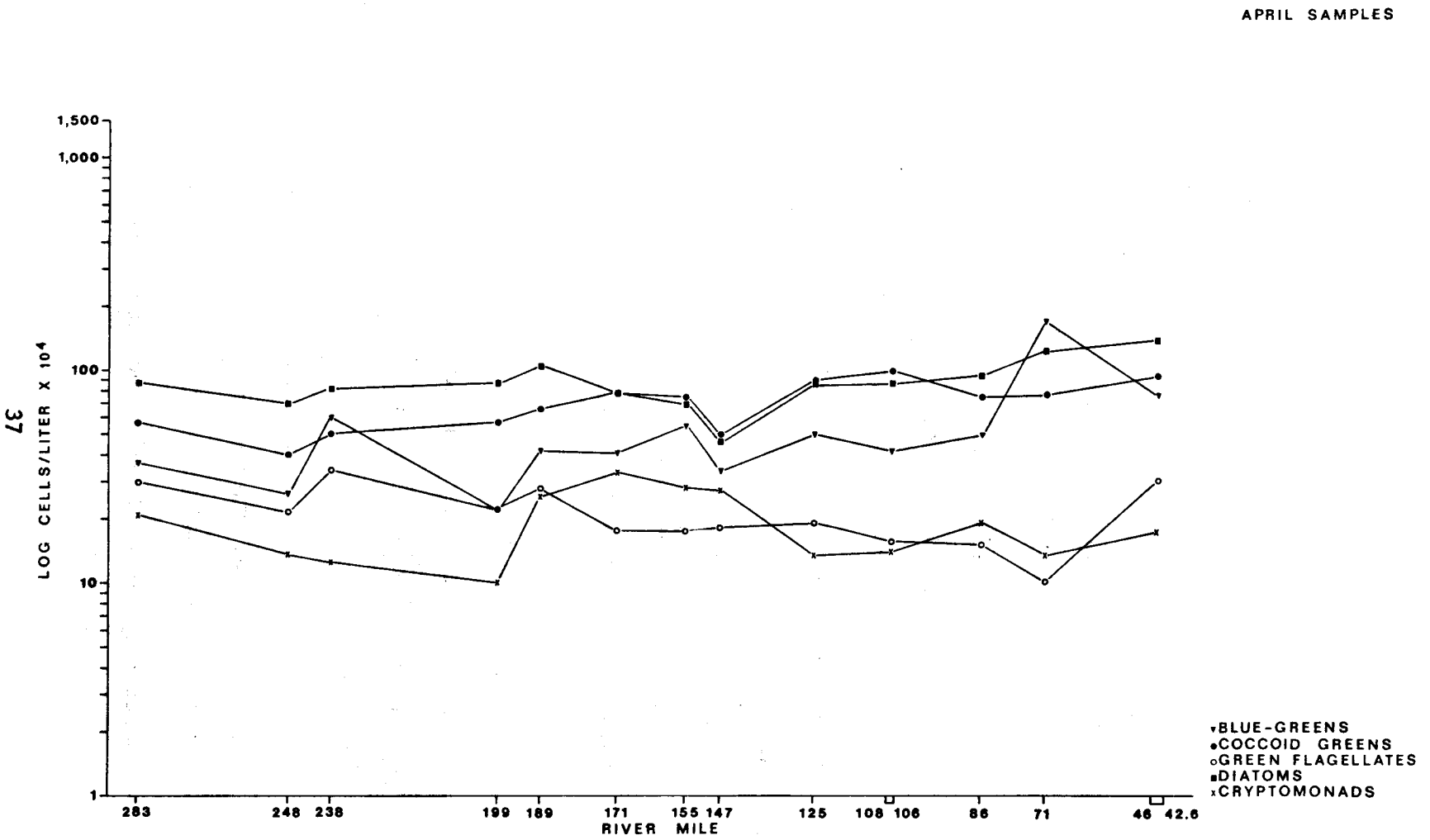


Figure 9

ACTUAL ABUNDANCE OF EACH TAXON BY RIVER MILE



to a maximum of 4.2 x 10^6 c/l at site two. The peak at RM 189 was due to an increase in the total cell numbers. The phytoplankton obtained the highest abundance at site two with 11.5 x 10^6 c/l. The gradual decrease in the population at RM 155 was due to an approximately 43% decline in the blue-greens along with lesser decreases in coccoid greens, diatoms, and cryptomonads. The lowest abundance was at site three with 1.8 x 10^6 c/l. Site one had the greatest abundance with 4.2 x 10^6 c/l. The cell numbers gradually increased downstream reaching the mean maximum peak at RM 45 with 15.6 x 10^6 c/l. This peak resulted from elevated cell numbers at site eight (40.4 x 10^6 c/l) and site nine (36.4 x 10^6 c/l). The increased number of cells at these two sites was attributed to increases in the eight major taxa, excluding diatoms and cryptomonads.

The January phytoplankton indicated at 75% reduction in abundance from the previous October sample (Figure 3). As mentioned earlier, this decrease was mainly due to a decrease in the abundance of blue-green algal cells and the absence of certain species (Figure 5). The total cell numbers during this sampling period ranged from a minimum of 1.35 x 10^6 c/l to a maximum of 2.36 x 10^6 c/l. The number of cells per liter deviated slightly (16.7%) from the mean, thus indicating that the phytoplankton throughout the study reach was relatively stable. The peak at RM 248 was attributed to increases in all the major taxa, excluding the green flagellates which decreased (Figure 8). A major decline in green flagellates, blue-greens,

cryptomonads, and dinoflagellates resulted in reduced total abundances from RM 199 to RM 171. The population from RM 155 to RM 86 was relatively stable. Although the coccoid greens increased along this reach, they were offset by decreases in the green flagellates and blue-greens. The greatest abundance for January was attained at RM 71 (2.3×10^6 c/l) with the highest cell numbers occurring at site four with 2.4×10^6 c/l. The diatoms at RM 71 increased by a factor greater than two over their previous population, while the blue-greens increased approximately by a factor of three over their previous abundance. The other taxa exhibited a general decrease in abundance at this station. The lowest abundance occurred at RM 45 (1.3×10^6 c/l). The abundance of 0.34×10^6 c/l occurred at site eight and ranged to a high of 1.8×10^6 c/l at site two. The variation was the result of significant changes in population sizes of certain taxa. The increase of the green flagellates was offset by major reductions in the diatoms and blue-greens, but not always in synchrony. The resultant modifications in community structure produced differences in the standing crop.

The total phytoplankton cell numbers during April increased 47% over the January sample (Figure 3). The abundance of the total phytoplankton ranged from a low of 1.83×10^6 c/l to a high of 4.03×10^6 c/l. The phytoplankton showed a greater degree of instability along the study reach in comparison to the January sample. The distributional pattern of phytoplankton for April was very similar

to that of October with the main differences occurring from RM 189 to RM 147 (Figures 6 and 9). In contrast to the sharp decline in cell numbers in this reach of the river during October, April was more stable, but exhibited a slight decrease in coccoid greens, blue-greens and diatoms at RM 147. The total population was rather stable from RM 108 to RM 86. The highest peak of abundance for this period (4.03×10^6 c/l) was reached at RM 71. This peak was due to increases in blue-greens and diatoms. The greatest concentration of cells at RM 71 occurred at site one with 6.95×10^6 c/l, and the lowest at site three with 2.28×10^6 c/l. The diatoms, constituting 33% of the total cell numbers during April, were most abundant at RM 45 with 1.37×10^6 c/l. The total number of cells ranged from 1.76×10^6 c/l at site five to 5.92×10^6 c/l at site eight.

The seasonal and biogeographical aspects of the phytoplankton community during each sampling period can be summarized as follows:

1) October had the greatest abundance of phytoplankton of the three sampling periods. The total cell numbers were very unstable throughout the study reach, probably due to flooding conditions during this sampling period. Light and temperature were considered to be the major limiting factors during October. The resuspension of sediments contributed to the decrease in depth of light penetration which influenced algal growth and development. The phytoplankton community was dominated by blue-greens with coccoid greens and

diatoms being subdominant. Each taxon followed a trend of increasing abundances with the downstream stations. The major fluctuating patterns in the total abundances and distributional patterns along the study reach usually resulted when at least four of the five major taxa increased or decreased simultaneously. These regions of maximum change in the total cell numbers could possibly be attributed to the fluctuation in turbidities and/or chemical or nutrient inputs. There appear to be three distinct zones showing major differences in the abundances of the standing crop of phytoplankton. The first zone occurred from RM 283 to 238 where the majority of the taxa decreased in abundance; zone two from RM 238 to 147 where the major fluctuations were prevalent; and zone three from RM 147 to 45 where all the taxa increased in abundance.

2) A reduction in temperature and light contributed to the low abundance of phytoplankton during January. The cell numbers were relatively stable along the study reach during this period. With the decrease in blue-greens, the coccoid greens became the most important taxon in January. Except for the blue-greens, all the taxa increased in relative abundance. The number of cells per liter as a whole increased gradually downstream, although the green flagellates and cryptomonads decreased. Coccoid greens and diatoms had a relatively stable increase downstream. Blue-greens had an erratic distributional pattern along the reach. Two regions showed major changes in total abundances. The decline in abundance

from RM 199 to 171 was attributed to decreases in cryptomonads, green flagellates, and blue-greens. RM 86 to RM 45 was characterized by a peak abundance at RM 71 followed by a major decline at RM 45. The fluctuating pattern in this region was attributed to major shifts in abundance of the blue-greens and diatoms.

3) An increase in the total cell numbers occurred during April along with increases in temperature and illumination. The total cell numbers remained relatively stable along the study reach. As with the other two sampling periods, the cell numbers increased at the downstream stations. The diatoms dominated the phytoplankton community during April while coccoid greens and blue-greens were subdominant. Generally, the major peaks of abundance along the reach were due to increases in at least four of the five major taxa. The maximum peak at RM 71 was due to an increase mainly in the blue-greens along with slight increases in diatoms and coccoid greens. Varying abundances in the blue-greens, green flagellates, and cryptomonads contributed to the erratic fluctuations of the total cell numbers along the study reach. The decline in abundance at RM 147 resulted mainly from decreases in the coccoid greens, diatoms, and blue-greens.

TEMPORAL AND SPATIAL DISTRIBUTION OF SELECTED GENERA

Distinct taxonomic transitions, not only among the taxa, but also among the genera of certain taxa, occurred during the sampling periods. The blue-greens dominated the phytoplankton throughout the study reach in October (Figure 7). In January coccoid greens were most abundant of the taxa (Figure 8). The degree of dominance usually varied at each river mile sampled. The coccoid greens held dominance through the study reach except at RM 71 where the diatoms predominated. Even though the diatoms were the most abundant of the taxa in April, from RM 155 to RM 108, the coccoid greens dominated the cell numbers (Figure 9). Variations in the abundances of each genus within the various taxa formed the essence of the community structure of the phytoplankton. Therefore, selected examples from each of the major taxa were studied to determine the role of these most important genera on the temporal and spatial distributions of the phytoplankton.

The cyanophycean (blue-green) assemblage constituting 76% of the total population in October, decreased to 18% in January with a slight increase to 20% in April (Figure 2, Table 2). During October 38.3×10^6 c/l were recorded for the blue-greens at RM 45, site 9. This was the greatest number of cells per liter for any taxon at any one site recorded for the entire study. The fluctuation in abundance of the blue-greens and their distribution along the river strongly influenced the size of the standing crop and the

structure of the phytoplankton community. The blue-green algae of consistant major importance were the genera *Microcystis*, *Merismopedia*, *Oscillatoria*, *Gomphosphearia*, and *Aphanothece*. The temporal and spatial distribution of each of these important genera is shown to illustrate their role in the blue-green assemblage. Of course, the generic level response is a more sensitive indicator than the reaction of the entire population.

In October the blue-green assemblage was dominated by *Microcystis* (almost exclusively *M. incerta*) (Figure 10, Table 5). The abundance of the population during this particular sampling period ranged from a minimum of 1.39×10^6 c/l to a maximum of 7.98×10^6 c/l. This wide range in abundances reflects the instability of the population throughout the reach during October. *Microcystis* displayed two major peaks of abundance in October. The first peak occurred at RM 238 with 7.16×10^6 c/l. The second peak at RM 45 consisted of 7.98×10^6 c/l. These regions of peak abundance were also maintained during the other two sampling periods.

Microcystis exhibited lesser importance to the blue-green assemblage during January. The cell numbers declined markedly by a factor of ca. 42 from the October samples. The lowest abundance for January was attained at RM 171 and RM 86 each with 0.02×10^6 c/l. The highest abundance of 0.25×10^6 c/l occurred at RM 199. Because of the differences in the minimum and maximum abundances, the cell numbers were considered rather unstable throughout the

Figure 10

ACTUAL ABUNDANCE OF MICROCYSTIS BY RIVER MILE

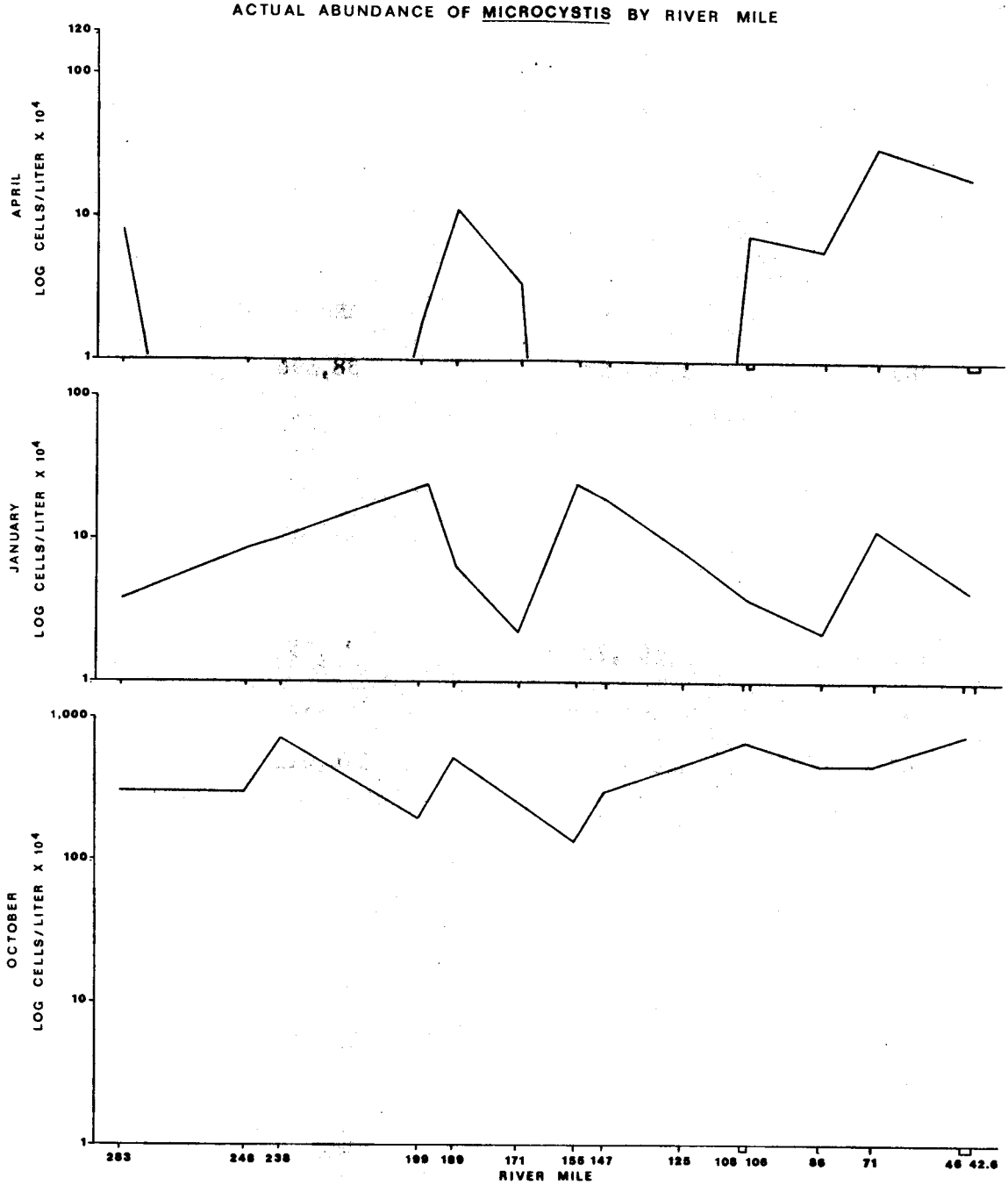


TABLE 5

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *MICROCYSTIS* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	3,045,521	38,596	80,162
248	3,005,605	87,090	--
238	7,165,156	102,924	--
199	1,991,200	247,415	18,803
189	5,239,273	66,307	117,769
171	2,605,781	23,751	35,627
155	1,389,486	245,436	--
147	3,085,107	196,612	--
125	4,736,524	85,110	--
108	6,963,265	40,246	79,832
86	4,860,232	23,751	63,337
71	4,788,976	122,718	334,505
45	7,980,198	45,524	206,641

reach during January. In contrast to the October sampling period, *Microcystis* dominated the blue-green assemblage only at RM 238-189, 155 and 147. During April *Microcystis* was of even less significance in the blue-green assemblage and cell numbers declined 29% from the January samples. *Microcystis* occurred intermittently throughout the study reach, being completely absent at five of the thirteen sampling stations and was never dominant during April. The greatest abundance occurred at RM 71 with 0.33×10^6 c/l.

Merismopedia spp. ranked second in dominance during October (Figure 11, Table 6). The abundances ranging from a low of 2.83×10^5 c/l at RM 248 to a high of 27.5×10^5 c/l at RM 86 illustrate the instability of *Merismopedia* during this period. The cell numbers showed peak concentrations along two regions of the river. The first peak occurred at RM 238 with 13.1×10^5 c/l. The second peak was attained downstream from RM 108 to RM 45. These regions of high cell concentrations did not persist throughout the January and April sampling periods, thus indicating seasonal influences on the population abundances. *Merismopedia* had intermittent spatial distributions in January and April. The abundance of the January sample ranged from 0 to 1.14×10^5 c/l. The importance of *Merismopedia* to the blue-green assemblage during January is illustrated by its dominance at RM 283 and RM 86. During April *Merismopedia* was found at only four stations. The overall cell numbers were reduced 74% from the January samples. Peak abundance

Figure 11

ACTUAL ABUNDANCE OF MERISMOPEDIA SPP. BY RIVER MILE

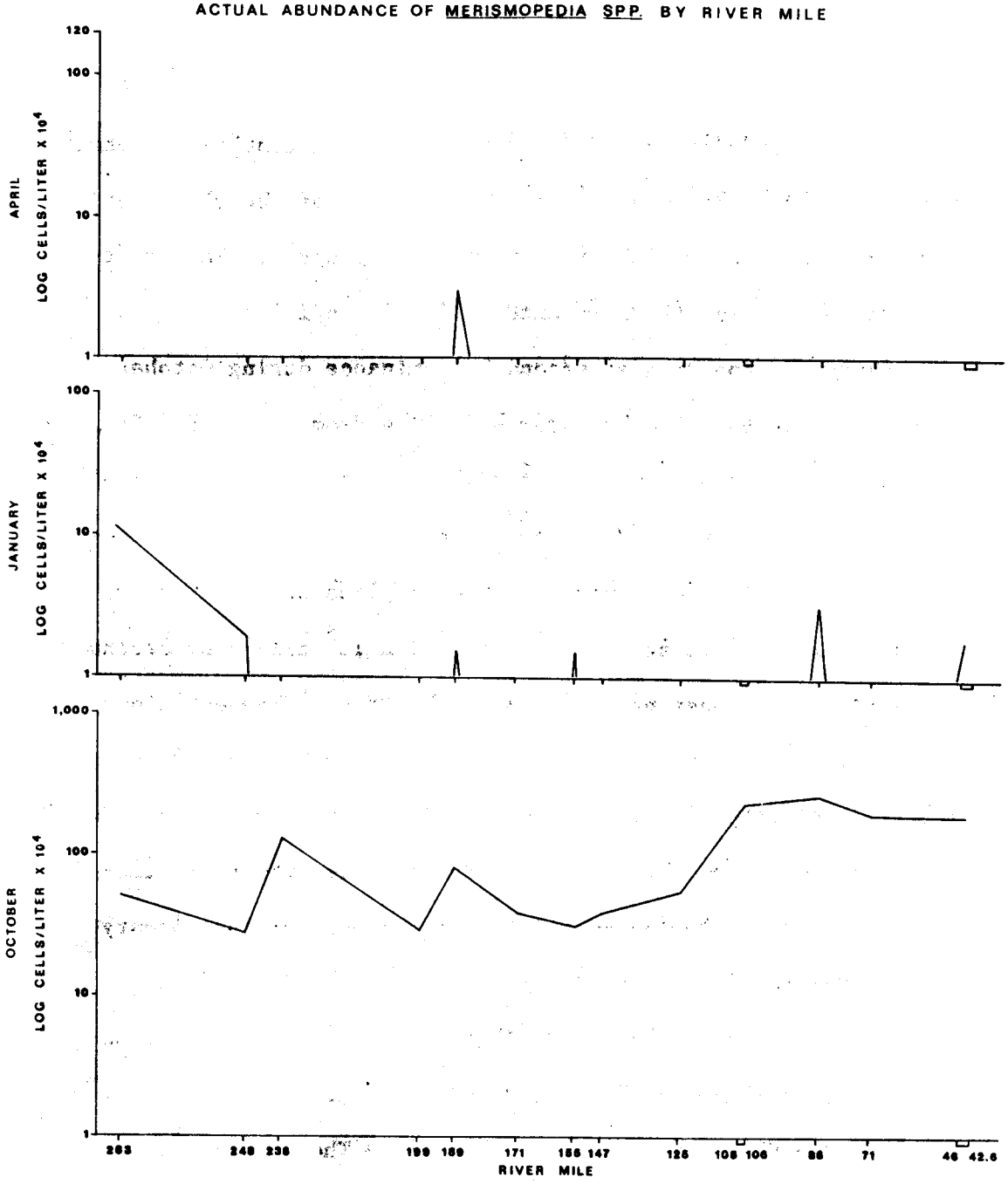


TABLE 6

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *MERISMOPEDIA* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	515,944	114,048	7,917
248	283,048	19,793	--
238	1,314,271	--	--
199	298,878	--	--
189	830,326	15,834	31,669
171	399,823	--	--
155	326,588	15,834	--
147	409,060	--	--
125	571,035	--	7,917
108	2,396,962	--	--
86	2,754,230	33,648	--
71	2,083,239	--	--
45	2,065,095	19,793	9,500

occurred at RM 189 with .31 x 10^5 c/l. *Merismopedia* never gained dominance during this period.

Oscillatoria, a filamentous blue-green, was subdominant during October at RM 283 (Figure 12, Table 7). The largest concentration of cells occurred during October when the abundance ranged from a minimum of 1.10 x 10^5 c/l at RM 238 to a maximum of 21.1 x 10^5 c/l at RM 283. *Oscillatoria* was relatively stable during October except for abundance peaks occurring at RM 283 and RM 71. The January cell numbers of *Oscillatoria* showed a reduction of 83% from the October samples. However, *Oscillatoria* gained greater importance in the blue-green assemblage during January exhibiting dominance at RM 248 and RM 171. The abundance ranged from 0 at RM 189 to 3.4 x 10^5 c/l at RM 248. During April three major peaks along the study reach were attributed to an increase in the cell numbers by a factor of two over the January samples. The first of these peaks occurred at RM 283 with 1.16 x 10^5 c/l. *Oscillatoria* was dominant in two other regions with peaks at RM 155 (2.38 x 10^5 c/l) and RM 71 (11.9 x 10^5 c/l). With a minimum of .15 x 10^5 c/l (RM 248) and a maximum of 11.9 x 10^5 c/l (RM 71), the *Oscillatoria* population demonstrated great instability throughout the reach during April.

Gomphosphaeria was present during each of the three collection periods, but did not contribute significantly to the blue-green assemblage until January and April (Figure 13, Table 8). During October the abundance of *Gomphosphaeria* ranged from 0 (RM 283 and

Figure 12

ACTUAL ABUNDANCE OF OSCILLATORIA SPP. BY RIVER MILE

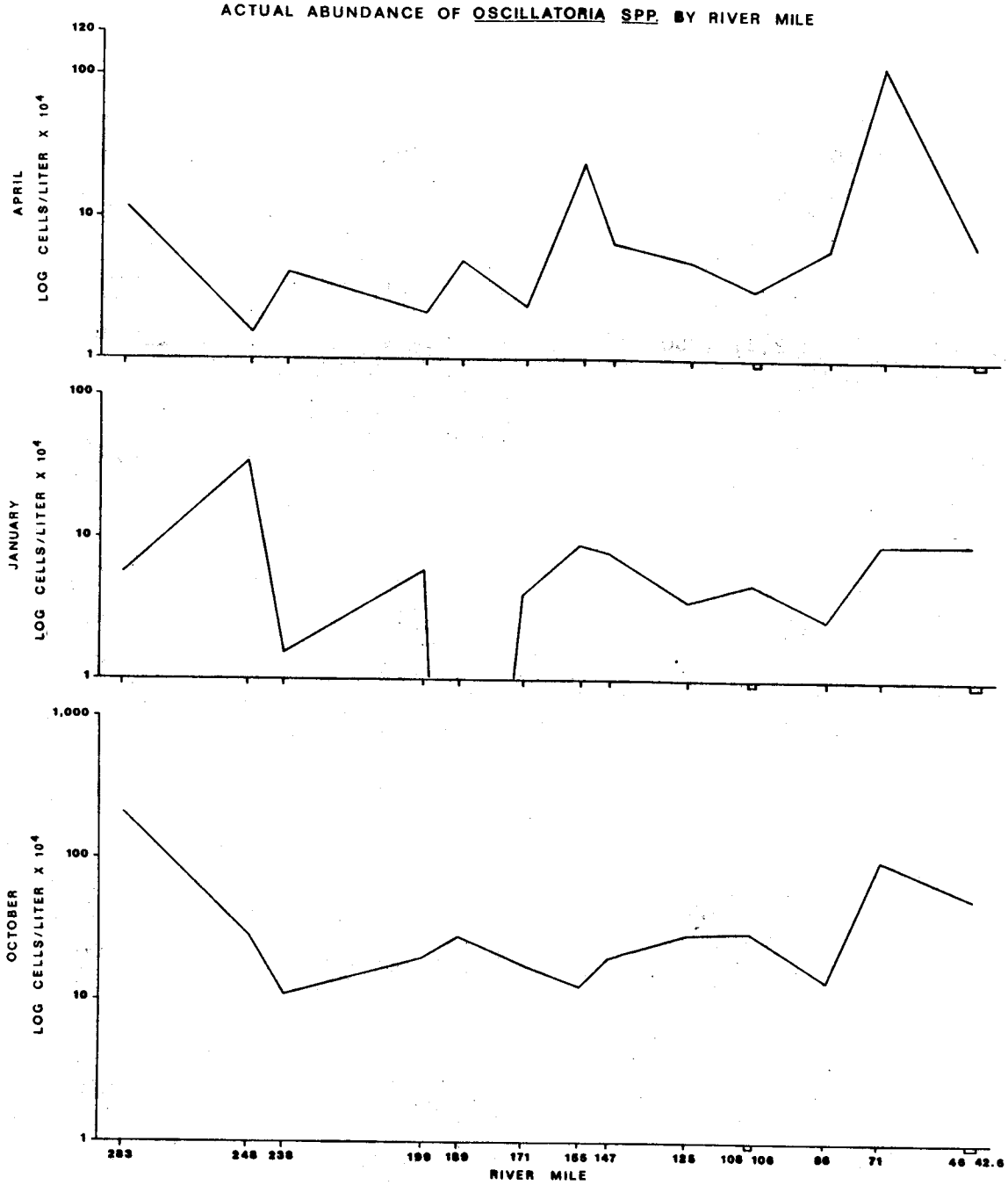


TABLE 7

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *OSCILLATORIA* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	2,111,280	56,410	116,780
248	295,909	340,443	15,834
238	110,842	15,834	42,225
199	201,891	59,379	22,762
189	283,043	--	49,483
171	181,108	39,586	24,741
155	130,635	89,069	238,508
147	208,488	79,173	67,297
125	295,909	36,617	50,472
108	306,135	47,503	32,988
86	142,511	26,720	62,348
71	1,005,497	90,059	1,195,512
45	540,135	90,653	64,525

Figure 13

ACTUAL ABUNDANCE OF GOMPHOSPHAERIA SPP. BY RIVER MILE

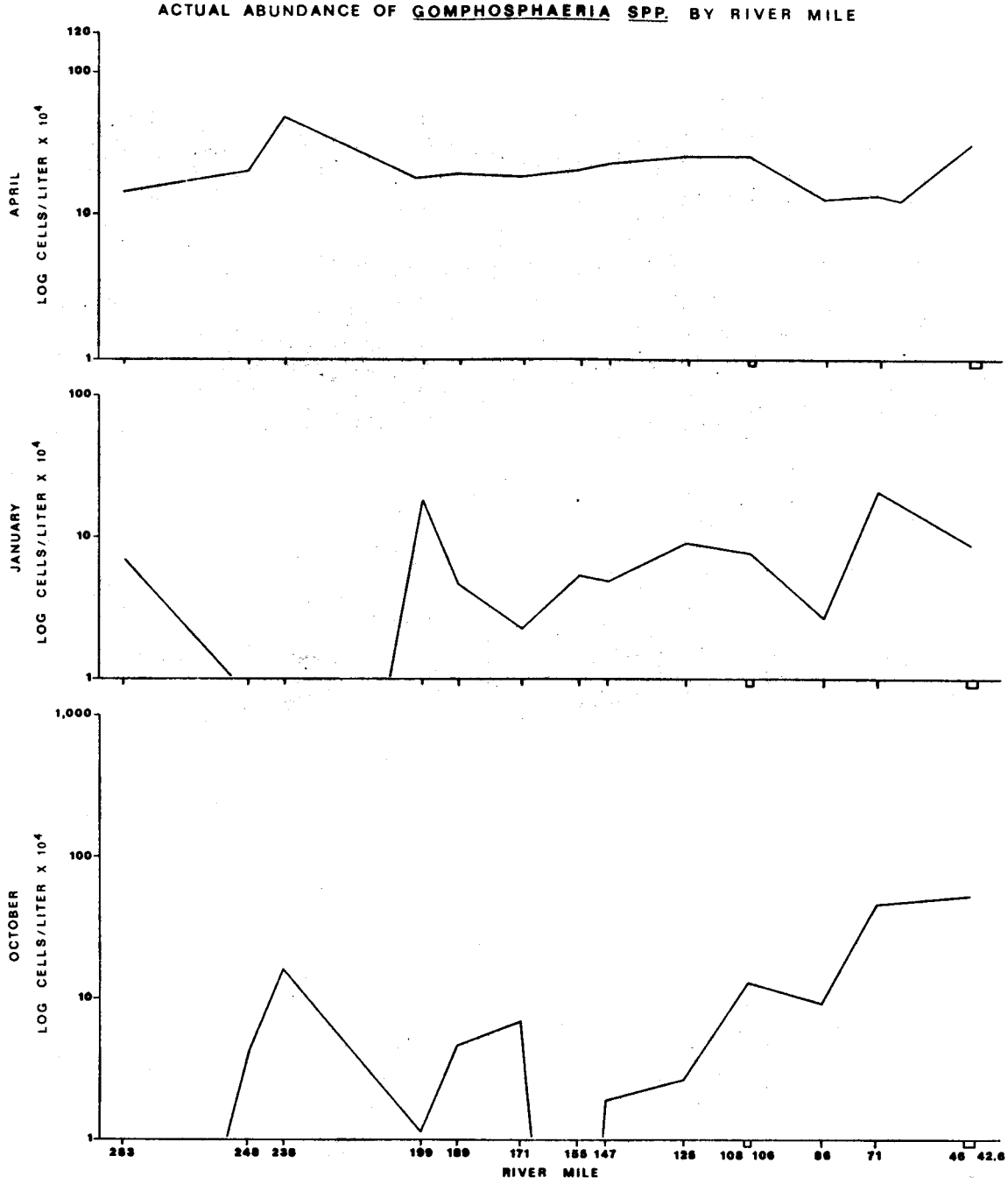


TABLE 8

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *GOMPHOSPHAERIA* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	--	69,276	143,501
248	39,586	7,917	203,870
238	158,346	--	482,955
199	11,875	184,077	183,087
189	47,503	48,493	198,922
171	69,276	23,751	187,046
155	--	55,421	207,829
147	19,793	50,142	229,601
125	27,710	95,007	266,219
108	134,594	81,152	268,528
86	97,976	28,700	135,583
71	487,903	221,684	143,501
45	563,887	95,403	321,442

155) to 5.6 x 10^5 c/l (RM 45). *Gomphosphaeria* never dominated the blue-greens at any particular station during October. The January cell numbers generally represented a 42% reduction from the October samples with an abundance ranging from 0 to only a maximum of 2.21 x 10^5 c/l at RM 71. *Gomphosphaeria* gained importance during January by becoming the dominant blue-green at RM 71 and 45. During April *Gomphosphaeria* increased by a factor of three over the January samples and dominated the blue-green assemblage along the study reach except at RM 155 and 71. The cell numbers were stable during this sampling period with abundances ranging from 1.35 x 10^5 c/l at RM 86 to 4.8 x 10^5 c/l at RM 238.

Aphanothece was generally of minor importance to the blue-green assemblage during this study (Figure 14, Table 9). Cell numbers ranged from 0 to 5.7 x 10^5 c/l during October and intermittent periods of complete absence occurred along the study reach. During January *Aphanothece* was absent at all the stations upstream of RM 125, but then gained importance by dominating the blue-green assemblage at RM 125 and 108. During April an abundance of .25 x 10^5 c/l was recorded for RM 283 but it did not reappear again in the study reach until RM 155. The greatest number of cells was attained at RM 125 with 1.1 x 10^5 c/l.

The predominant taxon of the January samples was composed of coccoid greens. These algae showed an increase in relative abundance from 8% in October to 34% in January (Table 2). The population

Figure 14

ACTUAL ABUNDANCE OF APHANOTHECE SPP. BY RIVER MILE

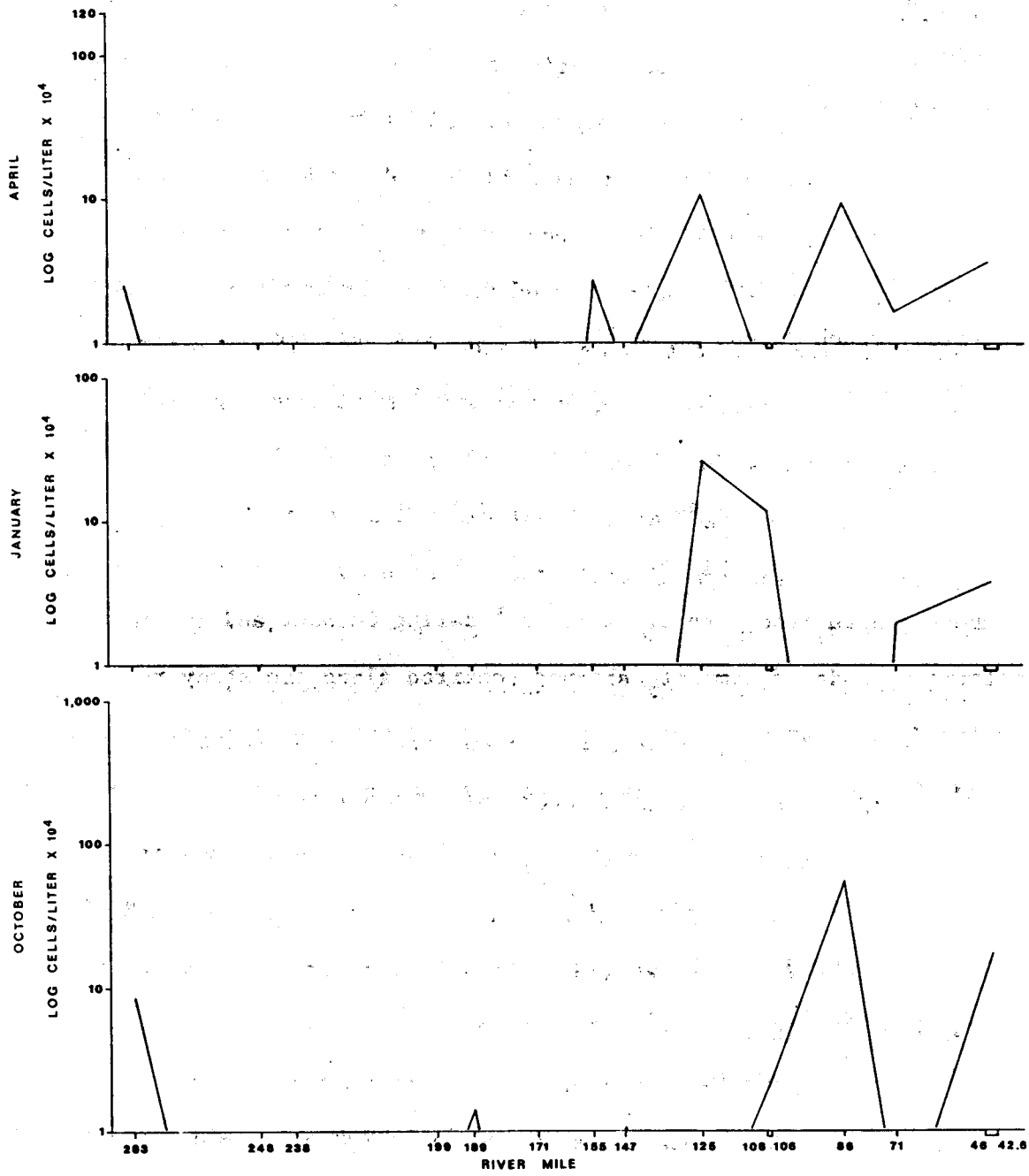


TABLE 9

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *APHANOTHECE* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	88,409	--	25,731
248	--	--	--
238	--	--	--
199	5,937	--	--
189	13,855	--	--
171	--	--	--
155	--	--	28,700
147	10,556	--	6,597
125	1,979	272,157	110,842
108	21,112	119,419	5,278
86	572,024	--	95,997
71	1,979	19,793	16,824
45	174,620	38,398	36,815

decreased slightly to 26% in April. The chief genera of the coccoid greens (Tetrasporales and Chlorococcales combined) were *Scenedesmus*, *Ankistrodesmus*, *Dictyosphaerium*, and *Kirchneriella*. Other species present but never constituting a major part of the assemblage were: *Oocystis* spp., *Coelastrum microporum*, *Gloeocystis vesiculosa*, *Crucigenia* spp., *Tetrastrum heteracanthum*, and *Micractinium pusillum*.

The coccoid green assemblage was dominated by *Scenedesmus* (mainly *S. bijuga* and *S. quadricauda*) throughout the entire reach during October, except at RM 199 (Figure 15, Table 10). *Scenedesmus* generally increased in abundance from upstream (RM 283) with 1.18 x 10^5 c/l to 3.24 x 10^5 c/l downstream (RM 45). However, this was not an uniform increase in numbers due to low cell numbers (minimum 0.55 x 10^5 c/l) interspersed throughout the reach. With the onset of cooler temperatures and lower light intensity during January, the *Scenedesmus* cell numbers declined 78% from the October samples. *Scenedesmus* never dominated the coccoid greens during January and was relatively stable with abundances ranging from 0.15 x 10^5 c/l to 0.47 x 10^5 c/l. *Scenedesmus* remained insignificant in the coccoid green assemblage during April. Cell numbers for the April sample were reduced approximately 8% from the January sample and ca. 80% from October. The range of abundances was from a minimum of 0.15 x 10^5 c/l at RM 199 to a maximum of 0.71 x 10^5 c/l at RM 45. As was noted during the previous collections, a general increase in the population occurred with the downstream stations.

Figure 15

ACTUAL ABUNDANCE OF SCENEDESMUS SPP. BY RIVER MILE

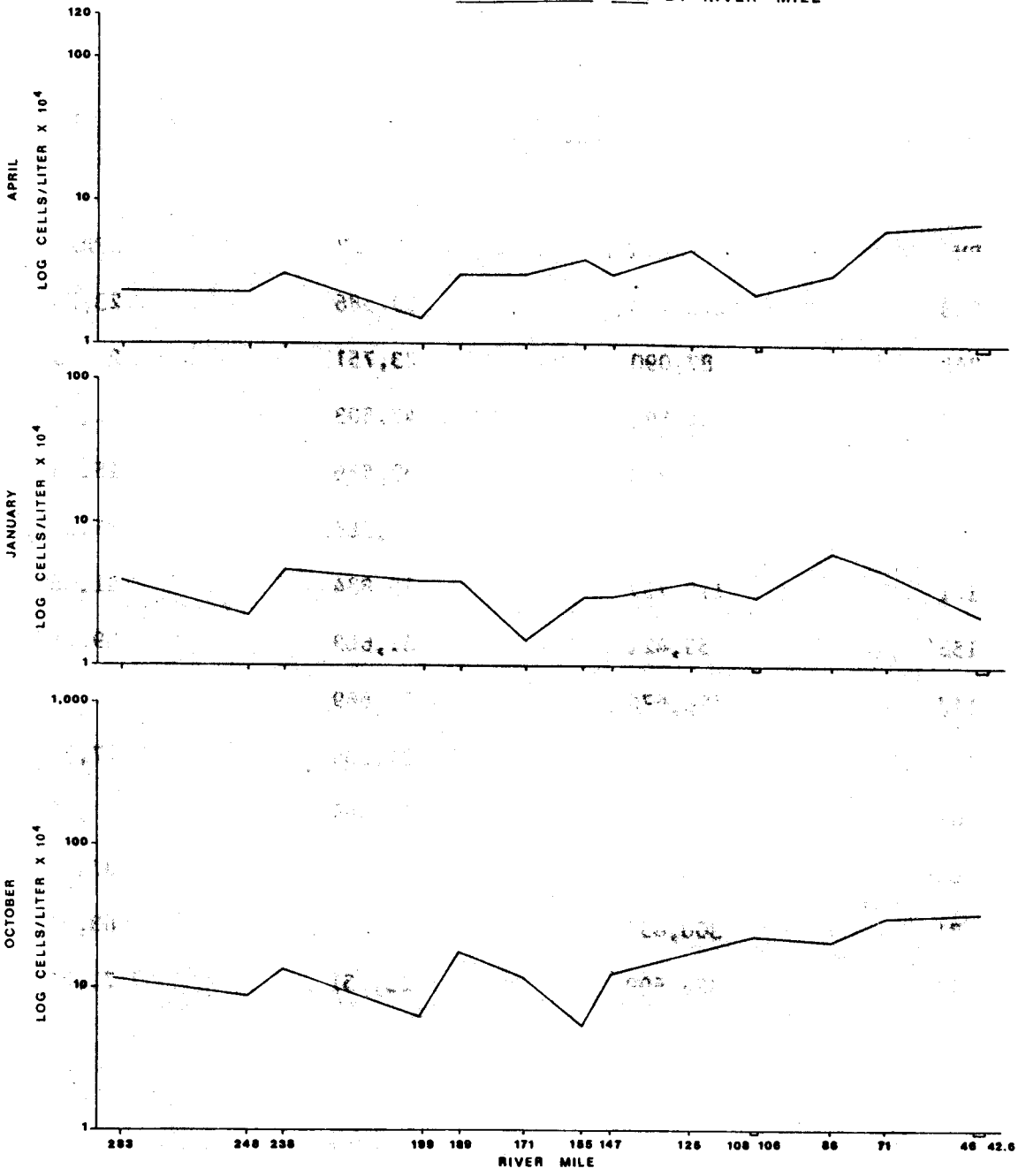


TABLE 10

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *SCENEDESMUS* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	118,759	39,586	23,751
248	87,090	23,751	23,751
238	134,594	47,503	31,669
199	63,338	39,586	15,834
189	174,180	39,586	31,669
171	118,759	15,834	31,669
155	55,421	31,669	39,586
147	126,676	31,669	31,669
125	174,180	39,586	47,503
108	229,601	31,669	23,751
86	205,849	63,338	31,669
71	300,857	47,503	63,338
45	324,609	23,751	71,255

Dictyosphaerium was also an important genus in the coccoid green assemblage (Figure 16, Table 11). During October the population ranged from 0 at RM 248 and 238 to a maximum of 1.90×10^5 c/l at RM 108. Although *Dictyosphaerium* was not dominant at any station within the reach, the high abundances of *Dictyosphaerium*, especially at the downstream stations, contributed significantly to the overall coccoid green assemblage. The January cell numbers increased by a factor of ca. five over the October samples, and *Dictyosphaerium* dominated the entire reach with abundances ranging from a minimum of 1.42×10^5 c/l to a maximum of 5.3×10^5 c/l. The relative importance of *Dictyosphaerium* to the coccoid green assemblage declined in April when cell numbers were reduced by 83% from January. *Dictyosphaerium* dominated only at RM 283 and 248. The instability of *Dictyosphaerium* during this period is reflected from the abundances ranging from 0.04×10^5 c/l (RM 147) to 1.74×10^5 c/l (RM 248).

Ankistrodesmus was of secondary importance in the coccoid green assemblage during the October sampling period (Figure 17, Table 12). The number of cells ranged from a low of 0.03×10^5 c/l at RM 238 to a high of 1.58×10^5 c/l at RM 108 and 86. The greatest number of cells of *Ankistrodesmus* occurred downstream from RM 147 to RM 45 but was dominant only at RM 199. A decrease of 50% from the October sample occurred in January, but *Ankistrodesmus* still remained an important component of the assemblage. The cell

Figure 16

ACTUAL ABUNDANCE OF DICTYOSPHAERIUM SPP. BY RIVER MILE

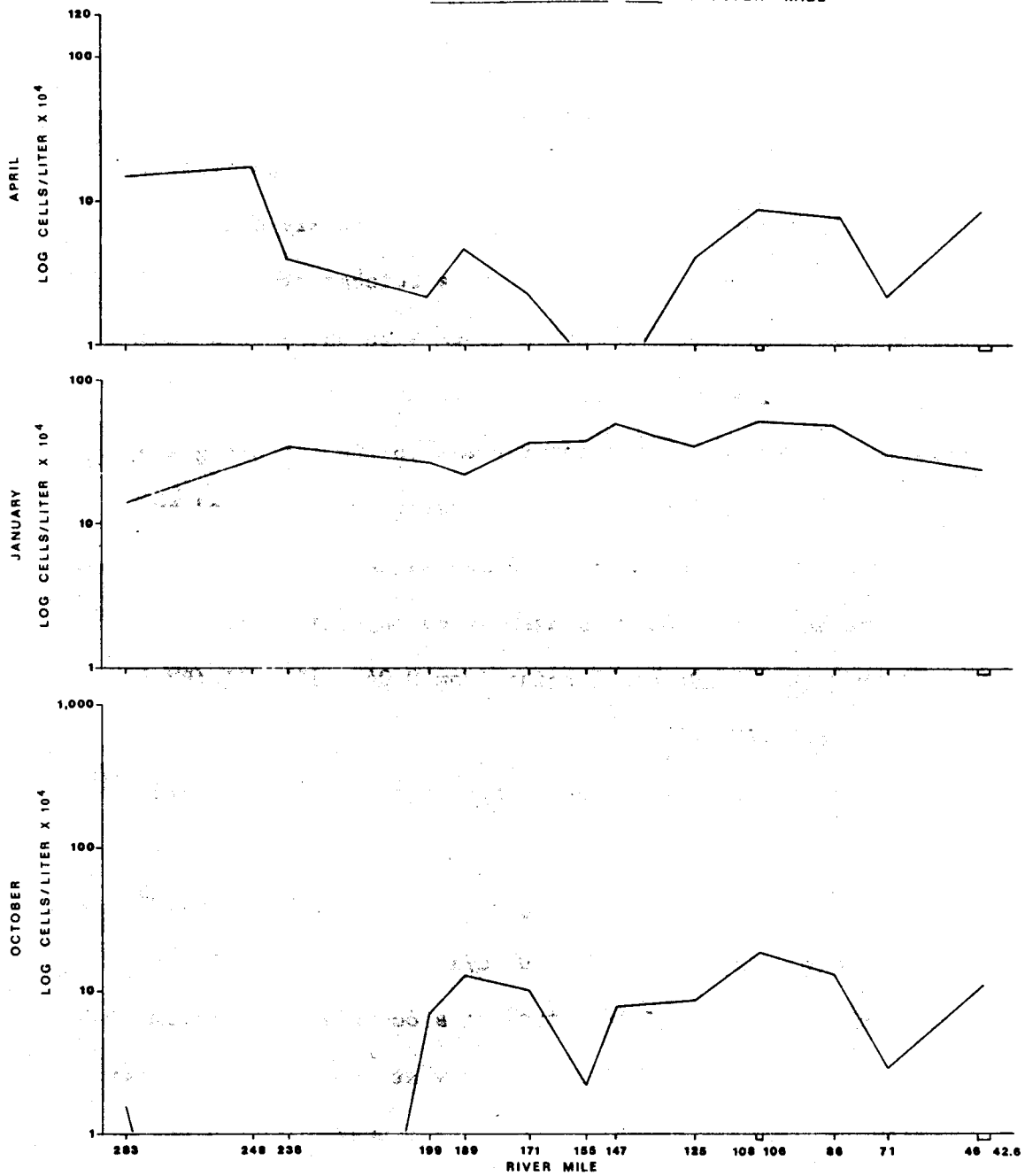


TABLE 11

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *DICTYOSPHAENUM* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	15,834	142,511	150,428
248	--	277,105	174,180
238	--	340,443	39,586
199	71,255	277,105	23,751
189	126,676	229,601	47,503
171	102,924	372,113	23,751
155	23,751	387,947	7,917
147	79,173	498,789	4,750
125	87,090	356,278	39,586
108	190,015	530,459	87,090
86	134,594	498,789	79,173
71	31,669	308,774	23,751
45	118,759	253,353	87,090

Figure 17

ACTUAL ABUNDANCE OF ANKISTRODESMUS SPP. BY RIVER MILE

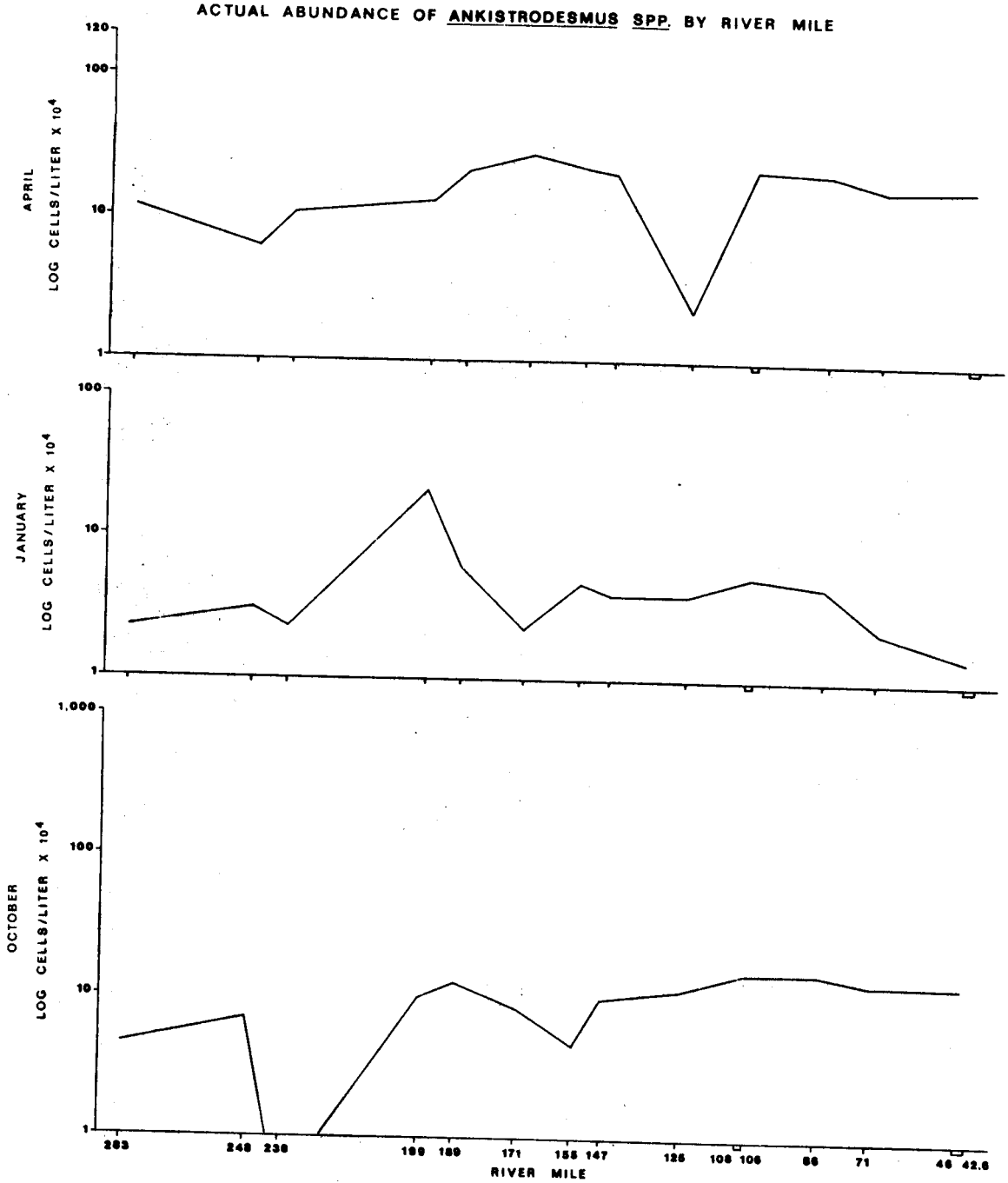


TABLE 12

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *ANKISTRODESMUS* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	47,503	23,751	118,759
248	71,255	31,669	63,338
238	3,958	23,751	110,842
199	102,924	213,767	134,594
189	126,676	63,338	221,684
171	87,090	23,751	285,022
155	47,503	47,503	229,601
147	102,924	39,586	213,767
125	118,759	39,586	23,751
108	158,346	55,421	229,601
86	158,346	47,503	221,684
71	134,594	23,751	174,180
45	134,594	15,834	182,097

numbers remained relatively stable throughout the reach except for a peak at RM 199 with 2.13 x 10^5 c/l. An increase in abundance by a factor of ca. three in the early spring resulted in the prevalence of *Ankistrodesmus* at most of the designated sampling stations. *Ankistrodesmus* was superseded in abundance only at RM 283, 248, and 125 by other coccoid greens. The number of cells ranged from a low of 0.23 x 10^5 c/l to a high of 2.83 x 10^5 c/l during April.

Kirchneriella was of minor importance in the October and January samples (Figure 18, Table 13). The number of cells during October ranged from 0.01 x 10^5 c/l at RM 71 to the peak abundance of 0.31 x 10^5 c/l at RM 189. During January there was a 52% increase from October, but it was still insignificant in the coccoid green assemblage. Cell numbers ranged from 0 to 0.47 x 10^5 c/l. *Kirchneriella* gained importance during April with an increase of a factor of seven over the January samples. *Kirchneriella* was subdominant at RM 238 to 155, 108, 86, and 45 and was dominant in the assemblage at RM 125. The abundance ranged from 0.31 x 10^5 c/l at RM 283 and 248 to 1.74 x 10^5 c/l at RM 125.

The Bacillariophyceae (diatoms), composing 33% of the total phytoplankton, predominated the April samples (Figure 2). The diatoms increased in relative abundance throughout the sampling periods. Centrales II (centric diatoms 6 - 15μ in size, composed primarily of *Cyclotella* spp.) was the most abundant group of diatoms throughout the sampling periods. Several species of the

Figure 18

ACTUAL ABUNDANCE OF KIRCHNERIELLA SPP. BY RIVER MILE

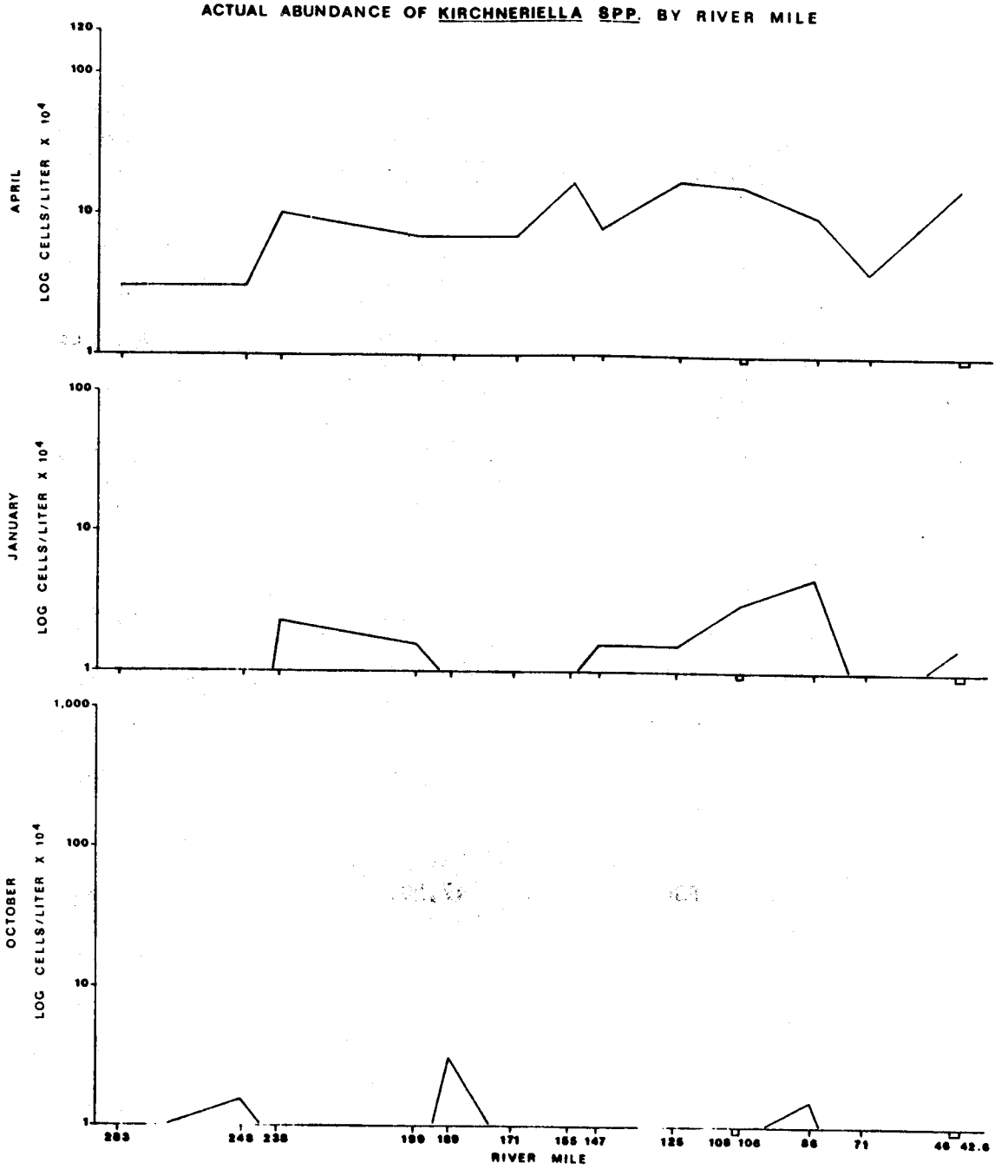


TABLE 13

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *KIRCHNERIELLA* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	7,917	--	31,669
248	15,834	--	31,669
238	7,917	23,751	102,924
199	2,375	15,834	71,255
189	31,669	7,917	71,255
171	5,542	7,917	71,255
155	7,917	7,917	166,263
147	7,917	15,834	79,173
125	7,917	15,834	174,180
108	7,917	31,669	166,263
86	15,834	47,503	102,924
71	1,583	5,542	39,586
45	7,917	15,834	158,346

filamentous genus *Melosira* (especially *M. islandica* and *M. granulata*) also constituted a major portion of the diatom assemblage. The major pennate genera were *Synedra, Navicula, Nitzschia,* and *Asterionella.*

The Centrales, composed mainly of *Cyclotella* spp. and *Stephanodiscus* spp., were the most important group of the diatom assemblage during October and dominated the entire reach (Figure 19, Table 14). They displayed fluctuating cell numbers throughout the reach, but generally increased in abundance downstream. Cell numbers ranged from a minimum of 0.84×10^5 c/l to a maximum of 8.58×10^5 c/l. The peak region of abundance occurred from RM 108 to RM 45. A high abundance at RM 71 persisted throughout the three sampling periods. During January increases in the Centrales occurred intermittently along the reach, but the overall cell numbers decreased 28% from the October samples. The population ranged from 1.38×10^5 c/l at RM 238 to 8.33×10^5 c/l at RM 71. The Centrales again held their dominance through the entire reach. During April the Centrales approximately doubled in abundance at the majority of the upstream stations until RM 171, where slight decreases in the population occurred. The cell numbers ranged from a low of 2.0×10^5 c/l at RM 86 to a high of 5.9×10^5 c/l at RM 189. Their importance in the diatom assemblage decreased in April when the Centrales lost dominance from RM 125 to the end of the study reach at RM 45.

Figure 19

ACTUAL ABUNDANCE OF CENTRALES BY RIVER MILE

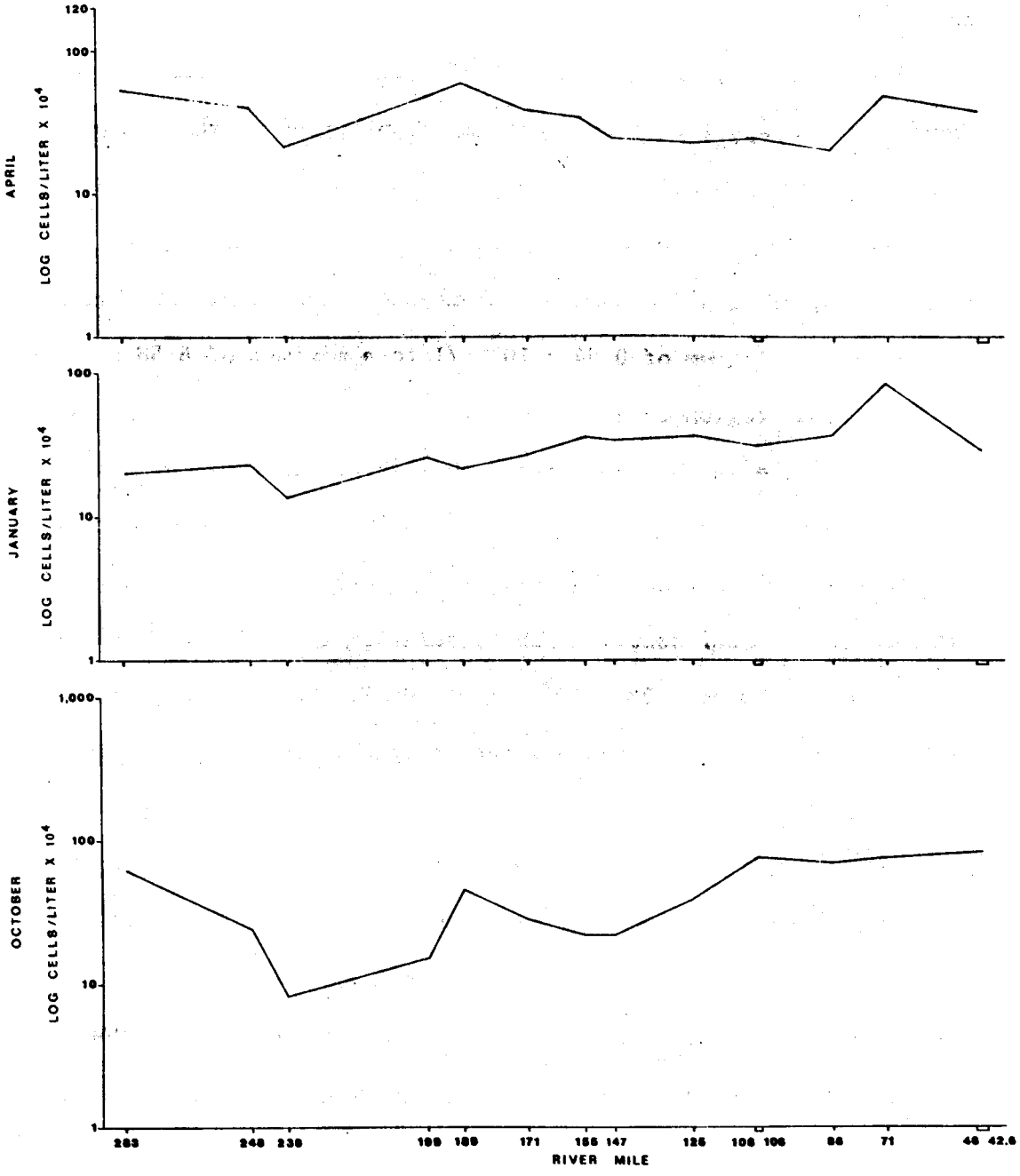


TABLE 14

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF CENTRALES* PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	629,425	202,880	540,355
248	247,415	234,550	408,730
238	84,451	138,552	217,725
199	152,408	255,332	478,996
189	466,131	217,725	590,828
171	286,012	270,177	383,989
155	226,632	351,330	333,516
147	226,962	335,165	246,755
125	394,875	359,247	228,612
108	761,380	315,372	248,075
86	700,681	372,113	201,891
71	765,009	833,295	478,996
45	858,619	286,606	377,259

*Combined *Cyclotella* and *Stephanodiscus* spp.

Melosira spp. were rather insignificant in their contribution to the diatom assemblage during October and January. The cell numbers ranged from 0.07 x 10^5 c/l at RM 199 and 125 to the peak abundance of 2.7 x 10^5 c/l at RM 283 during October followed by a slight decrease during January when cell numbers ranged from 0.31 x 10^5 c/l to 1.12 x 10^5 c/l. *Melosira* did not gain importance in the diatom assemblage until April when they increased by a factor of ca. six. The abundance of *Melosira* during April ranged from 0.42 x 10^5 c/l (RM 238) to 7.56 x 10^5 c/l (RM 45). *Melosira* dominated the assemblage from RM 125 to the end of the reach at RM 45 (Figure 20, Table 15).

The Volvocales (green flagellates) and the Cryptomonadales (cryptomonads) reaching their peaks during January, were never dominant in any specific sampling period (Figure 2). The green flagellates were represented in the three sampling periods by *Chlamydomonas* spp. (Figure 21, Table 16). Other genera observed at most of the stations were *Chlorogonium*, *Sphaerellopsis*, and *Pteromonas*. The abundances of *Chlamydomonas* during October ranged from 0.62 x 10^5 c/l at RM 171 to a high of 12.7 x 10^5 c/l at RM 45. This wide range of abundances illustrates their variability through the entire reach in October. During January the cell numbers tended toward a general decrease downstream. *Chlamydomonas* spp. ranged from 0.72 x 10^5 c/l at RM 45 to 3.20 x 10^5 c/l at RM 238. The noticeably low cell numbers that occurred at RM 171 during October

Figure 20

ACTUAL ABUNDANCE OF MELOSIRA SPP. BY RIVER MILE

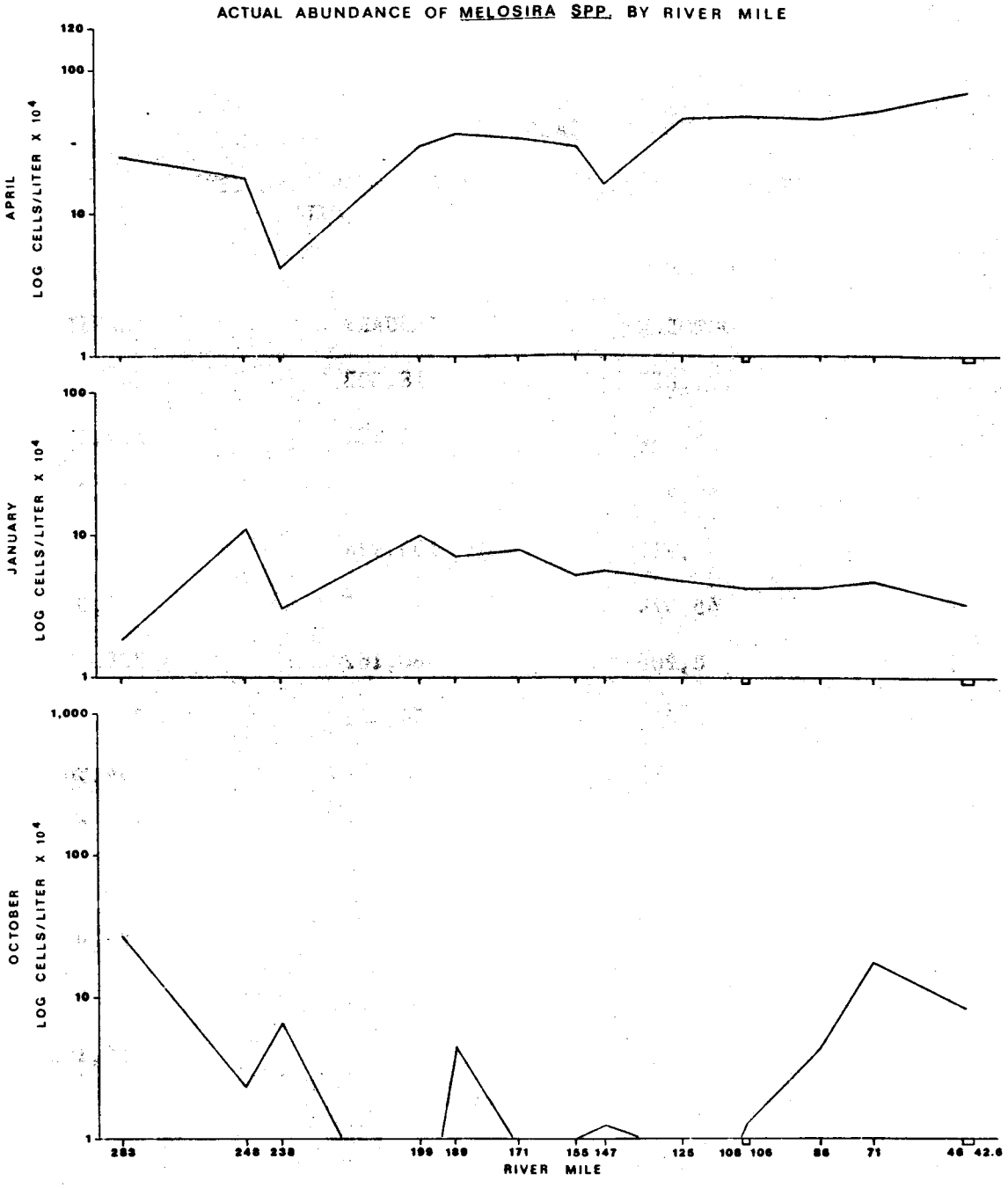


TABLE 15

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *MELOSIRA* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	271,827	18,803	245,436
248	24,741	112,821	179,128
238	67,297	31,669	42,225
199	7,917	103,914	300,857
189	45,524	73,235	376,071
171	8,906	80,162	338,464
155	10,886	54,431	297,888
147	13,195	58,060	164,943
125	7,917	49,483	483,944
108	13,195	44,204	498,789
86	45,524	45,524	487,903
71	179,128	51,462	542,335
45	84,451	34,440	756,102

Figure 21

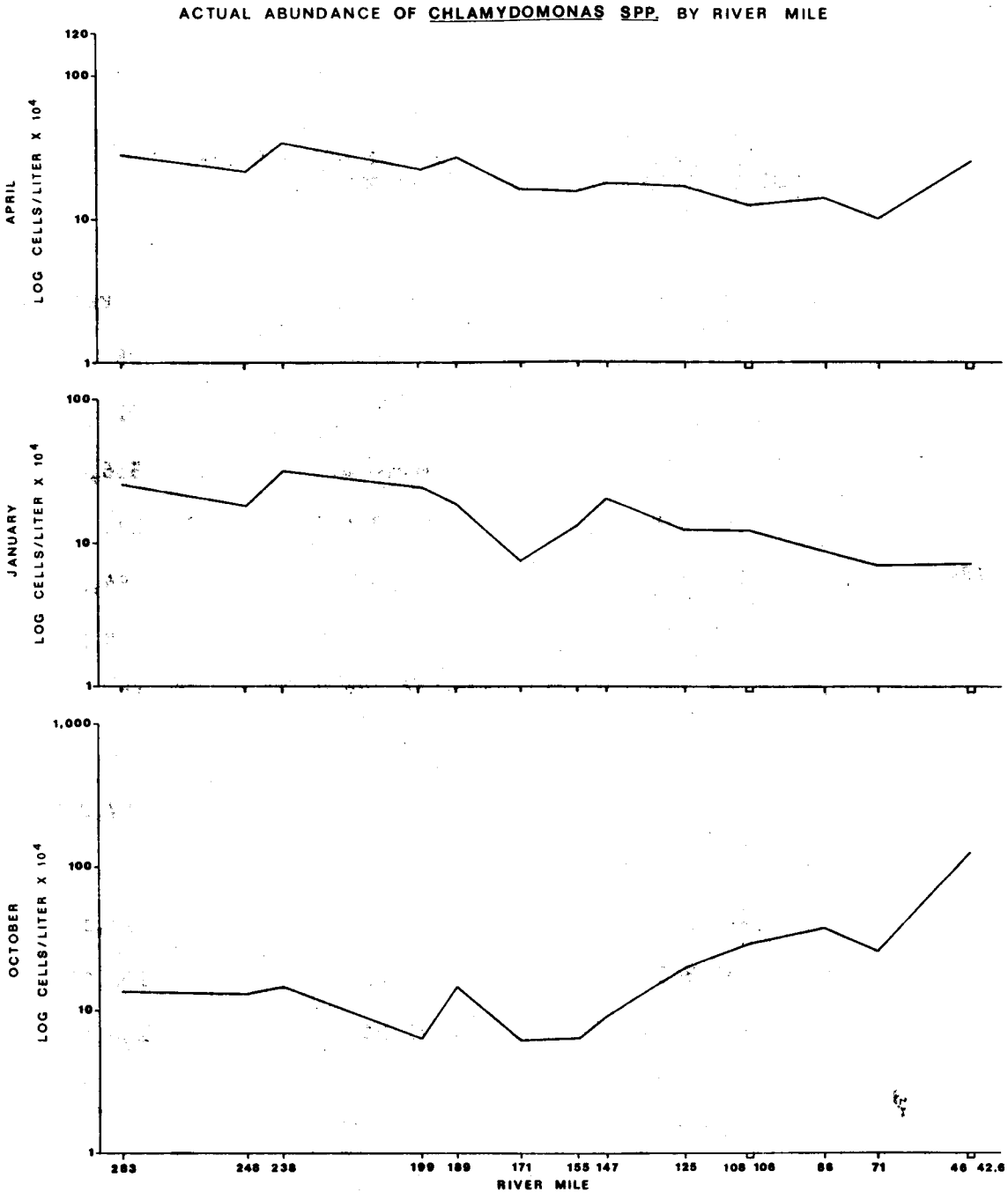

ACTUAL ABUNDANCE OF CHLAMYDOMONAS SPP. BY RIVER MILE
APRIL
LOG CELLS/LITER X 10⁴
120
100
10
1
JANUARY
LOG CELLS/LITER X 10⁴
100
10
1
OCTOBER
LOG CELLS/LITER X 10⁴
1,000
100
10
1
283
248 238
199 189
171
155 147
125
108 106
86
71
46 42.6
RIVER MILE

TABLE 16

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *CHLAMYDOMONAS* SPP. PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	137,233	255,332	283,043
248	132,614	185,066	216,736
238	146,470	320,650	336,485
199	64,328	249,394	223,663
189	146,470	188,035	264,239
171	62,348	78,183	158,346
155	63,338	136,573	151,418
147	89,729	208,488	170,221
125	199,911	127,666	167,252
108	289,641	125,357	127,336
86	376,071	89,069	141,521
71	254,343	73,235	102,924
45	1,274,685	72,047	250,582

were also observed in the January samples, indicating the influence of some abnormal environmental factors, possibly toxic chemicals. Cell numbers during April were relatively stable, ranging from 1.02×10^5 c/l at RM 71 to 3.36×10^5 c/l at RM 238.

The cryptomonads reached their highest relative abundance during January when they comprised 11% of the phytoplankton (Figure 2). Of the cryptomonads enumerated, *C. erosa* and *C. ovata* were the most abundant (Figure 22, Table 17). These two species were relatively uniform in abundance during October except for the low of 0.34×10^5 c/l at the extreme upstream station (RM 283). The cell numbers ranged from this low up to 3.95×10^5 c/l at RM 189. The January population of *Cryptomonas* was characterized by a gradual decrease in abundance within the study reach. The abundance ranged from the minimum of 0.96×10^5 c/l at RM 45 to a high of 2.51×10^5 c/l at RM 283. During April the *Cryptomonas* cell numbers exhibited a general decrease in abundance downstream until a zonational increase occurred between RM 199 and 125. This zone was again succeeded by a region of low abundance. This region of increased abundance also existed in the October samples. During April the cell numbers ranged from a low of 0.78×10^5 c/l at RM 199 to 2.35×10^5 c/l at RM 171.

The role of the most important genera in each of the major taxa can be summarized as follows:

Figure 22

ACTUAL ABUNDANCE OF CRYPTOMONAS SPP. BY RIVER MILE

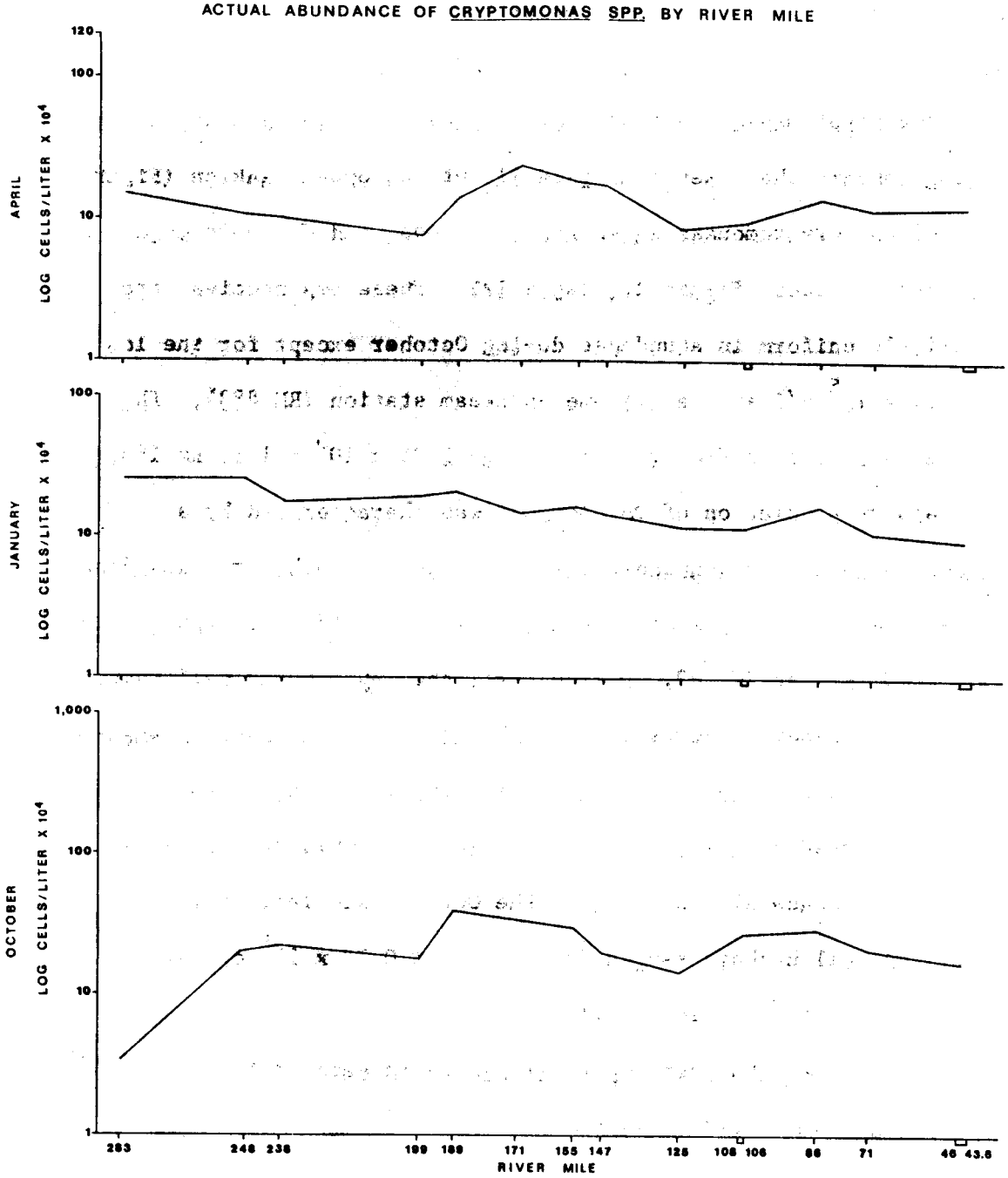


TABLE 17

ACTUAL ABUNDANCE (MEAN NUMBER OF CELLS/LITER)
OF *CRYPTOMONAS* SPP.* PER RIVER MILE

RM	OCTOBER	JANUARY	APRIL
283	34,308	251,374	150,428
248	206,839	253,353	106,883
238	221,684	178,139	102,924
199	182,097	194,963	78,183
189	395,865	206,839	141,521
171	345,392	149,439	235,539
155	309,764	166,263	184,077
147	209,808	146,470	175,500
125	149,439	121,728	88,079
108	276,445	119,419	98,966
86	298,878	169,232	144,490
71	213,767	111,831	119,749
45	173,300	96,195	124,301

*Combined *C. erosa* and *C. ovata*.

1) The blue-green assemblage was dominated by *Microcystis* throughout the study reach during October. Dominance at specific stations fluctuated among *Microcystis*, *Merismopedia*, *Oscillatoria*, *Gomphosphaeria*, and *Apthanothece* during January. The prevalence of *Microcystis* in the extreme upper reach of the river was superseded by *Merismopedia*. *Microcystis* dominated most of the middle reach of the river. Downstream, *Apthanothece*, *Merismopedia*, and *Gomphosphaeria* became the most abundant populations at RM 125 to 108, 86, and 71 to 45, respectively. *Gomphosphaeria* dominated the April blue-green assemblage, except at RM 155 and 71 where *Oscillatoria* was most abundant.

2) Fluctuations in dominance among the coccoid greens occurred throughout the sampling periods. The coccoid green assemblage during October was dominated almost exclusively by *Scenedesmus*, except at RM 199 where *Ankistrodesmus* superseded *Scenedesmus* in abundance. In January *Dictyosphaerium* dominated the coccoid greens in the entire reach with *Ankistrodesmus* being of secondary importance. The assemblage was predominated by *Ankistrodesmus* at the majority of the stations in April. *Dictyosphaerium* superseded *Ankistrodesmus* in abundance upstream at RM 283 and 248. *Kirchneriella* was the most abundant at RM 125.

3) The diatom assemblage was composed of both pennate and centric diatoms of which the Centrales were the most abundant. A general downstream trend of increased Centrales abundance occurred

during October and January. Even though the Centrales dominated the diatoms in October, their concentration of cells varied considerably among specific stations. In January the abundance of Centrales was relatively stable but gradually increased along the lower reach. During April high abundances of Centrales occurred intermittently through the reach, but the increase in *Melosira* spp. resulted in a dominance shift from *Cyclotella* and *Stephanodiscus* to *Melosira* spp. from RM 125 to 45.

4) The green flagellates were dominated by *Chlamydomonas* spp. throughout this study. The October cell numbers of *Chlamydomonas* showed the greatest range and instability of the three sampling periods. The largest concentration of *Chlamydomonas* spp. for the entire study occurred at RM 45 during October. In January the cell numbers decreased by one third from upstream to downstream stations. The April cell numbers were relatively stable with gradual decreases occurring downstream along the reach. Following the series of decreased abundances, the cell numbers doubled in abundance at the extreme lower reach.

5) *Cryptomonas* spp. were the most abundant of the cryptomonads and dominated the assemblage each sampling period. Except for the the low concentration of cells at the upstream station, the cell numbers during October were relatively uniform. A region of increased abundances did occur between RM 199 and RM 125 during October and April. The cell numbers generally decreased along the

reach in January, showing a reduction of 50% from the upstream to the downstream stations. The number of cells during April was relatively stable except from RM 199 to 108 where fluctuating abundances occurred.

6) These major generic taxa are more sensitive to changes in the ecosystem and are better indicators of changes in the temporal and spatial distribution of phytoplankton than are the major taxa.

DISCUSSION

The results of this study characterized the basic structure of the phytoplankton community in the Arkansas River. Of the eight taxa present in the river, five (coccoid greens, green flagellates, blue-greens, diatoms, and cryptomonads) comprised the bulk of the assemblage. The eight taxa were widely distributed throughout the study reach, but the concentration of cells in each taxon varied during the four sampling periods. The seasonal differences in light and temperature parameters are, in addition, modified by stream flow characteristics. These variations probably caused the irregular fluctuations of the total abundance of phytoplankton with each river mile.

The total phytoplankton assemblage reached peak abundance in October. The peak occurred as the result of the large concentration of blue-greens. The erratic distribution of the total cell numbers reflected the fluctuations in the abundance of blue-greens. The dominance of the blue-greens prevailed throughout the study reach in October (Figure 7). Examination of the relative abundance data revealed the stability of each taxon from the upstream stations to the downstream stations. Slight variations from the mean occurred intermittently along the reach. The total cell numbers for all phytoplankton generally showed increases from upstream to downstream during October, January, and April (Figure 3).

With the decrease of the blue-greens in January, the coccoid green assemblage became the most common of the taxa (Figure 8). The relative abundance of the other taxa increased, thus indicating a seasonal change in the composition of the phytoplankton community. The degree of dominance of the coccoid greens varied from river mile to river mile. The coccoid greens maintained dominance along the study reach except at RM 71 where the diatoms predominated. Increases in the total cell numbers were more prominent with the downstream stations.

The diatoms reached peak abundance during April and became the most abundant of the taxa (Figure 9). The relative abundance of each taxon in the April samples decreased from the January samples, except for a 2% increase in the blue-greens and an 11% increase in diatoms.

According to Hynes (1970), the seasonal changes in phytoplankton are more or less regular due to the influences of many climatic factors such as light, temperature, and rainfall. Since this study was limited to four widely spaced and long duration collection periods, the regularity of the seasonal changes in the phytoplankton of the Arkansas River could not be determined.

Comparison of the phytoplankton of the Arkansas River with other rivers in rather difficult due to the many differing features of rivers. Rivers vary in several aspects, such as flow rates, volume of water, depth of water, degree of climatic influences,

chemical characteristics, type of drainage basin, river morphology, quanity and type of pollutants, and the degree of regulation through dams and impounded reservoirs. Patrick (1961) studied the number and kinds of species from nine rivers in the eastern United States representing various ranges of differences such as those previously mentioned. She found that the kinds of species varied greatly among the rivers, but the number of species remained very similar. According to her data the total number of species from all subcommunities ranged from 57 to 140. The species, the euplanktonic subcommunity only, of the Arkansas River totaled 243 indicating that it is structurely more diverse and complex than previously studied systems.

The gross changes in the abundance of each taxon are a reflection of the transitions in dominance at the generic level. For most of the taxa, transitions occurred throughout the study reach indicating the possible interactions of certain local environmental factors. There were many varying fluctuations in the distribution of the phytoplankton, but there was a general trend toward the increase of cells downstream. Increases in the phytoplankton abundance downstream have been observed in other studies. Greenburg (1964) reported a gradual increase in phytoplankton along the reach of the Sacramento River. Through a statistical evaluation of the number of plankters and chemical and physical paramenters of water quality and movement, he concluded that water temperature

was the single most important factor affecting plankton development. Other studies have attributed increased plankton production to the impounded area or riverlakes in the river systems. A study by Brook and Rzoska (1954) determined the influence of the Gebel Aulyia Dam on the development of plankton in the Nile River. A 100-fold increase was observed in the phytoplankton from samples taken farthest from the dam to the dam itself. Compositional changes were also observed with a tendency for the dominant component to change from diatoms to blue-greens. Cushing's study (1964) of the Montreal River attributed the increased abundances downstream to the series of lake-like conditions in the upstream portions.

In the study of the Ohio River, Hartman (1965) concluded that the increased downstream population was probably attributed to the effects of local conditions rather than impoundments. He also concluded that navigational dams caused reductions in the phytoplankton. The conflicting cause and effect relationships reported in the literature suggest, therefore, that each system must be analyzed separately. A thorough knowledge of the various inputs effecting overall phytoplankton distribution is necessary before cause and effect relationships can be established for a specific system.

The study reach of the Arkansas River has two main stem lakes. Upstream Ozark Lake is located at RM 256.8, and midstream Lake Dardanelle is located at RM 205.5 with locks and dams. There are eleven additional lock and dam systems with smaller impoundments

located within this same reach. The direct effect of these impoundments on the algae of the Arkansas River was not studied in this report, but the fluctuating abundances of phytoplankton could possibly be attributed to these impoundments.

Several other factors probably influenced the phytoplankton populations along the study reach. Decreased abundances in October may be attributed to a reduction in light penetration due to increased turbidity resulting from flooding during this particular period of sampling. Nutrient increase, grazing by zooplankton, chemical limitations, and the introduction of plankton from back-water areas or tributaries could have also affected the assemblage. Further study would be necessary in order to determine the impact of these physico-chemical and biotic parameters.

Increases in total cell numbers during each sampling period at RM 125 are probably due to the influence of the outflow of sewage by Skillcutt Creek (see Figure 11, Volume I). The species present suggest an organic enrichment. Reductions in phytoplankton at RM 171 could be due to outflow from the paper mill located in the same vicinity.

Also needing consideration are the series of revetments and dikes which contribute to the formation of whirlpools and eddies in the river. Some phytoplankton are adaptable to these whirlpools and eddies and can maintain themselves and complete their life cycles. Other plankters, not being able to cope with this

sort of environmental stress, are deleted (Reid, 1961). The collection in this study included samples from whirlpools and eddies, as well as open stream points. Our data suggest higher concentrations in the open stream and reduced cell numbers along the dikes and revetments.

Turbidity of the river samples during each collection period seems to be associated with many of the erratic fluctuations in the phytoplankton abundances. The influence of turbidity was especially noted during the October sampling period. Increased turbidities during this period were attributable to flooding conditions. The effects of turbidity on phytoplankton have been reported in many studies. The 19% reduction in phytoplankton of Lake Erie from 1941 to 1942 was attributed to high turbidities (Chandler and Weeks, 1945). Chandler (1942) reported that turbidity affected the composition, size, duration and time of occurrence of phytoplankton pulses. The increased growth of algae in the Missouri River is attributed to the reduction of turbidity by the construction of dams on the river (Bartsch, 1959). According to Plumb's (1973) summation, the effects of suspended solids on algae are: (1) solids create turbid suspensions that reduce light penetration and reduce photosynthesis, (2) silt can encrust algae and smother them or remove them from the water by flocculation and precipitation, and (3) suspended solids could contribute essential nutrients as the result of dissolution and stimulate the growth

of algae. Also, the abrasive action of inorganic particles may damage algae cells (Hollis, et al., 1964).

Variations in the composition of phytoplankton due to turbidity have also been suggested by Hutchinson (1967). He associated the filamentous blue-greens *Aphanizomenon* and *Oscillatoria*, and the coccoid green *Dictyosphaerium* with low turbidities. *Cyclotella* and *Stephanodiscus*, centric diatoms, were considered to be among the forms most tolerant of high turbidities. In a study of the effects of turbidity on plankton in four flood control reservoirs of Mississippi, high turbidities were found to be deleterious to green and blue-green algae (McGaha and Steen, 1974). The increase in diatoms, especially *Melosira*, during the periods of high turbidity, was associated with the increase in silica.

The results from this present study on the Arkansas River were inconsistent with these findings. The high turbidities of the October sampling were compared to the abundances of the dominating genera in each taxon. Compositional changes did seem to be associated with the high turbidities, although these changes could have been due to some other factors. The decrease in abundance of the blue-greens *Merismopedia* (Figure 11), *Gomphosphearia* (Figure 13), *Oscillatoria* (Figure 12), and possibly *Microcystis* (Figure 10), seems to be associated with the high turbidities. The coccoid greens did not seem to be affected by turbidities. A decrease in diatoms was observed in association with the turbidities.

Contrary to Hutchinson's report, the Centrales (Figure 19) in this study did not appear to be very tolerant of high turbidites. *Melosira* (Figure 20) showed drastic decreases in association with the high turbidities. Factors affecting or limiting the expression of phytoplankton might vary from system to system; therefore, the transfer and application of cause-and-effect relationships must be employed with caution.

THE EFFECTS OF DREDGING ACTIVITIES ON PHYTOPLANKTON

The primary objective of the present study was to assess the possible environmental impact of dredging on the phytoplankton of the Arkansas River. Since this study was concerned mainly with the transitory nature of phytoplankton throughout the study reach, emphasis was placed on the region of intake of the dredge materials instead of on the region of discharge. The proposed study was designed to evaluate the changes, if any, in the phytoplankton from samples taken above the site of dredging, at the site of dredging, and below the site of dredging. Unforeseen inconsistencies in the concurrence of dredging activities with the proposed sampling procedures limited the actual study to only three of the thirteen sampling stations.

During the extent of the study period, active dredging of the river took place during July and January. Only the samples from the January collection were used in the analysis, since the samples from the abbreviated July sampling period were analyzed qualitatively. The dredging sites have previously been described in the general introduction (Volume I). Of major interest in this study, as has been in previous dredging studies, was the potential effect of increased turbidities in the immediate vicinity, as well as the downstream vicinity from the dredging site. Turbidity data of samples from the active dredging sites revealed no anomalies. The

inconsistency in these findings and other reports may be due to differences in dredging locations and sampling techniques. Station 5 at RM 189 was dredged only at site 1. Since this site was the most distal downstream site of the four sites, the dredging effects could not be adequately assessed. RM 171 was dredged at all four of the designated sites. Fluctuations were observed in the phytoplankton abundance at this river mile in comparison to the phytoplankton abundance at the preceding and succeeding river miles. Since similar fluctuations occurred throughout the study reach, other factors besides dredging are more likely to account for these changes.

The fate of the phytoplankton from RM 199 to RM 147 was examined in accordance with the presence and absence of the pollution-tolerant species at RM 171. The pollution-tolerant species were designated from a list of the 80 most tolerant species compiled by Palmer (1969). Palmer summarized 269 reports of 165 authors to construct a list of pollution-tolerant algae by major group, genera, and species. He determined the genera and species most emphasized by the workers which can be utilized for rating water quality in regard to organic pollution. From the list of tolerant species it was determined that 52 out of the 80 indicator species were not present in the Arkansas River; 68 species were not present in the dredging area. During January, 55 indicator species were not present, and 68 were not present in the dredging

area. The most tolerant species present in the Arkansas River and their rating number (according to emphases by workers) is listed in Table 18. An examination of the data of tolerant species within the stretch from RM 199 to RM 147 (Table 19) reveals that seven indicator species were present and not modified at each river mile within this designated area during January. *Scenedesmus dimorphus* and *Nitzschia acicularis* were the only species that appeared upstream and downstream from RM 171. *Melosira granulata* appeared at RM 171 and the two preceding stations. *Melosira varians*, *Synedra acus*, and *Synedra ulna* were deleted within this area. Two species, *Oscillatoria limosa* and *Synura uvella* were present at and below RM 171. *Coelastrum microporum* and *Actinastrum hantzschii* appeared for the first time in this stretch at RM 155. Local conditions such as outflow from the paper mill at RM 171 could possibly influence the presence or absence of species at this river mile and at the succeeding RM 155.

Site 1 of RM 45 was actively dredged in January. A comparison of phytoplankton data from site 1 with the next two downstream sites revealed no significant changes in the phytoplankton (Table 20). The abundances and percentages remained relatively stable. The other sites at the station were influenced by the outflow from the Mud Lake Bend area and were, therefore, considered not to be applicable in assessing the effects of dredging activities at site 1.

Table 18

Pollution - Tolerant Phytoplankton of the Arkansas River
(Adapted from Palmer, 1969)

Rating Number*	
2	*Nitzschia palea*
3	*Oscillatoria limosa*
4	*Scenedesmus quadricauda*
7	*Synedra ulna*
8	*Ankistrodesmus falcatus*
9	*Pandorina morum*
13	*Melosira varians*
14	*Cyclotella meneghiniana*
16	*Nitzschia acicularis*
17	*Navicula cryptocephla*
26	*Scenedesmus obliqus*
28	*Cryptomonas erosa*
31	*Surirella ovata*
32	*Lepocinclis ovum*
36	*Micratinium pusillum*
38	*Melosira granulata*
53	*Euglena pisciformis*
54	*Actinastrum hantzschii*
55	*Synedra acus*
57	*Synura uvella*
60	*Coelastrum microporum*
61	*Achnanthes minutissima*
63	*Scenedesmus dimorphus*
67	*Scenedesmus acuminatus*
69	*Pediastrum duplex*
72	*Trachelomonas volvocina*
73	*Dictyosphaerium pulchellum*
76	*Cryptomonas ovata*

*Rated in order of decreasing tolerance

Table 19

IMPACT OF DREDGING ON POLLUTION - TOLERANT SPECIES

	RIVER MILES				
	199	189	171	155	147
Ankistrodesmus falcatus	X	X	X	X	X
Cryptomonas erosa	X	X	X	X	X
Cryptomonas ovata	X	X	X	X	X
Cyclotella meneghiniana	X	X	X	X	X
Scenedesmus acuminatus	X	X	X	X	X
Scenedesmus quadricauda	X	X	X	X	X
Trachelomonas volvocinia	X	X	X	X	X
Scenedesmus dimorphus	X	X		X	X
Nitzschia acicularis	X			X	
Melosira granulata	X	X	X		
Melosira varians	X				
Synedra acus	X				
Synedra ulna		X			
Synura uvella			X	X	X
Oscillatoria limosa			X	X	
Actinastrum hantzschii				X	
Coelastrum microporum				X	

TABLE 20

ACTUAL ABUNDANCE (MEAN NO. OF CELLS/L.)

RIVER MILE 45	GREEN FLAGELLATES	COCCOID GREENS	EUGLENOIDS	BLUE-GREENS	GOLDEN BROWNS	DIATOMS	CRYPTOMONADS	DINO-FLAGELLATES	SUM
Site 1	114,801	506,707	3,958	558,169	3,958	459,203	59,379	35,628	1,741,803
Site 2	87,098	775,895	7,917	451,286	47,503	340,444	87,090	43,545	1,840,778
Site 3	47,504	641,301	7,917	510,666	11,876	471,079	39,586	23,752	1,753,681

RELATIVE ABUNDANCE (% COMPOSITION OF TOTAL POPULATION)

Site 1	7	30	0	30	0	26	3	2
Site 2	5	42	0	24	2	18	5	2
Site 3	2	37	0	28	0	27	2	1

Previous studies concerning dredging effects on phytoplankton are very limited in number. The major areas of concern have been focused on the physical and chemical alterations in the aquatic environment, and the resultant effect on phytoplankton. Much emphasis has been placed on increased turbidites and the possible release of chemical contaminants or nutrients from the dredged sediments.

The significance of turbidity changes attributed to dredging activities has not been definitely determined. In studying the influence of sediments on aquatic life, Cordone and Kelley (1961) state, "Short term discharge of sediment may do little visible damage to fishes, bottom fauna, or fish eggs, but may interrupt the entire biological complex through effects on algae."

In a literature review by May (1973), a study was cited concerning the dredging activities in upper Chesapeake Bay (Flemer, 1968). Dredging increased the turbidity over an area of 1.5 to 1.9 square miles around the disposal site and the turbidity plume reached a maximum distance of 3.1 miles. No gross effects on the phytoplankton were observed. Turbidity plumes are reported to be temporary (lasting a few hours) and to generally extend within 2,000 ft. of discharge (Lee and Plumb, 1974).

One of the problems encountered in evaluating turbidity influences is determining what turbidity levels constitute an objectionable condition (Harrison and Chisholm, 1974). The use

of turbidity measurements in evaluating the environmental impact of dredging has even been questioned. May (1973) believes that turbidity measurements have little use in the dredging program since they are not quanitative. He advocated measuring the amount of suspended solids in the water. According to May, the suspended solids measurement is the only way to meaningfully evaluate the effects of dredging on sediment.

Similar problems as with the use of turbidity measurements are likely to be encountered with the suspended solids measurements. The methods used and the interpretation of the results will probably vary with investigators. We might suggest that the submarine photometer be used to provide a light penetration curve and a record of the photosynthetic-respiration-compensation level. The depth of the euphotoic zone is of foremost importance in determining the effect of turbidity on the primary producers.

Because of the biological changes that could be influenced by the concentration of suspended solids, the type of suspended solids, the length of exposure, the presence of toxic material, the condition of the exposed organism, and the phase of the life-cycle of the organism; it has been suggested that rigid turbidity standards not be set (Lee and Plumb, 1974).

A theoretical model used to calculate the potential changes in photosynthesis and productivity showed a 50% reduction for 0.5 mg/l increase in suspended solids (Plumb, 1973). As pointed out

by Plumb, these results are questionable, since other conditions that could limit algae growth and the adaptability of the organisms were not taken into consideration.

Gannon and Beeton (1969) used laboratory bioassays to study the effect of dredged sediments from five locations in the Great Lakes area on phytoplankton. The results from this study based on optical density readings suggested that a decrease in the abundance of phytoplankton occurred, but that it was probably temporary. Gannon and Beeton also concluded from a carbon-14 study with bioassays that extracts from harbor sediments actually stimulated productivity. Due to a possible error in interpreting the results, the validity of this study has been questioned by Lee and Plumb (1974).

Studies have shown that one environmental impact of dredging is the release of aquatic plant nutrients. In studies reviewed by Slotta (1973), an increase occurred near a discharge plume from 50 to 1,000 times ambient total phosphorus and nitrogen levels. No increase in phytoplankton was observed. In contrast another study showed stimulation of algae when dredge spoils were placed with the receiving waters in closed bottle experiments. Light-dark bottle experiments at the dredging site also reported significant algal growths.

Churchhill and Brashier (1972) studied the effects of dredging on Lake Herman, North Dakota. The results showed a 300% increase in both orthophosphates and total phosphorus with no apparent changes in abundance or genera of the phytoplankton.

The possible release of contaminants from dredged sediments is presently under investigation. The Elutriate Test, which was designed to detect any significant release of chemical contaminants, is being evaluated, tested, and modified to assure reliability in the assessment of dredging effects in many of the various dredging locations across the United States (Lee, 1975).

In some dredging locations, the release and availability of organic and inorganic constitutents of dredged sediments to phytoplankton is unexpected. Both of these constitutents remain largely absorbed or insoluble in sediments (May, 1973; Lee, 1975). The heavy metal content in sediments has also been shown to have little or no effect on the aquatic environment. Many of the metals are in a form unavailable to aquatic organisms (Lee, 1975).

The immediate environmental impact of dredging has been the issue of most of the past dredging studies. Very few, if any, studies have considered what the possible long term environmental impact of dredging might be. One potential long term effect of dredging on rivers, and thus phytoplankton, is the progressive constriction of the river for navigational use. It has been determined that the combination of navigational works and levees cause significant rises in the stage of flood (Belt, 1975). Dredging activities can increase the velocity of the flow, thus reducing the retention time for some of the organisms. Even though the life-history of some of the species is very short, the increased

current velocity would hinder their regeneration. Selective pressure would result in changing the structure of the phytoplankton community down the river.

The need for additional dredging research is very evident from the literature reviewed. Most of the reports concerning phytoplankton are confined to generalizations with limited specific information. Areas of the dredging research program that need further emphasis are specific site locations and sampling procedures. In the present study of the Arkansas River several suggestions are offered to aid future studies in the proper evaluation of the impact of dredging operations.

RECOMMENDATIONS FOR DECREASING THE IMPACT OF DREDGING ON PHYTOPLANKTON

Two recommendations are given to improve the understanding of the relationship between dredging, its impact, and phytoplankton.

(1) It would be better to dredge when light and temperature are limiting in order to minimize mass destruction of the phytoplankton populations. Time of dredging is important since the abundances of phytoplankton vary with each season. What happens to the phytoplankton during dredging in one particular season does not necessarily reflect what will happen to the population in other seasons.

(2) In order to make a better assessment of the effects of dredging, the study area should be confined to a particular zone of dredging that is under the least influence of local conditions, such as sewage outflows, navigational locks and dams, etc., and with a more intensive sampling program.

NOTE

Presently there are several dredging studies sponsored by the U.S. Army Corps of Engineers, Waterways Experiment Station, that are nearing completion but are not available for review in this report. The reports that might offer some additional research results in the area of environmental impact are as follows:

1. Baseline Studies of Plankton Populations of the Columbia River Disposal Site (ID No. Y161 - 1A07D). Task 1A, Dredged Material Research, U.S. Army Eng. WES, Miscellaneous Paper D-75-1, January, 1975.
2. A Biological Assessment of the Standard Elutriate Test (ID No. Y141-1E06) Task 1E. Dredged Material Research, U.S. Army Eng. WES, Miscellaneous Paper D-74-9, November, 1974.
3. Assessment of Aesthetic and Ecological Significance of Turbidity in Various Aquatic Environments. (ID No. Y107 - 1001) Task 1D, Dredged Material Research, U.S. Army Eng. WES, Miscellaneous Paper D-73-3, July, 1973.
4. Assessment of Equipment, Methodologies, and Institutional Capabilities Available for Conduction or Developing Bioassays. Task 1D02, Dredged Material Research, U.S. Army Eng. WES, Miscellaneous Paper D-73-3, July, 1973.
5. Research Study for the Development of Dredged Material Disposal Criteria. Task 1E03, Dredged Material Research, U.S. Army Eng. WES, Miscellaneous Paper D-75-9, September, 1975.

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APPENDIX

TABLE 1

MEAN NUMBER OF CELLS PER RIVER MILE BY TAXON
EXPRESSED AS ACTUAL ABUNDANCE (CELLS/LITER)

OCTOBER

RM	GREEN FLAGELLATES	COCCOID GREENS	EUGLENOIDS	BLUE-GREENS	GOLDEN BROWNS	DIATOMS	CRYPTO-MONADS	DINOFLA-GELLATES
283	415,657	554,211	26,391	6,601,708	97,651	725,752	42,225	0
248	170,222	349,350	19,793	3,624,144	123,708	326,588	306,795	43,545
238	158,346	387,947	19,793	5,387,722	59,379	324,609	304,816	23,752
199	68,286	375,082	5,937	2,510,773	47,504	162,304	233,560	15,834
189	152,408	712,557	29,690	6,416,971	65,317	453,265	492,852	27,710
171	68,286	465,141	18,803	3,256,979	37,607	310,754	382,999	21,772
155	79,173	318,671	6,927	1,876,400	20,783	256,322	358,257	25,731
147	121,398	505,387	7,917	3,730,368	23,752	265,229	234,880	35,628
125	239,498	593,797	12,865	5,636,127	51,462	427,534	176,160	27,710
108	321,310	967,230	24,411	9,856,378	55,421	795,688	339,784	42,885
86	396,854	896,634	25,731	8,434,893	31,669	757,092	319,661	68,286
71	328,567	915,437	23,752	8,488,335	13,855	966,900	235,539	46,514
45	1,677,902	1,391,748	149,863	14,761,240	551,383	1,231,140	227,905	160,042

TABLE 1 (cont.)

MEAN NUMBER OF CELLS PER RIVER MILE BY TAXON
EXPRESSED AS ACTUAL ABUNDANCE (CELLS/LITER) JANUARY

RM	GREEN FLAGELLATES	COCCOID GREENS	EUGLENOIDS	BLUE-GREENS	GOLDEN BROWNS	DIATOMS	CRYPTO-MONADS	DINOFLA-GELLATES
283	262,260	360,237	19,793	280,074	94,017	220,009	293,930	33,648
248	201,891	451,286	11,876	362,216	32,659	366,175	319,660	111,831
238	348,361	577,963	27,710	462,305	15,835	328,568	217,726	75,214
199	255,332	554,211	13,855	532,438	36,617	374,092	283,043	52,452
189	194,963	596,766	13,855	130,635	29,689	308,774	248,405	43,545
171	93,028	558,169	8,907	92,038	65,317	366,175	185,067	26,720
155	154,387	639,321	13,855	405,761	97,976	418,627	194,963	50,472
147	232,240	731,030	14,515	315,929	85,770	403,782	171,541	40,906
125	161,315	716,515	6,927	622,497	70,266	469,100	167,253	38,596
108	156,366	848,470	10,556	537,716	41,565	374,094	138,552	38,266
86	101,935	863,975	8,906	140,532	50,472	419,617	157,356	38,597
71	79,173	713,546	9,896	454,255	21,772	908,510	130,635	43,545
45	89,069	527,292	8,313	290,169	20,584	319,463	115,196	32,065

TABLE 1 (cont.)

MEAN NUMBER OF CELLS PER RIVER MILE BY TAXON
EXPRESSED AS ACTUAL ABUNDANCE (CELLS/LITER) APRIL

RM	GREEN FLAGELLATES	COCCOID GREENS	EUGLENOIDS	BLUE-GREENS	GOLDEN BROWNS	DIATOMS	CRYPTO-MONADS	DINOFLA-GELLATES
283	302,836	570,045	50,472	374,092	36,617	891,685	209,808	22,762
248	217,725	409,720	55,421	267,208	44,534	702,660	136,573	13,855
238	340,443	514,624	98,966	609,632	11,875	831,316	126,676	23,751
199	227,622	574,004	48,493	224,653	9,896	882,778	101,935	56,410
189	278,095	672,970	66,307	422,585	51,462	1,019,352	253,353	69,276
171	176,159	794,698	39,586	413,678	143,501	786,781	330,547	32,658
155	176,159	756,102	48,493	559,159	68,286	697,712	278,095	23,751
147	182,097	504,068	43,545	337,804	73,894	457,883	269,188	27,710
125	190,015	894,654	63,338	500,769	67,297	865,954	133,604	38,596
108	157,026	971,188	61,359	420,276	84,451	869,583	139,872	53,441
86	152,408	746,205	82,141	499,779	81,152	941,169	192,984	74,224
71	103,914	779,854	73,235	1,700,240	29,689	1,239,057	133,604	21,772
45	308,774	938,595	93,424	779,854	64,525	1,372,463	173,784	32,460

TABLE 2

MEAN NUMBER OF CELLS PER RIVER MILE BY TAXON EXPRESSED AS RELATIVE ABUNDANCE (PERCENT OF TOTAL POPULATION)

OCTOBER

RM	GREEN FLAG.	COCCOID GREENS	EUGLE-NOIDS	BLUE-GREENS	GOLDEN BROWNS	DIA-TOMS	CRYPTO-MONADS	DINO-FLAG.
283	5	7	0	78	1	9	0	0
248	3	7	0	73	2	7	6	1
238	2	6	0	81	1	5	5	0
199	2	11	0	73	1	5	7	0
189	2	9	0	77	1	5	6	0
171	1	10	0	71	1	7	8	0
155	3	11	0	64	1	9	12	1
147	2	10	0	76	0	5	5	1
125	3	8	0	79	1	6	2	0
108	3	8	0	79	0	6	3	0
86	4	8	0	77	0	7	3	1
71	3	8	0	77	0	9	2	0
45	8	7	1	73	3	6	1	1

TABLE 2 (cont.)

MEAN NUMBER OF CELLS PER RIVER MILE BY
TAXON EXPRESSED AS RELATIVE ABUNDANCE
(PERCENT OF TOTAL POPULATION) JANUARY

RM	GREEN FLAG.	COCCOID GREENS	EUGLE-NOIDS	BLUE-GREENS	GOLDEN BROWNS	DIA-TOMS	CRYPTO-MONADS	DINO-FLAG.
283	17	23	1	18	6	14	19	2
248	11	26	1	21	2	21	18	1
238	20	33	2	9	1	19	12	4
199	12	26	1	25	2	18	13	2
189	12	38	1	8	2	20	16	3
171	7	40	1	7	5	26	13	2
155	8	32	1	21	5	21	10	3
147	12	37	1	16	4	20	9	2
125	7	32	0	28	3	21	7	2
108	7	40	0	25	2	17	6	2
86	6	49	0	8	3	24	9	2
71	3	30	0	19	1	38	6	2
45	6	38	1	21	1	23	8	2

TABLE 2 (cont.)

MEAN NUMBER OF CELLS PER RIVER MILE BY TAXON EXPRESSED AS RELATIVE ABUNDANCE (PERCENT OF TOTAL POPULATION)

APRIL

RM	GREEN FLAG.	COCCOID GREENS	EUGLE-NOIDS	BLUE-GREENS	GOLDEN BROWNS	DIA-TOMS	CRYPTO-MONADS	DINO-FLAG.
283	12	23	2	15	1	36	9	1
248	12	22	3	14	2	38	7	1
238	13	20	4	24	0	33	5	1
199	11	27	2	11	0	42	5	3
189	10	24	2	15	2	36	9	2
171	6	29	1	15	5	29	12	1
155	7	29	2	21	3	27	11	1
147	10	27	2	18	4	24	14	1
125	7	32	2	18	2	31	5	1
108	6	35	2	15	3	32	5	2
86	6	27	3	18	3	34	7	3
71	3	19	2	42	1	30	3	1
45	8	25	2	21	2	36	5	1

TABLE 2 (cont.)

MEAN NUMBER OF CELLS PER RIVER MILE BY TAXON EXPRESSED AS RELATIVE ABUNDANCE (PERCENT OF TOTAL POPULATION) APRIL

RM	GREEN FLAG.	COCCOID GREENS	EUGLE-NOIDS	BLUE-GREENS	GOLDEN BROWNS	DIA-TOMS	CRYPTO-MONADS	DINO-FLAG.
283	12	23	2	15	1	36	9	1
248	12	22	3	14	2	38	7	1
238	13	20	4	24	0	33	5	1
199	11	27	2	11	0	42	5	3
189	10	24	2	15	2	36	9	2
171	6	29	1	15	5	29	12	1
155	7	29	2	21	3	27	11	1
147	10	27	2	18	4	24	14	1
125	7	32	2	18	2	31	5	1
108	6	35	2	15	3	32	5	2
86	6	27	3	18	3	34	7	3
71	3	19	2	42	1	30	3	1
45	8	25	2	21	2	36	5	1

CODE NUMBERS FOR PHYTOPLANKTON FROM THE ARKANSAS RIVER

Chlorophyceae -- 1000
  Volvocales
    Carteria sp. 1111
    Chlamydomonas sp. 1 1102
    C. sp. 2 1103
    C. sp. 3 1106
    Chlorogonium sp. 1118
    Chloromonas sp. 1121
    Dysmorphococcus variabilis 1119
    Eudorina sp. 1104
    Gloeomonas sp. 1117
    Gonium sociale 1107
    G. sp. 1123
    Pandorina charkowiensis 1116
    P. morum 1101
    Pedinomonas sp. 1120
    Phacotus sp. 1122
    Pteromonas sp. 1105
    Sphaerellopis sp. 1109
  Tetrasporales
    Asterococcus sp. 1331
    Gloeocystis ampla 1201
    G. gigas 1206
    G. vesiculosa 1202
    Sphaerocystis shroeteri 1203
  Chlorococcales
    Actinastrum hantzschii 1317
    Ankistrodesmus convolutus 1303
    A. falcuatus 1304
    Chlorella sp. 1368
    Chodatella longiseta 1348
    C. genevensis 1374
    Closteriopsis sp. 1322
    Coccoid green sp. 1382
    Coelastrum microporum 1316
    C. reticulatum 1356
    C. scabrum 1339
    C. sp. 1387
    Crucigenia crudifera 1343
    C. irregularis 1333
    C. quadrata 1334
    C. rectangularis 1347
    C. tetrapedia 1344
    Dictyosphaerium erenbergianum 1576
    D. pulchellum 1302

D. sp. 1381
Dispora crucigenioides 1364
Elakatothrix viridis 1385
Euastropsis Richteri 1369
Franceia Droescheri 1305
Gloeoactinium limneticum 1386
Golenkinia radiata 1349
Krichneriella lunaris 1337
K. obesa 1313
K. subsolitaria 1346
Lagerheimia subsalsa 1391
Micratinium pusillum 1310
Nephrocytium agardhianum 1350
Oocystis borgei 1327
O. lacustris 1359
O. marsonii 1367
O. parva 1366
O. pusilla 1358
O. solitaria 1361
O. subsolitaria 1389
O. sp. 1371
Pachycladon umbrinus 1365
Pediastrum duplex 1314
P. simplex 1332
P. tetras 1319
P. tetras v. tetraedron 1390
Planktosphaeria sp. 1341
Quadrigula chodatii 1315
Q. closteriodes 1306
Scenedesmus abundans 1363
S. acuminatus 1311
S. arcuatus 1372
S. bijuga 1309
S. denticulatus 1354
S. dimmorphus 1325
S. hystrix 1370
S. quadracauda 1308
S. obliqus 1301
Schroederia setigera 1323
Tetraedron minimum 1307
T. regulare 1377
Tetrastrum heterachanthum 1357
Trochiscia reticularis 1373
Westella botryoides 1340

Euglenophyceae--2000

Euglenales

Euglena Allorgei 2123
E. pisciformis 2108
E. variablis 2101
E. sp. 2117

Lepocinclis ovum 2105
Phacus brevicaudus 2126
P. caudatus 2129
P. longicaudata 2111
P. sp. 2127
Strombomonas verrucosa 2102
S. sp. 2124
Trachelomonas scabra 2102
T. volvocina 2103

Conjugatophyceae --3000

Zygnemtales
Arthrodesmus 3208
Closterium 3203
Desmidium 3211
Euastrum 3207

Cyanophyceae--4000

Chroococcales
Aphanothece microspora 4215
A. nidulans 4216
A. saxicola 4217
Chroococcus pallidus 4221
C. turgidus 4220
Dactylococcopsis rhaphidioides 4226
Gloeocapsa sp. 4201
Gomphosphaeria aponia 4222
G. lacustris 4214
Holopedia sp. 4223
Merismopedia elegans 4219
M. glauca 4218
M. sp. 4203
Microcystis aeroginosa 4206
M. flos-aquae 4210
M. incerta 4204
M. marginata 4212
Rhabdoderma lineare 4113
Romeria lepoliensis 4115

Oscillatoriales
Ananbaena sp. 4104
Aphanizomenon sp. 4102
Lyngbya sp. 4106
Oscillatoria sp. 1 4101
Oscillatoria sp. 2 4105
O. limosa 4110

Chrysophyceae--5000

Chrysomonadales
Chromulina sp. 5102
Chrysococcus bisetus 5117
C. cordiformis 5104
C. minutus 5108

C. rufescens 5107
C. puntaformis 5105
C. triporus 5113
C. sp. 5106
Chrysophaeria parvula 5115
Dinobryon barvaricum 5306
D. divergens 5303
D. sertularis 5301
Hymenomonas sp. 5112
Kephryion cylindrica 5111
K. mastogophorum 5109
K. rubi-claustri 5116
K. sp. 5110
Mallomonas akrokomos 5204
M. caudata 5202
M. coronata 5208
M. pseudocoronata 5205
M. sp. 5201
Ochromonas 5101
Pseudokephyrion sp. 5114
Stichogloea sp. 5306
Synura petersenii 5207
S. uvella 5210
S. sp. 5206

Bacillariophyceae--6000

Centrales

Coscinodiscus lacustris 6120
C. Rothii 6121
Cyclotella atomus 6114
C. chaeotceras 6123
C. glomerata 6103
C. kutzingiana 6115
C. megenghiniana 6112
C. michiganiana 6113
C. ocellata 6108
C. stelligera 6102
Melosira ambigua 6111
M. distans 6110
M. granulata 6104
M. islandica 6105
M. varians 6107
Microsolenia sp. 6122
Rhizosolenia sp. 6106
Stephenodiscus astrea 6116
S. dubius 6117
S. invisitatus 6118
S. tenuis 6119
S. sp. 6130

Pennales

Achnanthes linearis 6401
A. linearis v. curta 6402
A. minutissima 6403
Amphiprora sp. 6804
Amphora sp. 6210
Asterionells formosa 6202
Carpartogramma crucicula 6521 (Staureneis)
Cymbella affinis 6602
C. tumida 6603
Diploneis sp. 6520
Epithemia turgida 6604
Frustulia sp. 6522
Gomphonema constrictum 6901
G. constrictum v. capitata 6902
G. olivaceum 6903
Gyrosigma sp. 6502
Meridion sp. 6214
Navicula auriculata 6512
N. canalis 6508
N. capitata 6514
N. capitata v. hungarica 6515
N. cryptocephala 6505
N. cryptocephala v. exilis 6507
N. cryptocephala v. veneta 6506
N. exigua 6511
N. luzonensis 6509
N. mutica 6518
N. sabinana 6513
N. ventralis v. chilensis 6516
N. veridula 6517
N. zanoi 6510
Nitzschia acicularis 6810
N. amphibia 6182
N. baccata 6813
N. dissipata 6816
N. filiformis 6811
N. fonticola 6814
N. luzonensis 6817
N. palea 6809
N. paradoxa 6819
N. sigma 6815
Pinnularia sp. 6519
Pleurosigma delicatulum 6523
Surirella angustata 6806
S. brightwelli 6807
S. ovalis 6805
S. ovata 6808
S. sp. 6803
Synedra actinastroides 6212

S. acus 6204
S. fasciculata 6211
S. ulna 6201
S. sp. 6213

Cryptomonadophyceae--7000
Cryptomonadales
Chilomonas sp. 6106
Chroomonas acuta 7103
C. sp. 7105
Cryptomonas erosa 7101
C. marsonii 7102
C. ovata 7104

Pyrrhophyceae--8000
Gymnodiniales
Gymnodinium fuscum 8108
G. sp. 8102
Ceratioles
Ceratium sp. 8303
Peridiniales
Glenodinium Steinii 8203
Peridinium inconspicum 8204
P. sp. 8201

Xanthophyceae--9000
Heterococcales
Centritiractus belonophorus 9101