

Ammonia Uptake by Phytoplankton and
Limnological Studies of Mountain Lake, Virginia

by

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(ABSTRACT)

The first comprehensive year-round investigation of Mountain Lake, Virginia since 1970-71 was begun in March 1985 and continued through November 1987. Monthly studies suggested that this unique natural lake is undergoing change. Whereas inorganic nitrogen, orthophosphate, Secchi disc transparency, and primary productivity continue to suggest an oligotrophic condition, important limnological changes are indicated by the greater seasonal hypolimnetic oxygen depletion and extractable chlorophyll a which at times approach mesotrophic levels. In addition, the decrease in alkalinity, the increase in sulfate levels, and the increase in pH fluctuations compared to the past, suggest that Mountain Lake is susceptible to damage or change by acid rain and perhaps other perturbations that effect pH alkalinity, or hardness.

Changes were also noted in phytoplankton composition. One hundred sixty-three taxa were identified which included

56.4% Chlorophyta, 17.8% Chrysophyta, 13.5% Cyanophyta, 8% Pyrrophyta, 3.7% Cryptophyta, and 0.6% Euglenophyta. Sixty percent of these taxa were new reports for Mountain Lake. Dominant pyrrophytes included Gymnodinium sp. and Peridinium wisconsinense. Dominant chlorophytes included Scenedesmus bijuga, Quadrigula chodatii, and Oocystis pusilla. Important cryptophytes were Cryptomonas erosa var. reflexa, C. pusilla, and C. pyrenoidifera. The most abundant cyanophyte was Aphanocapsa elachista var. conferta. The only diatom (chrysophyte) that ever dominated was Cyclotella meneghiniana.

Studies of ammonia uptake by the phytoplankton, using the ammonia analog [^{14}C]methylamine (MeA), revealed that during thermal stratification, phytoplankton succession was related to rapid ammonia uptake. Each successive phytoplankton community had significantly higher V_{max} values for ammonia (methylamine) until midsummer when ammonia-nitrogen levels were at a seasonal low. At that point, the V_{max} values dramatically declined and the community became dominated by blue-green algae. When allochthonous inputs of inorganic nitrogen renewed the levels of ammonia-nitrogen, V_{max} values increased and the community changed, replacing the blue-green algae. Communities dominated by green algae (Chlorophyta) had higher MeA (and

thus ammonia) uptake rates than those dominated by cryptophytes or blue-green algae (Cyanophyta).

The effect of various treatments and inhibitors on MeA uptake by the phytoplankton support the conclusion that ammonia uptake is a chemical, light-independent, energy-dependent process.

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Prologue

In March of 1985 a study of Mountain Lake, Virginia, was begun which would continue for 33 months. The study consisted of two phases. The first phase was a limnological study of the lake which consisted of monthly sampling to determine pH, hardness, alkalinity, nutrient levels (ammonia-nitrogen, nitrate-nitrogen, orthophosphate-phosphorus, sulfate, iron, and silica), rate of primary productivity by the phytoplankton, chlorophyll a levels of the phytoplankton, and composition and density of the phytoplankton populations.

The major objective of this phase was to characterize the lake and to assess changes by comparing the present physical, chemical, and biological properties of the lake as well as the phytoplankton composition and density with that reported by past investigators.

After the first year, it was realized that some important changes had occurred since the last yearlong study in 1970-71. These included the following:

1. oxygen in the hypolimnion was being depleted during late summer;
2. rates of primary productivity by the phytoplankton were greater;
3. greater seasonal pH fluctuations were seen; and

4. phytoplankton populations had different composition and greater density. In addition it was realized that ammonia was the more abundant and consistently available inorganic nitrogen source for the phytoplankton.

The second phase of the study was begun in March of 1986 and continued through November 1987. The major objectives were (1) to determine if the changes seen during the first year would be repeated and thus be indicative of real trends and, (2) to determine if a relationship between the ability of phytoplankton populations to rapidly or efficiently take up ammonia and the seasonal succession of populations would be revealed during thermal stratification.

These studies are described in detail and discussed in Chapters I-IV which were written as self-contained chapters in a format for submission to different peer-reviewed journals. The tables and figures relevant to each chapter have been placed after the body of that chapter. An Appendix section is included after Chapter IV which includes data, formulas, etc., which were too lengthy or inappropriate to be included in the text of the chapter.

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CHAPTER I

Mountain Lake, Virginia: An Oligotrophic Lake Under Increasing Stress

INTRODUCTION

Mountain Lake, Giles County, is a natural oligotrophic alpine lake located near the summit of Salt Pond Mountain at 1180 m elevation in the Allegheny range of southwest Virginia (Figure 1). Since its discovery in 1751, this lake has been regarded by laymen and scientists as a clean, unspoiled, and pristine aquatic habitat (Parker et al., 1975). The perpetuation of this condition to the present has resulted from a combination of many things, which include:

1. the relatively well-preserved state of the natural vegetation within the lake basin, a portion of which comprises an uncut virgin hemlock-rhododendron forest;
2. the large volume of clean precipitation, runoff and spring water feeding the lake, annually about equal to the lake's volume;
3. the limited recreational uses of the lake and surrounding land by visitors to the Mountain Lake hotel and associated facilities.

Historically, relatively few potential perturbations to Mountain Lake or its watershed have been recorded. These have included:

1. 19th and early 20th century grazing of sheep and/or cattle near the lake during summers;
2. construction of the hotel and cottages in the 1930's along with the county road (Rt. 700) (Figure 1);
3. salting of the road routinely in winter since about 1940;
4. loss of the American chestnut from blight spread in the 1920-30's;
5. summer leakage of the aging septic tanks for the cottages within the lake basin;
6. occasional stocking of the lake, usually with rainbow trout, and addition of tons of beach sand to the south end.

None of these potential perturbations, however, have been cited as the cause of any permanent change in the oligotrophic state of Mountain Lake (Obeng-Asamoah, 1971; Obeng-Asamoah and Parker, 1972).

Beginning in 1983, the Gal-Tex Corporation, which owns the Mountain Lake Hotel and most of the surrounding lake basin, embarked on a major development of the resort to accomodate 2,000 residents year-round. To minimize impact, the Corporation designated the entire forested area on its property a wildlife sanctuary, much of which is surrounded by the Jefferson National Forest. Nearly all the area around the east, west, and north rim of the lake is heavily wooded

with mixed hardwoods (maple, beech, oak, birch) and Canadian hemlock with an understory including rhododendron and mountain laurel.

Pursuant to the need for baseline information to aid decisions on the type of waste treatment facility for the Mountain Lake Hotel and resort, in the summer of 1984, a preliminary survey was conducted of Pond Drain which flows from the north end of the lake. During this survey, several observations were made on Mountain Lake which suggested that increased stress might be occurring. Four such observations were:

1. periodic appearance of copious foam or suds along the leeward shore;
2. placement of a large PVC pipe in the south end of the lake to a depth of one meter as part of an air conditioning system;
3. partial drainage of the lake to complete lakeshore construction projects and protect pilings from winter ice damage;
4. presence of a phytoplankton algal community vastly different from any previously reported.

A foam and water sample from the south shoreline of Mountain Lake in September 1984 contained 11,600 $\mu\text{g/L}$ of phosphate-phosphorus. After the hotel had closed in October, the foam had dissipated some, but a foam and water sample

still contained 92 $\mu\text{g/L}$ of orthophosphate-P, greatly exceeding levels for oligotrophic lakes. An investigation disclosed that waste water from a coin-operated laundromat had been piped to a septic tank located near the lake. Foam reached the lake 48 hours after laundromat use. The laundromat was closed until spring 1985 when a new plumbing line was installed with pump to shunt the laundry waste out of the lake basin to the hotel's major waste treatment system. Henceforth, no or low phosphate detergents were emphasized for most hotel uses. Within 6 months from the closing of the laundromat, phosphate-P dropped to $< 6 \mu\text{g/L}$ and visible foam disappeared.

The large PVC pipe, which had been installed to a depth of one meter as a source of cooling water for hotel air conditioning during the warmest days of late summer, proved inefficient for cooling. Investigations also showed that small fish used the pipe for a refuge and were inevitably entrapped when the pump was activated. Accordingly, the pipe was removed and the plan to air condition the hotel with lake water abandoned.

Lake lowering by opening a new dam and spillway at the north outflow into Pond Drain was accomplished to enable construction of concrete pilings on the Lakeside Club House and new boat house and dock. This lake lowering largely destroyed the shallow benthic macrophytes around the

lakeshore to a depth of one meter. By spring 1985, the dam was closed, and the lake level restored.

The observation of the different phytoplankton community, particularly a dominant species, Dinobryon divergens which had not been reported previously, raised the question of whether Mountain Lake already may have been altered irreversibly. Thus, we undertook a yearlong study of Mountain Lake, largely addressing aspects of biological limnology to permit a comparison of the lake's trophic state, relative to that of earlier studies, the most recent one being that of Obeng-Asamoah (1971) and Obeng-Asamoah and Parker (1972).

MATERIALS AND METHODS

The first yearlong study was March 1985 through February 1986, and included a reasonably comprehensive survey of physical, chemical, and biological characteristics each month. Table 1 summarizes the specific lake characteristics and methods used. These have been described more elaborately elsewhere (references cited; Parker and Parson, 1987).

RESULTS AND DISCUSSION

Pertinent background concerns Mountain Lake's shape, depth, morphometry, and origin. The lake is 0.9 km long and 0.25 km wide (Figure 2). Despite this small size, this lake

lies over three major geological formations. It is unique in being the only natural lake in the unglaciated southern Appalachians (Parker et al., 1975). With a mean depth of 9.75 m, its maximum depth of ca. 31 m is confined to one small location at the north end. The small area of Mountain Lake (189,000 m²) relative to that of the lake basin (ca. 1.0 km²) which receives ca. 150 cm water as precipitation per year explains the aforementioned point that about one lake volume of water flows through annually. Such a volume of water is important for maintaining a full lake, because Mountain Lake was formed about 2000 years ago by a natural rock slide near the headwaters of a small alpine stream (Marland, 1967; Parker et al., 1975). The natural dam at the north end of Mountain Lake apparently is still incompletely sealed so that underground water loss causes a drop in lake level during drought years (Parker et al., 1975).

Our yearlong study showed that the pH varied considerably with a low of 6.5 in March, April, August, and October and a high of 9.2 in June (Figure 3). Comparable fluctuations were not reported in previous yearlong studies. Roth and Neff (1964) reported a seasonal range of 6.6-7.6 (Figure 4) and Obeng-Asamoah (1971) reported a seasonal range of only 6.1-7.2 (Figure 5). The maximum pH coincided with the peak in water hardness of 78 in June, significantly up from the 23 mg CaCO₃/L of May (Figure 6). The normally low

alkalinity (Figure 7) and low hardness make this lake sensitive to activities that would change these parameters. The temporary perturbation that occurred in June probably was caused by concrete work and addition of limestone paths near the water's edge.

Biological data also revealed that a possible disturbance may have occurred in June concurrent with the peak in pH. Phytoplankton primary productivity integrated to a depth of 17 m shows the rate in June was less than half of that in April (Figure 8). The production rate then recovered with a high of 70.88 mg C fixed/m²/hr in August. This reduction of productivity in June was not from low photosynthetically available radiation (Table 2). The number of cells/mL also suggest a disturbance may have occurred in June. The number of cells/mL was reduced from 667 in May to 510 in June (23.5% less) (Figure 9). The reduction in productivity and in cell density cannot be explained by the ratio of available nitrogen to phosphorus either. The ratio of N:P expressed as mg/L indicates that there is virtually no difference in the ratios when a comparison is made between April, May, June and July (Figure 10). The analytical data imply that nitrogen is somewhat limited during the spring and summer with the exception of August. Determination of the Shannon-Weaver Diversity Index (Shannon and Weaver, 1964) for phytoplankton each month during the study is shown in Figure

11. The decline in diversity from May through July suggests that the disturbance in June also affected the number of species present. It is normally expected that species diversity will increase during the summer (Moss, 1973) and such has occurred previously in Mountain Lake (Obeng-Asamoah and Parker, 1972).

Several important measurements indicated that the lake had changed since former yearlong studies were conducted. Oxygen levels had declined to <5.7 ppm at a depth of 17 m by June and continued to decline to nearly 0 ppm by October. In contrast, oxygen profiles from Roth and Neff (1964) declined up to November to a level of only 5.5 ppm at 20 m, and the profiles of Obeng-Asamoah (1971) declined to October but reaching only 7.2 ppm at 21 m. Figures 12-14 show oxygen profiles for July and October and illustrates these differences for these studies.

In addition to the discovery of anaerobic conditions at the bottom, the observation of Dinobryon divergens dominance suggests that the phytoplankton community may have changed since 1970-71. Table 3 shows a comparison of the dominant species present in three months between 1970-71 and 1985-86. It is clear that no single species occurs in both lists. Even though plankton tows were used by Obeng-Asamoah (1971) and Utermohl settling chambers were used in the current study to concentrate the samples so that enumeration procedures could

be completed, the very different results probably are not due just to the difference in methods. Another comparison (Table 4) of vertical distribution of species suggests that species were not only different in 1971, but the lake contained fewer phytoplankton cell numbers then than presently. In the 1971 study of Obeng-Asamoah, a continuous-flow centrifuge was used to concentrate the samples for enumeration, and in the current study Utermohl settling chambers were used. These two methods give quite similar results. A comparison of species lists for the two studies, however, also showed dramatic differences. Of the 108 species identified in the current study, 61% were not reported by any and all previous investigators (Hutchinson and Pickford, 1932; Grover and Coker, 1940; Coker and Hayes, 1940; Forest, 1954; Whitford, 1964; Obeng-Asamoah, 1971) going back to the 1930's.

CONCLUSIONS

The current study has suggested that Mountain Lake is susceptible to disturbance, but that the rapid turnover of the water in the lake gives it the capacity to recovery quite rapidly. The lake is becoming more productive and the phytoplankton community is markedly different from the past. A continuation of these studies should determine longer term effects: Are the phytoplankton populations different because of the temporary disturbance or due to natural succession as

the lake undergoes eutrophication? What will happen to the productivity of the lake when the lawn near the lake is fertilized or additional forest is cleared? Will nutrient levels be reduced when the cottages (with old septic systems) in the lake basin are removed? Will the anaerobic conditions of the bottom continue or will this also recover from the temporary disturbance? Will construction projects cause turbidity problems? Beyond these questions, long-term information on this unique natural ecosystem should contribute further to our understanding of the eutrophication process.

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Table 1. List of variables, methods and instruments used

Water Samples	Kemmerer Bottle (Wildco Wildlife Supply Company, Saginaw, MI)
°C	Yellow Springs Instrument, S-C-T Meter, Model 33 (Yellow Springs Instrument Company, Yellow Springs, OH)
pH	Corning pH Meter Model 610A (Corning Medical, Corning Glass Works, Medford, MA)
Hardness	Titrimetric, EDTA (APHA-AWWA-WPCF, 1985)
Alkalinity	Titrimetric, Methyl purple (APHA-AWWA-WPCF, 1985)
Primary Productivity	Uptake of $^{14}\text{C-HCO}_3$ (Parker and Samsel, 1984; Parker et al., 1977; Parker and Parson, 1987)
Extractable Chlorophyll <u>a</u>	Fluorometric (Parker et al., 1982) Turner Designs Fluorometer, Model 10-005R (Turner Designs, Inc., Mt. View, CA)
	Spectrophotometric (APHA-AWWA-WPCF, 1985) Perkin-Elmer Spectrophotometer, Model 552 Perkin- Elmer, Norwalk, CT)
Phytoplankton	Utermohl settling
Inorganic Nitrogen	NH ₄ -N: Phenate (Lind, 1979); NH ₃ -N: Cadmium reduction (APHA-AWWA-WPCF, 1985); PO ₄ -P:
Phosphate	Ascorbic acid, Isobutanol extraction (Murphy and Riley, 1962)
O ₂ Dissolved	Modified Winkler (APHA-AWWA-WPCF, 1985)
Photosynthetically Available Radiation	Li-Cor, Inc., Quantum Radiometer/Photometer (Li-Cor, Inc., Lincoln, NE)
Transparency	Secchi disk

Table 2. Solar Radiation and Transparency

MONTH	LIGHT AT SURFACE ($\mu\text{Ein}\cdot\text{m}^2\cdot\text{sec.}^{-1}$)	1% LIGHT (meter)	SECCHI DISC (meter)
March	1700	7-8	3.3
April	ND	ND	3.6
May	1540	8-9	6.0
June	1540	9-10	8.2
July	1200	8-9	5.5
August	1500	7-8	4.4
September	ND	ND	6.0
October	1500	10-11	9.6
November	130	4-5	5.8
December	1000	6-7	5.8
January	400	8	8.8
February	1500	6-7	7.0

Table 3. Comparison of Phytoplankton Ranks: 1970 and 1985

JULY			
Species	1970 Rank	Species	1985 Rank
<u>Bambusina brebissonii</u>	1	<u>Scenedesmus bijuga</u>	1
Kützing		(Turp.) Lagerheim	
<u>Staurastrum ophiura</u>	2	<u>Asterionella formosa</u>	2
Lundell		Hassall	
<u>Radiofilum conjuctivum</u>	3	<u>Gymnodinium</u> sp.	3
Schmidle			
<u>Quadricula chodatii</u>	4	<u>Cyclotella meneghiniana</u>	4
(Tan-Ful.) G. M. Smith		Kützing	
<u>Sphaerocystis schroeteri</u>	5	<u>Chilomonas paramecium</u>	5
Chodat		Ehrenberg	
<u>Mougeotia</u> sp.	6	<u>Peridinium wisconsinense</u>	6
		Eddy	
<u>Micrasterias radiosa</u>	7	<u>Chroococcus minutus</u>	7
Ralfs		(Kütz.) Rabenhorst	
<u>Quadrigula lacustris</u>	8	<u>Spondylosium planum</u>	8
(Chod.) G. M. Smith		(Wolle) West & West	
<u>Micrasterias radiata</u>	9	<u>Chromulina ovalis</u>	9
Hassall		Klebs	
<u>Staurastrum arctison</u>	10	<u>Tabellaria fenestrata</u>	10
(Ehren.) Lundell		(Lyng.) Kützing	

Table 3 (Cont'd.)

AUGUST

Species	1970	Rank	Species	1985	Rank
<u>Staurastrum ophiura</u>		1	<u>Peridinium wisconsinense</u>		1
Lundell			Eddy		
<u>Radiofilum conjuctivum</u>		2	<u>Gymnodinium</u> sp		2
Schmidle					
<u>Desmidium cylindricum</u>		3	<u>Cryptomonas pyrenoidifera</u>		3
Greville			Geitler		
<u>Bambusina bresbissonii</u>		4	<u>Scenedesmus bijuga</u>		4
Kützing			(Turp.) Lagerheim		
<u>Sphaerocystis schoerteri</u>		5	<u>Asterionella formosa</u>		5
Chodat			Hassall		
<u>Quadrigula lacustris</u>		6	<u>Chlorochromonas minuta</u>		6
(Chod.) G. M. Smith			Lewis		
<u>Quadrigula chodatii</u>		7	<u>Chilomonas paramecium</u>		7
(Tan.-Ful.) G. M. Smith			Ehrenberg		
<u>Scenedesmus</u> sp.		8	<u>Chroococcus minutus</u>		8
			(Kütz.) Rabenhorst		
<u>Dictyosphaerium</u> sp.		9	<u>Chromulina ovalis</u>		9
			Klebs		
<u>Micrasterias radiosa</u>		10	<u>Elakatothrix gelatinosa</u>		10
Ralfs			Wille		

Table 3 (Cont'd.)

SEPTEMBER			
Species	1970 Rank	Species	1985 Rank
<u>Radiofilum conjuctivum</u> Schmidle	1	<u>Cyclotella meneghiniana</u> Kützing	1
<u>Quadrigula lacustris</u> (Chod.) G. M. Smith	2	<u>Chroococcus minutus</u> (Kütz.) Rabenhorst	2
<u>Tabellaria flocculosa</u> (Lyng.) Kützing	3	<u>Chlorochromonas minuta</u> Lewis	3
<u>Tabellaria fenestrata</u> (Lyng.) Kützing	4	<u>Chromulina ovalis</u> Klebs	4
<u>Staurostrum ophiura</u> Lundell	5	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	5
<u>Bambusina brebissonii</u> Kützing	6	<u>Cryptomonas pyrenoidifera</u> Geitler	
<u>Sphaerocystis schroeteri</u> Chodat	7	<u>Elakatothrix gelatinosa</u> Wille	7
<u>Gonatozygon pilosum</u> Wille	8	<u>Peridinium cinctum</u> (Muell.) Ehrenberg	8
<u>Mougeotia</u> sp.	9	<u>Chroococcus dispersus</u> (V. Keiss) Lemmerman	9
<u>Planktosphaeria</u> <u>gelatinosa</u> G. M. Smith	10	<u>Chilomonas paramecium</u> Ehrenberg	10

Table 4. Comparison of Vertical Distribution of Algae: 1971 and 1985

Depth (m)	MARCH 1971	
	Algae	Cells/mL
0	<u>Cyclotella</u>	44
	<u>Dictyosphaerium</u>	7
	Others, mainly microalgae	9
	Flagellates	5
1	<u>Cyclotella</u>	61
	<u>Planktosphaeria</u>	16
	<u>Oocystis</u>	5
	Others	5
6	<u>Cyclotella</u>	73
	<u>Planktosphaeria</u>	16
	Flagellates	6
	<u>Radiofilum</u>	4
	<u>Oocystis</u>	4
	<u>Dictyosphaerium</u>	2
17	<u>Cyclotella</u>	53
	<u>Planktosphaeria</u>	25
	<u>Dictyosphaerium</u>	6
	Flagellates	3
	<u>Tabellaria</u>	2
	Dinoflagellates	2
	Others	2

Table 4 (Cont'd.)

Depth (m)	MARCH 1985	
	Algae	Cells/mL
0	Dinoflagellates	130
	Flagellates	13
	<u>Asterionella</u>	4
1	Dinoflagellates	127
	Flagellates	22
	<u>Asterionella</u>	4
	<u>Tabellaria</u>	4
6	Dinoflagellates	275
	Flagellates	39
	<u>Asterionella</u>	13
	<u>Tabellaria</u>	4
	<u>Botryococcus</u>	4
17	Dinoflagellates	88
	Flagellates	26
	<u>Asterionella</u>	18
	<u>Tabellaria</u>	4
	<u>Bambusina</u>	4

Table 4 (Cont'd.)

Depth (m)	APRIL 1971	
	Algae	Cells/mL
0	<u>Cyclotella</u>	76
	<u>Planktosphaeria</u>	7
	Flagellates	7
	<u>Oocystis</u>	3
	Dinoflagellates	1
1	<u>Sphaerocystis</u>	80
	<u>Cyclotella</u>	57
	<u>Oocystis</u> and Flagellates	5
6	<u>Cyclotella</u>	76
	<u>Planktosphaeria</u>	45
	Flagellates	13
	<u>Ankistrodesmus</u>	3
	Other	4
	Dinoflagellates	1
17	<u>Cyclotella</u>	79
	Flagellates	12

Table 4 (Cont'd.)

APRIL 1985		
Depth (m)	Algae	Cells/mL
0	Flagellates	114
	Dinoflagellates	67
	<u>Synedra</u>	9
	<u>Tabellaria</u>	4
1	Dinoflagellates	130
	Flagellates	100
	<u>Asterionella</u>	9
	<u>Synedra</u>	9
	<u>Tabellaria</u>	4
6	<u>Navicula</u>	4
	Dinoflagellates	88
	Flagellates	87
	<u>Asterionella</u>	4
17	<u>Synedra</u>	4
	Flagellates	30
	Dinoflagellates	26
	<u>Synedra</u>	9
	<u>Navicula</u>	4

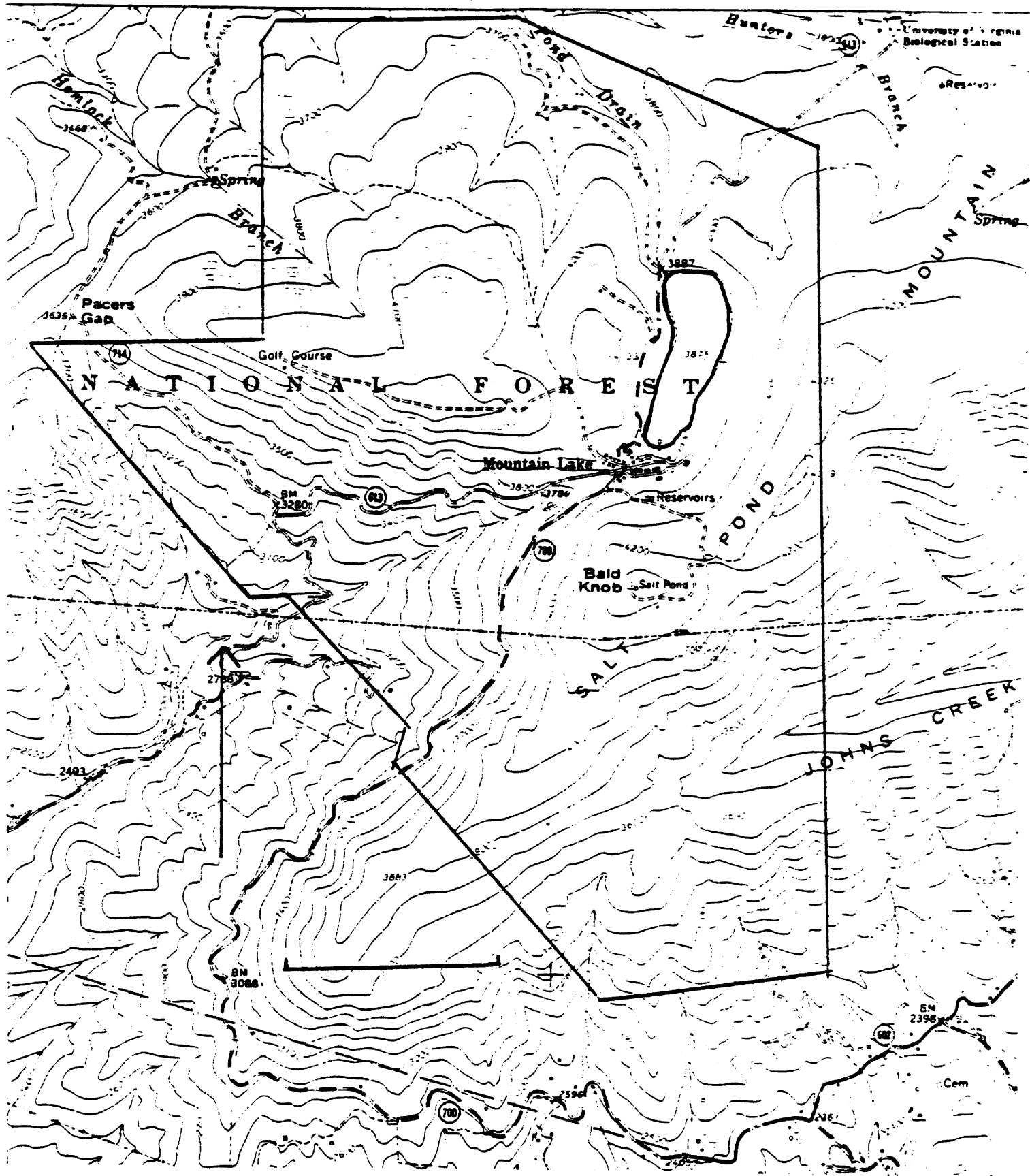


Figure 1. Portion of U.S. Geological Survey map (Eggleston, Va. 1977) showing location of Mountain Lake ($37^{\circ}21'56''\text{N}$, $80^{\circ}31'39''\text{W}$), outline of the resort-owned property, Pond Drain, Little Stony Creek, Rt. 700, etc. Line is one kilometer and arrow points north.

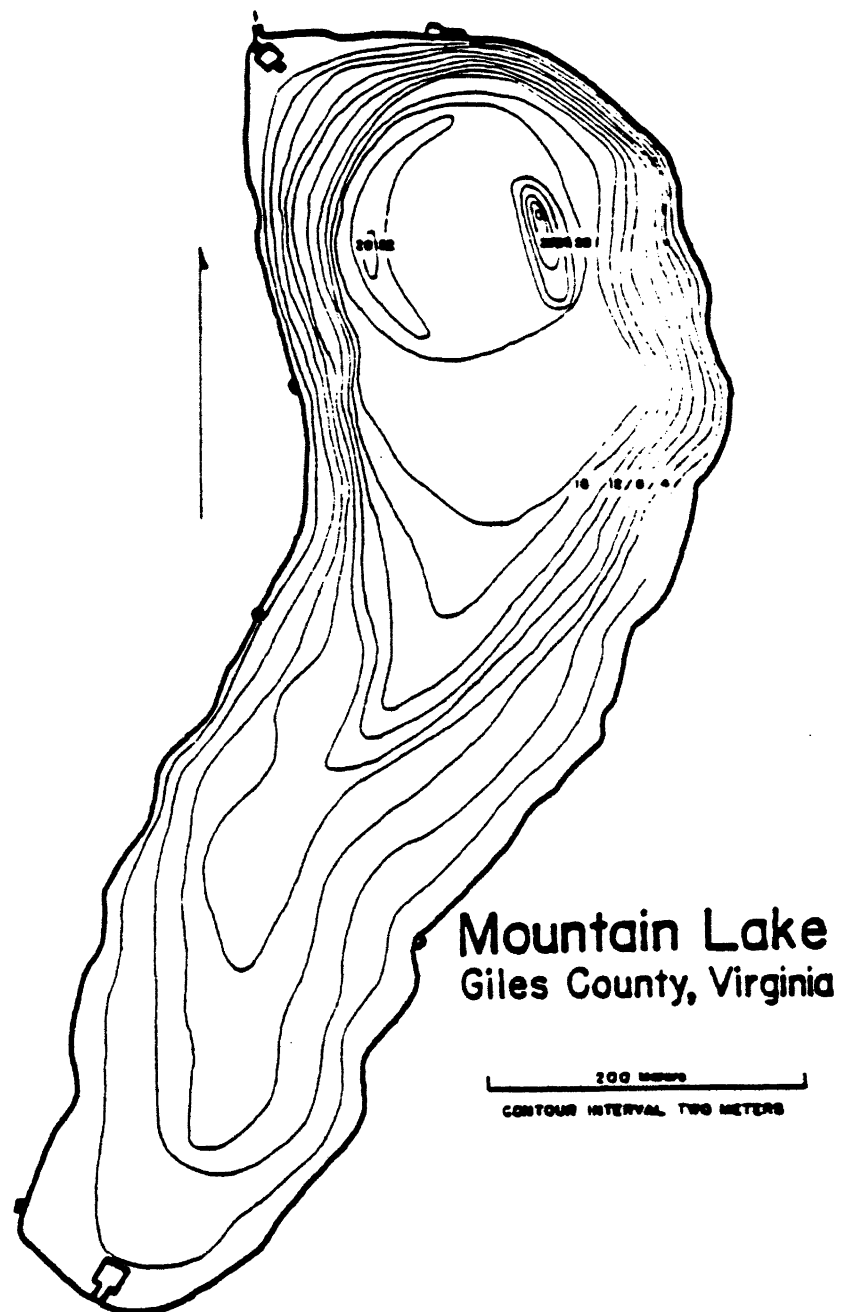


Figure 2. Morphometric map of Mountain Lake, modified by Parker et al. (1975) from Deevey et al. (1957) and Roth and Neff (1964).

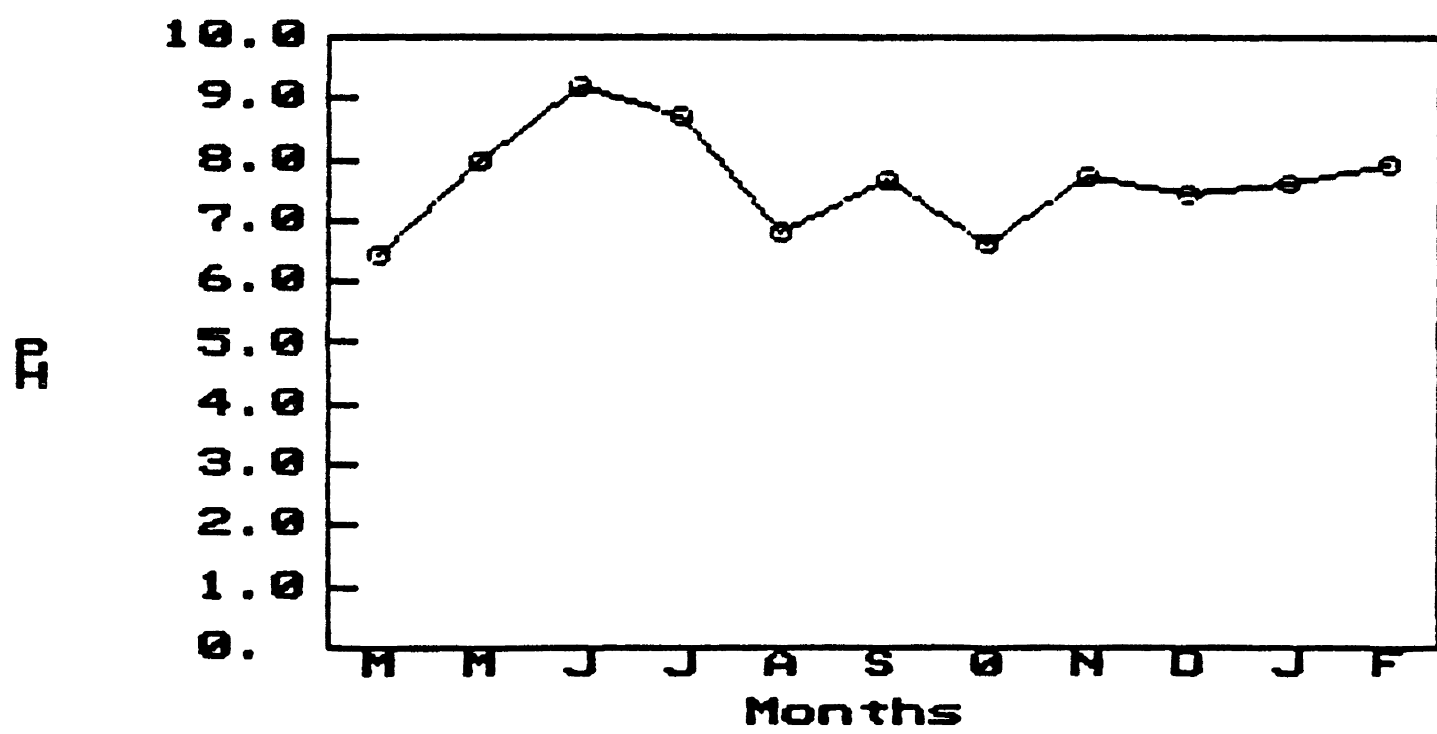


Figure 3. Monthly pH of Mountain Lake surface water, 1985-86.

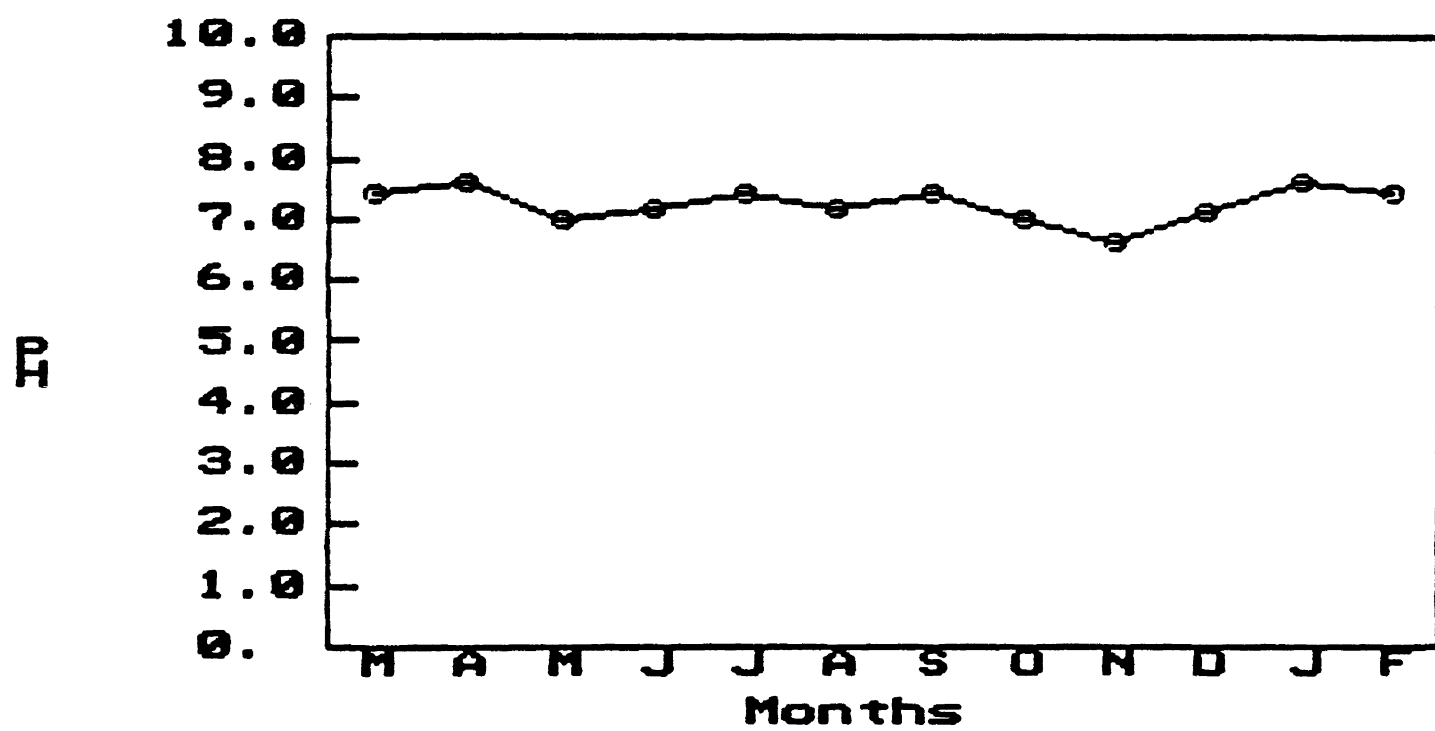


Figure 4. Monthly pH of Mountain Lake surface water, 1962-63 (from Roth and Neff, 1964).

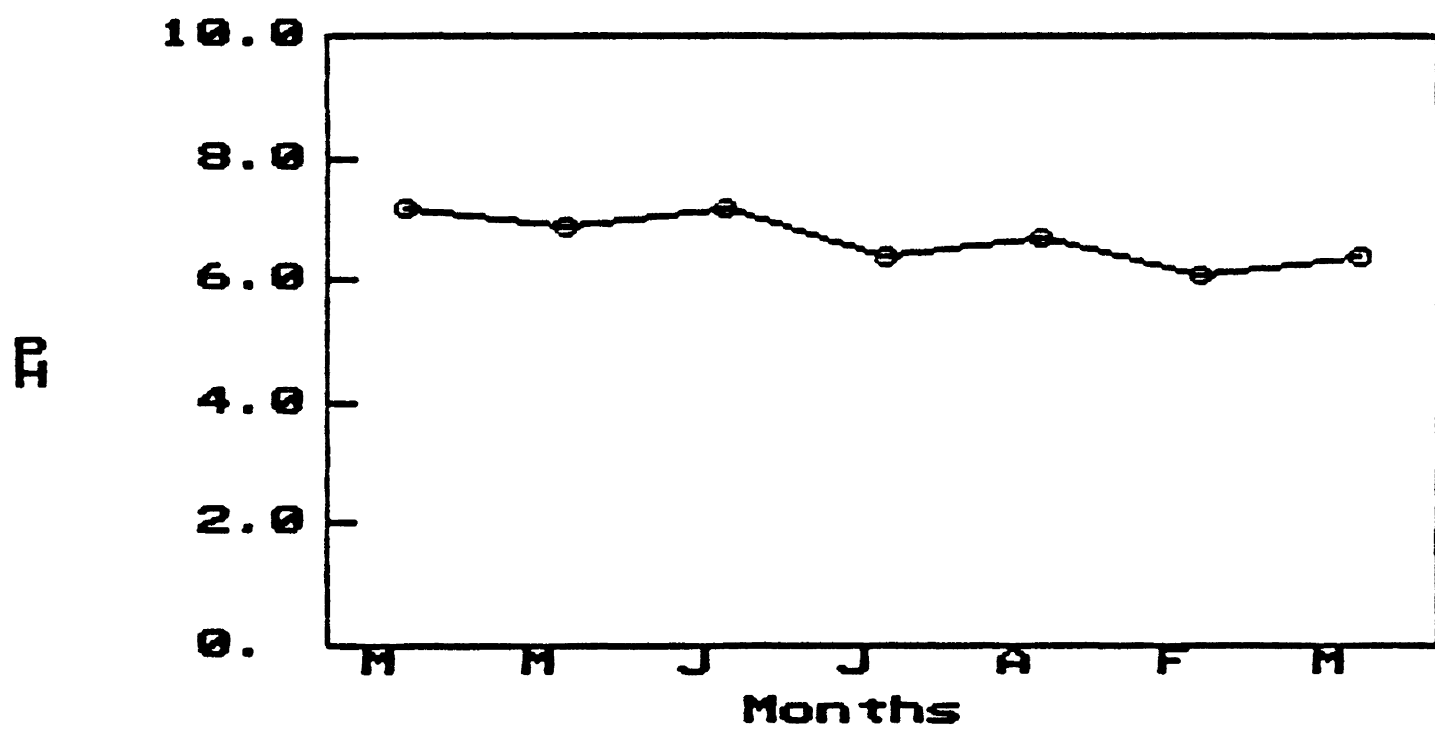


Figure 5. Monthly pH of Mountain Lake surface water, 1970-71 (from Obeng-Asamoah, 1971).

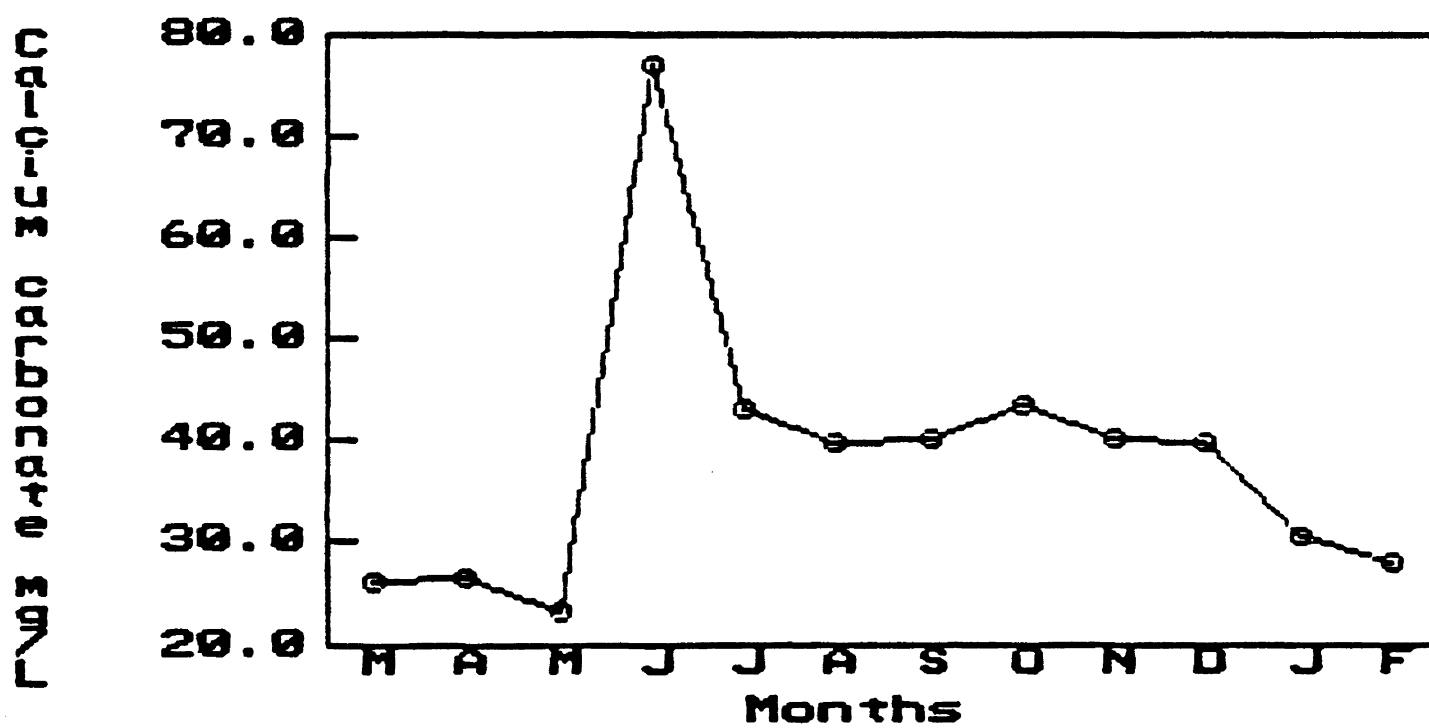


Figure 6. Monthly hardness values for Mountain Lake, mean of all depths, 1985-86.

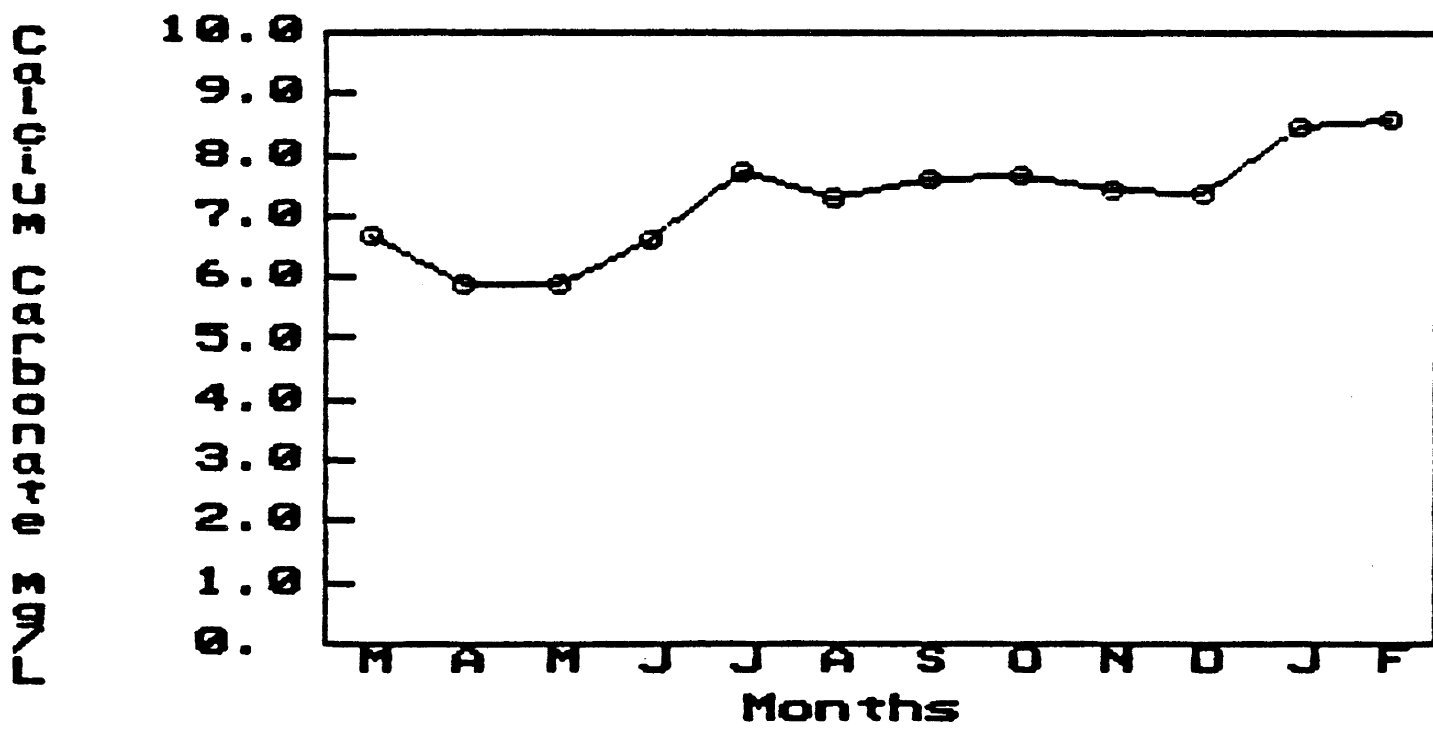


Figure 7. Monthly alkalinity values for Mountain Lake, mean of all depths, 1985-86.

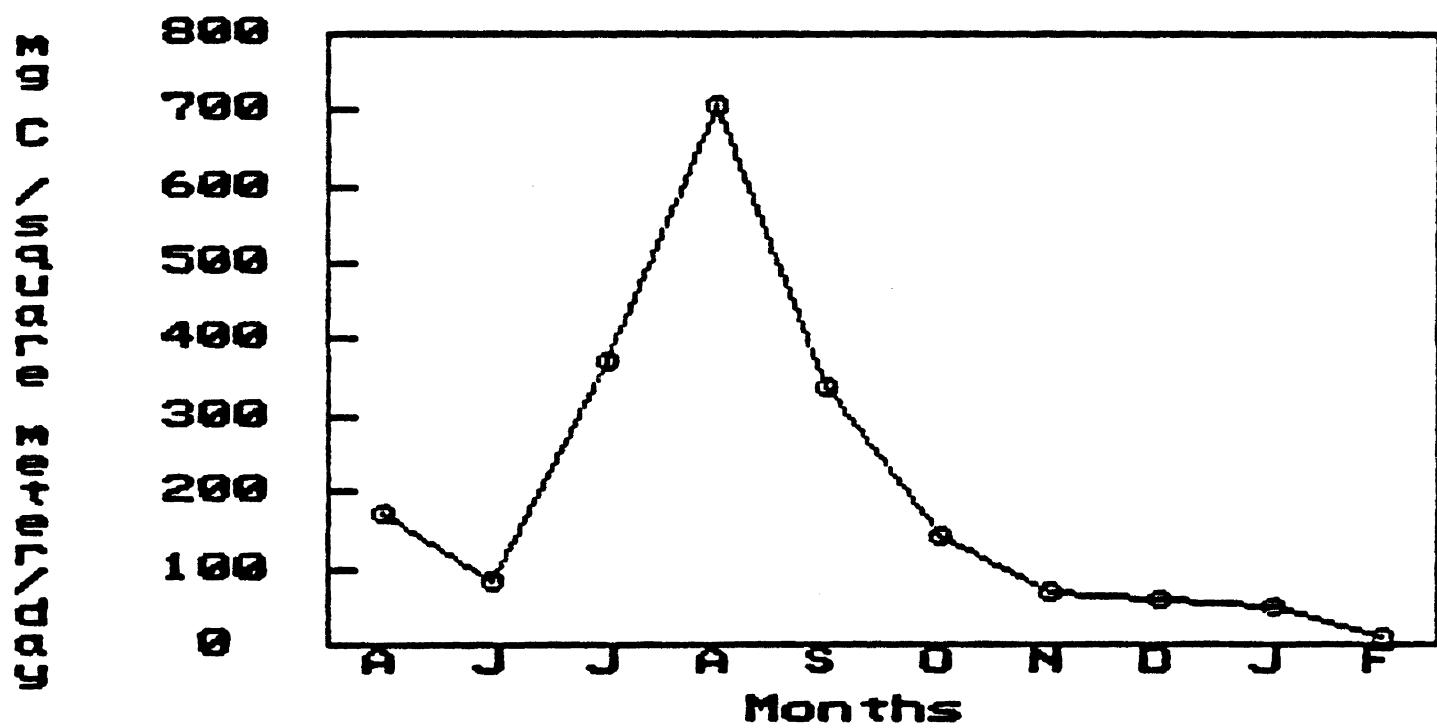


Figure 8. Monthly primary productivity (mg C fixation/m²/day) for Mountain Lake, integrated to base of the photic zone, 1985-86.

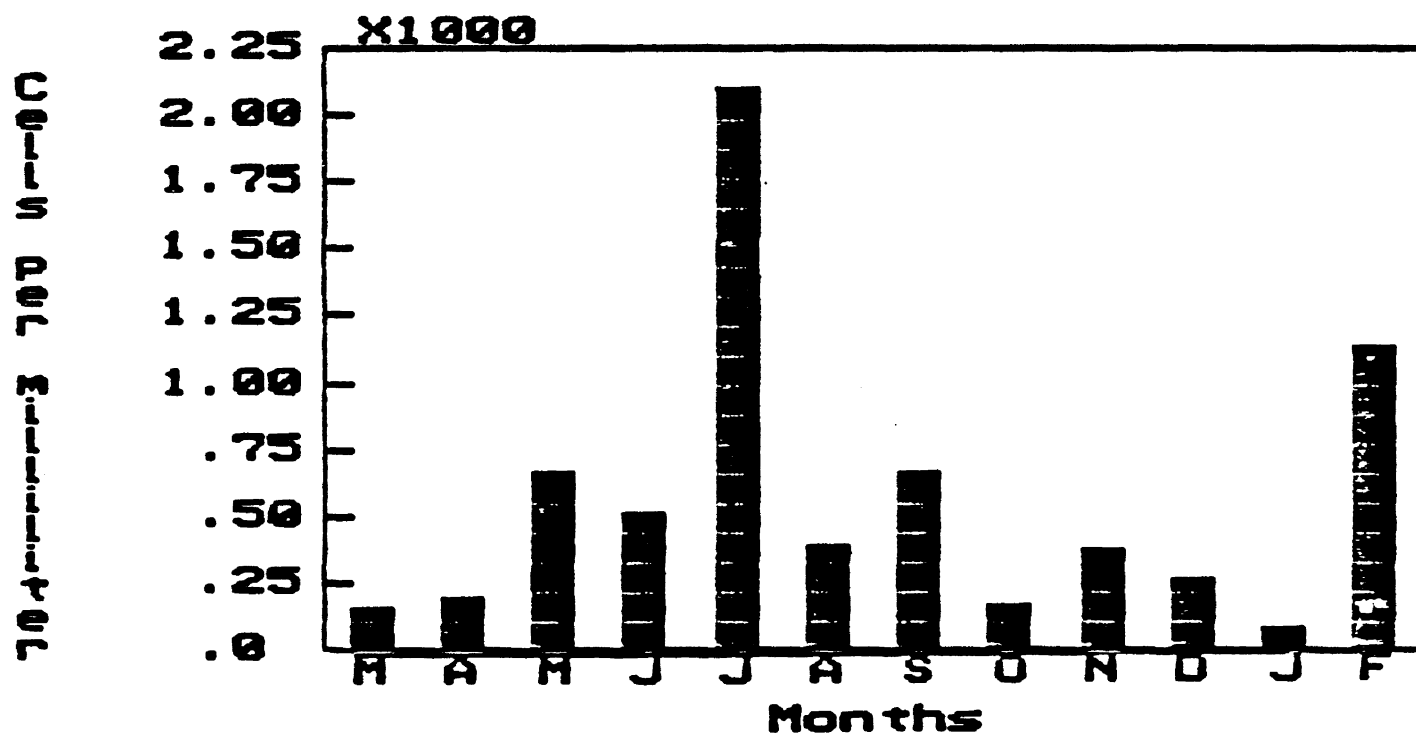


Figure 9. Monthly cell counts/mL at 1.0 m in Mountain Lake, 1985-86.

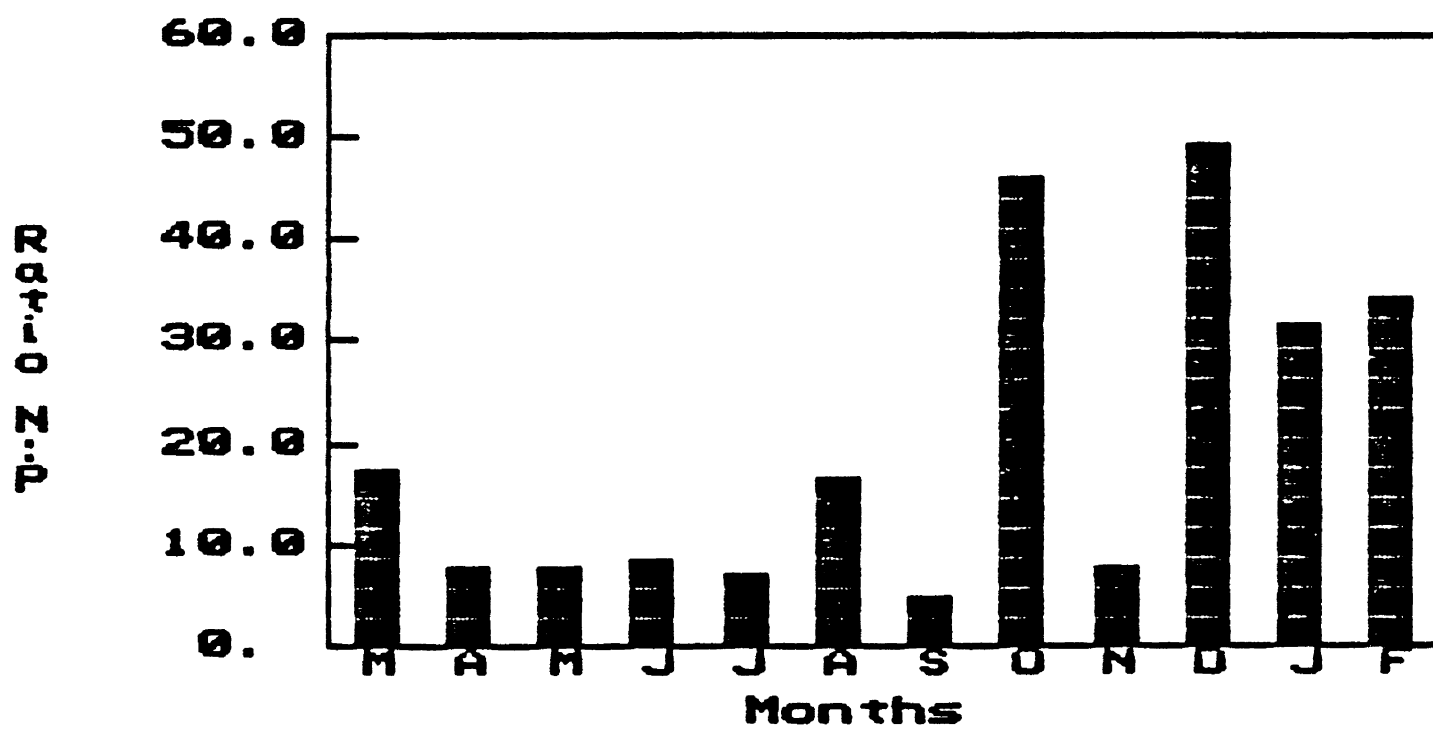


Figure 10. Monthly inorganic nitrogen ($\text{NH}_4\text{-N} + \text{NO}_3\text{-N}$)/orthophosphorus ($\text{PO}_4\text{-P}$) ratio for Mountain Lake, 1985-86.

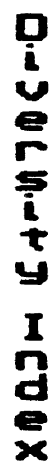


Figure 11. Monthly Shannon-Weaver diversity indices for phytoplankton at 1.0 meter in Mountain Lake, 1985-86.

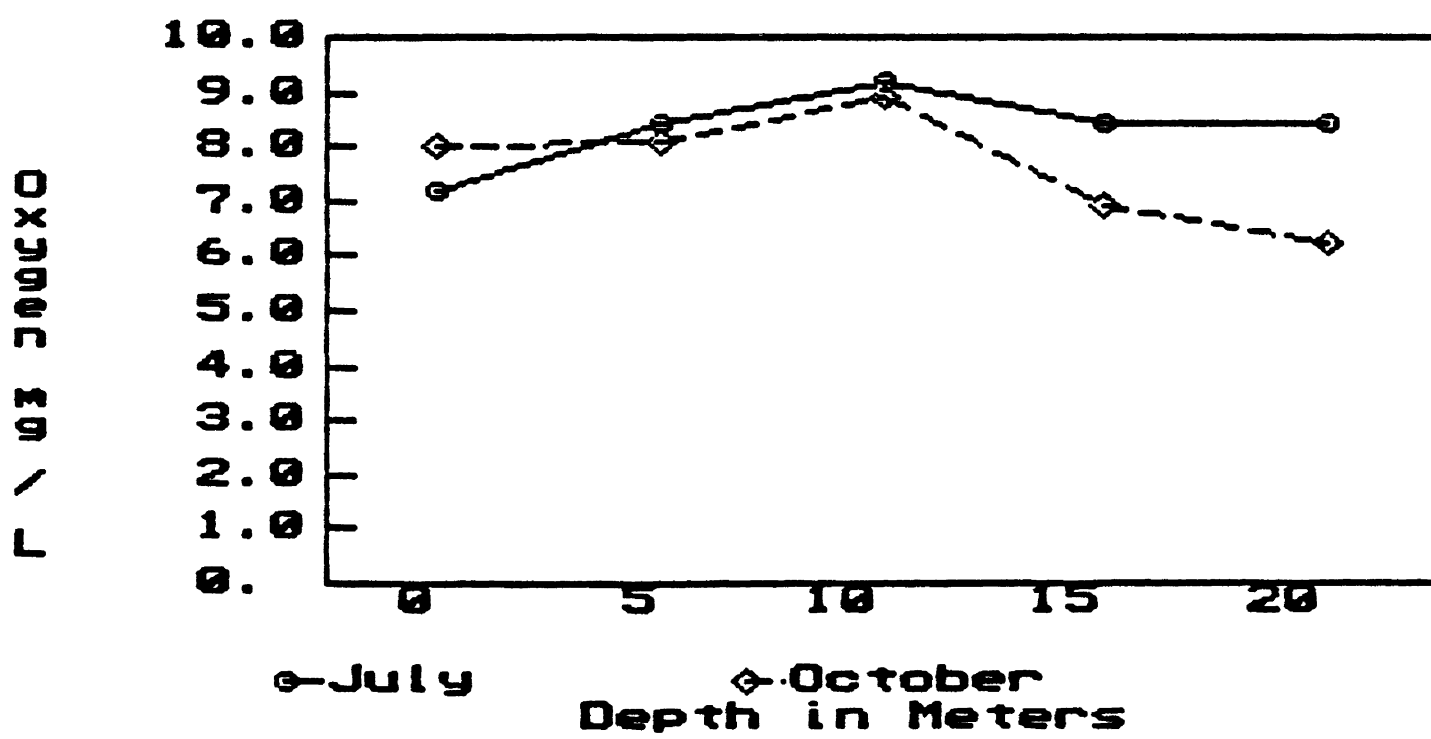


Figure 12. Dissolved oxygen depth profiles for July and October, 1963 at Mountain Lake (from Roth and Neff, 1964).

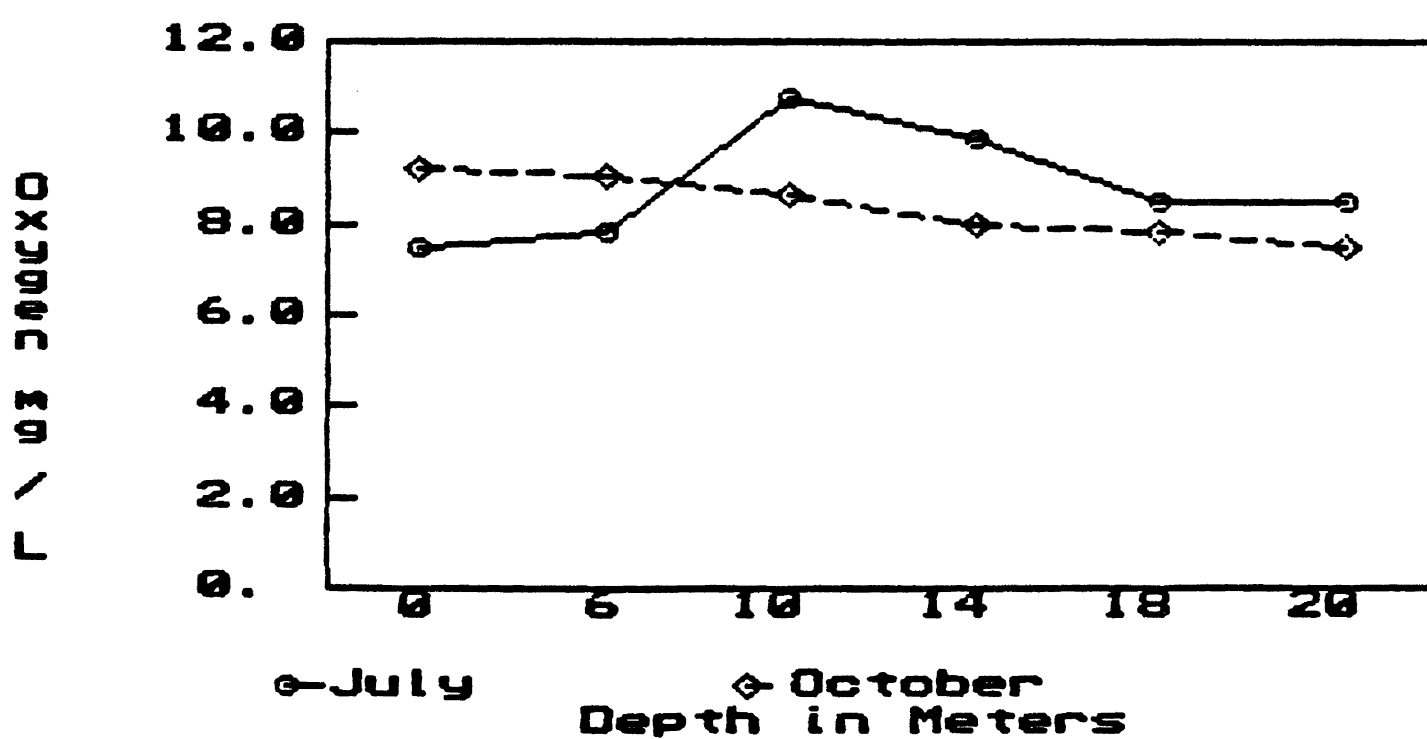


Figure 13. Dissolved oxygen depth profiles for July and October, 1971 at Mountain Lake (from Obeng-Asamoah, 1971).

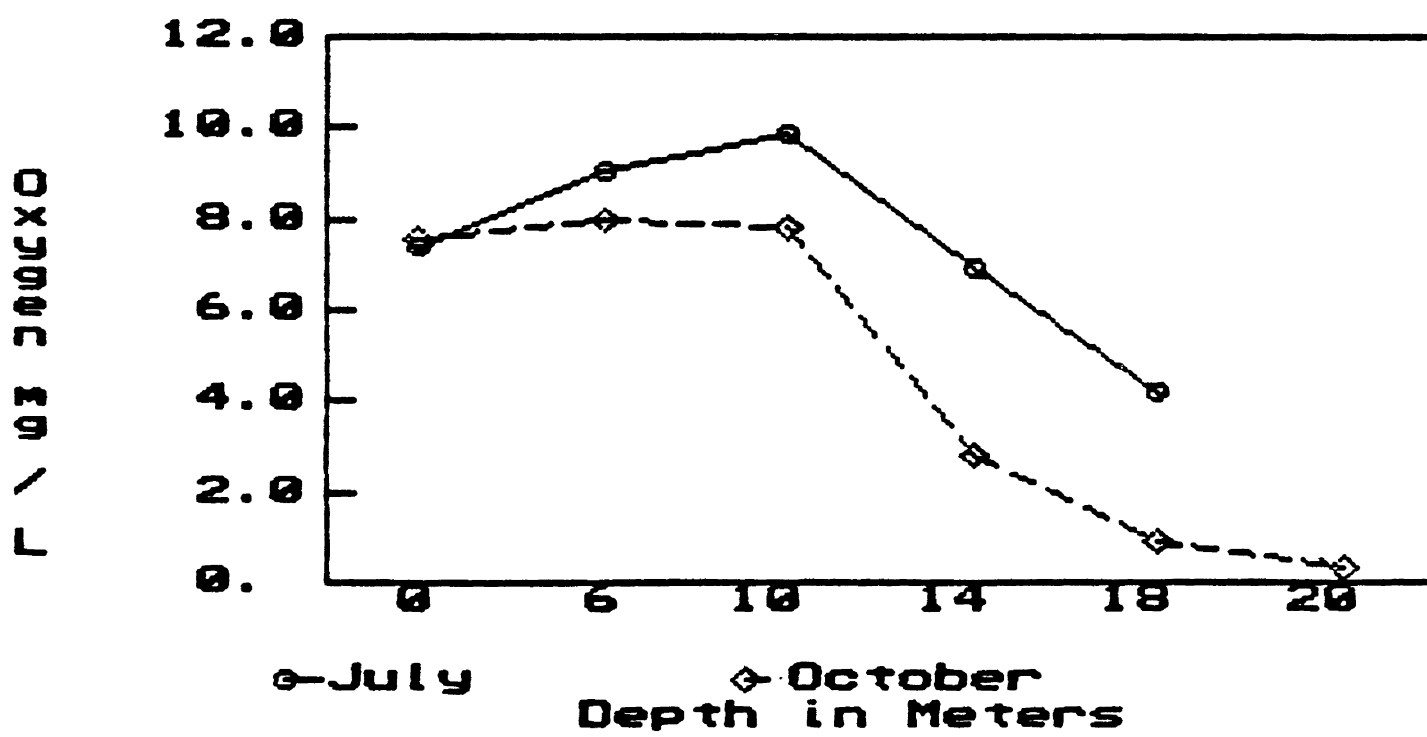


Figure 14. Dissolved oxygen depth profiles for July and October, 1985 at Mountain Lake.

CHAPTER II

Phytoplankton Studies in a Natural Lake in the Southern Appalachian Mountains in Virginia

In the spring of 1985 a phytoplankton study was begun which encompassed community structure as well as limnological characteristics of Mountain Lake, Giles County, Virginia. The study was completed in November of 1987. This present study represents the longest and most comprehensive study ever done on this lake. Mountain Lake is an important lake to limnologists because it is the only natural lake in the southern Appalachians and is important economically because it is the central focus of a resort hotel. The lake had not been thoroughly studied since 1970, although notable research on the lake includes studies of phytoplankton (Williams, 1930; Hutchinson and Pickford, 1932; Coker and Hayes, 1940; Grover and Coker, 1940; McCalla, 1942; Whitford, 1964), studies of macrophytes (Dubay and Simmons, 1981; Jarvis, 1988), limnology (Roth and Neff, 1964; Obeng-Asamoah, 1971; Obeng-Asamoah and Parker, 1972; Simmons and Neff, 1973), paleontology (Marland, 1967), geology (Parker et al., 1975), and seasonal protozoan colonization (Van Brunt, 1984).

In the fall of 1984 several observations made it obvious that it was time for another comprehensive study of the lake. These included the presence of foam on the lake suggesting

phosphate pollution from detergents; dominant alga, Dinobryon that had not been reported before; and activities around the lake by the corporation that operates the resort that might disturb the lake which included lowering the lake level for construction of a new boat house, the installation of an air conditioning system which would use lake water to cool the hotel, and the plan to operate the hotel all year rather than just in the summer and early fall.

The present investigation sought to determine phytoplankton community structure, relative abundance, diversity, and seasonal periodicity and compare it to the past as well as to update the limnological characteristics of the lake.

MATERIALS AND METHODS

Mountain Lake originated from a natural rock slide and the damming of a small mountain stream about 2,000 years ago (Marland, 1967; Parker et al., 1975). It is ovoid with a maximum length of 0.9 and maximum width of 0.25 kilometer; half of the volume and 60% of the area lie above the 6-meter contour with 99% of both area and volume occurring in the upper 22 meters (Roth and Neff, 1964). In the only previous yearlong study, low nutrient levels were paralleled by low phytoplankton productivity (Obeng-Asamoah and Parker, 1972). The dominant attached macrophyte (Nitella flexilis), however,

was considered a significant contributor to the productivity of the lake (Dubay and Simmons, 1979).

Monthly sampling and data collection began in March 1985 and continued through November 1987. North (22 meter depth) and south (12 meter depth) sampling sites were marked with buoys. The first eight months samples were collected from 4 depths (0.1, 1, 6, 10 meters) at the south site and from 5 depths (0.1, 1, 6, 10, 17 meters) at the north site, our choice being based on experimental depths used by Obeng-Asamoah and Parker (1972). Subsequent sampling was limited to the north site as statistical analysis showed no significant difference between the two sites at identical depths or between any location for several surface transects. Table 5 summarizes our methods and equipment or instruments used. Physical measurements included temperature, light, transparency, and conductivity. Chemical measurements included orthophosphate, ammonia, nitrate, nitrite, sulfate, silica, iron, alkalinity, hardness, pH, and oxygen. Biological measurements included primary productivity (^{14}C method), chlorophyll *a* standing crop of phytoplankton, and phytoplankton identification and enumeration.

Phytoplankton species seen in plankton tows and in Utermohl chambers were identified to species level where possible using Anton and Duthie (1981), Bourrelly (1968; 1970), Desikachary (1959), Prescott (1951), Rabenhorst (1933;

1937), Smith (1933), and Whitford and Schumacher (1984).

Algal enumeration was accomplished by settling 100 mL of lake water treated with acid-Lugol's preservative (APHA-AWWA-WPCF, 1985) in Utermohl chambers and viewing with a Wild inverted microscope. The monthly abundance of species was determined from the mean of nine samples (north and south sites) for the first eight months and thereafter from five samples (north site). Natural units which represented an organism (single cells, filaments, or colonies) were counted.

Phytoplankton and limnological data were quantified and compared with previous investigators. To compare the present trophic state with the past, both a phytoplankton index (Nygaard's) and limnological index (Carlson's) were used. Species diversity values were calculated using a formula of Shannon and Weaver (1964) with values expressed in bits per individual because logarithms to the base 2 were used.

RESULTS AND DISCUSSION

Temperature

Figure 15 shows six profiles, illustrating the pattern of thermal stratification for 1985-86. A thermocline at about 4 meters was evident in May and persisted until late October when it began at about 11 meters. By late November the water column temperature was nearly isothermal and remained so through February. A layer of ice covered the lake from December 24 through February 20 with one partial

melting in January. The ice reached 22 cm maximum thickness on January 18, 1986.

The patterns seen in 1986-87 are similar to those seen for 1985-86 except that in the spring of 1986, stratification was first evident in April rather than May. One other difference seen in the winter of 1986-87 was that the formation of surface ice was almost a month later (January) and the maximum thickness was only 18 cm. The temperature maximum of 22°, 24°, and 23° were reached in July of 1985, 1986, and 1987 respectively. Complete temperature profiles are seen in Appendix A.

These patterns of stratification and temperature maxima were very similar to those seen by Roth & Neff (1964) and Obeng-Asamoah & Parker (1972).

Alkalinity, pH, Hardness and Sulfate

Figure 16 (A-C) shows alkalinity along with pH fluctuations and hardness. Note the wide fluctuations in pH with a low of 5.7 in May 1986 and a high of 9.19 in June 1985. The maxima in hardness and pH coincide. These maxima are not explained by high productivity rates or high cell densities. These wide fluctuations in pH have not been reported in other year-round studies of Mountain Lake. Roth & Neff (1964) reported a pH range of 6.6-7.6 for the surface water, and

Obeng-Asamoah (1971) reported a pH range of 6.1-7.2 in the upper 1 meter.

Although complete pH, alkalinity, hardness, and sulfate data are not available from any single previous study, sulfate levels (Table 6) in 1985-86 were significantly higher than 1970-71 (Obeng-Asamoah, 1971). In addition, total alkalinity data from Marland (1967), using same statistical comparison as outlined in Table 6, is significantly higher than in our study. Complete sulfate data are shown in Appendix B. The annual increase in sulfate levels between 1971 and 1985 may be due to acid rain conditions in the area as the annual deposition of sulfate from rainfall is quite high. Annual wet depositions of $20.0 \text{ kg} \cdot \text{ha}^{-1}$ and $23.6 \text{ kg} \cdot \text{ha}^{-1}$ of sulfate were measured during 1985-1986 and 1986-87, respectively near Mountain Lake (Boris Chevone, Atmospheric Deposition Project, Virginia Polytechnic Institute and State University). These values are within the range currently measured in most of eastern North America, but exceeded the $9 - 14 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ considered the maximum allowable safe range for protection of sensitive aquatic ecosystems (Schindler, 1988), such as Mountain Lake.

Schindler (1988), discussing the impact of acid rain on freshwater ecosystems used the ratio of alkalinity to Ca^{2+} and Mg^{2+} as a measure of a lake's sensitivity to disturbance by acid rain and suggested that changes of this ratio over time

may be a way of measuring the impact of acid rain. The mean (n=32) ratio of alkalinity to Ca^{2+} and Mg^{2+} (using EDTA hardness levels which measures both of these ions) during our study was 0.200. According to Schindler (1988), lakes in pristine areas usually have values of 0.6-1.1 and sensitive lakes in areas of high acid deposition have values of < 0.2 . The pH of the rain, monitored less than one mile from the lake, during the time of our study ranged from 3.93-5.11 (Boris Chevone, National Atmospheric Deposition Study, Virginia Polytechnic Institute and State University) with a mean (n=108) value of 4.36. In addition, according to Schindler (1988), as acidification of a lake occurs, alkalinity drops and sulfate increases.

The low alkalinity and hardness make this lake sensitive to processes or activities that would change these measurements. During the first week of May (1985), the dam and spillway, which partially control the level of water in the lake, were closed to permit the lake to return to normal levels. This caused the lake water to come into contact with new concrete pillars as well as cement 'waste' in this construction area. At this same time, limestone paths were added near the lake edge. The temporary maxima in pH and hardness coincided or just followed these construction activities near the water's edge.

Sulfate data also support the conclusion that construction activities caused this temporary disturbance. Figure 17 shows that the maximum level of sulfate seen in 1985-86 was in May when the lake water was allowed to come in contact with 'cement waste' which is known to contain sulfates.

Dissolved Oxygen

Earlier studies (using same methods as ours) showed that depletion of oxygen at the greatest depths was maximal in November with 5.5 mg/L at 20 meters (Roth and Neff, 1964) and in October with 7.2 mg/L at 21 meters (Obeng-Asamoah, 1971). In our present study, oxygen levels began dropping in midsummer every year with levels < 5.0 mg/L by July, < 4.0 mg/L by August, and < 3.0 mg/L by September. Figure 15 shows oxygen profiles to illustrate these patterns. The annual hypolimnetic lows in the present study were 0.3 mg/L (12% saturation) in late October, 1.15 mg/L (14% saturation) in early October, and 0.95 (13% saturation) in mid-November of 1985, 1986, and 1987, respectively. This change was one of the most significant findings of our study. Complete oxygen profiles and oxygen saturation levels are shown in Appendix C.

A comparison of current areal hypolimnetic oxygen deficits with the past show the same trend in oxygen

depletion. Roth & Neff (1964) reported a deficit of $0.0035 \text{ mg O}_2 \cdot \text{cm}^{-2} \cdot \text{day}^{-1}$ and Obeng-Asomoa (1971) reported a deficit of $0.0016 \text{ mg O}_2 \cdot \text{cm}^{-2} \cdot \text{day}^{-1}$. In the present study rates were 0.0078 , 0.0078 , and $0.0098 \text{ mg O}_2 \cdot \text{cm}^{-2} \cdot \text{day}^{-1}$ for 1985, 1986, and 1987, respectively. These rates are almost three times higher than those of Roth & Neff (1964) and more than five times higher than those of Obeng-Asomoa (1971). These rates are still lower than the upper limits of $0.017 \text{ mg O}_2 \cdot \text{cm}^{-2} \cdot \text{day}^{-1}$ given by Hutchinson (1957) and $0.025 \text{ mg O}_2 \cdot \text{cm}^{-2} \cdot \text{day}^{-1}$ given by Mortimer (cited in Hutchinson, 1957) for oligotrophic lakes.

There is only one feasible explanation for the greater depletion of hypolimnetic oxygen seen during the present study. The accumulation of dead organic matter has probably increased because of the annual inputs of nutrients from the septic systems from the cottages which are along the southern shore of Mountain Lake. These cottages have been in place for many years.

Nitrogen, Phosphorus, Silica

Figure 18 shows the monthly mean levels (5 depths) of nitrate-nitrogen, ammonia-nitrogen, and orthophosphate-phosphorus. During the study, nitrate-nitrogen plus ammonia-nitrogen ranged from 15-87 ppb which falls within the classification of oligotrophic or ultra-oligothrophic lakes (Wetzel, 1975; OECD, 1982). The

pattern of declining nitrate-nitrogen during thermal stratification seen during the summer of 1985 was not repeated during the summers of 1986 and 1987, but ammonia-nitrogen was generally the most abundant nitrogen source during the summer months. Orthophosphate-phosphorus levels were consistently low throughout, necessitating concentration through extraction. Even though orthophosphate-phosphorus levels were low, ranging from 0.8-7.5 ppb, low N:P ratios suggest that nitrogen rather than phosphorus may sometimes be limiting. This may have been the case in April, May, June, July, September, and November of 1985, May of 1987, and October of 1986 and 1987 (Figure 19). Soluble silica (Figure 20) fluctuated over a rather narrow range from 0.3-1.6 ppm. These levels are rather low compared to other temperate lakes [which commonly have 1.2-12 ppm (Reynolds, 1984)], and its impact on diatom populations will be discussed later. For complete monthly nutrient data, see Appendix D. A comparison of current nutrient levels (Table 6) with the last yearlong study (Obeng-Asamoah, 1971) shows that with the exception of orthophosphate-phosphorus and sulfate, nutrient levels are similar to what they were 15 years ago. The higher levels of orthophosphate-phosphorus obtained by Obeng-Asamoah (1971) may be inaccurate because concentration-extraction was not used, and all other data

from 1970-71 suggest Mountain Lake was at least as oligotrophic then as now.

Not enough ammonia data was available from the 1971 study for comparison. During our study ammonia levels steadily increased with 1987 levels being significantly higher than the two previous years; whereas, nitrate levels did not significantly change during our study.

^{14}C Primary Productivity

Table 7 shows the monthly photosynthetic rates at the five selected depths. Productivity was usually greatest in the upper 1 meter. Light inhibition at the surface is probable, because rates at the surface relative to 1 meter were lower 14 out of 20 months. Our highest rate of $25.6 \text{ mg C} \cdot \text{m}^{-3} \cdot \text{hr}^{-1}$ at 0.1 meter in August 1985 is 2.8 times higher than any value obtained by Obeng-Asamoah (1971) and 1.5 times higher than any value reported by Parker (1975). Table 8 shows available solar radiation and primary productivity values for the water column by integration to a depth of 17 meters, a depth approximating the compensation point (see Table 7). The highest rate on a daily basis of $1,281.88 \text{ mg C} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ was more than 2.5 times higher than reported by Simmons and Neff (1973). These rates, including our annual mean of $200.31 \text{ mg C} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ for 1985-86, characterize

oligotrophic lakes (Wetzel, 1975). The formula used to determine photosynthetic efficiency is shown in Appendix E.

Chlorophyll a

Spectrophotometric measurement of extracted chlorophyll a for phytoplankton standing crop is shown in Table 9. Annual means for chlorophyll a were 3.30, 2.17, and 2.43 mg·m⁻³ for 1985, 1986, and 1987. These means are classified as oligotrophic but the highest value approaches mesotrophic levels (Wetzel, 1975; OECD, 1972).

Phytoplankton Identification and Enumeration

During the present study 163 taxa were identified which included 92(56.4%) Chlorophyta, 29(17.8%) Chrysophyta, 22(13.5%) Cyanophyta, 13(8%) Pyrrophyta, 6(3.7%) Cryptophyta, and 1(0.6%) Euglenophyta. Table 10 shows the complete species list and the rank of dominant phytoplankton by month based on settling chamber analysis. During the first year of the study (1985-86), the dinoflagellates, Gymnodinium sp. and Peridinium inconspicuum dominated during the spring. No Gymnodinium species had been reported in previous studies except that of Van Brunt (1984) who observed colonization of polyurethane foam pieces. The green alga, Scenedesmus bijuga, that dominated in early summer also was not recorded by Obeng-Asamoah (1971), but was reported by

Forest (1954). Its abundance in 1985 was associated with the high pH in June and July and the high hardness value of July, both of which would accompany increases in bicarbonate ion. Some Scenedesmus species can take up bicarbonate which favors their presence in lakes with neutral or more basic pH (Goldman et al., 1972). By late summer dinoflagellates regained their dominance with Peridinium wisconsinense and Gymnodinium sp. being most abundant. P. wisconsinense is another species not previously reported. The fall and early winter were dominated by Cyclotella meneghiniana, an important part of the phytoplankton species reported previously. Also in the fall the blue-green Chroococcus minutus first became important and persisted until early winter. Cryptomonad species (Cryptomonas pyrenoidifera, C. pusilla, C. erosa var. reflexa) dominated with Cyclotella during the winter. These cryptomonads were important, especially under the ice from late December to late February. None of these Cryptomonas species had been previously reported.

During the second year (1986-87) of our study, Cryptomonas pusilla dominated in the spring along with lesser numbers of Cyclotella meneghiniana. Cryptomonas pusilla continued to be an important species throughout the summer along with Stichococcus bacillaris, Peridinium wisconsinense, Dinobryon elegantissima, and in late summer,

Aphanocapsa elachista var. conferta. None of these species had previously been reported. The fall phytoplankton was dominated by Aphanocapsa elachista var. conferta along with the cryptophytes already mentioned plus Cryptomonas ovata, Quadrigula chodatii, and Gymnodinium sp. Only the Quadrigula species had previously been reported. The cryptophyte species present in the fall plus Gymnodinium dominated through the winter.

During the spring of the third year (1987) of our study, two cryptophyte species, Cryptomonas pusilla, and C. erosa var. reflexa, continued to dominate along with Gymnodinium sp. These two cryptophytes persisted through early summer. The dominant midsummer species were Scenedesmus bijuga and Quadrigula chodatii, but by late summer Aphanocapsa elachista var. conferta dominated along with Q. chodatii. A. elachista var. conferta continued to dominate in early fall but was then replaced by Scenedesmus bijuga, Oocystis pusilla, and Cryptomonas pusilla.

Relative abundances of the dominant groups of algae also are shown in Figure 21. It can be seen that pyrophytes generally dominated in winter and early spring. Chlorophytes dominated during the summer. Cyanophytes reached their greatest dominance during the fall. Another trend that can be seen is an increase in cyanophytes during the study. Chrysophyte dominance was not repeated at the same season

each year but rather began in the fall of 1986 and continued until the following spring. Cryptophytes were consistently present throughout the study. They reached their greatest dominance during the winter of 1985-86 and remained very important throughout the following year and into the summer of 1987.

Monthly counts (natural unit·mL⁻¹) are graphed in Figure 22. The highest count of 1810 units·mL⁻¹ occurred in June 1986 and probably exceeds densities present during Obeng-Asamoah's (1971) study. This earlier study stated that highest counts (based on plankton tows) occurred in the summer with 4 cell·mL⁻¹ in July, 5 in August, and 62 in September; however, cell counts based on concentration by centrifugation reached 189 cells·mL⁻¹ in February 1970. The seasonal densities showed that two phytoplankton peaks occurred in the first year, namely July 1985 and February 1986. This pattern is uncommon for oligotrophic lakes, which more often show spring and fall peaks more or less corresponding to the dimictic condition. However, a major summer peak is seen in some lakes that are covered by ice for several months during the winter (Ilmavirta and Kotimaa, 1974; Round, 1981). The February 1986 peak was largely due to cryptophytes. High cell densities of cryptomonads under the ice in winter has been observed in other lakes (Verduin, 1959). Their abundance may be explained by their heterotrophic habit and their ability

to survive under low light (Verduin, 1959; Morgan and Kalf, 1979). It has long been known that some cryptomonads can grow at low temperatures on organic substrates (Wright, 1964). The high cell densities of these algae do not accompany high primary productivity rates as would be expected if their main energy source is light. Furthermore, ice was 13 cm thick with about 10 cm of snow on top of it, so available light was much reduced.

Note that the two maxima of July 1985 and June 1986 seen during our study may have been due to unusual conditions. In July 1985, the phytoplankton was dominated by Scenedesmus bijuga which, as explained in an earlier section, often thrive under more alkaline conditions such as those which persisted in early summer that year. In June 1986, the phytoplankton was dominated by Stichococcus bacillaris which is sometimes a truly planktonic species, but also grows commonly on rock surfaces and as an epiphyte on trees as well as on soil (Round, 1981). This alga may have been introduced into the lake as the result of a change in the lake level seen during the winter, spring, and early summer. A lake level increase of 91 cm occurred from January to June. (See Appendix F for lake fluctuation data.) By May, S. bacillaris was the third most abundant species. It reached its dominance in June and disappeared by July. However, even

discounting these two maxima, the number of organisms per mL is clearly much higher than in 1970 (Obeng-Asamoah, 1971).

The contribution by diatoms to phytoplankton density was not very important. Of the 11 diatom taxa reported, only Cyclotella achieved dominance during our study. One cannot argue that silica levels are low because most of the silica is tied up in diatoms. The maximum cell density reached by any diatom taxa was only 313 cells·mL⁻¹. Also, when the levels of silica are plotted against diatom cell densities, no significant correlation exists; instead low diatom cell densities occur over the entire range (0.3-1.6 ppm) of silica. See Appendix G. Silica levels (Figure 20) in the lake are sometimes below the levels of 0.5 ppm and 0.8 ppm which Lund (1954) reported to be limiting to Asterionella and Tabellaria, respectively; and certainly are always lower than that needed for optimum growth of planktonic diatom species which Hutchinson (1967) suggested to be a few milligrams per liter. Thus it may be concluded that silica levels in Mountain Lake are generally limiting to most planktonic diatom species. Complete monthly phytoplankton densities by species is shown in Appendix H.

Comparisons of dominant algal species present July to September 1970 (Obeng-Asamoah, 1971) with the same months in the current study (1985-87) show dramatic differences (Table 11). Indeed only two species occur in both lists. Probably

some differences in these abundance lists may be attributed to differences in methods, but it doesn't account for much of the differences in species, because most of our taxa can be identified by Obeng-Asamoah's plankton tow technique, and all of Obeng's taxa are easily recognized in our settling chambers. Furthermore, differences exist in total species present. Sixty percent of the 163 species identified in our study were not reported by previous investigators (Williams, 1930; Hutchinson and Pickford, 1932; Grover and Coker, 1940; Forest, 1954; Whitford, 1964; Obeng-Asamoah, 1971; Van Brunt, 1984). Indeed, several algal taxa have been reported only rarely in North America and one, namely Lobocystis dichotoma, has been described only from one other location (Thompson, 1952; Parker et al., 1984).

In addition to dramatic changes in phytoplankton species composition, the biomass of Nitella megacarpa, an attached macrophyte, is reduced to 10% (Jervis, 1988) of its level when it was last investigated during the summer of 1973 (Dubay and Simmons, 1981).

Species Diversity

The Shannon-Weaver Diversity Index, calculated monthly for the phytoplankton, is shown in Figure 23. Annual maxima of 3.07, 3.05, and 3.44 occurred in August 1985, September 1986, and October 1987, respectively. The pattern suggested by Moss (1973) of an increase in diversity during the summer

in oligotrophic lakes is seen in the summers of 1986 and 1987. The decline seen in May-July 1985 is due to the predominance by Scenedesmus bijuga which, as discussed earlier, may have been the result of a temporary rise in pH and alkalinity. The unusually low summer diversity in June 1986 is due to the predominance of Stichococcus bacillaris which, also, was noted earlier. The lowest diversity seen during our study was in March 1986. This was due to the predominance of Cryptomonas pusilla which had survived the harsh environmental conditions under the ice. The diversity index is a useful tool in analyzing the impact of environmental changes, either those produced by man or by natural events, on phytoplankton populations.

Trophic State

Levels of inorganic nitrogen, orthophosphate, and photosynthetic rates clearly place the lake in the oligotrophic category whereas extractable chlorophyll *a* suggest mesotrophic conditions (Wetzel, 1975; OECD, 1982). Many indices have been developed which use variables, such as, species present, or species relative abundance to determine trophic state. All of these have limitations. For example, Obeng-Asamoah (1971) used Nygaard's Compound Index. This index is calculated using the sums of algal taxa observed in the following formula:

Myxophyceae + Chlorococcales + Centrales + Euglenineae
Desmidiacea

where values <1 indicate oligotrophy and values >1 indicate eutrophy. Obeng-Asamoah (1971) obtained 1.8, indicating eutrophic conditions in Mountain Lake. This disagrees with other indicators of trophic state obtained by Obeng-Asamoah (1971). In the present study a value of 1.59 was obtained when the index was calculated using the complete species list (Table 10).

One problem with Nygaard's Compound Index is that although it is generally true that Volvocales and Chlorococcales are common to fertile lakes (Hutchinson, 1967), some important exceptions are found in Mountain Lake. For example, Oocystis, Botryococcus, Gloeocystis, and Sphaerocystis are either common in unproductive lakes or important in soft water lakes (Hutchinson, 1967). These four genera are represented by a total of 12 species in this lake, so including them in the calculation of the index makes the lake appear more eutrophic than other measurements indicate. Also, there are several Desmidiaceae included in the denominator that are shown by Brook (1965) to be more characteristic of eutrophic rather than oligotrophic lakes. These include three species of Cosmarium and four species of Closterium. Analysis of the species present indicates that there is a mixture of oligotrophic and eutrophic species.

In addition to the oligotrophic Desmidiaceae and Chlorococcales already mentioned, other species present that are characteristic of oligotrophic lakes by Hutchinson (1957) are the five Peridinium, four Dinobryon species, and Cyclotella meneghiniana. Genera present that are characteristic of eutrophic lakes include Scenedesmus, Chlorella, Pediastrum, Fragilaria, Synedra, and Melosira along with 22 myxophycean species (Hutchinson, 1967). Finally, note that the Cryptophyceae, Chrysophyceae and Dinophyceae, which are often abundant in Mountain Lake, are not represented in Nygaard's formula. Instead, the Myxophyceae, which may be limited by low pH and temperature, and the Centrales, which probably are limited by silica availability, are part of Nygaard's formula.

A more modern index is the Trophic State Index (TSI) of Carlson (1977). The index is calculated using the Secchi disc reading in the following formula: $TSI = 10 \frac{(6 - \ln SD)}{\ln 2}$. This numerical index ranges from 0-100 and is based on the premise that a relationship exists between algal biomass and Secchi disc transparency. Although this index has some shortcomings (Lorenzen, 1980; Megard et al., 1980; Edmondson, 1980), calculation of TSI from Secchi disc readings is particularly attractive, because this parameter has been commonly recorded previously. Thus, trophic states from the past and present can be compared. The index has been

expanded so that it can also be calculated using surface chlorophyll a. In fact, if both transparency and chlorophyll a are measured, one shortcoming of the index is overcome (Carlson, 1980). The TSI formula (Carlson, 1977) using $\text{mg}\cdot\text{m}^{-3}$ of surface chlorophyll a is calculated as follows:

$$\text{TSI} = 10 \frac{[(6 - 2.04 - 0.68 \ln \text{chl})]}{\ln 2}$$

The Trophic State Indices using chlorophyll a and transparency are shown in Figure 24. Figure 25 shows a comparison of TSI for 1962 and for 1985 based on Secchi disc readings from Roth and Neff (1964) and from our study. A difference of 10 units on the scale represents a doubling in algal biomass (estimated by chlorophyll a). Only the month of March 1985 shows such an increase from 1962 to 1985. The annual mean TSI values for 1962, 1985, 1986, and 1987 are 33.6, 35.2, 33.3, and 33.7 respectively. Based on Carlson's Index (1977), Mountain Lake shows little change for these years.

The various tests applied, which include phosphorus, inorganic nitrogen levels, Secchi disc transparency, primary productivity, Carlson's trophic state indices, all suggest that Mountain Lake is still oligotrophic. However, indicators that it is changing are extractable chlorophyll a, late summer oxygen depletion in the hypolimnion, and

higher primary productivity. Also, the phytoplankton are very different from those of earlier reports, such as Obeng-Asamoah (1971), and are a mixture of both oligotrophic and eutrophic species. Important algal community changes are the late summer dominance of blue-green algae and the reduction of the attached macrophyte, Nitella megacarpa.

The temporary perturbation which caused the change in pH clearly indicates that this lake can easily be disturbed but the rapid turnover of water in the lake [70-80% of the water in the lake is replenished each year (Marland, 1967).] helps to restore the more natural state. However, if the anaerobic conditions in the lake's muds become seasonally prolonged, one may expect even more drastic changes in the lake will follow.

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Table 5. List of Major Variables, Methods/Instruments Used With Their Sources.

PHYSICAL

Temperature	Yellow Springs Instrument, S-C-T Meter, Model 33 (Yellow Springs Instrument Company, Yellow Springs, OH)
Conductivity	Yellow Springs Instrument, S-C-T Meter, Model 33,
Light	LI-COR, INC., Quantum/Radiometer/Photometer (LI-COR, INC., Lincoln, NE) Pyranograph (Belfort Instrument Company, Baltimore, MD)
Transparency	Secchi disc

BIOLOGICAL

Phytoplankton	Utermohl settling; plankton tows Spectrophotometry (APHA-AWWA-WPCF, (1985) Perkin-Elmer Spectrophotometer 552 (Perkin-Elmer, Norwalk, CT)
Primary productivity	^{14}C (Parker and Samsel, 1974; Parker et al. 1977, Parker and Parson, 1987)

CHEMICAL

Phosphate	Ascorbic acid, Isobutanol extraction [Murphy and Riley (1962), modified by Strickland and Parsons (1975)]

Table 5 (Cont'd.)

Ammonia	Phenate (Lind, 1979)
Nitrate	Cadmium reduction* (APHA-AWWA-WPCF, 1985)
Nitrite	Diazotization* (APHA-AWWA-WPCF, 1985)
Sulfate	Turbidimetric, Barium chloride* (APHA-AWWA-WPCF, 1985)
Silica	Heteropoly blue* (APHA-AWWA-WPCF, 1985)
Iron	Atomic absorption (APHA-AWWA-WPCF, 1985) Perkin-Elmer Atomic Absorption Spectrophotometer 2380 (Perkin-Elmer, Norwalk, CT)
Alkalinity	Titrimetric, Methyl purple (APHA-AWWA-WPCF, 1985)
Hardness	Titrimetric, EDTA (APHA-AWWA-WPCF, 1985)
pH	Corning pH Meter Model 610A (Corning Medical, Corning Glass Works, Medford, MA)

* Hach reagents (Hach Company, Loveland, CO) used with Perkin-Elmer 552 Spectrophotometer.

Table 6. Annual nutrient levels based on monthly mean comparisons from selected depths with analysis of variance and multiple comparison results (least significant difference, Sokal & Rohlf, 1981). Means (by row) with the same letter are not significantly different ($\alpha = 0.05$ level).

Nutrient	1971*	1985-86	1986-87	1987 (Spring-Fall)	F-value	P-value
**Nitrate-N	0.0310 ^a	0.0109 ^b	0.0174 ^{a,b}	0.0138 ^b	3.30	0.0326
Ammonia-N	-	0.0119 ^b	0.0169 ^b	0.0397 ^a	10.55	0.0004
Phosphate-P	0.0350 ^a	0.0017 ^b	0.0015 ^b	0.0026 ^b	24.26	0.0001
**Silica	0.5090 ^b	0.9733 ^a	0.7050 ^{a,b}	0.9326 ^a	3.69	0.0217
**Sulfate	2.540 ^a	4.972 ^b	-	-	-	-

*Obeng-Asomoa 1971

**Indicates same method as ours.

Table 7. Photosynthetic rates of phytoplankton from selected depths for Mountain Lake, Virginia, 1985-87.

Date	mgC • m ⁻³ • hr ⁻¹					Lake Mean
	Depth (meters)					
	.1	1	6	10	17	
April 13, 1985	2.66	1.54	1.06	0.74	1.07	1.45
June 13, 1985	1.52	2.08	0.70	0.67	-	1.24
July 22, 1985	6.81	6.44	3.17	0.74	0.11	4.17
August 17, 1985	25.60	17.80	2.30	0.25	0.13	10.20
September 23, 1987	3.27	7.21	2.52	0.55	0.08	3.02
October 26, 1985	1.39	1.69	1.47	0.64	0.05	1.12
November 29, 1985	1.10	1.97	0.16	0.06	0.01	0.49
December 19, 1985	0.11	0.23	0.59	0.08	0.02	0.21
January 18, 1986	0.16	0.70	0.55	0.12	0.01	0.31
February 16, 1986	0.03	0.10	0.11	0.01	0.02	0.07
March 22, 1986	0.20	0.35	0.69	0.18	0.01	0.29
July 30, 1986	6.36	5.85	7.61	2.21	0.47	4.50
August 28, 1986	8.75	9.15	13.82	5.40	1.68	7.76
October 9, 1986	3.64	4.16	1.11	0.17	0.01	1.82

Table 7 (Cont'd.)

Date	mgC • m ⁻³ • hr ⁻¹					Lake Mean
	Depth (meters)					
	.1	1	6	10	17	
June 16, 1987	4.73	4.35	1.42	2.02	0.30	2.57
July 22, 1987	3.55	5.24	1.34	0.39	0.08	2.12
August 25, 1987	2.24	3.73	1.76	0.69	0.07	1.70
September 27, 1987	2.74	4.00	5.77	1.48	0.17	2.83
October 17, 1987	0.34	0.61	0.63	0.29	0.02	0.38
November 14, 1987	2.11	4.88	3.16	1.29	0.10	2.31

Table 8. Monthly phytoplankton primary productivity, available solar radiation, and photosynthetic efficiency for Mountain Lake, Virginia, 1985-87. Rates integrated to 17 m, approximately the compensation depth; daily rates based on 10 hours.

Date	mgC · m ⁻² · day ⁻¹	Solar Radiation g · cal · cm ⁻² · day ⁻¹	Photosynthetic Efficiency
April 13, 1985	171.60	329.2	0.029
June 13, 1985	84.48	581.6	0.032
July 22, 1985	372.25	473.6	0.173
August 27, 1985	708.88	550.0	0.283
September 23, 1985	339.10	264.0	0.174
October 26, 1985	141.16	355.1	0.057
November 29, 1985	67.50	165.6	0.090
December 19, 1985	59.10	407.8	0.032
January 18, 1986	49.00	303.0	0.033
February 16, 1986	10.03	394.6	0.012
March 22, 1986	48.31	838.7	0.013
July 30, 1986	656.45	848.7	0.170
August 28, 1986	1,281.88	594.0	0.475
October 9, 1986	197.00	298.4	0.145

Table 8 (Cont'd.)

Date	Solar Radiation		Photosynthetic Efficiency
	mgC · m ⁻² · day ⁻¹	g · cal · cm ⁻² · day ⁻¹	
June 16, 1987	32.92	377.1	0.019
July 22, 1987	260.19	677.4	0.084
August 25, 1987	234.56	582.3	0.044
September 27, 1987	472.29	631.6	0.164
October 17, 1987	63.25	616.0	0.023
November 14, 1987	366.25	396.0	0.203

Table 9. Monthly chlorophyll *a* concentration at selected depths for Mountain Lake, Virginia, 1985-87. The values per depth are means of duplication; lake mean is mean of 10 samples (2 per depth).

Date	mg Chl a • m ⁻³					Lake Mean
	Depth (meters)					
	.1	1	6	10	17	
March 19, 1985	5.30	5.60	7.32	6.79	4.92	5.99
April 13, 1985	6.64	6.43	7.52	6.92	4.78	6.64
May 25, 1985	4.70	7.61	4.43	3.07	2.40	4.44
June 15, 1985	1.02	2.39	2.05	4.19	2.73	3.09
July 22, 1985	11.41	9.49	10.60	14.95	8.89	11.31
August 27, 1985	9.57	7.17	5.56	7.33	5.03	7.17
September 23, 1987	1.60	2.08	2.48	1.31	0.96	1.77
October 26, 1985	0.53	0.96	1.12	1.04	1.12	0.94
November 29, 1985	3.32	1.28	1.12	1.03	0.85	1.50
December 19, 1985	0.71	0.56	0.84	0.43	0.86	0.68
January 18, 1986	0.79	1.20	1.03	1.11	0.96	1.13
February 16, 1986	1.03	1.36	1.28	0.79	0.71	1.03
Annual mean = 3.30						
March 22, 1986	0.72	0.61	0.37	1.14	0.28	0.70
April 30, 1986	0.84	0.58	0.64	0.16	0.80	0.61
May 25, 1986	0.68	0.34	0.83	0.75	0.51	0.62
June 17, 1986	0.69	0.77	0.80	0.48	0.56	0.66

Table 9 (Cont'd.)

Date	mg Chl a • m ⁻³					Lake Mean
	Depth (meters)					
	.1	1	6	10	17	
July 30, 1986	1.33	0.88	0.89	0.42	0.29	0.76
August 28, 1986	4.40	4.16	3.76	1.84	0.96	3.03
September 21, 1986	3.12	5.58	3.68	1.60	0.56	2.96
October 9, 1986	1.60	2.24	2.00	1.28	0.72	1.57
November 24, 1986	5.37	5.44	5.44	3.32	3.84	4.89
December 18, 1986	3.36	3.92	4.48	3.04	3.92	3.75
February 11, 1987	2.08	3.68	6.41	6.89	2.64	4.34
Annual Mean = 2.17						
March 27, 1987	2.80	2.64	2.40	2.80	3.28	2.79
April 27, 1987	4.00	5.53	10.65	4.49	1.68	5.27
May 26, 1987	0.88	0.72	4.65	2.16	1.44	1.98
June 16, 1987	0.96	1.20	1.20	5.45	1.28	2.02
July 22, 1987	1.84	1.44	1.76	3.68	1.28	2.00
August 25, 1987	1.60	2.00	2.16	3.04	1.28	2.02
September 27, 1987	1.84	1.22	1.92	2.88	1.20	1.83
October 17, 1987	1.92	1.84	1.76	2.00	2.24	1.95
November 14, 1987	2.88	2.08	2.00	1.28	1.93	2.04
Spring-fall mean = 2.43						

Table 10. Phytoplankton taxa and their numerical rank in Mountain Lake, 1985-87. After the name, the month, its numerical rank, and year is given in parentheses: JA=January; F=February; MR=March; AP=April; MY=May; JU=June; JL=July; AU=August; S=September; O=October; N=November; D=December. Taxa without a rank were seen only in plankton tows. *Indicates taxa not reported previously.

Division Chlorophyta (Chlorophyceae)

Ankistrodesmus falcatus (Corda) Ralfs

*Ankistrodesmus falcatus var. mirabilis West & West

*Arthrodesmus phimus Turner (JU=14.5, JL=12)⁸⁵⁻⁸⁶

*Arthrodesmus quadratus (Schm.) Teiling (MY=15, JU=10)⁸⁵⁻⁸⁶

*Arthrodesmus subulatus Kuetzing

Bambusina brebissonii Kuetzing

*Bambusina confervacea West & West (MR=7.5)⁸⁵⁻⁸⁶

*Botryococcus sudeticus Lemmermann (MR=7.5)⁸⁵⁻⁸⁶

Botryococcus braunii Kuetzing

Bulbochaete sp.

Chlamydomonas sp. (JU=11.5, O=10)⁸⁵⁻⁸⁶

(S=17.5, O=11.5, F=10)⁸⁶⁻⁸⁷

(MR=6.5, AP=6, MY=6, AU=21.5, S=15.5)⁸⁷⁻⁸⁸

*Chlorella vulgaris Beyerinck (JU=3)⁸⁷⁻⁸⁸

*Closterium baillyanum Brébisson

*Closterium costatum Corda

*Closterium nematodes Josh

Closterium moniliferum (Bréb.) Ehrenberg

*Coelastrum microsporum Naegeli

Table 10 (Cont'd.)

Cosmarium dentatum Borge

*Cosmarium denticulatum Borge

*Cosmarium phaseolus Brébisson

Crucigenia rectangularis (Naeg.) Gay (MY=12.5)⁸⁵⁻⁸⁶
(AU=19.5)⁸⁶⁻⁸⁷ (JL=6, AU=7, S=6, O=12.5)⁸⁷⁻⁸⁸

Crucigenia quadrata Morren (AU=4, S=11)⁸⁶⁻⁸⁷
(N=14.5)⁸⁷⁻⁸⁸

Crucigenia irregularis Wille (AU=13.5, O=6, N=14.5)⁸⁷⁻⁸⁸

Cylindrocapsa sp. (N=14.5)⁸⁷⁻⁸⁸

*Desmidium baileyi (Ralfs) Nordstedt

Desmidium aptogonum

*Desmidium grevillii (Kuetz.) Debary

Dictyosphaerium pulchellum Wood (O=18)⁸⁶⁻⁸⁷
(AU=21.5, O=19)⁸⁷⁻⁸⁸

*Elakatothrix gelatinosa Wille
(MY=3, JU=9, JL=13, AU=11, S=7, O=4, D=7, F=6)⁸⁵⁻⁸⁶
(JU=6.5, JL=19, AU=8.5, S=10, F=10)⁸⁶⁻⁸⁷
(AP=8, MY=11.5, JL=10, AU=7, S=13, O=8, N=7)⁸⁷⁻⁸⁸

*Genicularia spirotaenia DeBary

Gloeocystis gigas (Kuetzing) Lagerheim)
(MY=7.5, O=11.5)⁸⁶⁻⁸⁷
(MY=8, JU=5, JL=5, AU=11, S=8)⁸⁷⁻⁸⁸

Gloeocystis major Gerneck ex Lemmermann (AU=12)⁸⁷⁻⁸⁸

Gloeocystis paroliniane (Menegh.) Naegeli
(JU=6.5, O=18)⁸⁶⁻⁸⁷

Gloeocystis vesiculosa Naegeli (JU=8, JL=6, O=9)⁸⁶⁻⁸⁷
(JU=4, AU=4, O=4, N=12)⁸⁷⁻⁸⁸

Table 10 (Cont'd.)

Gloeocystis planctonica (West & West) Lemmermann
(N=14.5)⁸⁶⁻⁸⁷
(AU=3, S=9)⁸⁷⁻⁸⁸

Gonatozygon kinahani (Arch.) Rabenhorst (N=8)⁸⁵⁻⁸⁶

*Gonatozygon monotaenium DeBary (O=7)⁸⁵⁻⁸⁶

*Gonatozygon pilosum Wolle

*Hyalotheca dissiliens (Smith) Brébbisson

*Lobocystis dichotoma Thompson

Kirchneriella obesa (W. West) Schmidle

*Mesotaenium sp. (F=5)

*Micrasterias furcata Ralfs

Micrasterias mahabuleshwariensis Hobs

*Micrasterias radiata var. dichotoma (Wolle) Cushman
(JU=11.5)⁸⁷⁻⁸⁸

Micrasterias radiata Hassal
(JL=21, AU=12.5, S=13.5, O=11.5, N=8.5)⁸⁶⁻⁸⁷
(AP=10, JL=12, N=10)⁸⁷⁻⁸⁸

Micrasterias radiata var. gracillima G. M. Smith

*Micrasterias radiata var. alata Prescott et Scott

Micrasterias radiosa Ralfs

Micrasterias rotata (Grev.) Ralfs

Mougeotia sp.

*Nephrocytium agardhianum Naegeli

Oedogonium sp.

Oocystis sp. (AU=13.5)⁸⁵⁻⁸⁶
(JL=16.5, O=9, N=14.5)⁸⁶⁻⁸⁷

Table 10 (Cont'd.)

*Oocystis pusilla Hansgirg(JL=16.5)⁸⁵⁻⁸⁶ (AU=19.5)⁸⁶⁻⁸⁷(JL=14, S=7)⁸⁷⁻⁸⁸Oocystis borgeii Snow(MY=6, JU=10.5, S=9, D=11.5)⁸⁶⁻⁸⁷(JU=8, JL=8, AU=5, S=2, N=1)⁸⁷⁻⁸⁸Oocystis iremosphoeria G. M. Smith*Pediastrum duplex var. rugulosum Raciborski*Pediastrum biradiatum MeyenPediastrum integrum Naegeli*Pediastrum sculptatum G. M. SmithPediastrum tetras forma evoluta West(S=15.5, O=24)⁸⁷⁻⁸⁸Phacus sp. (JL=16.5, AU=19.5, S=15.5, O=7)⁸⁶⁻⁸⁷(O=15.5, N=14.5)⁸⁷⁻⁸⁸*Pleurotaenium trabecula (Ehren.) NaegeliQuadrigula chodatii (Tan-Ful.) G. M. Smith(JL=13.5, AU=5, S=5, O=3, N=6, D=8, F=7.5)⁸⁶⁻⁸⁷(JL=2, AU=2, S=5, N=14.5)⁸⁷⁻⁸⁸*Quadrigula pfitzeri (Schroder) G. M. SmithQuadrigula Closteroides (Bohlin) Printz*Rhizoclonium sp.Scenedesmus arcuatus Lemmermann (O=15.5)⁸⁷⁻⁸⁸Scenedesmus bijuga (Turp.) Lagerheim(MY=7, JU=1, JL=1, AU=4, S=5, O=4.5, D=4, JA=6)⁸⁵⁻⁸⁶(JL=21, AU=10.5, S=13.5, O=8, N=14.5)⁸⁶⁻⁸⁷(JU=11.5, JL=1, AU=6, S=2, O=1, N=8)⁸⁷⁻⁸⁸

Table 10 (Cont'd.)

Scenedesmus quadricauda (Turp.) Brébisson

Scenedesmus quadricauda var. quadrispina (Chod.)
G. M. Smith (D=11.5)⁸⁶⁻⁸⁷

*Schoederia setigera (Schroed.) Lemmermann

*Sphaerellopsis gloeocystiformis Dill
(JL=10, AU=16)⁸⁵⁻⁸⁶

Sphaerocystis schroeteri Chodat (JU=14.5)⁸⁵⁻⁸⁶
(MY=5, O=18)⁸⁶⁸⁷ (JL=18, AU=4, O=24, N=14.5)⁸⁷⁻⁸⁸

*Spirogyra sp.

*Spondylosium planum (Wolle) West & West (JL=8, AU=16)⁸⁵⁻⁸⁶
(O=18)⁸⁶⁻⁸⁷ (MY=10)⁸⁷⁻⁸⁸

*Spondylosium vertebratum var. punctulatum West & West

*Staurastrum ankyroides Wolle

Staurastrum arctiscon (Ehren.) Lundell

*Staurastrum dakoti Taft

*Staurastrum leptacanthum Nordst

Staurastrum limneticum Schmidle

*Staurastrum ophiura Lundell

Staurastrum polymorphum Brébisson

Stichococcus bacillaris Naegeli (AP=12, MY=3, JU=1)⁸⁶⁻⁸⁷
(MY=8, JU=10, JL=7)⁸⁷⁻⁸⁸

*Stigeoclonium sp.

Stigeoclonium flagelliferum Kuetzing

*Stylosphaeridium stipitatum (Bachm.) Geitler & Gimesi

Tetraspora sp. (JL=5, AU=7, S=7)⁸⁶⁻⁸⁷

*Ulothrix subconstricta G. S. West

Unknown flagellate sp. (S=12, O=19)

Table 10 (Cont'd.)

Division Chrysophyta (Bacillariophyceae, Chrysophyceae, Xanthophyceae)

Unknown flagellate sp. 1 (MR=6.5, AP=3, MY=7.5, JU=10.5, N=8.5, F=4)⁸⁶⁻⁸⁷ (MR=6.5, AP=4, MY=3, AU=13.5, S=15.5, N=6)⁸⁷⁻⁸⁸

Unknown flagellate sp. 2 (D=6)⁸⁶⁻⁸⁷

*Asterionella formosa Hassal

(MR=4, AP=5, MY=12.5, JL=11, AU=11, S=11, D=8)⁸⁵⁻⁸⁶
(JL=16.5, S=6)⁸⁶⁻⁸⁷ (AU=9)⁸⁷⁻⁸⁸

*Chlorochromonas minuta Lewis

(AP=3, MY=6, AU=6, S=3, N=4.5, D=3, JA=5, F=2)⁸⁵⁻⁸⁶ (MR=8)

*Chromulina ovalis Klebs

(MR=5.5, AP=9, M=2, JU=4, JL=9, AU=9, S=4, O=3)⁸⁵⁻⁸⁶

Cyclotella meneghiniana Kuetzing

(JU=14.5, JL=4, S=1, O=1, N=1, D=1, JA=2, F=4)⁸⁵⁻⁸⁶
(MR=2, AP=2, MY=2, JU=5, JL=10, AU=19.5)⁸⁶⁻⁸⁷
(JL=18)⁸⁷⁻⁸⁸

Cymbella sp. (AP=6.5)⁸⁶⁻⁸⁷

Dinobryon divergens Imhof (JL=9, AU=14.5, O=14, N=7)⁸⁶⁻⁸⁷

*Dinobryon sociale Ehrenberg

Dinobryon elegantissimum Bourrelly (JL=3, O=18)⁸⁶⁻⁸⁷

Eunotia sp.

Fragilaria sp. (S=13, F=7)⁸⁵⁻⁸⁷
(MR=9, AP=12, MY=9.5)⁸⁶⁻⁸⁷

Gomphonema sp. (SP=8)⁸⁶⁻⁸⁷

Mallomonas acaroides Perty

Mallomonas sp. (JU=12, JL=7.5, AU=14.5, O=11.5, N=12, D=8)⁸⁶⁻⁸⁷
(S=11, O=12.5, N=3)⁸⁷⁻⁸⁸

Table 10 (Cont'd.)

Melosira sp. (N=14.5)⁸⁶⁻⁸⁷

Melosira varians Agardh

Meridion sp. (AP=12)⁸⁶⁻⁸⁷

*Navicula sp. (MY=15, D=6)⁸⁵⁻⁸⁶
(MR=4, AP=4, AU=19.5, N=10.5)⁸⁶⁻⁸⁷
(MR=10.5, AP=5, AU=21.5)⁸⁷⁻⁸⁸

*Navicula gracilis Ehrenberg (AP=8, JL=16.5)⁸⁵⁻⁸⁶
(AP=12)⁸⁶⁻⁸⁷

Neidium sp. (MR=5)⁸⁶⁻⁸⁷

Synedra sp. (AP=4)⁸⁵⁻⁸⁶
MR=9, AP=12, S=15.5, O=5, N=10.5)⁸⁶⁻⁸⁷
(MR=8, O=15.5)⁸⁷⁻⁸⁸

Synedra ulna (Nitzsch.) Ehrenberg

Synedra tenera Agardh

Synura sp. (AU=12)⁸⁵⁻⁸⁶ (AU=19.5)⁸⁶⁻⁸⁷

Surirella sp. (AP=12)⁸⁶⁻⁸⁷

Tabellaria fenestrata (Lyng.) Kuetzing
(MR=5.5, AP=6, MY=11, JL=11, AU=11, S=11, D=8)⁸⁵⁻⁸⁶
(MR=6.5, AP=6.5, F=10)⁸⁶⁻⁸⁷ (MR=9, AP=8)⁸⁷⁻⁸⁸

Tabellaria sp.

Division Cryptophyta (Cryptophyceae)

Chilomonas paramecium Ehrenberg
(AP=7, MY=5, JU=3, JL=5, AU=7, S=10)⁸⁵⁻⁸⁶

Cryptomonas sp. (JA=3)⁸⁵⁻⁸⁶

Cryptomonas erosa var. reflexa Marsson
(MY=8, AU=16, JA=4, F=3)⁸⁵⁻⁸⁶
(MR=3, AP=5, JU=3, JL=2, AU=6, S=12, O=4, N=3, D=3, F=3)⁸⁶⁻⁸⁷
(MR=3, AP=2, MY=2, JU=1, JL=3, AU=15, N=4)⁸⁷⁻⁸⁸

Table 10 (Cont'd.)

Cryptomonas ovata Ehrenberg (AP=10, MY=10, JL=14)⁸⁵⁻⁸⁶
 (JL=7.5, AU=8.5, S=2, N=4, D=4, F=7.5)⁸⁶⁻⁸⁷
 (MR=4, AP=8, MY=4, N=9)⁸⁷⁻⁸⁸

*Cryptomonas pyrenoidifera Geitler
 (MR=3, AP=2, MY=4, AU=3, S=6, O=5, N=2, O=2, JA=1, F=1)⁸⁵⁻⁸⁶
 (AP=12, JL=11)⁸⁶⁻⁸⁷
 (JU=6, JL=15.5)⁸⁷⁻⁸⁸

Cryptomonas pusilla Bachman
 (MR=1, AP=1, MY=1, JU=2, JL=1, AU=1, S=3, O=1,
 N=2, D=2, F=2)⁸⁶⁻⁸⁷
 (MR=4, AP=8, MY=4, N=9)⁸⁷⁻⁸⁸

Division Pyrrophyta (Dinophyceae)

*Glenodinium cinctum (Muell.) Ehrenberg (AU=19)⁸⁵⁻⁸⁶

Glenodinium minimum (Langtzsch) Bachman (F=5)⁸⁶⁻⁸⁷
 (MR=5, O=24)⁸⁷⁻⁸⁸

*Glenodinium oculatum Stein

*Glenodinium palustre (Lemm.) Schiller
 (JU=11.5)⁸⁵⁻⁸⁶

*Glenodinium pulvisculus (Ehr.) Stein (D=10)⁸⁶⁻⁸⁷

*Gymnodinium sp.
 (MR=2, AP=1, MY=1, JU=2, JL=3, AU=2)⁸⁵⁻⁸⁶
 (AU=12.5, S=4, O=6, N=1, D=1, F=1)⁸⁶⁻⁸⁷
 (M=1, AP=3, MY=5, JL=9, AU=17, O=19, N=11)⁸⁷⁻⁸⁸

Gymnodinium fuscum (Ehr.) Stein

*Gymnodinium tatricum Woloszynska

Peridinium cinctum (Muell.) Ehrenberg (S=8, O=6, N=6)⁸⁵⁻⁸⁶

*Peridinium cunningtonni Lemmermann

Peridinium inconspicuum Lemmermann (MR=1)⁸⁵⁻⁸⁶
 (JL=12, AU=19.5)⁸⁶⁻⁸⁷
 (MR=10.5, MY=8, JU=8, JL=15.5, N=14.5)⁸⁷⁻⁸⁸

Table 10 (Cont'd.)

*Peridinium wisconsinense Eddy(JU=8, JL=6, AU=1)⁸⁵⁻⁸⁶(JU=13, JL=4, AU=3, S=8)⁸⁶⁻⁸⁷(JL=12, AU=18.5, O=15.5)⁸⁷⁻⁸⁸*Peridinium volzii Lemmermann

Division Cyanophyta (Cyanophyceae, Cyanobacteria)

Unknown colonial sp. (JU=4)⁸⁶⁻⁸⁷Aphanocapsa elachista West & West (MY=15, AU=19)⁸⁵⁻⁸⁶
(MY=9.5, JL=13.5)⁸⁶⁻⁸⁷Aphanocapsa elachista var. conferta West & West
(JL=21, AU=2, S=1, O=2, N=2, D=8, F=6)⁸⁶⁻⁸⁷
(MY=11.5, JL=4, AU=1, S=1, O=5)⁸⁷⁻⁸⁸*Aphanocapsa rivularia (Carm.) Rabenhorst (JL=16.5)⁸⁵⁻⁸⁶Aphanothece sp. (O=7, N=14.5)⁸⁷⁻⁸⁸*Aphanothece saxicola Naegeli (O=11)⁸⁵⁻⁸⁶Aphanothece microscopia Nagel (S=10)⁸⁷⁻⁸⁸Chroococcus dispersus (V. Keiss) Lemmermann(S=9, O=9, N=7, D=5)⁸⁵⁻⁸⁶(JU=9, S=19.5)⁸⁶⁻⁸⁷(JU=8, JL=18, O=24)⁸⁷⁻⁸⁸Chroococcus minimus (Keissl.) Lemmermann (AU=16)⁸⁷⁻⁸⁸*Chroococcus minutus (Kuetz.) Rabenhorst(JL=7, AU=8, S=2, O=2, N=3)⁸⁵⁻⁸⁶

(MY=4)

*Chroococcus varius A. Braun in RabenhorstDactylococcopsis musicola Hustedt (O=24)⁸⁷⁻⁸⁸Eucapsis sp. (O=24)⁸⁷⁻⁸⁸

Table 10 (Cont'd.)

Gloeocapsa halmatodes Kuetzing

Gloeocapsa sp. (JL=16.5, AU=10.5)⁸⁷⁻⁸⁸

Microcystis aeruginosa Kuetzing

Microcystis firma (Bréb. et Lenom.) Schmidle

*Nostoc spongiaeforme C. A. Agardh (JL=16.5)⁸⁵⁻⁸⁶

Oscillatoria sp. (AU=19)⁸⁵⁻⁸⁶

*Oscillatoria angustissima West & West

*Phormidium sp.

Radiocystis geminata Skuja

Division Euglenophyta (Euglenophyceae)

Euglena sp.

Table 11. Comparison of phytoplankton ranks for three months in summer and fall in 1970 (Obeng-Asamoah, 1971) with the current study 1985-87. *Indicates species present in both studies.

July 1970		July 1985	
1	<u>Bambusina brebissonii</u>		<u>Scenedesmus bijuga</u>
2	<u>Staurostrum ophiura</u>		<u>Asterionella formosa</u>
3	<u>Radiofilum conjuctivum</u>		<u>Gymnodinium</u> sp.
4	* <u>Quadrigula chodatii</u>		<u>Cyclotella meneghiniana</u>
5	* <u>Sphaerocystis schroeteri</u>		<u>Chilomonas paramecium</u>
6	<u>Mougeotia</u> sp.		<u>Peridinium wisconsinense</u>
7	<u>Micrasterias radiosa</u>		<u>Chroococcus minutus</u>
8	<u>Quadrigula lacustris</u>		<u>Spondylosium planum</u>
9	<u>Micasterias radiata</u>		<u>Chromulina ovalis</u>
10	<u>Staurostrum arctiscon</u>		<u>Tabellaria fenestrata</u>
July 1986		July 1987	
1	<u>Cryptomonas pusilla</u>		<u>Scenedesmus bijuga</u>
2	<u>Cryptomonas erosa</u> var. <u>reflexa</u>		* <u>Quadrigula chodatii</u>
3	<u>Dinobryon elegantissimum</u>		<u>Cryptomonas erosa</u> var. <u>reflexa</u>
4	<u>Peridinium wisconsinense</u>		<u>Aphanocapsa elachista</u> var. <u>conferta</u>

Table 11 (Cont'd.)

5	<u>Tetraspora</u> sp.	<u>Gloeocystis</u> <u>gigas</u>
6	<u>Gloeocystis</u> <u>vesiculosa</u>	<u>Crucigenia</u> <u>rectangularis</u>
7	<u>Mallomonas</u> sp.	<u>Stichococcus</u> <u>bacillaris</u>
8	<u>Cryptomonas</u> <u>ovata</u>	<u>Oocystis</u> <u>borgei</u>
9	<u>Dinobryon</u> <u>divergens</u>	<u>Gymnodinium</u> sp.
10	<u>Cyclotella</u> <u>meneghiniana</u>	<u>Elakatothrix</u> <u>gelatinosa</u>

	August 1970	August 1985
1	<u>Staurastrum</u> <u>ophiura</u>	<u>Peridinium</u> <u>wisconsinense</u>
2	<u>Radiofilum</u> <u>conjunctivum</u>	<u>Gymnodinium</u> sp.
3	<u>Desmidium</u> <u>cylindricum</u>	<u>Cryptomonas</u> <u>pyrenoidifera</u>
4	<u>Bambusina</u> <u>brebissonii</u>	<u>Scenedesmus</u> <u>bijuga</u>
5	* <u>Sphaerocystis</u> <u>schoerteri</u>	<u>Asterionella</u> <u>formosa</u>
6	<u>Quadrigula</u> <u>lacustris</u>	<u>Chlorochromonas</u> <u>minuta</u>
7	* <u>Quadrigula</u> <u>chodatii</u>	<u>Chilomonas</u> <u>paramecium</u>
8	<u>Scenedesmus</u> sp.	<u>Chroococcus</u> <u>minutus</u>
9	<u>Dictyosphaerium</u> sp.	<u>Chromulina</u> <u>ovalis</u>
10	<u>Micrasterias</u> <u>radiosa</u>	<u>Elakatothrix</u> <u>gelatinosa</u>

	August 1986	August 1987
1	<u>Cryptomonas</u> <u>pusilla</u>	<u>Aphanocapsa</u> <u>elachista</u> var. <u>conferta</u>

Table 11 (Cont'd.)

2	<u>Aphanocapsa elachista</u> var. <u>conferta</u>	<u>*Quadrigula chodatii</u>
3	<u>Peridinium wisconsinense</u>	<u>Gloeocystis planctonica</u>
4	<u>Crucigenia quadrata</u>	<u>Gloeocystis vesiculosa</u>
5	<u>*Quadrigula chodatii</u>	<u>Oocystis borgei</u>
6	<u>Cryptomonas erosa</u> var. <u>reflexa</u>	<u>Scenedesmus bijuga</u>
7	<u>Tetraspora</u> sp.	<u>Crucigenia rectangulais</u>
8	<u>Elakatothrix gelatinosa</u>	<u>Elakatothrix gelatinosa</u>
9	<u>Cryptomonas ovata</u>	<u>Asterionella formosa</u>
10	<u>Scenedesmus bijuga</u>	<u>Cryptomonas pusilla</u>

	September 1970	September 1985
1	<u>Radiofilum conjunctivum</u>	<u>Cyclotella meneghiniana</u>
2	<u>Quadrigula lacustris</u>	<u>Chroococcus minutus</u>
3	<u>Tabellaria flocculosa</u>	<u>Chlorochromonas minuta</u>
4	<u>Tabellaria fenestrata</u>	<u>Chromulina ovalis</u>
5	<u>Staurastrum ophiura</u>	<u>Scenedesmus bijuga</u>
6	<u>Bambusina brebissonii</u>	<u>Cryptomonas pyrenoidifera</u>
7	<u>*Sphaerocystis schroeteri</u>	<u>Elakatothrix gelatinosa</u>
8	<u>Gonatozygon pilosum</u>	<u>Peridinium cinctum</u>
9	<u>Mougeotia</u> sp.	<u>Chroococcus dispersus</u>
10	<u>Planktosphaeria gelatinosa</u>	<u>Chilomonas paramecium</u>

Table 11 (Cont'd.)

	September 1986	September 1987
1	<u>Aphanocapsa elachista</u> var. <u>conferta</u>	<u>Aphanocapsa elachista</u> var. <u>conferta</u>
2	<u>Cryptomonas ovata</u>	<u>Scenedismus bijuga</u>
3	<u>Cryptomonas pusilla</u>	<u>Cryptomonas pusilla</u>
4	<u>Gymnodinium</u> sp.	* <u>Sphaerocystis schroeteri</u>
5	* <u>Quadrigula chodatii</u>	<u>Quadrigula chodatii</u>
6	<u>Asterionella formosa</u>	<u>Crucigenia rectangularis</u>
7	<u>Tetraspora</u> sp.	<u>Oocystis pusilla</u>
8	<u>Peridinium wisconsinense</u>	<u>Gloeocystis gigas</u>
9	<u>Oocystis borgeii</u>	<u>Gloeocystis planctonica</u>
10	<u>Elakatothrix gelatinosa</u>	<u>Aphanothece microspora:</u>

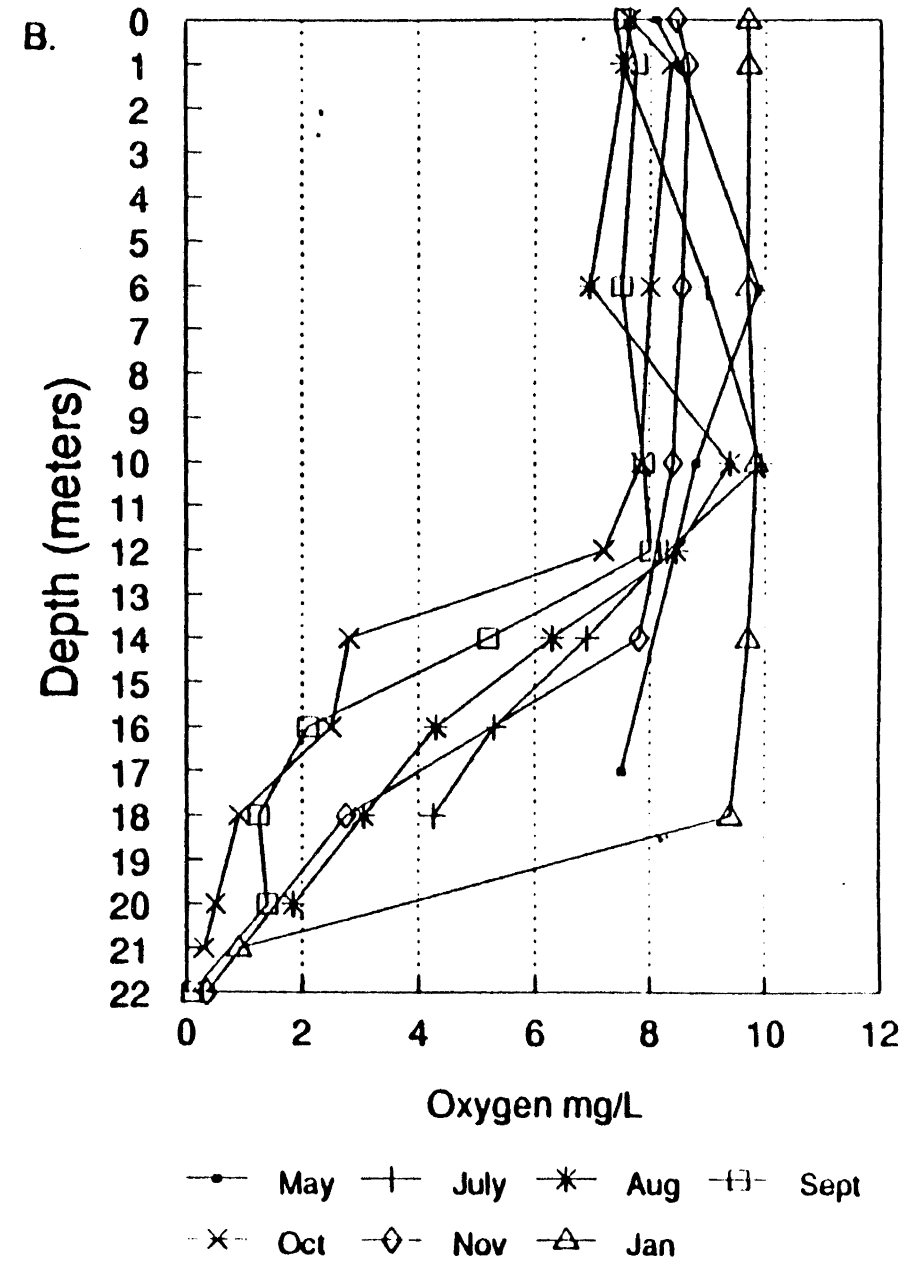
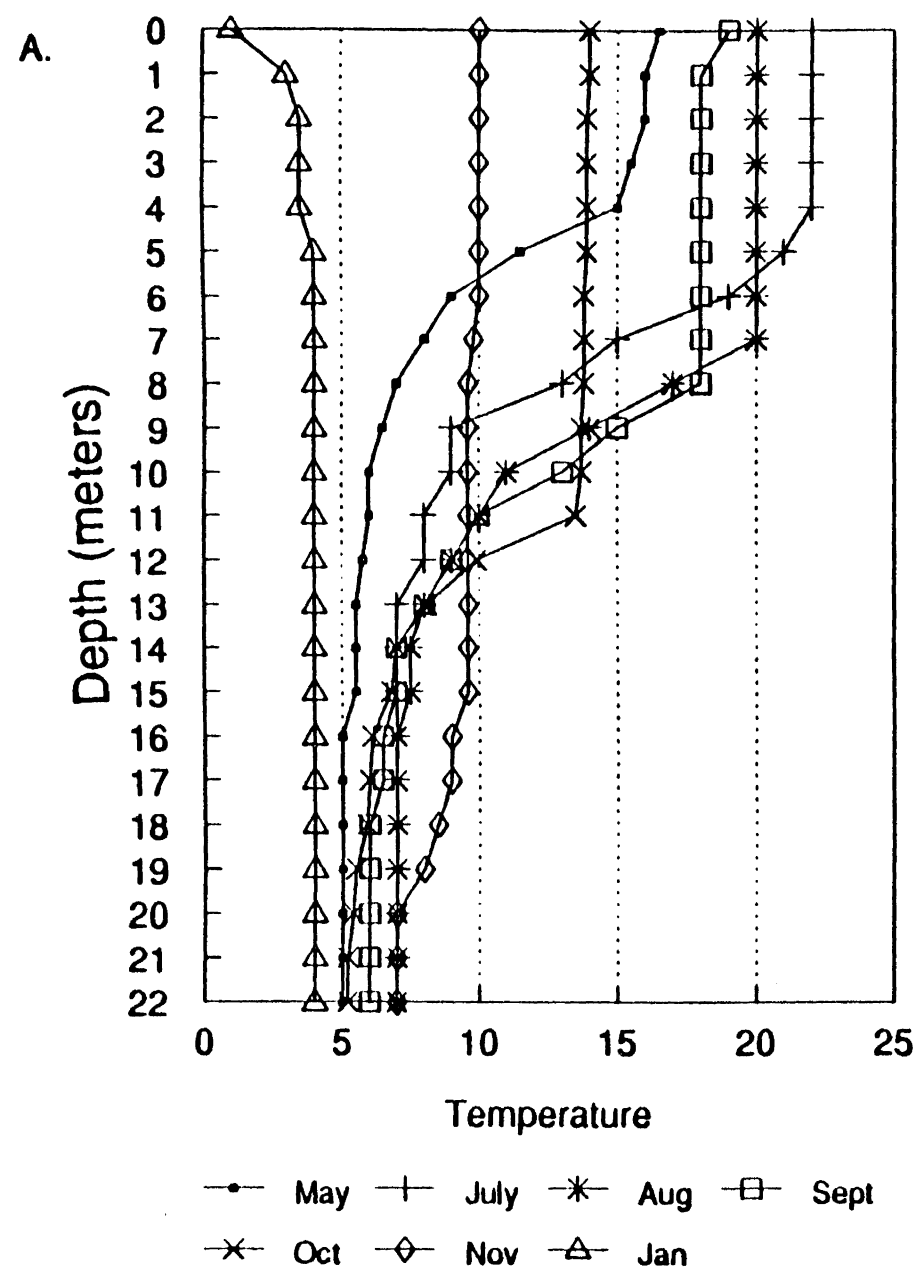


Figure 15. Temperature (A) and oxygen (B) profiles for Mountain Lake, Virginia, illustrating the 1985-86 seasonal patterns.

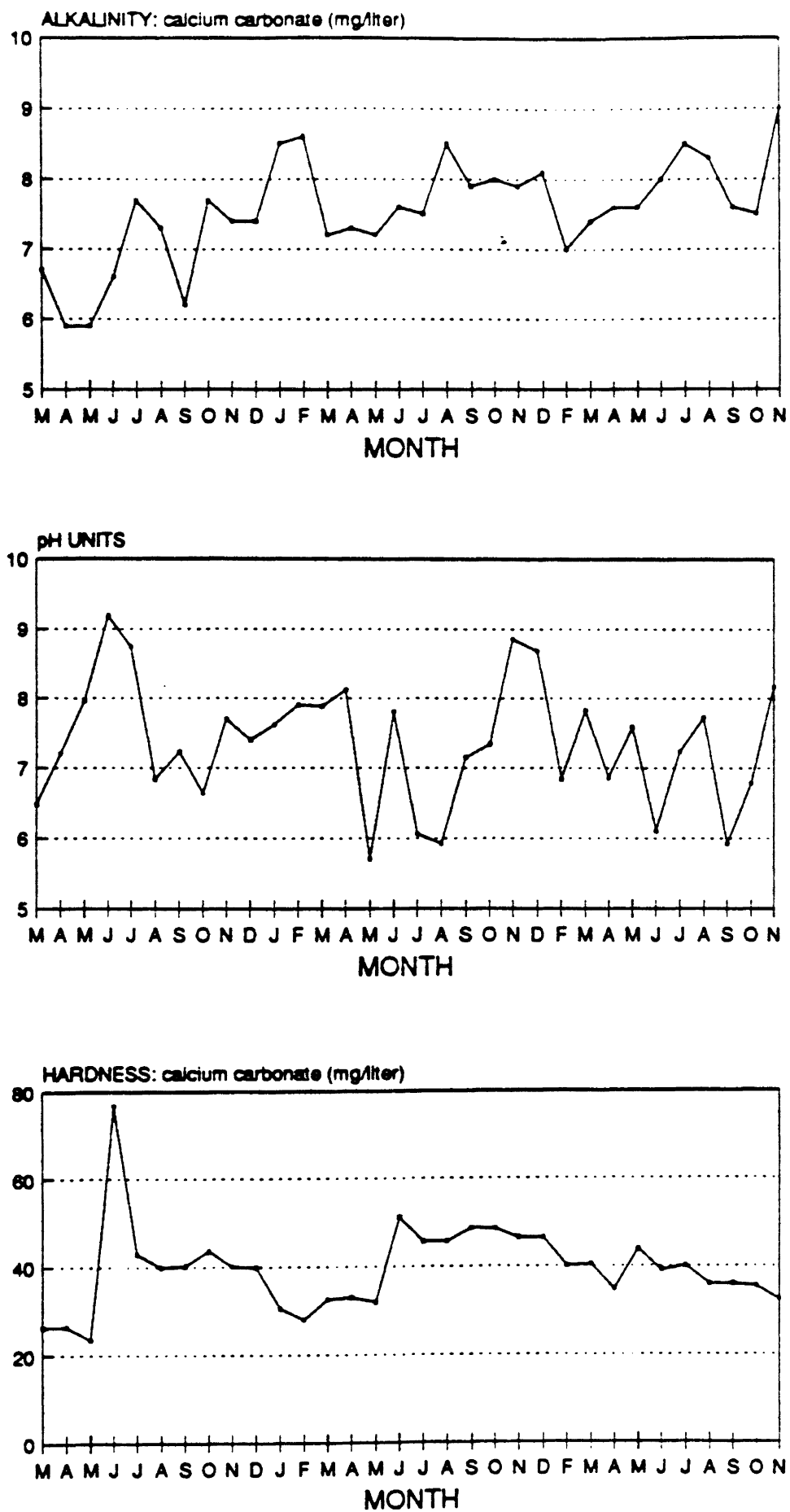


Figure 16. Seasonal variations in alkalinity (mg CaCO_3/L), pH, and hardness (mg CaCO_3/L) for Mountain Lake, Virginia, 1985-87.

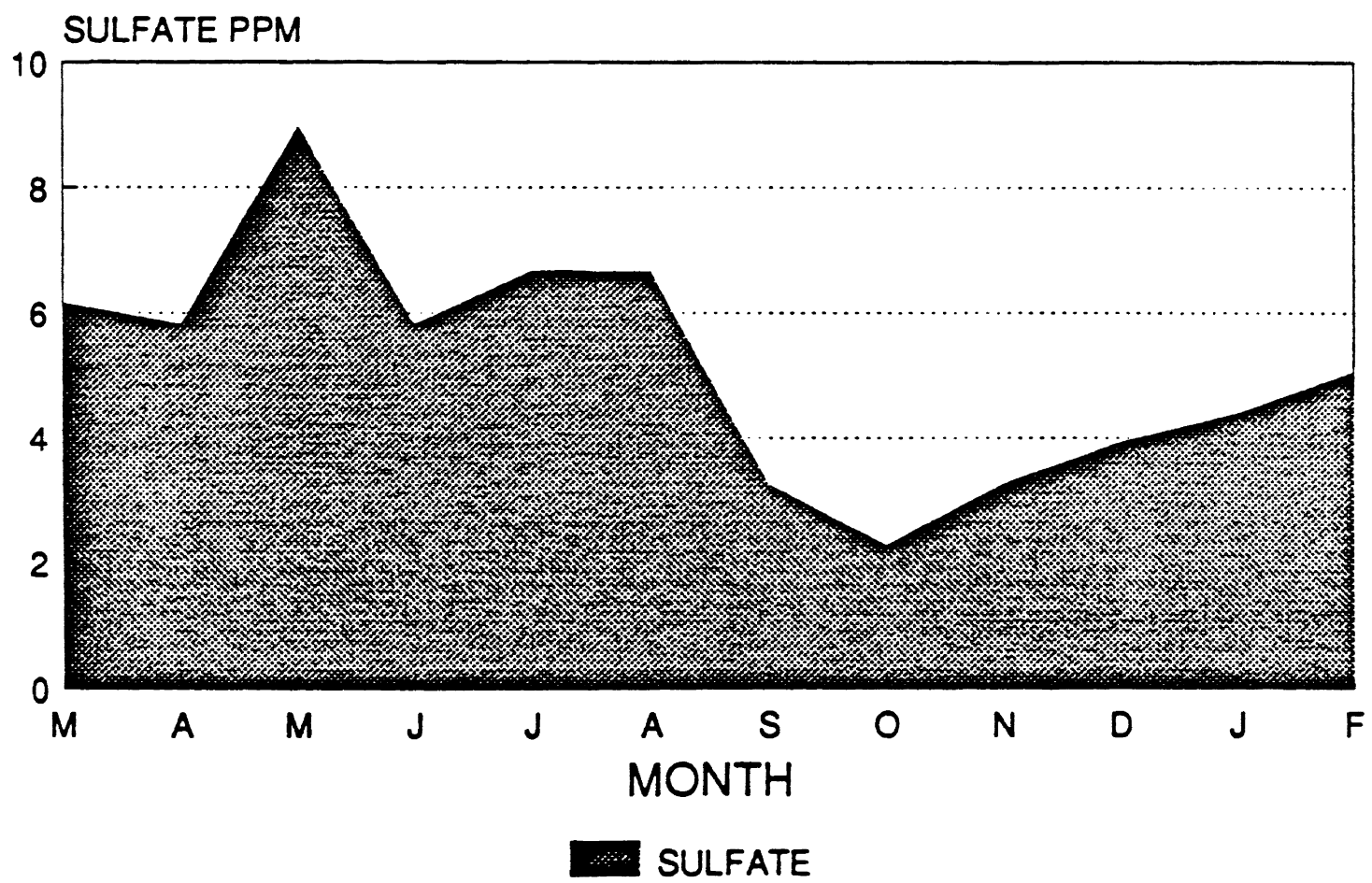


Figure 17. Seasonal levels of sulfate in Mountain Lake, Virginia, 1985-86. Values are means from five selected depths.

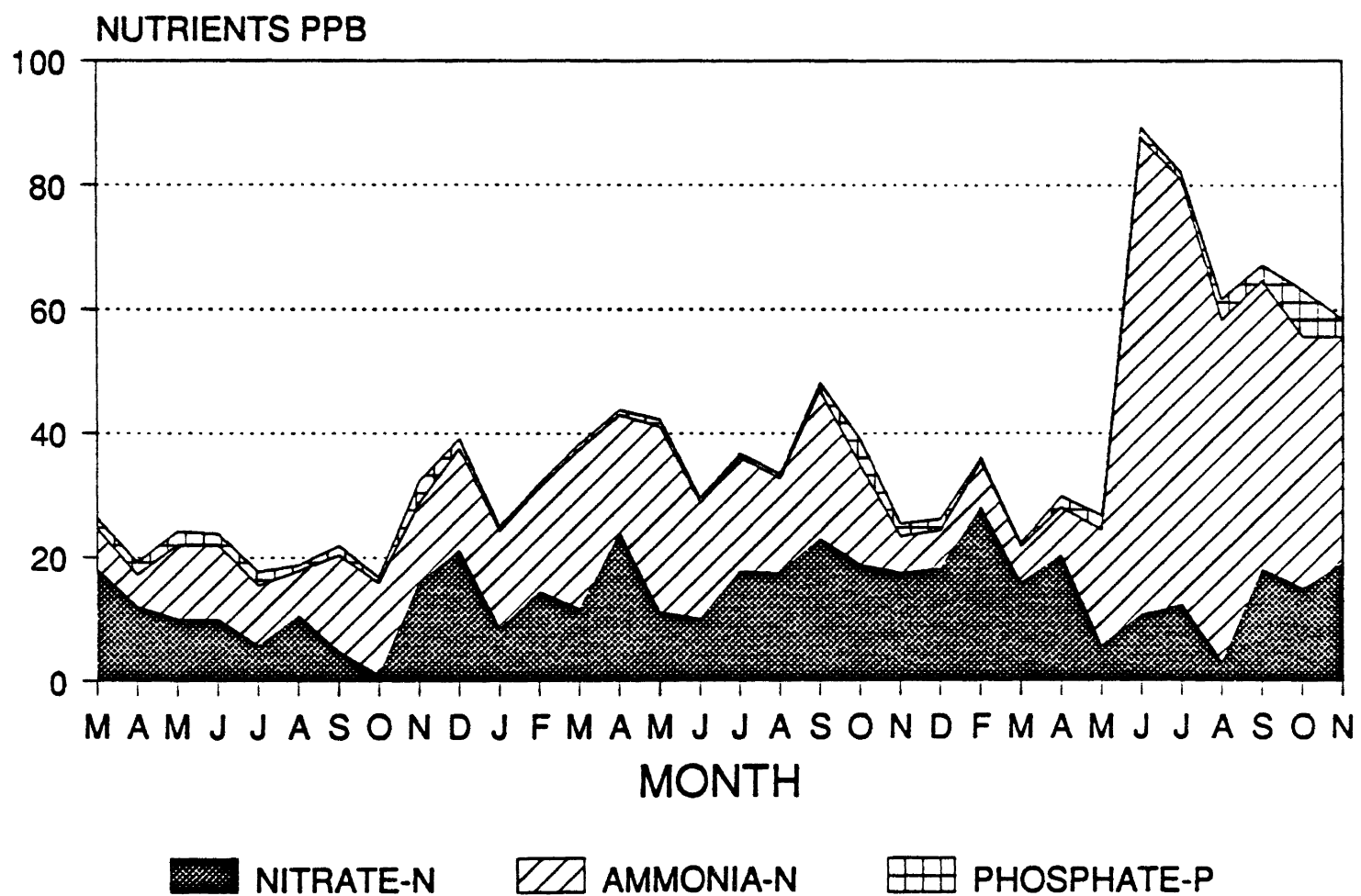


Figure 18. Seasonal levels of nitrate-nitrogen, ammonia-nitrogen, and orthophosphate-phosphorus in Mountain Lake, Virginia, 1985-87. Values are means from five selected depths. In these area graphs, vertical scale applies to nitrate; others are layered above for easy comparison.

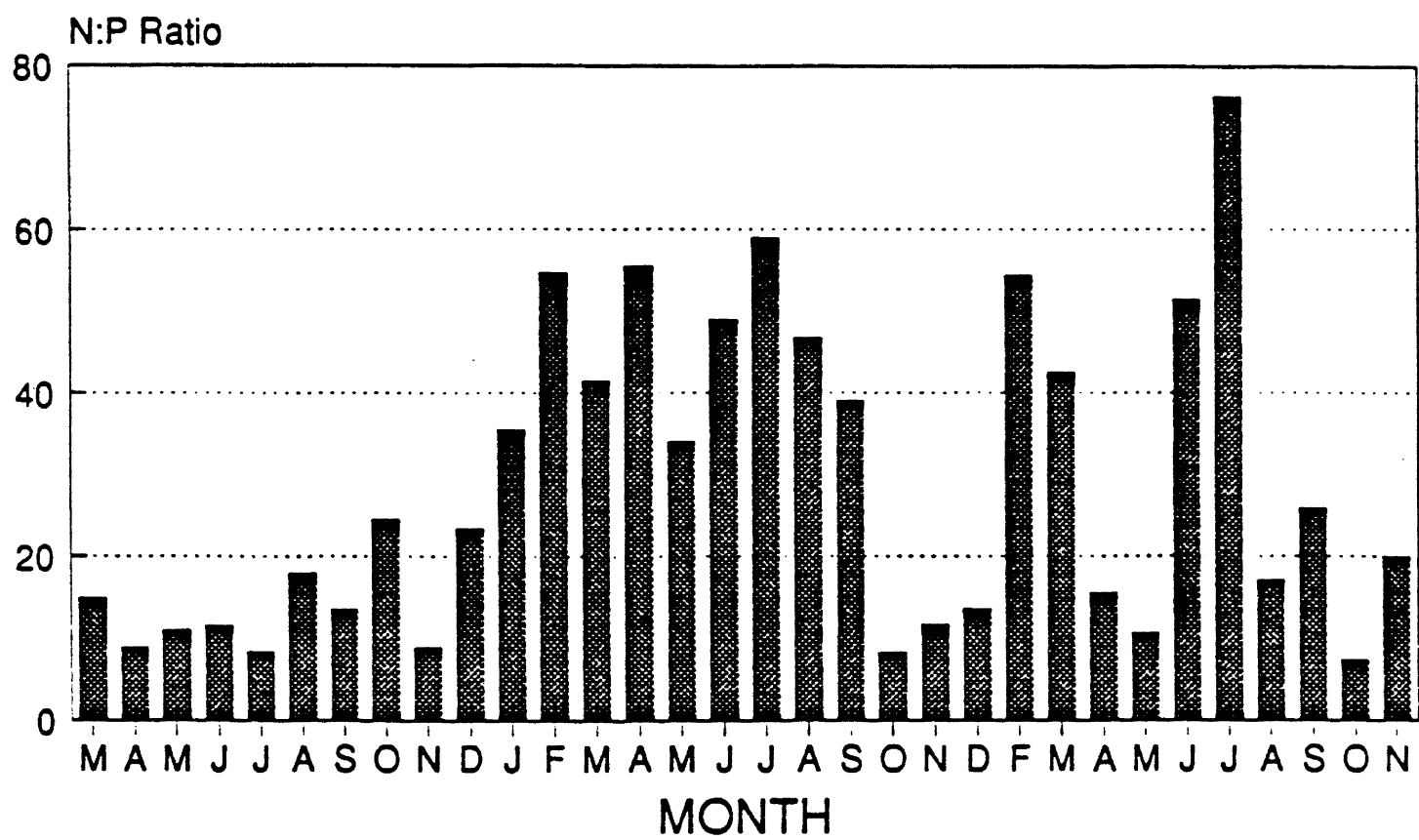


Figure 19. Seasonal ratios of inorganic nitrogen to orthophosphate-phosphorus in Mountain Lake, Virginia, 1985-87.

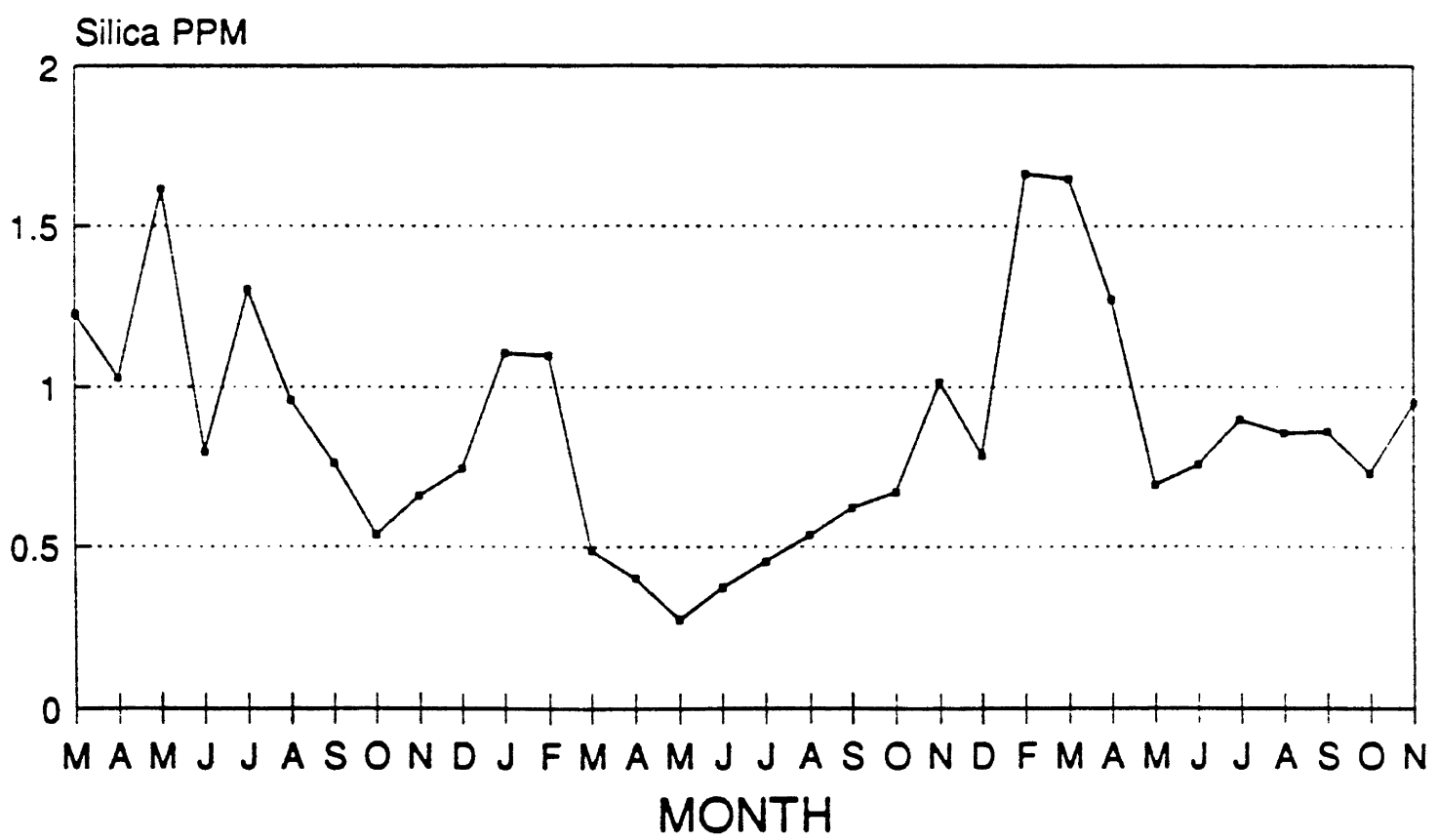


Figure 20. Seasonal levels of silica in Mountain Lake, Virginia, 1985-87. Values are means from five selected depths.

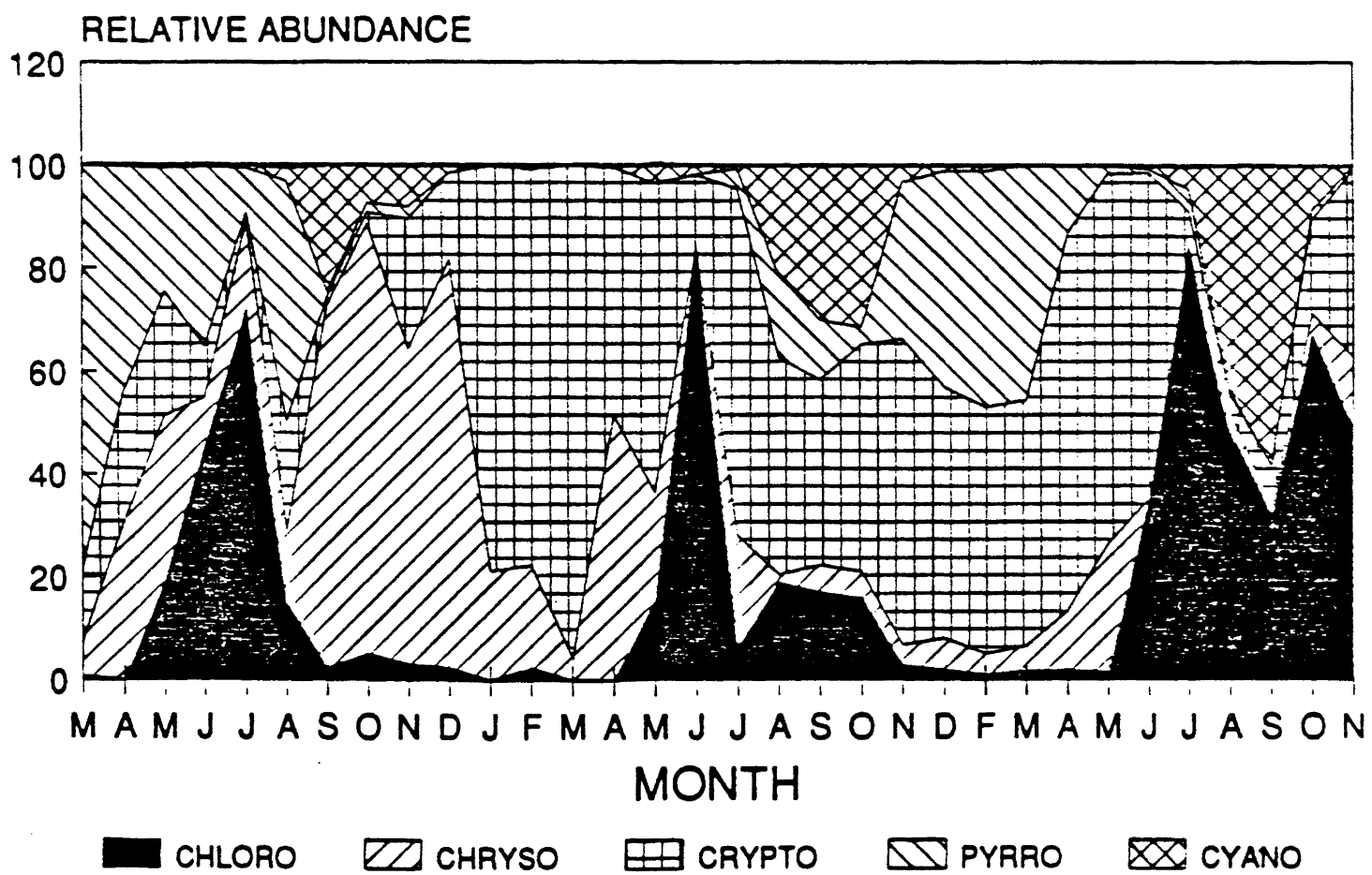


Figure 21. Seasonal % abundance values for five major groups of phytoplankton in Mountain Lake, Virginia, 1985-87. In these area graphs, the vertical scale applies to lowest group; others are layered above for easy comparison.

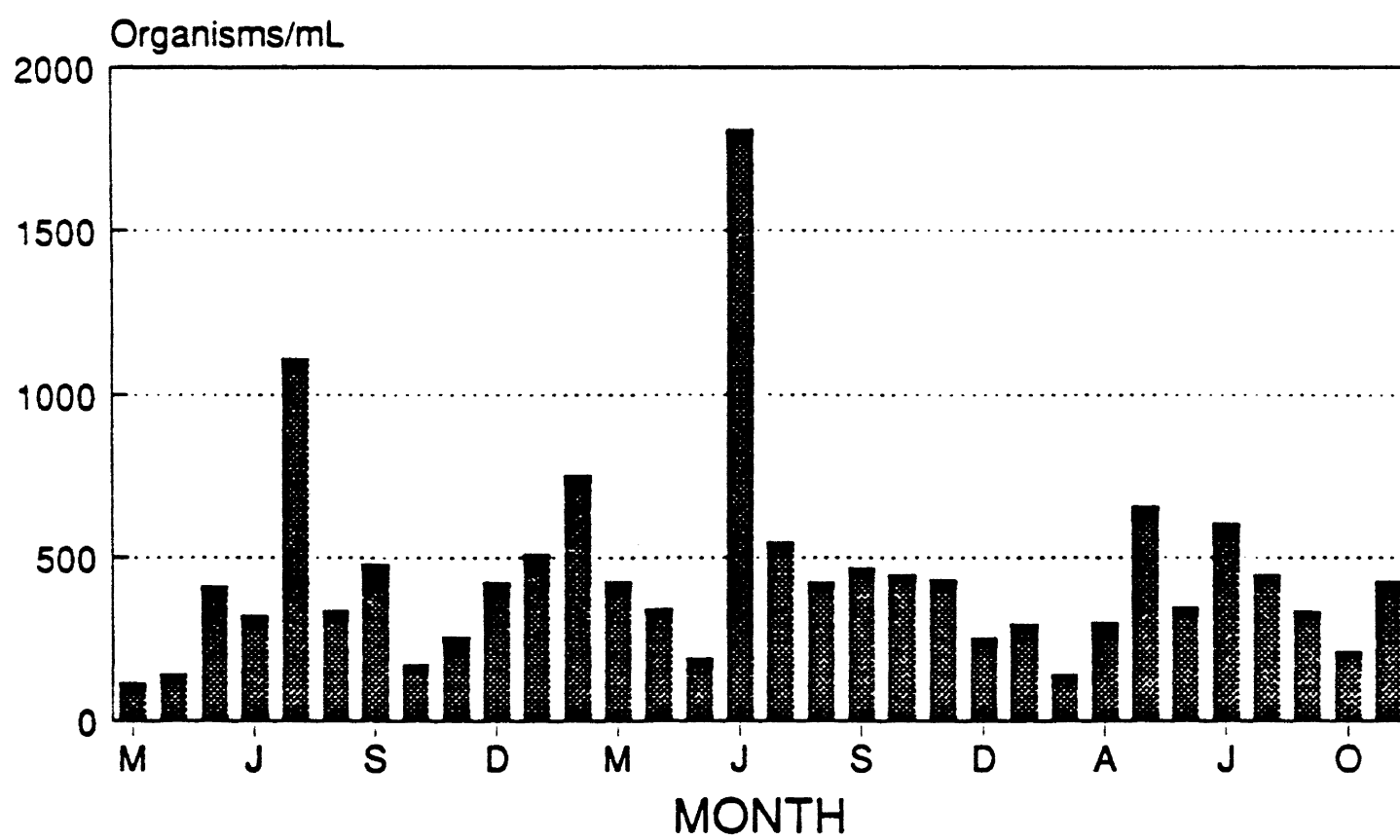


Figure 22. Seasonal variations in phytoplankton density in Mountain Lake, Virginia 1985-87.

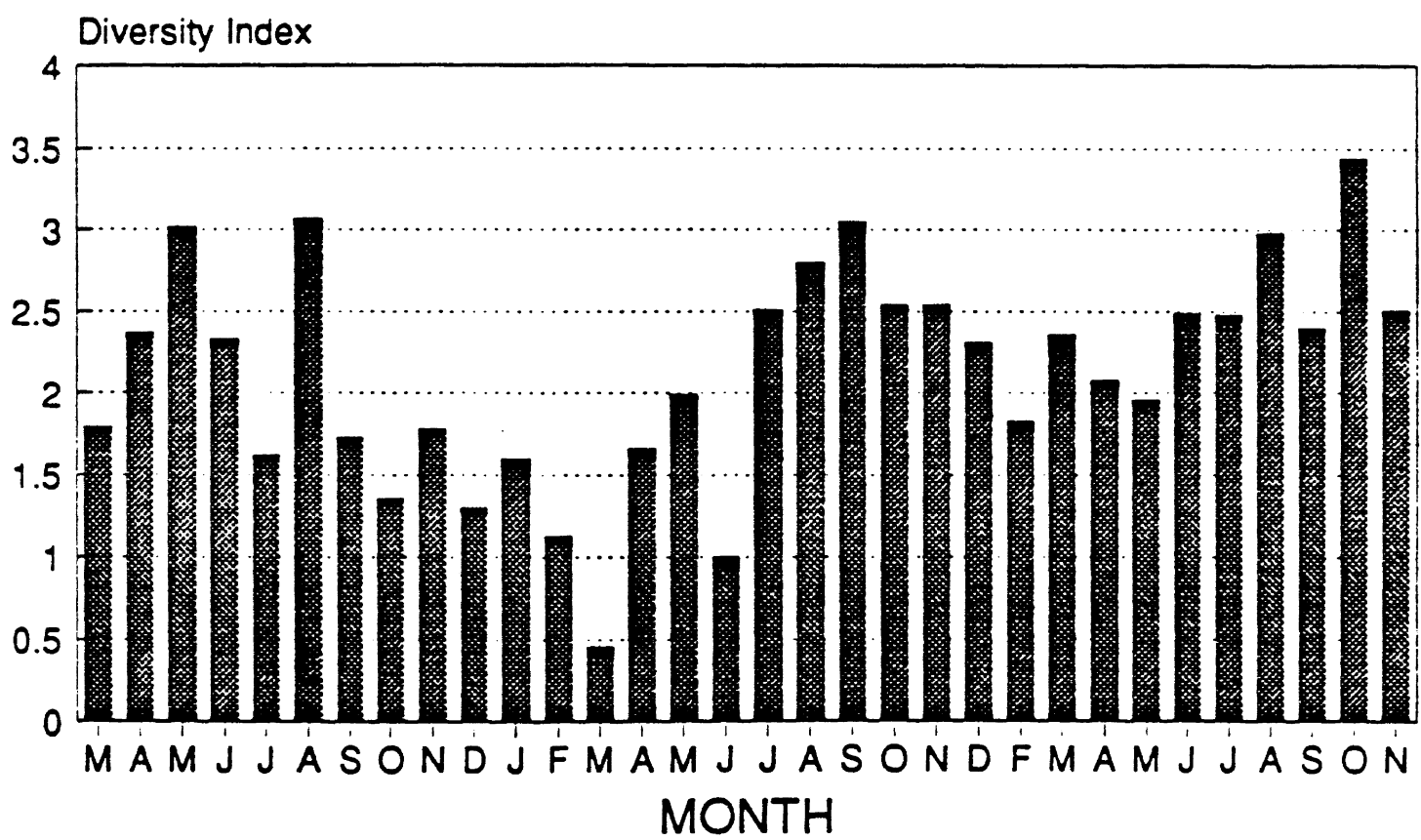


Figure 23. Monthly Shannon-Weaver Diversity Index for Mountain Lake, Virginia, 1985-1987.

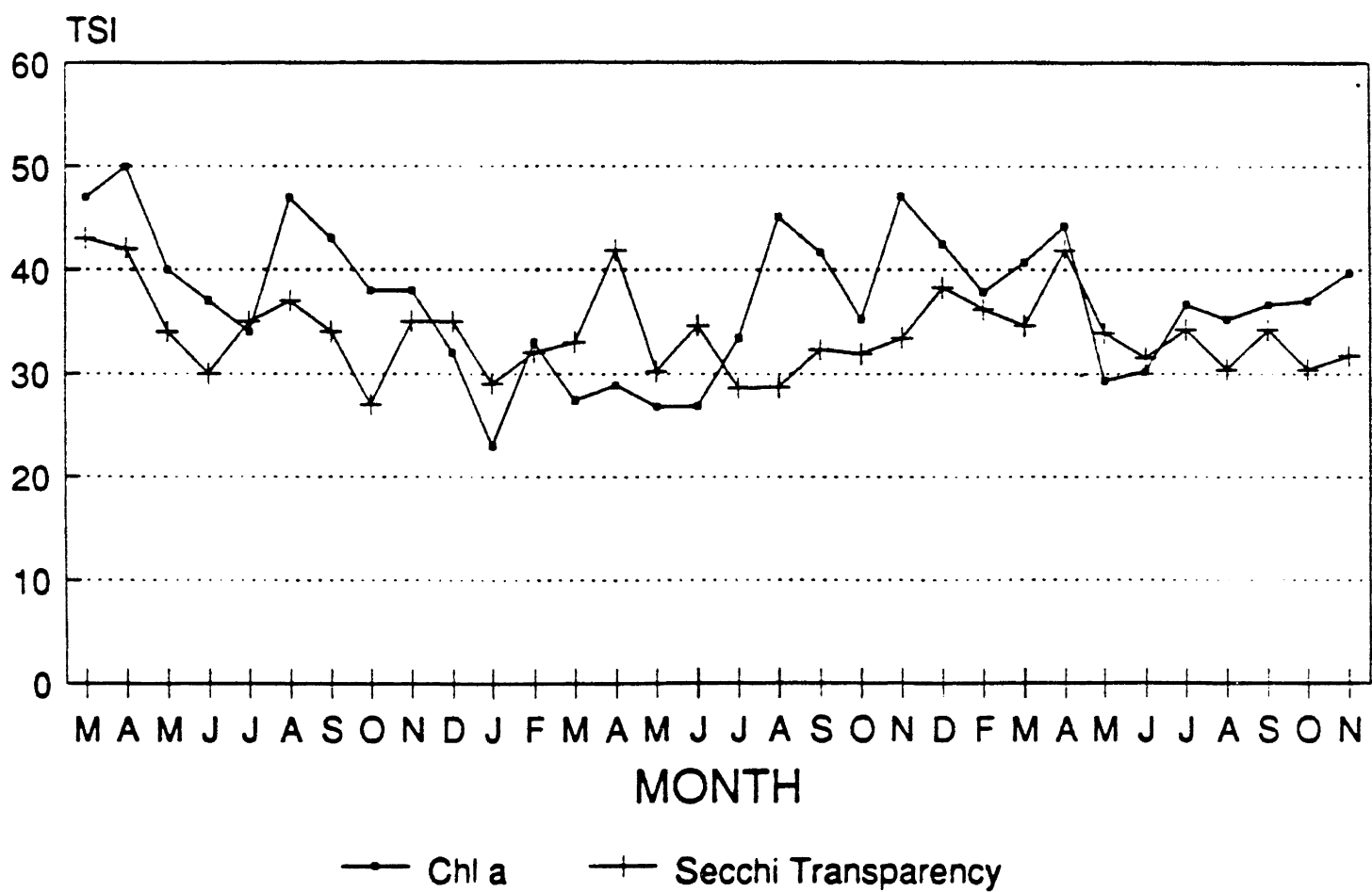


Figure 24. Seasonal Trophic State Index (TSI) (Carlson, 1977) values based on chlorophyll *a* and Secchi disc transparency for Mountain Lake, Virginia, 1985-87.

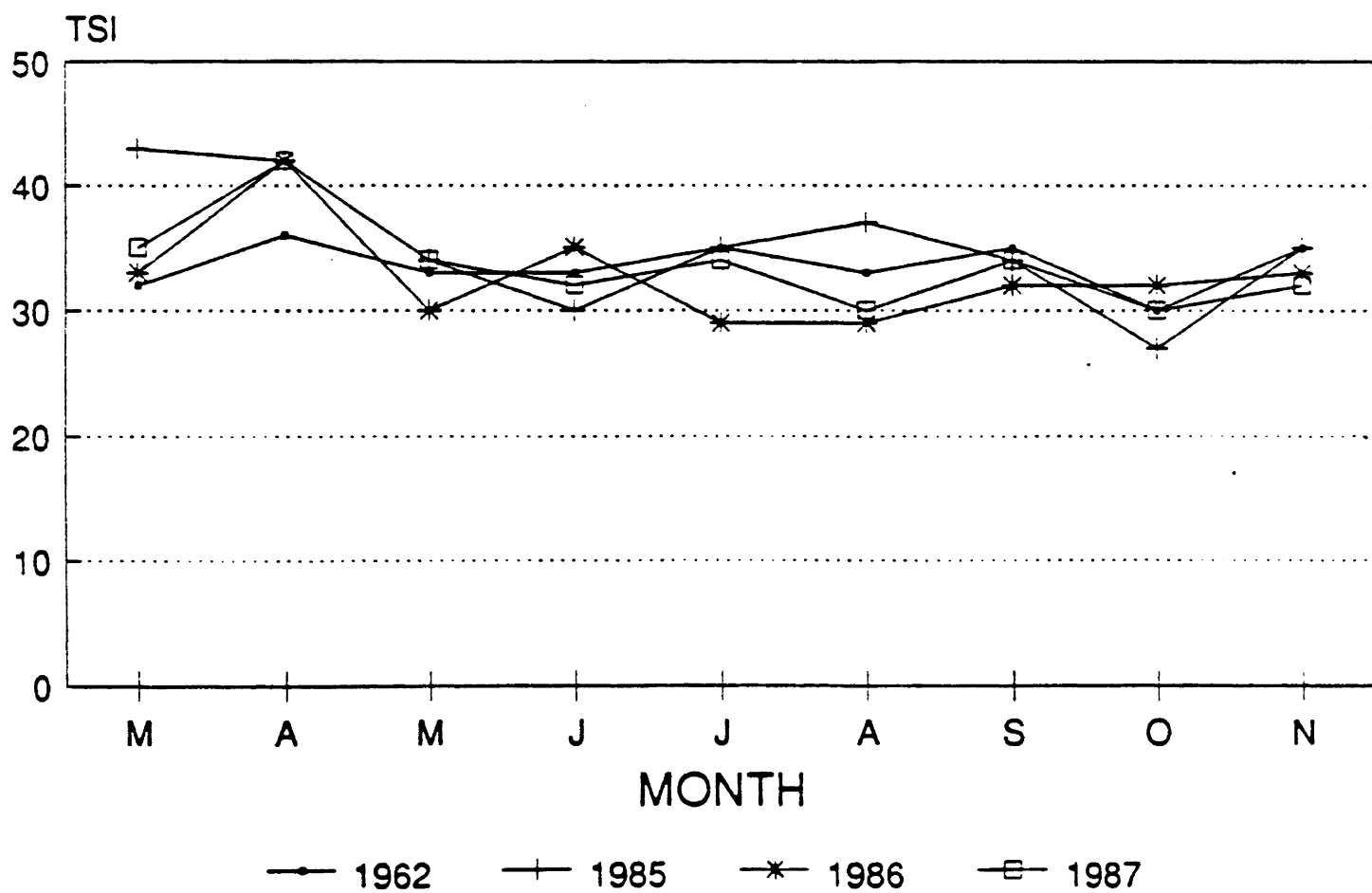


Figure 25. Comparison of Carlson's (1977) Trophic State Index for 1962 and 1985-1987 using Secchi disc transparency readings.

CHAPTER III

Algal Flora in Mountain Lake, Virginia: Past and Present

Mountain Lake, Virginia (37°22'N., 80°32'W) is a unique lake located at an elevation of 1180 meters in the Alleghany Mountains. It is the only natural lake in the southern Appalachians and has remained relatively pristine because of its remote location with limited access to the public and the lack of development around it except for a resort hotel whose owners have consciously tried to protect the lake. Even though Mountain Lake has been studied by many researchers because of its close proximity to the Virginia Tech campus and the University of Virginia's Mountain Lake Biological Station, most phytoplankton research has been limited to the warm summer months except for that of Obeng-Asamoah and Parker (1972).

During phytoplankton and limnological studies of Mountain Lake from March 1985-November 1987, 163 phytoplankton taxa were identified. When our species list was compared with that of earlier reports, 60% were new reports for Mountain Lake. The current study, besides being the longest and most comprehensive study ever done on the lake, utilized improved settling techniques for algal concentration and enumeration. Thus knowledge about species

present in the lake and their relative abundance throughout the year has been expanded.

The purpose of the present paper is to provide a complete list of algal taxa reported for Mountain Lake, past and present, and to indicate which taxa were most abundant. Only published reports, theses or dissertations from the past are included and no attempt is made to settle disputes about proper identification of the attached algal macrophytes.

The species list was compiled from our study as well as from the following sources shown in chronological order.

Williams (1930)

Hutchinson and Pickford (1932)

Coker and Hayes (1940)

Grover and Coker (1940)

Forest (1954)

Whitford (1964)

Obeng-Asamoah and Parker (1972)

Dubay and Simmons (1981)

Van Brunt (1984)

Jervis (1988)

Information about methods and time of collection of previous studies is included so that differences seen over the years can be evaluated by the reader.

Williams (1930)

Collections were made with a tow-net (pore size not specified) every afternoon during July 1930 between 2:00-4:00 P.M. Collections were not concentrated further but all samples were brought up to a volume of 30 mL and 0.5 mL was placed on a slide for identification and enumeration.

Hutchinson and Pickford (1932)

On July 19, 1931, three plankton samples were taken from the surface, 2 meters, and between 7-10 meters. On August 1, 1931, 19.2 liters from 6 depths were concentrated by straining. The species present on both days were identified and the concentrated samples were used for enumeration.

Coker and Hayes (1940)

Water was collected with a Foerst water bottle from the surface, 2, 5, 10, 20, 30, 40, 50, and 60 ft. on July 16, 1937. Four aliquots of water each 16 mL in volume were concentrated by centrifugation. The bottom portion of three of the tubes were added to the fourth tube for continued centrifuging. The bottom 1 mL of the fourth tube was then viewed for enumeration in a Sedgewick-Rafter counting cell.

Grove and Coker (1940)

Collections (225) were made at 2 P.M. and midnight between July 13 and August 1, 1937. Hauls were made at the surface, 2, 5, 10, 20, 30, 40, 50, and 60 ft. Collections were fixed with 5% formalin. Samples were concentrated to 10 mL and counted in a Sedgewick-Rafter counting cell.

Forest (1954)

Forest's checklist includes algae collected from Mountain Lake by classes at the University of Virginia Mountain Lake Biological Station in the summers of 1935, 1936, 1942, and 1953. In addition, reports of algae from Mountain Lake by Meyer (1940) and Strickland (1940) are included.

No information is included as to the methods used in collection or concentration, but in the summer of 1953, most of the 165 taxa collected and identified were preserved and used to start an algal section in the Herbarium of the Mountain Lake Biological Station.

Whitford (1964)

Collections were made (with a No. 120 plankton net) primarily during the summer and autumn of 1952 and winter and spring of 1953 with a few made during the summers of 1956 and

1962. A few collections from the surface and two meter depth were concentrated by centrifuging.

Obeng-Asamoah and Parker (1972)

Every few weeks from January 1970 through early spring of 1971 collections were made with a Wisconsin tow net of 76 μm pore size drawn along the entire center of the lake and counted in a Sedgewick-Rafter chamber. In addition to the surface samples mentioned, samples were collected, concentrated with a Foerst Continuous-flow Centrifuge, and enumerated from 0.01, 1, 6 and 10 meter depths for four dates in late winter and early spring of 1971.

Dubay and Simmons (1981)

Benthic macrophytes (including algal forms) were collected during July and August 1973. Samples were collected along five underwater transects by SCUBA divers and a hand-operated Ekman dredge.

Van Brunt (1984)

Algal flagellates and other plankton were identified after colonization of polyurethane units during four 21 day periods. Water containing the plankton from the polyurethane units was squeezed out and examined microscopically to identify and to determine the number of species present but

not the relative abundance of each species. On the days that the polyurethane units were collected, a single plankton tow was taken using a 10 μ m mesh plankton net. The plankton tow sample was also used to determine the species present.

Jervis (1988)

During the summer of 1986 and the summer of 1987, algal macrophytes were collected by hand by SCUBA divers or by sampling with an Ekman dredge along the same five transects as described by Dubay and Simmons (1981). Species were identified and biomass was measured.

This Study (1985-1987)

Water samples were collected monthly (except January 1987) from March 1985-November 1987 from 0.1, 1, 6, 10, and 17 meters with a Kemmerer water sampler and preserved with acid Lugol's. Volumes of 100 mL for each sample were settled for 60 hours in Utermohl chambers 4° C (to reduce convection currents) and viewed under an inverted Wild microscope for identifying and enumerating species. Also, plankton tows were taken monthly, examined alive a few hours after collection using a Zeiss microscope with Nomarski optics, and species were identified. Only settled samples were used to estimate species densities, but both the preserved and live samples were used to compile the species list.

Table 12 shows algal taxa (phytoplankton and macrophytes) reported for Mountain Lake by all the investigators listed above. The list includes 331 taxa: 180 Chlorophyceae, 45 Cyanophyceae, 25 Bacillariophyceae, 23 Dinophyceae, 20 Chrysophyceae, 16 Euglenophyceae, 13 Cryptophyceae, 5 Charophyceae, 3 Xanthophyceae, 1 Chloromonadaceae. Ninety-two of the taxa listed had not been reported for Mountain Lake previous to our study. Table 13 summarizes the abundant species in Mountain Lake. In the past and currently, the lake is dominated by green algae with almost equal representation from the other classes. The only algal macrophyte of any importance has been and continues to be Nitella.

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Strickland, J. C., Jr. 1940. The Oscillatoriaceae of Virginia. Am. J. Bot. 27:628-633.

Van Brunt, M. R. 1984. Seasonal patterns of colonization of protozoa in an oligotrophic lake. Blacksburg, Virginia: Virginia Polytechnic Institute and State University, 94 pp. M.S. Thesis.

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Charlottesville, Virginia: University of Virginia, 25 pp. M.S. Thesis.

Table 12. Taxa are arranged according to Prescott (1978). The numbers following taxa indicate those reporting; 1 = Williams; 2 = Hutchinson and Pickford; 3 = Coker and Hayes; 4 = Grover and Coker; 5 = Forest; 6 = Whitford; 7 = Obeng-Asamoah and Parker; 8 = Dubay and Simmons; 9 = Van Brunt; 10 = Jervis; 11 = our study. An asterisk following the number indicates that the taxon was considered abundant by the author. An asterisk preceeding the taxon indicates that it is a new report for Mountain Lake, Virginia.

Division Chlorophyta

Sub-phylum Chlorophyceae

Ankistrodesmus falcatus (Corda) Ralfs 6, 7, 11

*Ankistrodesmus falcatus var. mirabilis West & West 11

Arthrodesmus incus (Bréb.) Hassall 5

Arthrodesmus octocornis Ehrenberg 5

*Arthrodesmus phimus Turner 11

*Arthrodesmus quadratus (Schm.) Teiling 11

*Arthrodesmus subulatus Kuetzing 11

Arthrodesmus sp. 6

Bambusina brebissonii Kuetzing 7*, 11

*Bambusina confervacea West & West 11

*Botryococcus sudeticus Lemmermann 11

Botryococcus braunii Kuetzing 7, 11

Botryococcus protuberans var. minor G. M. Smith 7

Bulbochaete spp. 5, 7, 11

Table 12 (Cont'd.)

<u>Carteria</u> spp.	9
<u>Chaltosphaeridium</u> spp.	5
<u>Chlamydomonas reinhardi</u>	Dangeard 9
<u>Chlamydomonas cienkowskii</u>	Schmidle 7
<u>Chlamydomonas globosa</u>	Snow 7
<u>Chlamydomonas</u> sp.	1, 6, 9, 11
<u>Characium cylindricum</u>	1
<u>Chlorella vulgaris</u>	Beyernick 7, 11*
* <u>Closterium baillyanum</u>	Brébisson 11
* <u>Closterium costatum</u>	Corda 11
<u>Closterium lunula</u> forma <u>gracilis</u>	Messik 7
* <u>Closterium nematodes</u>	Josh 11
<u>Closterium moniliferum</u> (Bréb.)	Ehrenberg 7, 11
<u>Closterium sigmoideum</u> (Lagerh.)	Norstedt 7
<u>Closterium</u> sp.	1, 6, 7
* <u>Coelastrum microsporum</u>	Naegeli 11
<u>Cosmarium botrytis</u>	Meneghini 6, 7
<u>Cosmarium commensurale</u>	Nordst 7
<u>Cosmarium contractum</u>	Kirchner 2
<u>Cosmarium dentatum</u>	Wolle 4, 7, 11
<u>Cosmarium denticulatum</u>	Borge 6, 11
<u>Cosmarium denticulatum</u> forma <u>borgei</u>	Irene-Marie 7

Table 12 (Cont'd.)

<u>Cosmarium furcatospermum</u>	West & West	5
<u>Cosmarium margaritatum</u>	(Lund.) Roy and Biss	7
<u>Cosmarium monomazum</u>	Lundell	7
* <u>Cosmarium phaseolus</u>	Brébisson	11
<u>Cosmarium portianum</u>	Archer	5
<u>Cosmarium pseudoconnatum</u>	Norstedt	5
<u>Cosmarium pseudopyramidatum</u>	Lundell	5
<u>Cosmarium quadratulum</u>	(Gay) DeToni	5
<u>Cosmarium sexangularis</u>	Lundell	5
<u>Cosmarium</u> sp.	6, 7	
<u>Cosmocladium saxonicum</u>		1
<u>Cosmocladium</u> spp.		5
<u>Crucigenia rectangularis</u>	(Naeg.) Gay	3, 7, 11
<u>Crucigenia quadrata</u>	Morren	3, 4, 7, 11
<u>Crucigenia irregularis</u>	Wille	7, 11
* <u>Cylindrocapsa</u> sp.		11
* <u>Desmidium baileyi</u>	(Ralfs) Nordstedt	11
<u>Desmidium cylindricum</u>	Gréville	7*
* <u>Desmidium aptogonum</u>	Brébisson	11
<u>Desmidium</u> spp.		5
* <u>Desmidium grevillii</u>	(Kuetz.) Debary	11
<u>Dictyosphaerium ehrenbergianum</u>	Naegeli	7
<u>Dictyosphaerium pulchellum</u>	Wood	5, 6, 7, 11

Table 12 (Cont'd.)

<u>Dictyosphaerium reniforme</u>	Bulnh. 5
<u>Dictyosphaeriopsis</u> spp.	3*, 4*
<u>Dimorphococcus lunatus</u>	A. Braun 3, 4
* <u>Elakatothrix gelatinosa</u>	Wille 11*
<u>Eremosphaera viridis</u>	DeBary 4, 5
<u>Euastrum elegans</u>	Kuetzing 7
<u>Euastrum sinuosum</u>	Lenor 7
<u>Euastrum verrucosum</u>	Ehrenberg 5
<u>Eudorina elegans</u>	Ehrenberg 6
* <u>Genicularia spirotaenia</u>	DeBary 11
<u>Gloeoaetium limneticum</u>	G. M. Smith 5
<u>Gloeocystis gigas</u>	(Kuetzing) Lagerheim 7, 11
<u>Gloeocystis major</u>	Gerneck ex Lemmermann 11
<u>Gloeocystis paroliniana</u>	(Menegh.) Naegeli 11
<u>Gloeocystis vesiculosa</u>	Naegeli 7, 11
* <u>Gloeocystis planctonica</u>	(West & West) Lemmermann 11*
<u>Gloeocystis</u> sp.	6
<u>Gonatozygon kinahani</u>	(Arch.) Rabenhorst 6, 11
* <u>Gonatozygon monotaenium</u>	DeBary 11
<u>Gonatozygon pilosum</u>	Wolle 7, 11
<u>Gonatozygon</u> spp.	5
<u>Hyalotheca dissiliens</u>	(Smith) Brébisson 1, 11
* <u>Lobocystis dichotoma</u>	Thompson 11
<u>Kirchneriella lunaris</u>	(Kirch.) Moebius 2, 7

Table 12 (Cont'd.)

- *Kirchneriella obesa (W. West) Schmidle 11
- Kirchneriella spp. 5
- *Mesotaenium sp. 11
- Micrasterias americana (Ehren.) Ralfs 4
- Micrasterias fimbriata var. spinosa Bissel 7
- Micrasterias papillifera Brébisson 5
- *Micrasterias furcata Ralfs 11
- Micrasterias mahabuleshwariensis Hobs 7, 11
- Micrasterias radiata Hassall 1*, 6*, 7, 11
- *Micrasterias radiata var. dichotoma (Wolle) Cushman 11
- Micrasterias radiata var. gracillima G. M. Smith 5, 11
- *Micrasterias radiata var. alata Prescott et Scott 11
- Micrasterias radiosa Ralfs 6, 7, 11
- Micrasterias radiosa var. ornata, f. elegantior
West & West 6
- Micrasterias rotata (Grev.) Ralfs 1, 4*, 5, 7, 11
- Microspora stagnorum (Kuetz.) Lagerheim 5
- Microspora sp. 6
- Mougeotia sp. 1, 7, 11
- *Nephrocytium agardhianum Naegeli 11
- Netrium digitus (Ehren.) Tzigsoha & Rothe 7
- Oedogonium sp. 1, 7, 11
- Onychonema filiforme (Ehren.) Roy & Biss. 5

Table 12 (Cont'd.)

<u>Oocystis</u> sp. 11
* <u>Oocystis pusilla</u> Hansgirg 11*
<u>Oocystis borgei</u> Snow 7, 11*
<u>Oocystis crossa</u> Wittrock 7
<u>Oocystis elliptica</u> West & West 7
<u>Oocystis eremosphaeria</u> G. M. Smith 11
<u>Ourococcus</u> spp. 5
<u>Palmella</u> spp. 5
<u>Pandorina morum</u> (Muell.) Bory 6
<u>Pediastrum araneosum</u> (Racib.) G. M. Smith 7
<u>Pediastrum boryanum</u> (Turp.) Meneghini 7
* <u>Pediastrum duplex</u> var. <u>rugulosum</u> Raciborski 11
* <u>Pediastrum biradiatum</u> Meyen 11
<u>Pediastrum integrum</u> Naegeli 6, 7, 11
* <u>Pediastrum sculptatum</u> G. M. Smith 11
* <u>Pediastrum tetras</u> forma <u>evoluta</u> West 11
<u>Penium margaritaceum</u> (Ehren.) Bréisson 5
<u>Penium</u> sp. 6, 7
<u>Planktosphaeria gelatinosa</u> G. M. Smith 4, 5, 7
* <u>Pleurotaenium trabecula</u> (Ehren.) Naegeli 11
<u>Pleurotaenium</u> sp. 1
<u>Protoderma viride</u> Kuetzing 7
<u>Protoderma</u> spp. 5

Table 12 (Cont'd.)

- Quadrigula chodatii (Tan.-Ful.) G. M. Smith 2, 7, 11*
- Quadrigula lacustris (Chod.) G. M. Smith 2*, 6, 7*
- *Quadrigula pfitzeri (Schroder) G. M. Smith 11
- *Quadrigula closteroides (Bohlin) Printz 11
- Quadrigula spp. 5
- Radiofilum conjunctivum Schmidle 7*
- *Rhizoclonium sp. 11
- *Scenedesmus arcuatus Lemmermann 11
- Scenedesmus bijuga (Turp.) Lagerheim 5, 11*
- Scenedesmus obliquus (Turp.) Kuetzing 7
- Scenedesmus quadricauda (Turp.) Brébisson 7, 11
- *Scenedesmus quadricauda var. quadrispina (Chod.)
G. M. Smith 11
- Scenedesmus sp. 7
- *Schoederia setigera (Schroed.) Lemmermann 11
- *Sphaerellopsis gloeocystiformis Dill 11
- Sphaerocystis schroeteri Chodat 6, 7
- Sphaerocystis spp. 5
- Sphaerozoma granulatum Roy & Bissett 6
- *Spirogyra sp. 11
- Spirotaenia condensata Brébisson 5
- Spirotaenium sp. 6
- Spondylosium granulatum Roy from S. papillosum
West & West 5

Table 12 (Cont'd.)

- *Spondylosium planum (Wolle) West & West 11
- Spondylosium pygmaeum (Cooke) W. West 5
- *Spondylosium vertebratum var. punctulatum
West & West 11
- *Staurastrum ankyroides Wolle 11
- Staurastrum arctiscon (Ehren.) Lundell 1*, 2, 5, 7, 11
- Staurastrum curvatum W. West 3*, 4*
- *Staurastrum dakoti Taft 11
- *Staurastrum leptacanthum Nordst 11
- Staurastrum limneticum Schmidle 4*, 11
- Staurastrum ophiura Lundell 1*, 6*, 11
- Staurastrum ophiura var. cambricum (Lund.)
West & West 2, 7*
- Staurastrum orbiculare Ralfs 5
- Staurastrum polymorphum Brébisson 5, 11
- *Stichococcus bacillaris Naegeli 11
- *Stigeoclonium flagelliferum Kuetzing 11
- *Stigeoclonium sp. 11
- *Stylosphaeridium stipitatum (Bachm.) Geitler & Gimesi 11
- *Tetraspora lubrica 1
- *Tetraspora sp.
- *Ulothrix subconstricta G. S. West 11
- Urococcus sp. 3

Table 12 (Cont'd.)

Xanthidium antilopaeum (Bréb.) Kuetzing 2, 7

Xanthidium armatum (Bréb.) Rabenhorst 6

Xanthidium subhastiferum West & West 6

Xanthidium spp. 5

Volvox aureus Ehrenberg 2, 4, 5, 7

Volvox tertius Meyer 4, 7

Volvox sp. 1

Zygnema sp. 7

Unknown flagellate sp. 7, 11

Sub-phylum Charophyceae

Chara braunii Gemlin 8

Chara schweinitzii A. Braun 6

Chara spp. 3, 10

Nitella flexilis (L.) Agardh 5, 6, 8*

Nitella megacarpa T. F. Allen 10*

Chrysophyta

Sub-phylum Xanthophyceae

Chlorosaccus spp. 5

Ophiocytium capitatum Wolle 7

Vaucheria spp. 5

Sub-phylum Chrysophyceae

Unknown flagellate sp. 1 11*

Unknown flagellate sp. 2 11

Chlorochromonas minuta Lewis 11

Table 12 (Cont'd.)

Chromulina ovalis Klebs 11

Chromulina sp. 6*, 9

Dinobryon cylindricum Imhof 9

Dinobryon divergens Imhof 9, 11

Dinobryon elegantissimum Bourrelly 11*

Dinobryon sertularia Ehrenberg 6, 9

*Dinobryon sociale Ehrenberg 11

Dinobryon sp. 4

Mallomonas acaroides Perty 9, 11

Mallomonas caudata Irvanoff 9

Mallomonas sp. 9, 11

Synura adamsi G. M. Smith 9

Synura sphagnicola Korshikov 9

Synura uvella Ehrenberg 9

Synura spp. 9, 11

Uroglena volvox Ehrenberg 9

Uroglenopsis americana Lemmermann 9

Sub-phylum Bacillariophyceae (Diatomaceae)

*Asterionella formosa Hassall 11

Cyclotella compta (Dhr.) Kuetzing 7*

Cyclotella meneghiniana Kuetzing 6*, 7, 11*

Cyclotella operculata (Agardh) Kuetzing 5

*Cymbella sp. 11

Table 12 (Cont'd.)

<u>Diatoma</u> spp.	5
* <u>Eunotia</u> sp.	11
<u>Fragilaria</u> sp.	7, 11
<u>Gomphonema</u> sp.	6, 7, 11
<u>Melosira varians</u> Agardh	11
<u>Melosira</u> sp.	11
* <u>Meridion</u> sp.	11
* <u>Navicula gracilis</u> Ehrenberg	11
* <u>Navicula</u> sp.	11
* <u>Neidium</u> sp.	11
<u>Odontidium</u> spp.	5
<u>Pinnularia</u> sp.	6
* <u>Synedra tenera</u> Agardh	11
* <u>Synedra ulna</u> (Nitzsch.) Ehrenberg	11
<u>Synedra</u> sp.	6, 7, 11
<u>Suriella</u> sp.	11
<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	1, 2, 3, 7*, 11
<u>Tabellaria flocculosa</u> (Roth.) Kuetzing	6*, 7*
<u>Tabellaria</u> sp.	11
<u>Vanheurckia</u> sp.	1

Table 12 (Cont'd.)

Division Cryptophyta

Cryptophyceae

Chilomonas paramecium Ehrenberg 9, 11*Chilomonas sp. 9Chroomonas norstedii Hansgirg 9Chroomonas sp. 9Cryptochrysis commutata Pascher 9Cryptomonas erosa Stein 9*Cryptomonas erosa var. reflexa Marsson 11*Cryptomonas obovoidea Pascher 9Cryptomonas ovata Ehrenberg 9, 11**Cryptomonas pyrenoidifera Geitler 11**Cryptomonas pusilla Bachman 11*Cryptomonas spp. 9, 11*Cyathomonas truncata Fromental 9

Division Pyrrophyta

Dinophyceae

Ceratium hirundinella (O. F. Muell.) Dujardin 6Glenodinium borgei (Lemm.) Schiller 7*Glenodinium cinctum (Muell.) 11*Glenodinium minimum (Langtzensch) Bachman 11*Glenodinium oculatum Stein 11*Glenodinium palustre (Lemm.) Schiller 11

Table 12 (Cont'd.)

<u>Glenodinium pulvisculus</u> (Ehr.) Stein 6, 11
<u>Glenodinium</u> spp. 9
<u>Gymnodinium</u> sp. 9, 11*
<u>Gymnodinium fuscum</u> (Ehr.) Stein 9, 11
<u>Gymnodinium rotundatum</u> Klebs 9
* <u>Gymnodinium tatricum</u> Woloszynska 11
<u>Gymnodinium triceratium</u> Skuja 9
<u>Gyrodinium</u> sp. 9
<u>Hemidinium nasutum</u> Stein 5, 9
<u>Hemidinium</u> sp. 9
<u>Peridinium cinctum</u> (Muell.) Ehrenberg 7, 11
* <u>Peridinium cunningtonni</u> Lemmermann 11
<u>Peridinium inconspicuum</u> Lemmermann 6, 7, 9, 11*
<u>Peridinium willei</u> Huitfeld-Kaas 6*, 7
* <u>Peridinium wisconsinense</u> Eddy 11*
* <u>Peridinium volzii</u> Lemmermann 11
<u>Peridinium</u> spp. 9

Division Cyanophyta

Cyanophyceae

Unknown colonial sp. 11
<u>Anabaena</u> sp. 3, 4, 6, 7
<u>Anacystis</u> sp. 6
<u>Aphanocapsa delicatissima</u> West & West 7

Table 12 (Cont'd.)

- Aphanocapsa elachista West & West 7, 11*
- Aphanocapsa elachista var. conferta West & West 11
- Aphanocapsa endophytica G. M. Smith 7
- *Aphanocapsa rivularia (Carm.) Rabenhorst 11
- Aphanothece sp. 11
- Aphanothece gelatinosa (Henn.) Lemmermann 7
- *Aphanothece saxicola Naegeli 11
- Aphanothece microscopica Nagel 6, 7, 11
- Chroococcus dispersus (V. Keiss) Lemmermann 7, 11
- Chroococcus dispersus var. minor G. M. Smith 6*
- *Chroococcus minimus (Keissl.) Lemmermann 11
- *Chroococcus minutus (Kuetz.) Rabenhorst 11*
- Chroococcus minor (Kuetz.) Naegeli 7
- *Chroococcus varius A. Braun in Rabenhorst 11
- Coccochloris stagnina Spreng. from Aphanothece
stagnina (Spreng.) A. Braun 5
- Coelosphaerium spp. 5
- *Dactylococcopsis musicola Hustedt 11
- *Eucapsis sp. 11
- *Gloeocapsa halmatodes Kuetzing 11
- Gloeocapsa punctata Naegeli 7
- Gloeocapsa sp. 11
- Gomphosphaeria wichurae (Hilse) Drouet & Daily 7
- Gomphosphaeria spp. 5

Table 12 (Cont'd.)

<u>Hapalosiphon arboreus</u>	West & West	5
<u>Hapalosiphon pumilus</u>	(Kuetz.) Kirchner	7
<u>Merismopedia glauca</u>	(Ehren.) Naegeli	7
<u>Merismopedia punctata</u>	Meyen	7
<u>Merismopedia tenuissima</u>	Lemmermann	7
<u>Merismopedia</u>	sp. 2,	7
<u>Microcystis aeruginosa</u>	Kuetzing	7, 11
<u>Microcystis incerta</u>	Lemmermann	7
<u>Microcystis firma</u>	(Bréb. et Lenom.) Schmidle	11
* <u>Nostoc spongiaeforme</u>	C. A. Agardh	11
<u>Oscillatoria</u>	sp. 6*,	7, 11
<u>Oscillatoria agardhii</u>	Gomont	5
* <u>Oscillatoria angustissima</u>	West & West	11
<u>Phormidium uncinatum</u>	(Agardh) Gomont	
* <u>Phormidium</u>	sp. 11	
* <u>Radiocystis geminata</u>	Skuja	11
<u>Rivularia beccariana</u>	(De Not.) Born & Flah.	5
<u>Scytonema mirabile</u>	(Dillw.) Born	
<u>Sacconema</u>	spp. 5	

Division Euglenophyta

Euglenophyceae

<u>Anisonema acinus</u>	Dujardin	9
<u>Astasia</u>	sp. 9	
<u>Entosiphon obliquum</u>	Klebs	9

Table 12 (Cont'd.)

Entosiphon sulcatum Dujardin 9

Euglena oxyuris Schmarha 9

Euglena spirogyra Ehrenberg 9

Euglena sp. 9, 11

Notosolenus spp. 9

Peranema trichophorum (Ehren.) Stein 6, 9

Peranema sp. 9

Phacus caudatus Huebner 5

Phacus longicaudus Huebner 5

Phacus pleuronectes Muller 5, 9

Phacus pyrum Ehrenberg 5, 9

Phacus triqueter (Ehren.) Dujardin 5

Phacus sp. 11

Trachelomonas hispida Perty 9

Trachelomonas horrida Palmer 9

Tropidoscyphus sp. 9

Division Chloromonadophyta

Gonyostomum semen Drising 9

Table 13. Abundant Algal Taxa in Mountain Lake, Virginia:
Past (*) and Present (!). Authorities are shown in previous
table.

Chlorophyceae

Bambusina brebissonii *

Chlorella vulgaris !

Desmidium cylindricum *

Dictyosphaeriopsis spp. *

Elakatothrix gelatinosa !

Gloeocystis planctonica !

Micrasterias radiata *

Micrasterias rotata *

Oocystis pusilla !

Oocystis borgei !

Quadrigula chodatii !

Quadrigula lacustris *

Radiofilum conjunctivum *

Scenedesmus bijuga !

Staurastrum arctiscon *

Staurastrum curvatum *

Staurastrum ophiura *

Staurastrum ophiura var. cambricum *

Table 13 (Cont'd.)

Charophyceae

Nitella flexilis *

Nitella megacarpa *

Chrysophyceae

Chlorochromonas minuta !

Chromulina ovalis !

Chromulina sp. *

Dinobryon elegantissimum !

Bacillariophyceae

Asterionella formosa !

Cyclotella compta *

Cyclotella meneghiniana * !

Tabellaria flocculosa *

Cryptophyceae

Chilomonas paramecium !

Cryptomonas erosa var. relflexa !

Cryptomonas ovata !

Cryptomonas pyrenoidifera !

Dinophyceae

Gymnodinium sp. !

Peridinium inconspicuum !

Peridinium willei *

Peridinium wisconsinense !

Table 13 (Cont'd.)

Cyanophyceae

Anacystis *Aphanocapsa elachista var. conferta !Chroococcus dispersus var. minor *Chroococcus minutus !

CHAPTER IV

AMMONIA* UPTAKE OF PHYTOPLANKTON AND SEASONAL SUCCESSION IN AN OLIGOTROPHIC LAKE DURING THERMAL STRATIFICATION

Nitrogen has long been recognized as one of the principal nutrients limiting production in natural waters. Algae utilize inorganic nitrogen as molecular nitrogen, nitrate, nitrite, ammonia and some forms of organic nitrogen. Even though many forms of nitrogen may be used, nitrogen limits production even in some eutrophic waters, such as Lake Rotorua, New Zealand (White and Payne, 1978). Nitrogen deficiency also limited algal production in Lakes Ontario and Erie (Lange, 1971; Munawar and Burns, 1976; Sridharan and Lee, 1977; Murphy, 1980). Axler et al. (1981), investigating the importance of regenerated nitrogen to phytoplankton productivity in a meso-oligotrophic lake estimated the degree of coupling between ammonia production processes and primary production by performing regression analyses. Their results indicated a significant correlation.

Ammonia is a widespread nitrogenous source in the biosphere, second only in abundance to atmospheric nitrogen gas, and is believed the preferred nitrogen source for

*The terms ammonia and methylamine are used to refer to either compound without defining its state of protonation. procaryotes, algae, fungi, and plants.

McCarthy et al. (1977), investigating the nutrient availability and phytoplankton preferences in the Chesapeake Bay, stated that the most striking feature of their data was that, in spite of tremendous environmental variability, ammonia was the preferred form of nitrogen. Irrespective of the ambient levels of nitrate, ammonia levels of $> 0.5-1.0$ microgram-atom N per liter prevented the utilization of nitrate by the phytoplankton. Even when nitrate accounted for $>90\%$ of the total N available, ammonia was preferred. The preference for ammonia by algae is not limited to marine species. Procházková et al. (1970), investigating nitrogen metabolism in several reservoirs, found a preference for ammonia even though nitrate concentrations were six times higher. Extrapolation of their data suggested that when ammonia concentrations were >160 microgram N-ammonia per liter, little or no nitrate would be used (Procházková et al., 1970). Similar preferences for ammonia by phytoplankton have been reported for other freshwater lakes around the world (Takahashi and Saijo, 1981; Berman et al., 1984).

Another approach used to determine whether algae use nitrate or ammonia is an assay for nitrate reductase. Nitrate must be reduced to ammonia before it can be incorporated into organic forms. The assay involves measuring the NADH-dependent formation of nitrite in phytoplankton extracts. Nitrate reductase is induced by the

presence of nitrate and repressed by ammonia; enzyme synthesis, and nitrate utilization begins when ammonia levels are >0.5 - 1.0 micromolar (Eppley et al., 1969a). Thus the presence of nitrate reductase implies that nitrate and not ammonia is the important nitrogen source (Eppley et al., 1970). Nitrate reductase has been isolated from several green algae and although a high evolutionary stability would be expected because of the importance of its role, this isn't the case. For example, the prosthetic groups and the number of subunits in purified enzyme from two closely related green algae, *Ankistrodesmus baunii* and *Chlorella vulgaris* (De la Rosa and Vega, 1981) were different.

Uptake rates of nitrate or ammonia by algae usually give hyperbolas when plotted against corresponding environmental concentrations, and thus uptake by phytoplankton conforms to Michaelis-Menten kinetics in the ocean (Eppley, et al., 1969b; Syrett, 1962) and in fresh water (Toetz et al., 1973; Murphy, 1980; Takahashi and Saijo, 1981; Vymazal, 1987). Thus half-saturation constants can be calculated using the Michaelis-Menten equation which allow comparisons to be made between populations or communities. The equation is: $v = V_{max} \cdot S / (K_m + S)$, where v is uptake velocity, S is substrate concentration, V_{max} is the maximum uptake velocity attained at saturating levels of S , and K_m is equal to S when $v = V_{max}/2$. The half-saturation constant, K_m , may be

ecologically important because it shows the population's ability to use low levels of nutrients; the V_{max} , maximum velocity, is also of ecological importance, because it is best taken as the maximum specific growth rate of the organism imposed by external conditions (Eppley et al., 1969b).

The ability of algae to take up and assimilate ammonia rapidly would be an important aspect of its ability to compete, especially under oligotrophic conditions. A few nitrate and ammonia uptake rates have been calculated for phytoplankton from marine habitats using nitrogen-15 under culture conditions. Eppley et al. (1969b) determined the half-saturation constants for 17 marine species. Generally, a species with a low K_m for ammonia also had a low K_m for nitrate; large cells tended to have high K_m values; and oceanic species had lower K_m rates than neritic or littoral species (Eppley, 1969b). Thus it appears that species living in more oligotrophic conditions tend to have lower K_m values than those in more productive conditions, and thus have the ability to use lower levels of nitrate and ammonium. MacIsaac and Dugdale (1969) determined the half-saturation constants for natural phytoplankton populations in Alaskan coastal waters and the northeastern tropical Pacific Ocean. Their data suggest that the half-saturation constants are related to the nutrient and productivity regime of the area

inhabited by the community. The K_m values for both nitrate and ammonia were lower in oligotrophic regions than in eutrophic regions (MacIsaac and Dugdale, 1969).

Nutrient uptake rates of algae also may be important in their ability to use temporarily elevated patches of nutrients that may be encountered due to nutrient regeneration from dead cells, excretion from zooplankton, diffusion from nutrient-rich water below the thermocline, or runoff (Goldman et al., 1979; Turpin et al., 1981). The impact of a single zooplankter is demonstrated by calculations which indicate that an oceanic copepod such as *Oithona* or *Clausocalanus* can excrete enough ammonia in 5 seconds to increase the level by about 5 microgram-atom N/liter in a volume of water equal to its volume (McCarthy and Goldman, 1979).

The use of nitrogen-15 in oligotrophic waters has some limitations because the low algal population densities coupled with low nutrient levels cause isotope enrichment levels to approach the lower level of the mass spectrometer sensitivity (MacIsaac and Dugdale, 1969). Although these problems can be overcome to some extent by prolonged incubation times and large sample volumes, another method has been developed which allows measurement of ammonia uptake in oligotrophic waters and thus has greater sensitivity (Vincent, 1979). This method uses an analogue of ammonia

called methylammonia (methylamine) which is labeled with ^{14}C . Methylamine (MeA) has been successfully used in uptake studies with bacteria, fungi, and algae (Smith and Walker, 1978; Vincent, 1979; Wheeler, 1980; Kleiner and Fitzke, 1981; Wheeler and McCarthy, 1982, Koike et al., 1983; Barnes et al., 1983; Mazzuco and Benson, 1984; Boussiba et al., 1984). These studies clearly show that methylammonia is transported by the same transport system as ammonia. Koike et al. (1983) concluded that the use of [^{14}C] methylamine was a promising technique for studying the kinetics of ammonia transport by marine microorganisms especially in oligotrophic waters. The use of the analogue must, however, be limited to uptake kinetics and not to metabolic assimilation because it is not metabolized by algae (Wheeler and McCarthy, 1982).

Could the ability to take up ammonia give a species an advantage over others in an oligotrophic lake and thus be responsible in part for the seasonal succession that has been observed by limnologists and phycologists for decades? Two possible strategies for nutrient utilization are recognized. One strategy is to utilize efficiently a resource (low K_m) and the other is to utilize rapidly a resource (high V_{max}). These strategies have implications for growth rates. It has been shown generally that algae with efficient uptake systems (able to utilize low levels of nutrients) have lower maximum intrinsic growth rates than those with less efficient uptake

systems (Eppley et al., 1969b; Fuhs et al., 1972). Only a few studies utilizing [^{14}C] methylamine to study ammonia uptake in natural populations have been done. The uptake rates for natural communities were determined for several lakes in New Zealand (Vincent, 1979; Vincent, 1981) and for a tropical high-altitude lake in Peru-Bolivia (Vincent et al., 1984). An additional study was done with natural phytoplankton from Chesapeake Bay (Wheeler and McCarthy, 1982). None of these studies determined the species present in the natural populations nor attempted to relate species abundance with uptake rates. Wheeler and McCarthy (1982) did, however, do fractionation procedures which allowed a conclusion about the contribution of different size classes to total uptake.

The major objective of this research was to determine if a relationship exists between seasonal change in phytoplankton and efficiency of uptake (K_m) or uptake rates (V_{max}) of ammonia which might explain phytoplankton community seasonal succession in oligotrophic ecosystems. Other objectives were to determine if ammonia was preferentially utilized over nitrate and to understand further the characteristics of the ammonia transport system.

Materials and Methods

Study Area.

Mountain Lake, Virginia is the only natural lake in the southern Appalachians and has remained relatively undisturbed. It occupies an area of 189,000 m² with a mean depth of approximately 9.74 meters (Marland, 1967). The phytoplankton and limnological studies conducted on the lake from March 1985-March 1987 indicated that nutrient levels were within the range of oligotrophic lakes, but the lake is more productive than in the past, chlorophyll *a* at times approaches mesotrophic levels, and oxygen is almost depleted at greatest depths by the end of the summer. Generally the level of ammonia-nitrogen was consistently higher than nitrate-nitrogen. Pyrrophytes generally dominated the phytoplankton in winter and early spring, and chlorophytes during the summer. Cryptophytes were consistently present throughout the study. Cyanophytes reached their greatest dominance late summer or fall. Chrysophyte dominance, which included diatoms, did not show any repeated pattern during our study. The low alkalinity (usually < 9 mg CaCO₃/L) and hardness (usually < 50 mg CaCO₃/L) make the lake susceptible to pH fluctuations. Limnological data for Mountain Lake are reported elsewhere (Parson and Parker, 1988).

Ammonia uptake measurements.

Ammonia uptake was estimated using [^{14}C] methylamine (MeA), an analog of ammonia. Water samples were collected from one meter depth at approximately two-week intervals. Samples were transported within 30 minutes to the laboratory and placed in a lighted ($100\ \mu\text{Einstein}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$) incubator set at 18°C . These were the light and temperature conditions used for all uptake experiments in which K_m and V_{max} were estimated. As soon as samples reached 18°C , uptake experiments were begun. Water samples were dispensed into 50 mL screw-cap test tubes. In the two May uptake experiments, triplicate samples (at pH 7.5) were injected with 0.2, 0.4, 0.5, 0.6, 0.8, 1.0, or 10.0 μCi [^{14}C] methylamine-hydrochloride (New England Nuclear, 49.0 mCi/mmol specific activity), which gave final concentrations of 0.006, 0.012, 0.015, 0.018, 0.024, 0.030, and 0.300 μM MeA, respectively. In the June through November uptake experiments, triplicate samples (at pH 7.4-7.6) were then injected with 0.5 mL (1 μCi) [^{14}C] methylamine-hydrochloride (New England Nuclear, 49.0 mCi/mmol specific activity) plus 0.5 mL unlabelled methylamine-hydrochloride (Eastman Kodak Company) to bring the final methylamine concentration to 1, 5, 10, 25, 50, 100, 500, or 2500 μM . Four or five of these concentrations were used per experiment. (Adjustments in the concentrations of MeA used became necessary in order to

saturate the uptake systems.) Samples were incubated for 30 seconds or one minute under light and temperature regime described above and then 25-30 mL were filtered onto 0.8 μ m Nuclepore polycarbonate filters. Ten mL of scintillation cocktail (Ecoscint, National Diagnostics, Mansville, NJ) were added with the filter to scintillation vials. Activity was counted with a Beckman 4100 Scintillation Counter. Radioactivity for uptake was corrected for passive isotope adsorption and filter retention by subtracting activity from controls (triplicates) which were formalin-fixed samples carried through the same procedures as described. Uptake rates were calculated and the mean uptake rate at each concentration was used (Sherr et al., 1982; Wheeler, 1980; Balch, 1986; Hellebust et al., 1985) in the construction of Hanes plots from which K_m and V_{max} values were determined using least-squares regression analysis. (See Appendix I and Appendix J.)

V_{max} values are expressed as uptake per hour as is the tradition realizing that these are overestimates because uptake was not linear over that time period. Uptake was linear for less than five minutes. Comparison of V_{max} values with those of other researchers should be done with this in mind. However, trends in V_{max} values within Mountain Lake would not be affected.

Sequential Vmax values were compared by testing for significant differences in the slopes (parallelism) from Hanes Plots, since Vmax values are determined from the reciprocal of the slope. The test for differences in slope was carried out using the Statistical Program from Social Sciences, Release 2.2, which was run using the Virginia Tech Computing Center IBM 3084. (See Appendix K.)

In addition to the uptake experiments described, the effect of pH, temperature, darkness, ammonia, 3(3,4-dichlorophenyl)-1, 1-dimethyl urea (DCMU), carbonyl cyanide m-chlorophenylhydrazone (CCCP), dinitrophenol (DNP), and sodium arsenate on uptake rates were tested using a final MeA concentration of 10, 50, 500, or 2500 μ M with 1 μ Ci activity. DCMU, CCCP, DNP, and sodium arsenate were ordered from Sigma Chemical Co., St. Louis, Missouri. Controls for CCCP and DCMU experiments were samples treated with 0.1 mL ethanol because this solvent was used in these inhibitors. DCMU is an inhibitor of photosynthesis (photosystem II); CCCP, DNP, and sodium arsenate are inhibitors of oxidative phosphorylation. All of these procedures are summarized in Table 14.

Periodically, experiments were run to check for incorporation of MeA by the phytoplankton. Incorporated MeA is defined here as that radioactivity which is insoluble in cold 5% trichloroacetic acid (Wheeler and McCarthy, 1982;

Balch, 1985). At the end of one minute incubation periods using 1 μCi of activity with a final MeA concentration of 500.4 μM , 25-30 mL samples were filtered onto 0.8 μm Nuclepore filters which were then put into 5% TCA (trichloroacetic acid) for five minutes. The TCA solution and each 0.8 μm filters were then refiltered onto a 0.2 μm Nuclepore filter and rinsed with TCA. Activity remaining on the 0.2 μm filter was compared with untreated controls.

Chemical analysis.

Water samples from one meter depth were analyzed for hardness, alkalinity, pH, ammonia-nitrogen, nitrate-nitrogen, orthophosphate-phosphorus, and silica using methods as described elsewhere (Parson and Parker, 1988a).

Chlorophyll a analysis.

Water samples collected from one meter were analyzed spectrophotometrically (APHA-AWWA-WPCF 1985) within two hours.

Phytoplankton identification and enumeration.

Water samples from one meter were treated with acid-Lugol's preservative (APHA-AWWA-WPCF 1985). Samples (100 mL) were settled in Utermohl chambers for 60 hours at

4° C (to prevent convection currents), viewed with a Wild inverted microscope, and identified to species level where possible using Anton and Duthie (1981), Bourrelly (1968; 1970), Desikachary (1959), Prescott (1951), Rabenhorst (1933; 1937), Smith (1933), and Whitford and Schumacher (1984).

The Percent Similarity Index was calculated from sequential phytoplankton communities using the following equation: $PS = \sum(x_i \text{ or } y_i, \text{ whichever is lower})$, where x_i is the percent composition of species i in the first community and y_i is the percent composition of that species in the second community (Brower and Zar, 1984).

Nitrate reductase assay.

Each month during our study, a nitrate reductase assay was conducted using the method described by Eppley (1978). The assay was carried out at a temperature of 10° C as recommended by Kristiansen (1983) and 21° C as described by Eppley et al. (1969a). Water samples from one meter depth were concentrated by centrifugation or filtration before the assay was run. This step was necessary to have enough biomass (measured by chlorophyll a concentration) of phytoplankton to run the assay.

Acetylene reduction assay.

In late September, when blue-green dominated the phytoplankton, it became desirable to test for nitrogen fixation by the phytoplankton. The indirect method of C_2H_2 reduction of assaying for nitrogenase activity was utilized. Our method was a modification of those described by Stewart et al. (1967; 1970; 1971) and Mague (1978). Water samples from one meter depth were collected and transported back to the laboratory for a 30:1 concentration by centrifugation in a Foerst continuous-flow centrifuge prior to the assay. The assay was carried out in triplicate with 3.0 mL of concentrated lake water in 25 mL capacity serum bottles. Treatments and controls used were as follows:

Tubes (1): lake water without phytoplankton cells with acetylene incubated in light and in dark;

Tubes (2): lake water with phytoplankton cells with acetylene incubated in light and in dark;

Tubes (3): lake water with phytoplankton cells with acetylene plus NH_4Cl giving a final concentration of 18 mM incubated in light and dark;

Tubes (4): lake water with phytoplankton cells with acetylene plus glucose giving final concentration of 0.5% incubated in light and dark; and

Tubes (5): lake water with phytoplankton cells and no acetylene incubated in light and dark.

Acetylene gas used was from commercially prepared canisters. Serum bottles were incubated at 18° C for 48 hours under 110 $\mu\text{Einstein}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$ of light or in dark. To obtain lake water without phytoplankton cells, water was filtered through 0.2 μm Nuclepore filters.

After 48 hours, 1 mL gas was removed from all serum bottles and injected into 3 mL Vacutainer tubes to which 2 mL of air was then added. Vacutainer tube contents were then analyzed for acetylene by gas chromatography.

Results

Uptake experiments.

Table 15 summarizes K_m and V_{max} data. The range of V_{max} seen during the study was great with a low of 5.0 ng MeA-N $\cdot\text{L}^{-1}\cdot\text{hr}^{-1}$ in May to a high of 7,900,000 ng MeA-N $\cdot\text{L}^{-1}\cdot\text{hr}^{-1}$ in October. A very dramatic increase in V_{max} was seen every two weeks from the middle of May until the end of July. Then a steady decrease in V_{max} was seen until the end of September. A second trend of increasing V_{max} values was again seen during the month of October. These same trends are seen regardless of the units used to express V_{max} . Hanes Plots used to determine kinetic parameters for May through November are shown in Figures 26-30.

The results of the test for differences in sequential Vmax values (differences in slope) and other comparisons are summarized in Table 16. The Vmax rates from May through July steadily increased and the changes were significantly different. Sequential Vmax values were not significantly different on only three occasions.

The same trend of increasing values was seen in Km values from the middle of May until the end of July, but for the remainder of the study no trend was discerned. Unlike the Vmax values (MeA uptake) which are independent of ambient ammonia concentrations, Km values (MeA) are influenced by ambient ammonia levels, so trends may be somewhat obscured.

The effect of inhibitors and other treatments on MeA uptake is summarized in Table 17. DNP and sodium arsenate both significantly reduced MeA uptake ($> 21\%$). MeA uptake was least affected by the inhibitor DCMU (2.1%). CCCP alone or with DCMU reduced uptake by 8.5 - 17.2% but the differences were statistically significant only on one occasion. MeA uptake under dark conditions compared to light conditions was only very slightly reduced (1.3%). All of these treatment experiments were conducted when *Aphanocapsa elachista* var. *conferta* dominated.

The effect of pH on MeA uptake is shown in Table 18. The maximum uptake occurred at pH 7 with a reduction of 23.5% at pH 6. The reduction in uptake from pH 6 to pH 5 was 40.0%.

The effect of temperature on MeA uptake is shown in Table 19. The highest rate of MeA uptake was at 18° C. This rate is 2.8 times greater than the rate at 4° C, and thus a Q_{10} of 2.0. (See Appendix L.) If this increase is considered with respect to Q_{10} values, it is seen that this increase resembles the Q_{10} of chemical reactions rather than one of diffusion which is a physical process which have Q_{10} of 1.2 - 1.3 (Meyer and Anderson, 1959). (The Q_{10} of any process is the number of times that the rate of a process increases with a 10° C rise in temperature.) The Q_{10} for enzymatic reactions is usually between 1.4 - 2 (Meyer and Anderson, 1959). The drop in uptake rate at 28° C also indicates an enzymatic reaction is involved in this MeA uptake process.

The effect of ammonia on MeA uptake is illustrated in Figure 31. It can be seen that MeA uptake is lower with 20 μ M ammonium chloride than with 5 μ M ammonium chloride. In Figure 32, the interception of the two lines on the Y-axis in the Lineweaver-Burke Plot supports the idea that ammonia competitively inhibits MeA uptake. A secondary Lineweaver-Burke Plot (Palmer, 1981) used to determine the K_i (concentration of an inhibitor that doubles the apparent value of K_m) for ammonia of 9.57 μ M is shown in Figure 33. *Scenedesmus bijuga* and *Gloeocystis vesiculosa* were the dominant species in the Mountain Lake water samples when the ammonia inhibition experiment was done.

When the activity (cpm) of labelled MeA retained on 0.2 μ M Nuclepore filters after TCA (5%) treatment was compared to untreated 0.8 μ M filters, <20% remained, which indicates that most of the MeA is not incorporated by the phytoplankton.

Nitrate reductase assay.

All nitrate reductase assays were negative. This is what would be expected from the lower levels of nitrate compared to ammonia.

Acetylene reduction assay.

There was no difference between any of the treatments in the level of acetylene produced, thus it can be implied that no nitrogen fixation was occurring at the time of the test. The cool temperature of the lake and general lack of heterocystous bluegreens also support this observation that N_2 fixation is very low or lacking altogether.

Chemical analyses.

Figure 34 shows the concentration of nutrients at one meter depth during thermal stratification. Nitrate-N concentrations ranged from 0 (not-detectable) to 1.4 μ M. From the end of July to the end of August, levels were not-detectable. Ammonia-N was without a doubt the most

abundant inorganic nitrogen source in Mountain Lake during thermal stratification, with concentrations ranging from 0.1 to 5.7 μM . There was a general decline in available ammonia-nitrogen during the summer. Besides ground water, the major source of allochthonous inorganic nitrogen for Mountain Lake is rain. Rainfall data has been collected for several years within a mile of Mountain Lake (Boris Chevrone, National Atmospheric Deposition Study, Virginia Polytechnic Institute and State University). During the summer, rainfall was low with only 6.9, 1.6, and 2.5 cm during June, July, and August, respectively. The increase in inorganic nitrogen seen in September coincided with 10.4 cm of rain in early September. The huge increase in inorganic nitrogen in early June is not, however, explained by rainfall. The observed levels in June and early July are three times higher than any measured by us during a 33 month limnological study on Mountain Lake from March 1985 through November 1987. The increase in ammonia may have been related to the material used to resurface the tennis courts, which are in the direct watershed of Mountain Lake, in May. A test of the material used for resurfacing revealed that it did contain ammonia. Whether or not this was the cause is still uncertain.

Silica concentrations (Figure 34) ranged from 10.2 to 35.8 μM . Diatoms never dominated the phytoplankton during thermal stratification. These levels are probably limiting

to most planktonic diatoms. This statement is supported by year-round phytoplankton information which shows that only one diatom species, *Cyclotella meneghiniana* Kuetzing, ever dominated the phytoplankton (Chapter 2).

Chlorophyll a analyses.

Chlorophyll a levels ranged from 0.721 to 3.151 $\mu\text{g/L}$ (Table 20). These levels are characteristic of oligotrophic lakes, but the highest is approaching mesotrophic levels (Wetzel, 1975). The level of chlorophyll a per cell is highest when *Cryptomonas* species were dominant and lowest when *Aphanocapsa* dominated.

Phytoplankton identification and enumeration.

A total of 40 taxa were identified during the study period with 47.5% chlorophytes, 17.5% chrysophytes, 15% cyanophytes, 10% cryptophytes, and 10% pyrrophytes. The dominant taxa and its rank (based on number of cells/L) and its periodicity is summarized in Table 21. Figure 35 shows the relative abundance of the taxa by major divisions. Cryptophytes dominated in late spring, chlorophytes dominated early to midsummer and again in the fall, and cyanophytes dominated in late summer and early fall. Pyrrophytes were an important component of the phytoplankton only in spring, and chrysophytes were an important component in both the

spring and the fall, but neither of these groups reached the dominance of the others.

Figure 36, which shows the Percent Similarity for sequential phytoplankton communities, emphasizes what is apparent from Table 21, that the phytoplankton communities changed quite dramatically from May through July; species composition and relative abundance stabilized for several weeks with the dominance by *Aphanocapsa* in August and September, then October and November communities again showed change.

Discussion

When the phytoplankton population data was summarized (Table 21), it was seen that from the middle of May until the end of July, when the Vmax values were steadily increasing, the most abundant species (based on number of cells/L) changed with each uptake experiment. The succession of dominant species from May 15 to July 29 was *Cryptomonas erosa* var. *reflexa*, *Cryptomonas pusilla*, *Gloeocystis vesiculosa*, *Quadrigula chodatii*, *Scenedesmus bijuga*, and *Crucigena quadrata*. The dominant species in May were cryptophytes, in June and July they were chlorophytes. (See Figure 30.) During the month of August and September, the steady decline in Vmax was accompanied by domination of the blue-green alga, *Aphanocapsa elachista* var. *conferta*. Then during the month

of October and into November, the chlorophytes again dominated with a succession of *Scenedesmus bijuga* to *Oocystis pusilla*. This dominance again by chlorophytes was accompanied by higher Vmax rates than when *Aphanocapsa* dominated.

Some interesting relationships can be noted when the Vmax data (Table 15) are compared with phytoplankton data. First, from May through the end of July when the dominant species (and community composition) is changing with each uptake experiment, the Vmax values not only steadily increased, but they were very significantly different. Second, when the phytoplankton is dominated by *Aphanocapsa elachista* var. *conferta*, the Vmax values were not significantly different on two out of the three comparisons (July 29 vs. August 18, August 18 vs. August 31, and August 31 vs. September 16), and when *Aphanocapsa elachista* var. *conferta*'s dominance ended, there was a significant change in Vmax. Third, a comparison of the Vmax values when *Scenedesmus bijuga* dominated on two occasions, July 15 and October 17, were not significantly different.

Thus it appears that phytoplankton populations with higher Vmax for ammonia replace those with lower Vmax values in a seasonal succession until the phytoplankton becomes dominated by the blue-green algae. The ability to take up ammonia rapidly (as implied from MeA data) rather than

efficient uptake give a species a competitive advantage up to a point. The dominance by *Aphanocapsa elachista* var. *conferta* in late July and August may be due to an ability to utilize dissolved organic matter or to store previously available nitrogen in the form of cyanophycin granules (polypeptide) or phycocyanin (phycobiliprotein) which they may use under nitrogen-limiting conditions (Stewart, 1972). The occurrence of blue-green algae when dissolved organic carbon is high and inorganic nutrients are low was first observed by Pearsall (1932). This observation has since been supported by observations around the world (Singh, 1955; Brook, 1959; Vance, 1965; Horne and Fogg, 1970). The negative results of the C_2H_2 reduction assay ruled out the fixation of nitrogen by the phytoplankton which was dominated by *Aphanocapsa*.

Aphanocapsa, and perhaps other non-heterocytous blue-greens, may then have a successful strategy which involves utilization of organic compounds or stored intracellular nitrogen rather than the ability to utilize rapidly inorganic nutrients which seems to be the successful strategy of the green algae that gained dominance in June and July. The strategy to utilize rapidly inorganic nutrient may have again become successful when inorganic nitrogen levels increased in late September through November when the green algae regained dominance. Although only ammonia uptake was

of interest in this study, research by others indicates that if a species has the capacity to uptake ammonia rapidly, it probably has the ability to uptake other nutrients rapidly also (Eppley, 1969b).

Negative tests for nitrate reductase confirm that ammonia rather than nitrate was preferred by the phytoplankton in Mountain Lake. The levels of ammonia (0.1 to 5.7 μM) were usually above the levels shown by McCarthy et al. (1977) to prevent the utilization of nitrate by phytoplankton.

Seasonal trends in V_{max} values for MeA or ammonia have been investigated by few. Vincent et al. (1984), investigating the seasonal dynamics of nutrient limitation in a tropical lake (16° S latitude), measured MeA uptake rates over a one year period. Although no clear trend emerges from their data, the V_{max} rates were highest in March (late summer) for two out of the three sites sampled. La Roche (1983) measured ammonia uptake in Bedford Basin, Nova Scotia, and found that the summer rate was higher than the spring rate in this eutrophic environment.

The relationship between species composition of a natural population and V_{max} values of MeA, ammonia, or nitrate have been investigated by few. Sherr et al. (1982) compared the uptake rates of nitrate and ammonia of *Peridinium cinctum* and nanoplankton during a spring bloom of

P. cinctum in Lake Kinneret, Israel, to try to explain the dominance of the dinoflagellates. The nanoplankton had greater affinities and higher uptake rates for both nitrate and ammonia, so it was concluded that some other strategy enabled the dinoflagellates to dominate (Sherr et al., 1982). Attempts by Toetz et al. (1973) to correlate nitrate uptake rates with changes in composition and density of the phytoplankton in Lake Carl Blackwell, Oklahoma, were unsuccessful, but the highest uptake rates occurred in midsummer when nitrate levels were relatively low and dinoflagellates and euglenoids were relatively more abundant than diatoms. If their (Toetz et al. 1973) ammonia uptake experiments had been more successful, perhaps other relationships would have been seen.

The highest uptake rates of MeA (by green algae) during our study when inorganic nitrogen levels were lowest was somewhat expected as enhanced rates of uptake of ammonia and MeA by cultured green algae, diatoms, and natural populations under nitrogen deficient conditions has been reported (Meyers, 1951; Eppley and Renger, 1974; Healey and Hendzel, 1979; Pelley and Bannister, 1979; Vincent, 1981; Hellebust et al., 1985, Suttle and Harrison, 1988). The opposite has been reported, however, for blue-green algae (Vincent, 1979).

The MeA uptake rates reported in the present paper are similar to those reported from other studies on a

nmol•cell⁻¹•min⁻¹ basis (Table 22).

Although it was not possible to characterize the mechanism of MeA (and by analog ammonia) uptake by every phytoplankton community, some generalizations can be proposed from the inhibitor and treatment studies. When the phytoplankton community was dominated by *Aphanocapsa* and *Chroococcus* or *Aphanocapsa* and *Scenedesmus*, MeA uptake appears to be a chemical, light-independent, and energy-dependent process. In addition, MeA is probably transported by the same system as ammonia. The supportive evidence includes:

1. No significant inhibition of MeA uptake by darkness or DCMU, but significant inhibition by CCCP, DNP, and sodium arsenate.
2. There is not a ten-fold increase in uptake per pH unit increase.
3. Q_{10} values resemble those typical of chemical reactions.
4. Ammonia competitively inhibits MeA uptake.

It may have been fortuitous that during the summer of our study allochthonous inputs of inorganic nitrogen by rainfall were low. The low rain conditions helped make trends and relationships clearer than they would have been otherwise.

The interaction between the non-heterocystous blue-green algae and the nutrients in Mountain Lake leave unanswered questions. What conditions led to their dominance during the summer of 1987? An investigation into the role of organic nutrients and the phytoplankton in oligotrophic ecosystems, such as, Mountain Lake, would be worthwhile. In addition, Table 22 shows there are more reports about MeA and ammonia uptake from alga cultures than natural populations and the reported values vary tremendously. More long-term investigations of nutrient uptake and phytoplankton density and composition are needed to understand the causes of seasonal species composition and succession in freshwater ecosystems.

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Table 14. Summary of special treatment procedures used for MeA uptake by phytoplankton from 1 meter depths in Mountain Lake, Virginia during thermal stratification 1987.

Treatment	Date	Pre-Incubation (minutes)	Incubation temperature	$\mu\text{Einsteins} \cdot \text{m}^{-2} \cdot \text{sec}^{-1}$	[MeA] μM	Incubation (minutes)
pH (5, 6, 7)	10-22	0	11°	110	2500	1
Temperature (4°, 18°, 28° C)	10-17	0	4°, 18°, 28°	110	500	1
Light/dark	9-30	60	18°	110/ 0	2500	1
NH ₄ Cl (5 μM , 20 μM)	10-22	0	18°	110	10, 50	1
DCMU ¹ (1 μM)	8-18	20	18°	110	500, 2500	1
CCCP ² (5mM)	8-18	20	18°	110	500	1
DCMU + CCCP	8-31	30	18°	110	500	5
DNP ³ (0.4mM)	9-16	120	18°	110	2500	1
Sodium Arsenate (1mM)	9-16	120	18°	110	2500	1

¹3 (3,4-dichlorophenyl)-1, 1-dimethyl urea

²carbonyl cyanide m-chlorophenylhydrazine

³dinitrophenol

Table 15. *MeA kinetics for the phytoplankton community at 1 meter depth in Mountain Lake, Virginia, during thermal stratification 1987.*

Date	Km(μ M MeA-N)	Vmax(ng MeA-N $\cdot$ L $^{-1}$ $\cdot$ hr $^{-1}$)	Vmax(ng MeA-N $\cdot$ μ g $^{-1}$ chl $\cdot$ hr $^{-1}$)	Vmax (ng MeA-N $\cdot$ cell $^{-1}$ $\cdot$ hr $^{-1}$)
May 15	4.5×10^{-3}	5.0	1.6	5.4×10^{-8}
May 30	1.5×10^{-1}	7.1	1.0×10^1	1.8×10^{-8}
June 18	2.1	1.8×10^3	1.5×10^3	10.0×10^{-4}
June 30	4.6×10^1	1.7×10^5	9.1×10^4	3.3×10^{-1}
July 15	5.1×10^1	7.2×10^5	2.6×10^5	1.6×10^{-1}
July 29	3.1×10^2	7.2×10^6	3.7×10^6	1.1
August 18	9.6×10^2	2.3×10^6	1.2×10^6	1.4×10^{-1}
August 31	1.2×10^3	2.1×10^6	1.0×10^6	1.1×10^{-1}
September 16	1.5×10^3	9.4×10^5	5.9×10^5	2.4×10^{-1}
September 30	9.9×10^2	8.3×10^5	5.9×10^5	9.2×10^{-2}
October 17	2.1×10^3	3.2×10^6	1.7×10^6	2.0
October 29	7.0×10^3	7.9×10^6	4.7×10^6	4.0
November 18	2.7×10^3	2.0×10^6	9.4×10^5	2.6

Table 16. *Statistical test results for differences in sequential Vmax values using test for differences in slope (parallelism). *Indicates significant difference at the 0.05 level.*

Dates of Comparison (1987)	P value
May 15/May 30	0.002*
May 30/June 15	0.005*
June 15/June 30	0.003*
June 30/July 15	0.003*
July 15/July 29	0.002*
July 29/August 18	0.004*
August 18/August 31	0.450
August 31/September 16	0.001*
September 16/September 29	0.286
September 29/October 17	0.011*
October 17/October 29	0.058*
October 29/November 18	0.122
July 15/October 17	0.349

Table 17. Summary of the effect of inhibitors and various treatments on MeA uptake by phytoplankton from one meter depth in Mountain Lake, Virginia. *Indicates that the rate of MeA uptake was significantly reduced. (ANOVA, $\alpha = 0.05$)

Inhibitor or Treatment	Date	% Reduction in Uptake	Dominant Species (Based on number of cells)
DNP	9-16-87	*21.1%	<i>Aphanocapsa elachista</i> var. <i>conferta</i> ; <i>Scenedesmus bijuga</i>
Sodium arsenate	9-16-87	*21.1%	<i>Aphanocapsa elachista</i> var. <i>conferta</i> ; <i>Scenedesmus bijuga</i>
DCMU + CCCP	8-31-87		<i>Aphanocapsa elachista</i> var. <i>conferta</i> ; <i>Chroococcus minimus</i>
5 min. incubation		*12.2%	
15 min. incubation		17.2%	
60 min. incubation		11.6%	
Dark	9-30-87	1.3%	<i>Aphanocapsa elachista</i> var. <i>conferta</i> ; <i>Scenedesmus bijuga</i>
DCMU	8-15-87	2.1%	<i>Aphanocapsa elachista</i> var. <i>conferta</i> ; <i>Chroococcus minimus</i>
CCCP	8-15-87	8.5%	<i>Aphanocapsa elachista</i> var. <i>conferta</i> ; <i>Chroococcus minimus</i>

*See Table 2 for concentrations used, etc.

Table 18. *The effect of pH on MeA uptake by phytoplankton in Mountain Lake, Virginia, on October 22, 1987. (S.E. = standard error)*

pH	[MeA] μM	Temperature C	V = ng MeA-N $\cdot\text{L}^{-1}\cdot\text{hr}^{-1}$ (S.E.)	Dominant Species
7.0	2500	11°	1.0 x 10 ⁶ (2.2 x 10 ⁵)	<i>Scenedumus bijuga</i> ;
6.0	2500	11°	7.7 x 10 ⁵ (1.4 x 10 ⁵)	<i>Gloeocystis vesiculosa</i>
5.0	2500	11°	4.6 x 10 ⁵ (1.2 x 10 ⁵)	

Table 19. *The effect of temperature on MeA uptake by phytoplankton in Mountain Lake, Virginia, on October 17, 1978. (S.E. = standard error of mean)*

Temperature	[MeA] μM	$V = \text{ng MeA-N} \cdot \text{L}^{-1} \cdot \text{hr}^{-1}$ (S.E.)	Dominant Species
4°	500	2.1×10^5 (4.6×10^4)	<i>Scenedumus bijuga</i> ;
18°	500	6.0×10^5 (3.1×10^5)	<i>Gloeocystis vesiculosa</i>
28°	500	4.2×10^5 (2.7×10^5)	

Table 20. *Chlorophyll a* from phytoplankton at one meter depth in Mountain Lake, Virginia during chemical stratification 1987.

Date	Chlorophyll a (ug/L)	Chlorophyll a (pg/cell)
May 15	3.15	6.1
May 30	0.72	1.8
June 16	1.20	6.6×10^{-1}
June 30	1.84	1.9
July 15	2.72	6.2×10^{-1}
July 29	1.92	2.9×10^{-1}
August 18	1.84	1.1×10^{-1}
August 31	1.60	1.9×10^{-1}
September 16	1.60	4.2×10^{-1}
September 30	1.28	2.4×10^{-1}
October 17	1.84	1.1
October 29	1.68	8.6×10^{-1}
November 18	2.08	2.8

Table 21. Species rank and seasonal distribution of phytoplankton from 1 meter depth in Mountain Lake Virginia, during thermal stratification 1987.

Species Name	May		June		July		August		September		October		November
	15	26	17	30	15	29	18	31	15	30	17	29	18
A. Cryptophytes													
<i>Cryptomonas erosa</i> var. <i>reflexa</i> Marrson	1	2	3	7.5	14.5	16	12	-	-	-	-	17	6
<i>Cryptomonas pusilla</i> Bachman	2	1	5	9	8	12	18	-	16	10	13	5	3
<i>Cryptomonas ovata</i> Ehrenberg	7	5.5	-	-	10.5	-	-	-	-	14	-	-	-
<i>Cryptomonas pyrenoidifera</i> Geitler	-	-	6	5	8	16	-	-	-	-	-	-	-
B. Chlorophytes													
<i>Micrasterias radiata</i> Hassall	7	-	-	16	14.5	16	-	-	17	-	15.5	-	-
<i>Elakatothrix gelatinosa</i> Wille	5	4	-	4	13	5	11	9.5	12	-	10.5	7	10
<i>Gloeocystis gigas</i> (Kuetz.) Lagerheim	-	5.5	2	-	-	-	-	-	-	-	-	-	-
<i>Gloeocystis vesiculosa</i> Naegeli	-	-	1	-	-	6	8	4	10	3	2	7	7
<i>Chlorella vulgaris</i> Beyernick	-	-	4	-	-	-	-	-	-	-	-	-	-
<i>Scenedesmus bijuga</i> (Turp.) Lagerheim	-	-	8	12	1	11	13.5	9.5	5	2	1	3	8.5
<i>Oocystis borgei</i> Snow	-	-	7	-	-	7	-	-	2	6.5	4	-	-
Unknown green flagellate	-	-	-	7.5	-	-	18	-	-	-	15.5	15	-
<i>Quadrigula chodatii</i> (Tan.-Ful.) G. M. Smith	-	-	-	1	4	3	3	6	7	4	9	-	-
<i>Gloeocystis planctonica</i> West & West Lemmermann	-	-	-	3	10.5	10	7	8	8	6.5	-	-	-

Table 21 (Cont'd.)

Species Name	May		June		July		August		September		October		November
	15	26	17	30	15	29	18	31	15	30	17	29	18
<i>Staurostrum limneticum</i> Schmidle	-	-	-	16	-	-	-	-	-	-	-	-	-
<i>Oocystis pusilla</i> Hansgirg	-	-	-	16	-	-	4	5	-	-	-	1	1
<i>Crucigenia rectangularis</i> (A. Braun) Gay	-	-	-	-	5	-	-	-	6	11	11.5	13.5	-
<i>Sphaerocystis schroeteri</i> Chodat	-	-	-	-	6	4	5	7	13	5	-	8	-
<i>Crucigenia quadrata</i> Morren	-	-	-	-	10.5	1	9	11	3	9	-	-	4
<i>Dictyosphaerium pulchellum</i> Wood	-	-	-	-	-	-	18	-	11	8	8	-	-
<i>Pediastrum tetras</i> forma <i>evoluta</i> West	-	-	-	-	-	-	-	-	-	-	1	13.5	-
<i>Gloeocystis parolinian</i> (Menegh.) Naegeli	-	-	-	-	-	-	-	-	-	-	10	-	-
<i>Crucigenia irregularis</i> Wille	-	-	-	-	-	-	-	-	-	-	7	-	-
C. Cyanophytes													
<i>Aphanocapsa elachista</i> var. <i>conferta</i> West & West	-	-	-	2	3	2	1	1	1	1	3	2	-
<i>Chroococcus minimus</i> (Keissl.) Lemmermann	-	-	-	-	-	-	2	2	9	12	-	-	-
Unknown colonial bluegreen	-	-	-	-	-	-	6	-	-	-	-	-	-
<i>Aphanotheca gelatinosa</i> (Henn.)	-	-	-	-	-	-	-	-	4	-	-	-	-
<i>Aphanothece</i> sp. Lemmermann	-	-	-	-	-	-	-	-	-	-	6	9	8.5
<i>Dactylococcapsis musicola</i> Hustedt	-	-	-	-	-	-	-	-	-	-	15.5	-	-

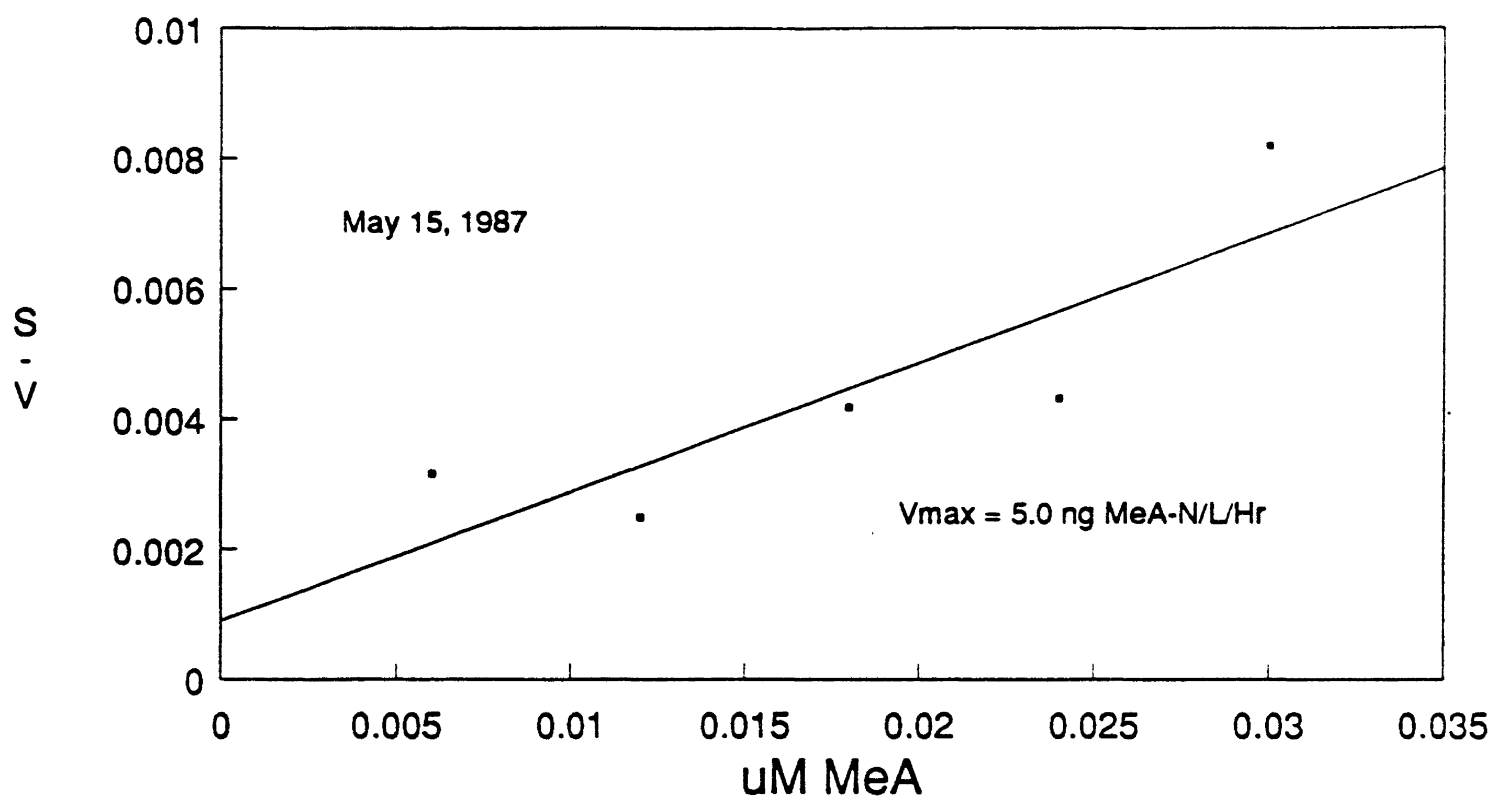
Table 21 (Cont'd.)

Species Name	May		June		July		August		September		October		November
	15	26	17	30	15	29	18	31	15	30	17	29	18
D. Pyrrophytes													
<i>Gymnodinium</i> sp.	3	-	-	13	8	8	18	13.5	14	13	10.5	16	-
<i>Peridinium inconspicuum</i> Lemmermann	-	-	-	10.5	-	14	13.5	12	15	-	-	-	-
<i>Glenodinium minimum</i> (Langtزش) Bachmann	-	-	-	6	-	-	-	-	-	-	15.5	-	-
<i>Peridinium wisconsinse</i> Eddy	-	-	-	-	12	13	-	-	-	-	-	-	-
E. Chrysophytes													
Unknown flagellate	4	3	-	16	-	-	18	-	-	-	-	12	11
<i>Navicula</i> sp.	7	-	-	16	-	-	15	13.5	-	-	-	-	12
<i>Dinobryon cylindricum</i> Imhof	-	-	-	-	2	9	-	-	-	-	5	4	-
<i>Asterionella formosa</i> Hassall	-	-	-	-	-	-	10	3	-	-	-	-	-
<i>Synedra</i> sp.	-	-	-	-	-	-	-	-	-	-	-	18	-
<i>Mallomonas</i> sp.	-	-	-	-	-	-	-	-	-	-	-	11	5
<i>Dinobryon divengens</i> Imhof	-	-	-	-	-	-	-	-	-	-	-	-	2

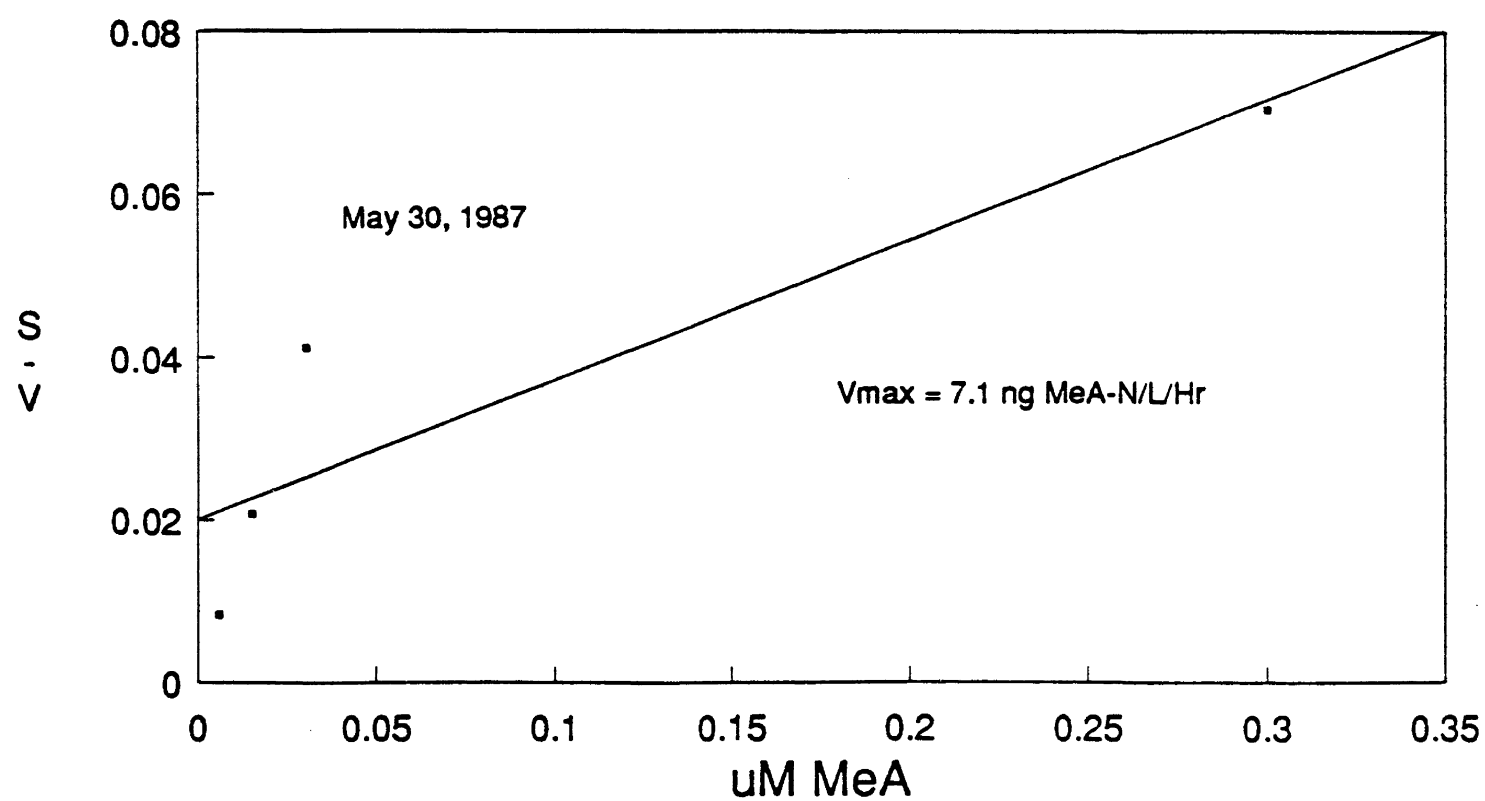
Table 22. Uptake rates of methylamine and ammonia by phytoplankton normalized to $\text{nmol} \cdot \text{cell}^{-1} \cdot \text{min}^{-1}$

Organism/location	Uptake or range of uptake rates ($\text{nmol} \cdot \text{cell}^{-1} \cdot \text{min}^{-1}$)	Source
A. Methylamine		
<i>Chlamydomonas angulosa</i>	$5.3 \times 10^{-7} - 12.6 \times 10^{-7}$	Hellebust et al. 1985
<i>Cyclotella cryptica</i>	5,500-33,200	Wheeler 1980
<i>Phaeodactylum tricornutum</i>	3.03×10^{-6}	Wright & Syrett 1983
<i>Skeletonema costatum</i>	ca. 2.0×10^{-6}	Balch 1985
<i>Gonyaulax polyedra</i>	ca. 5.0×10^{-6}	Balch 1985
<i>Chlorella pyrenoidosa</i> *	$\leq 0.4 \times 10^{-6} - 1.6 \times 10^{-6}$	Pelley & Bainster 1979
Natural populations in Mountain Lake, Virginia	$6.4 \times 10^{-6} - 4.8 \times 10^{-6}$	Present paper
B. Ammonia		
<i>Ditylum brightwellii</i>	1.63×10^{-6}	Eppley & Rogers 1970
Mixed blue-green populations in Lake Carl, Blackwell, Oklahoma	$1.41 \times 10^{-6} - 1.06 \times 10^{-6}$	Toetz et al. 1973
<i>Thalassiosira pseudonana</i>	ca. $8.33 \times 10^{-7} - 5.83 \times 10^{-7}$	Parslow et al. 1984

*Uptake per cell is estimated using the number of cells per innoculum which may be somewhat
< the number of cells concentrated to make the 1 μL volume of cells used in the experiments described.



—●— Hanes Plot



—●— Hanes Plot

Figure 26. Hanes Plots for May 15, 1987 (top) and for May 30, 1987 (bottom) with correlation coefficient (r) values of 0.85 and 0.91 respectively.

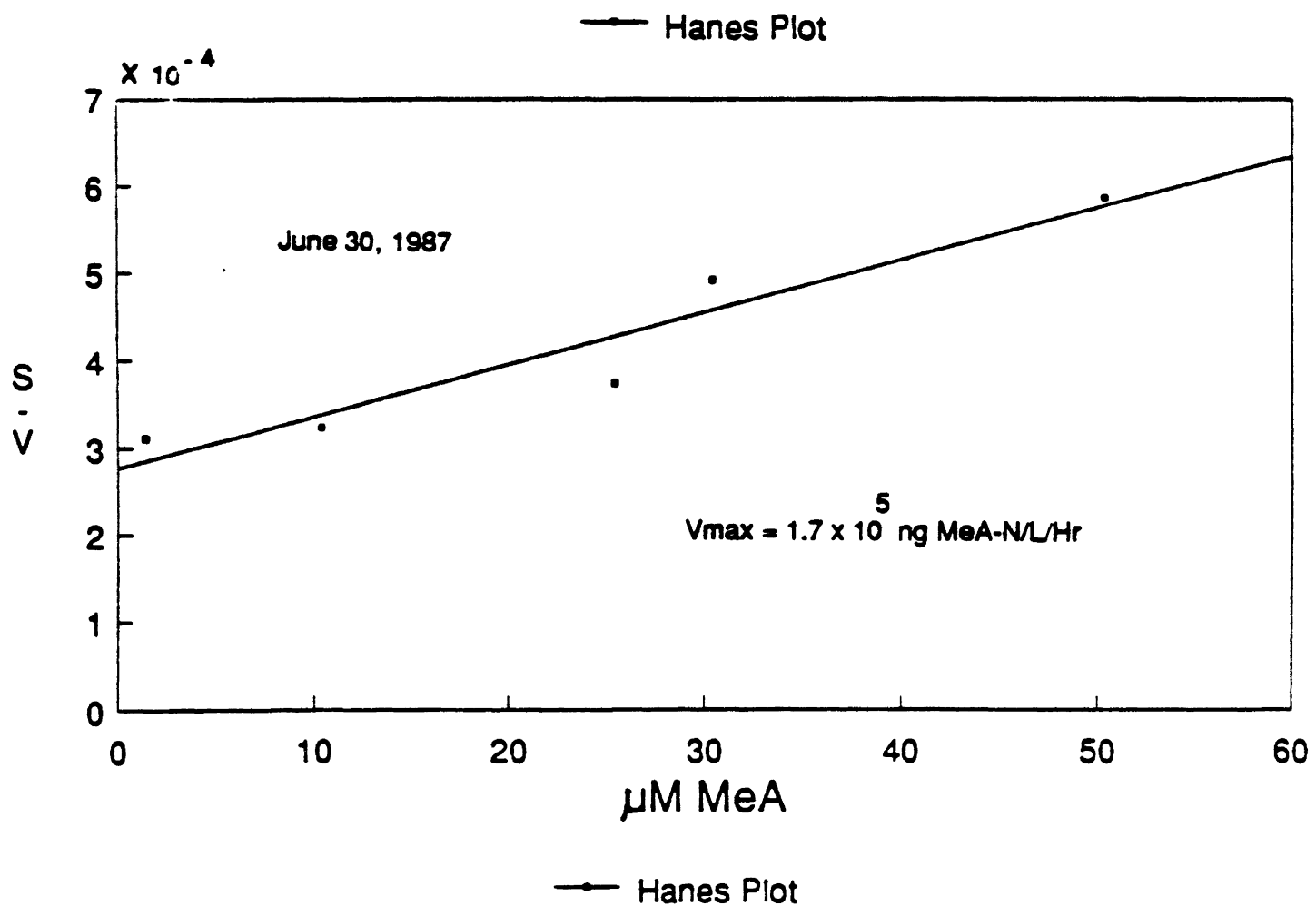
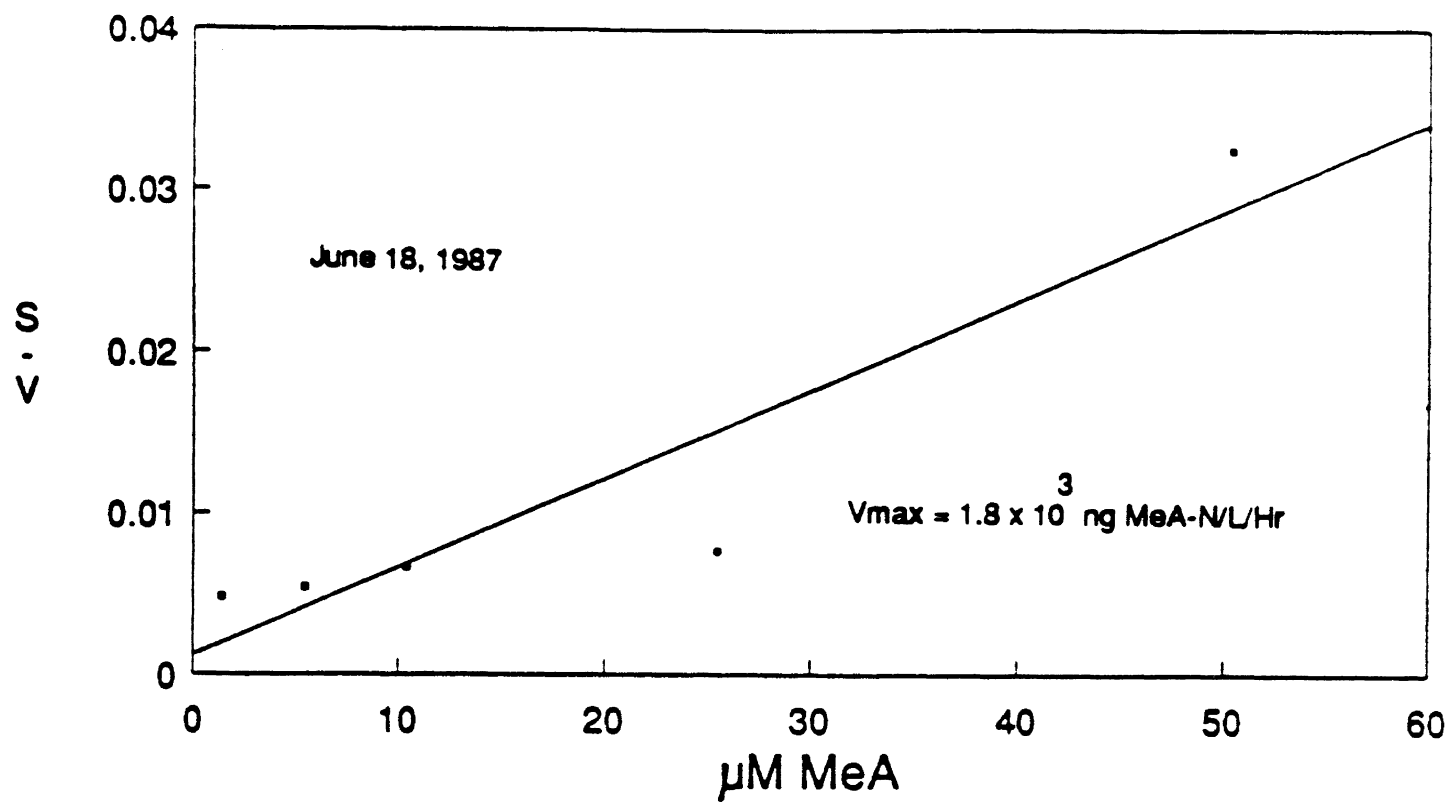


Figure 27. Hanes Plot for June 18 and June 30, 1987 with correlation coefficient (r) values of 0.92 and 0.95 respectively.

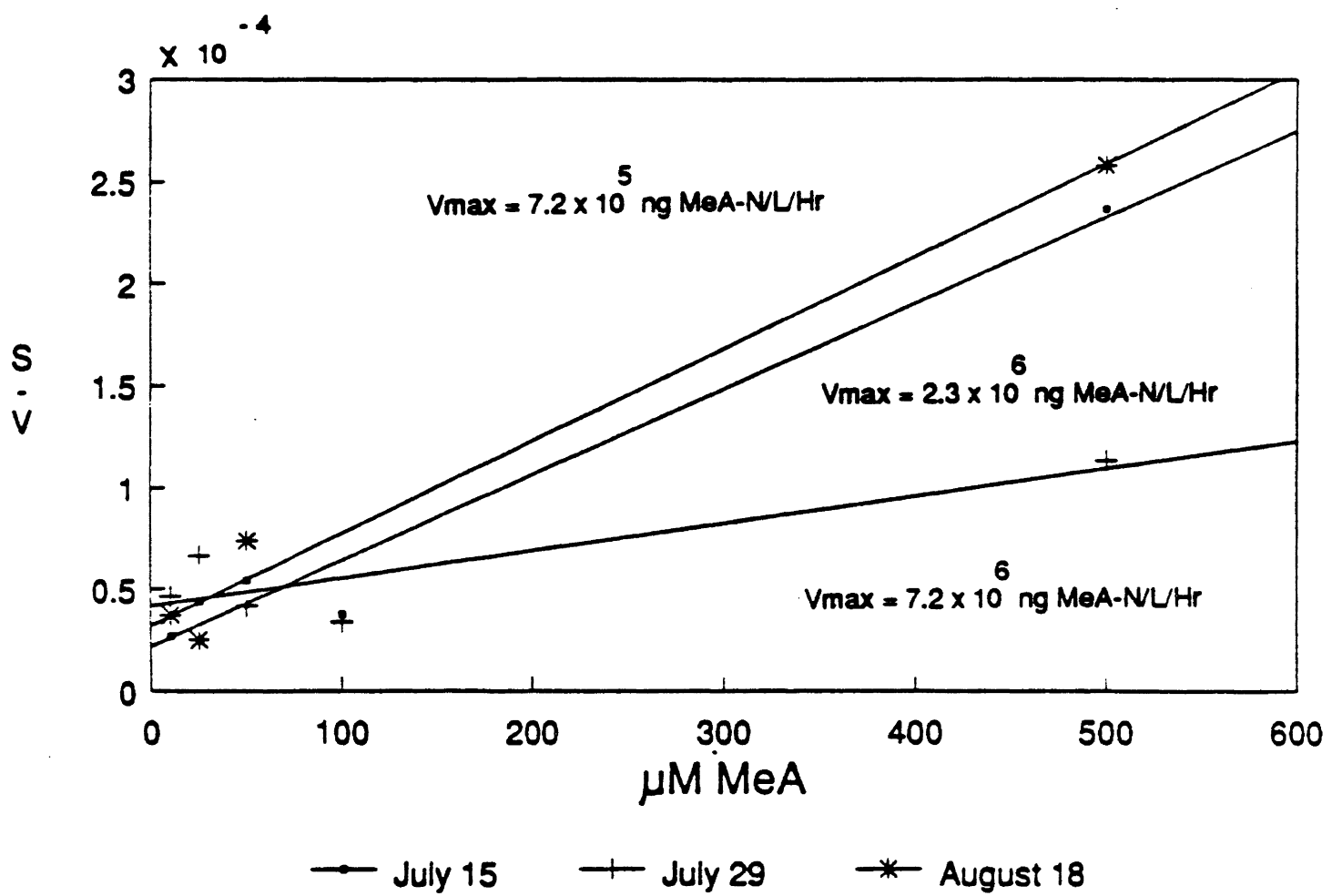


Figure 28. Hanes Plots for July 15, July 29, and August 18, 1987 with correlation coefficient (r) values of 0.98, 0.87, and 0.99 respectively.

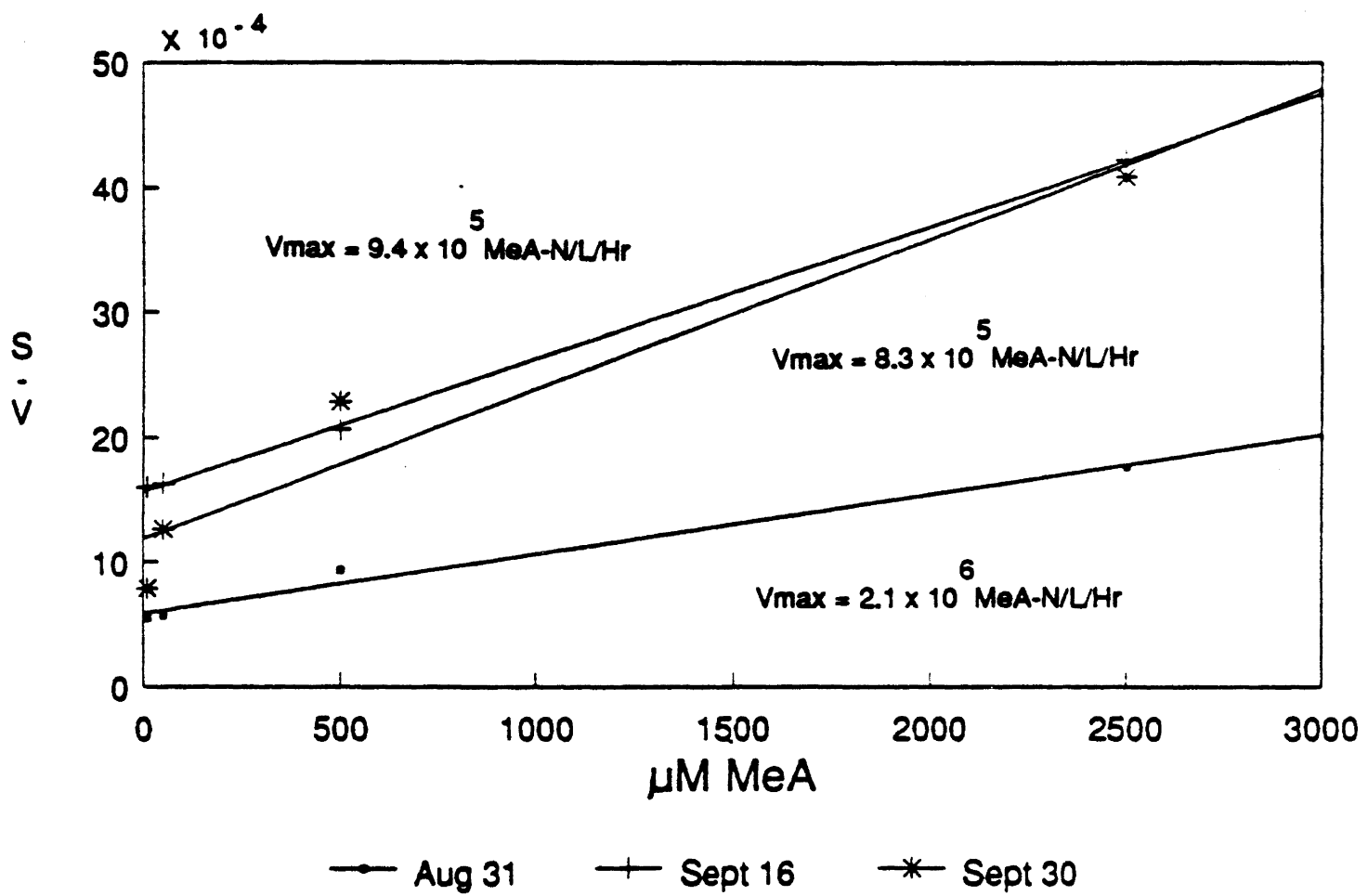


Figure 29. Hanes Plots for August 31, September 16, and September 30 with correlation coefficient (r) values of 0.99, 0.99, and 0.93 respectively.

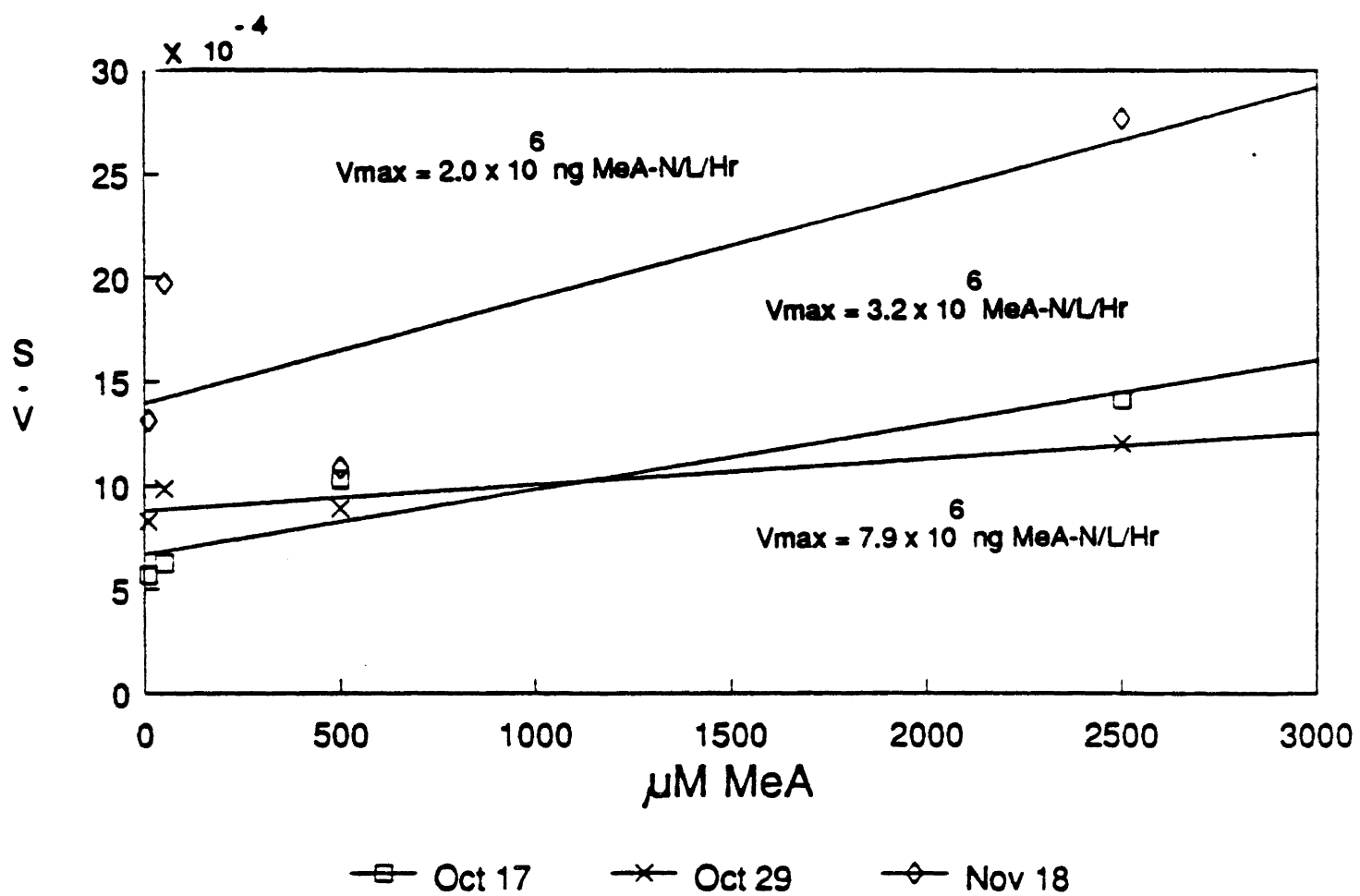


Figure 30. Hanes Plots for October 17, October 29, and November 18 with correlation coefficient (r) values of 0.93, 0.90, and 0.79 respectively.

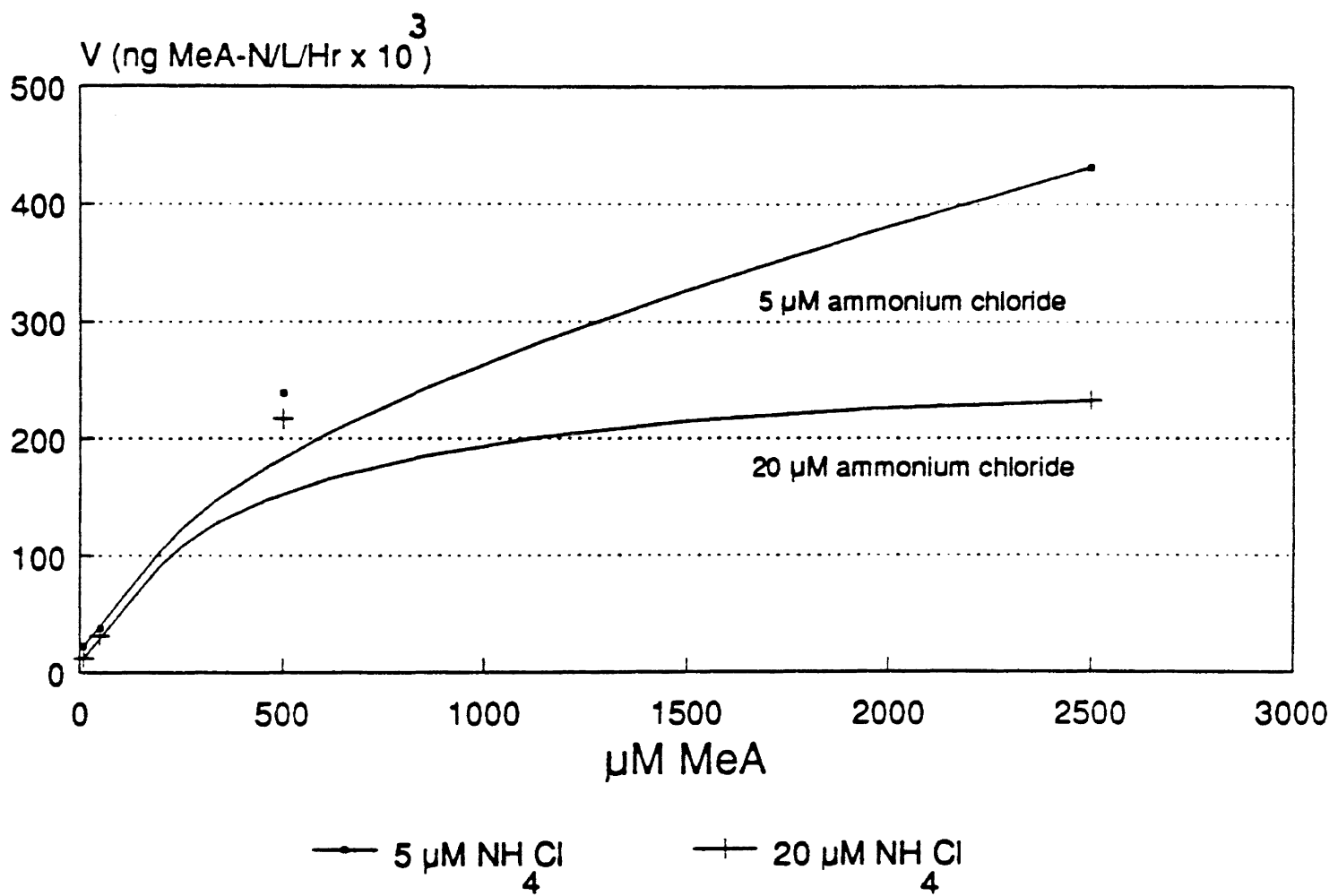


Figure 31. Effect of ammonia concentration on MeA uptake by phytoplankton on October 22, 1987.

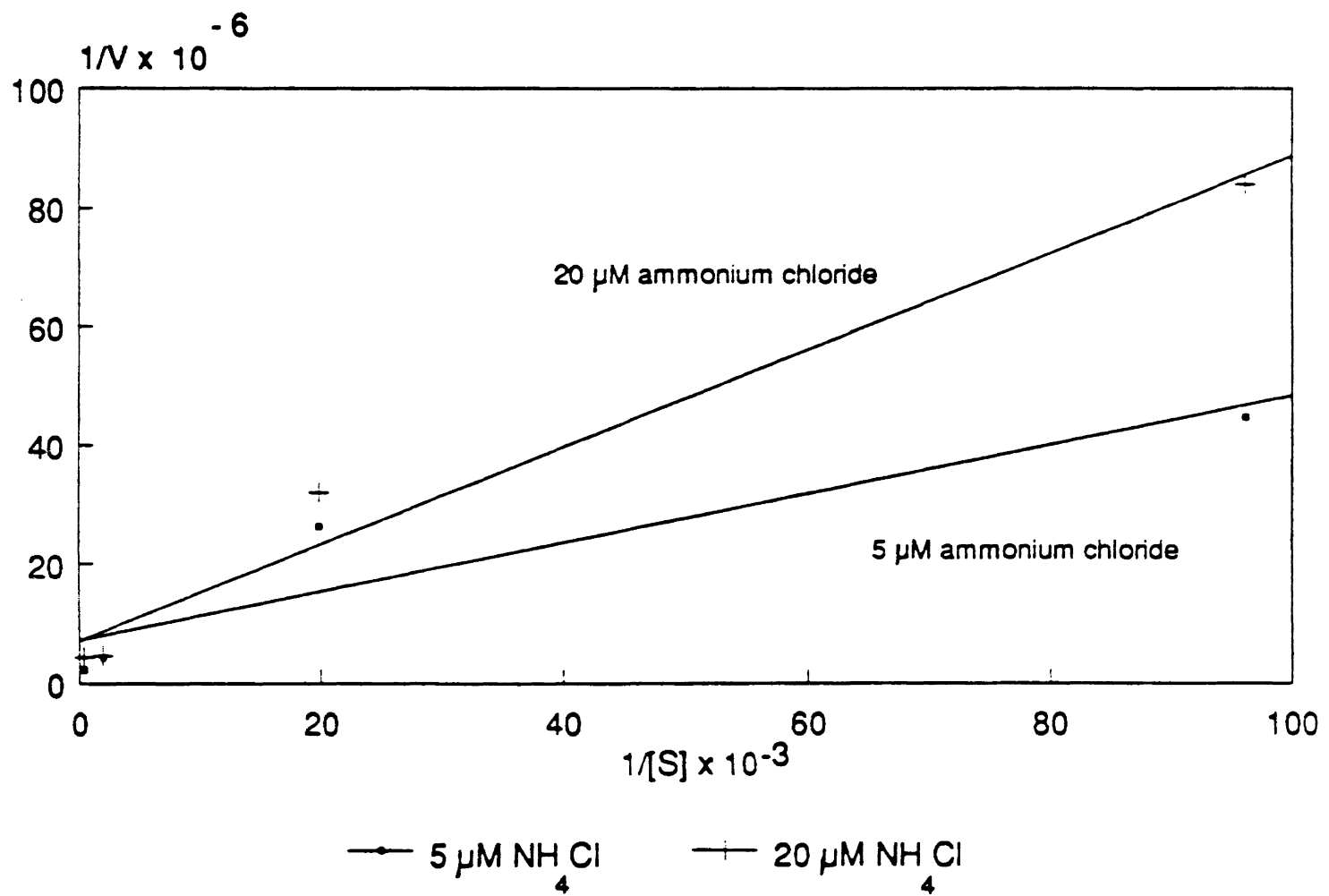


Figure 32. Lineweaver-Burke Plot showing competitive inhibition by ammonia on MeA uptake by phytoplankton on October 22, 1987.

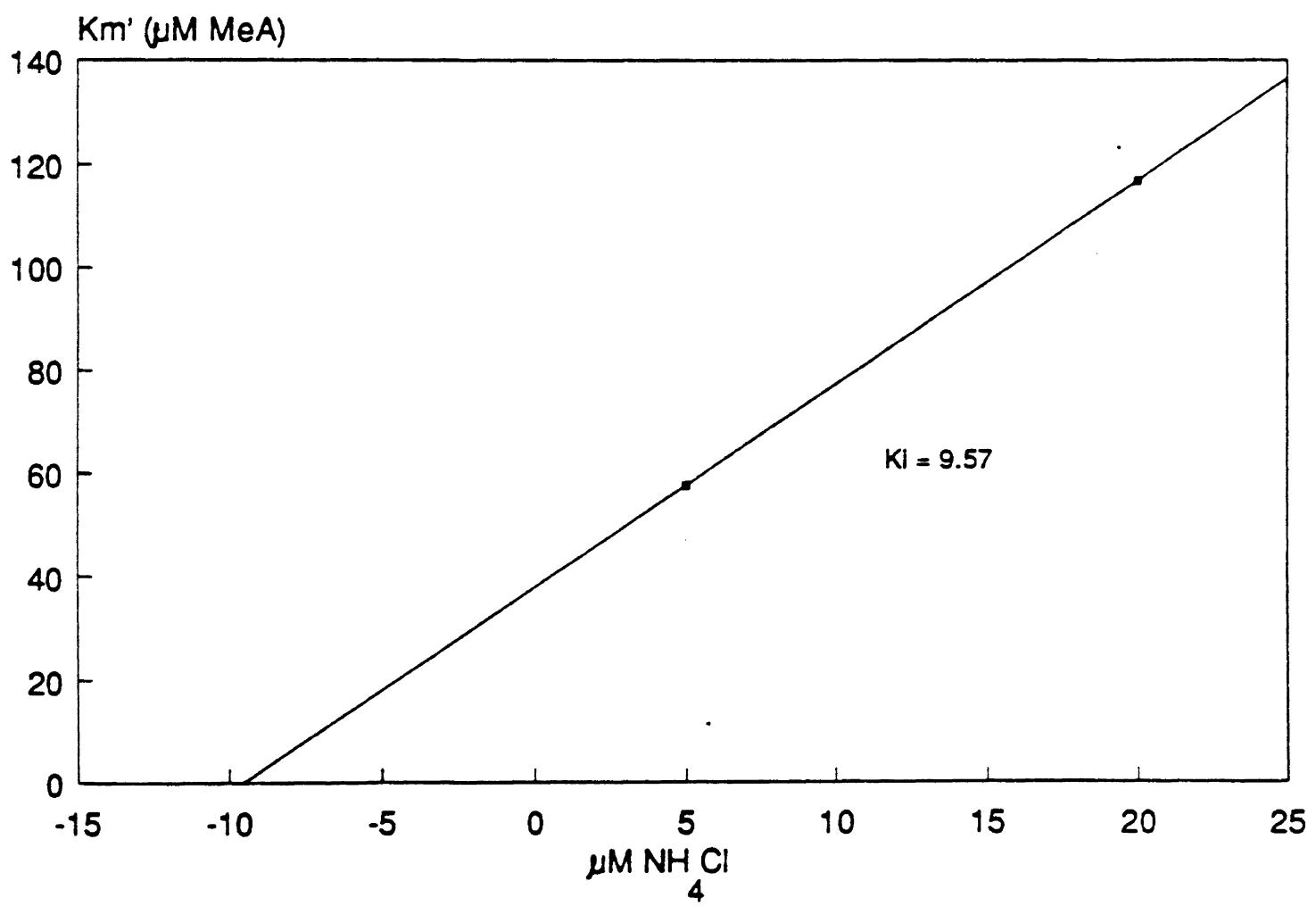


Figure 33. Secondary Lineweaver-Burke Plot to determine K_i of ammonia.

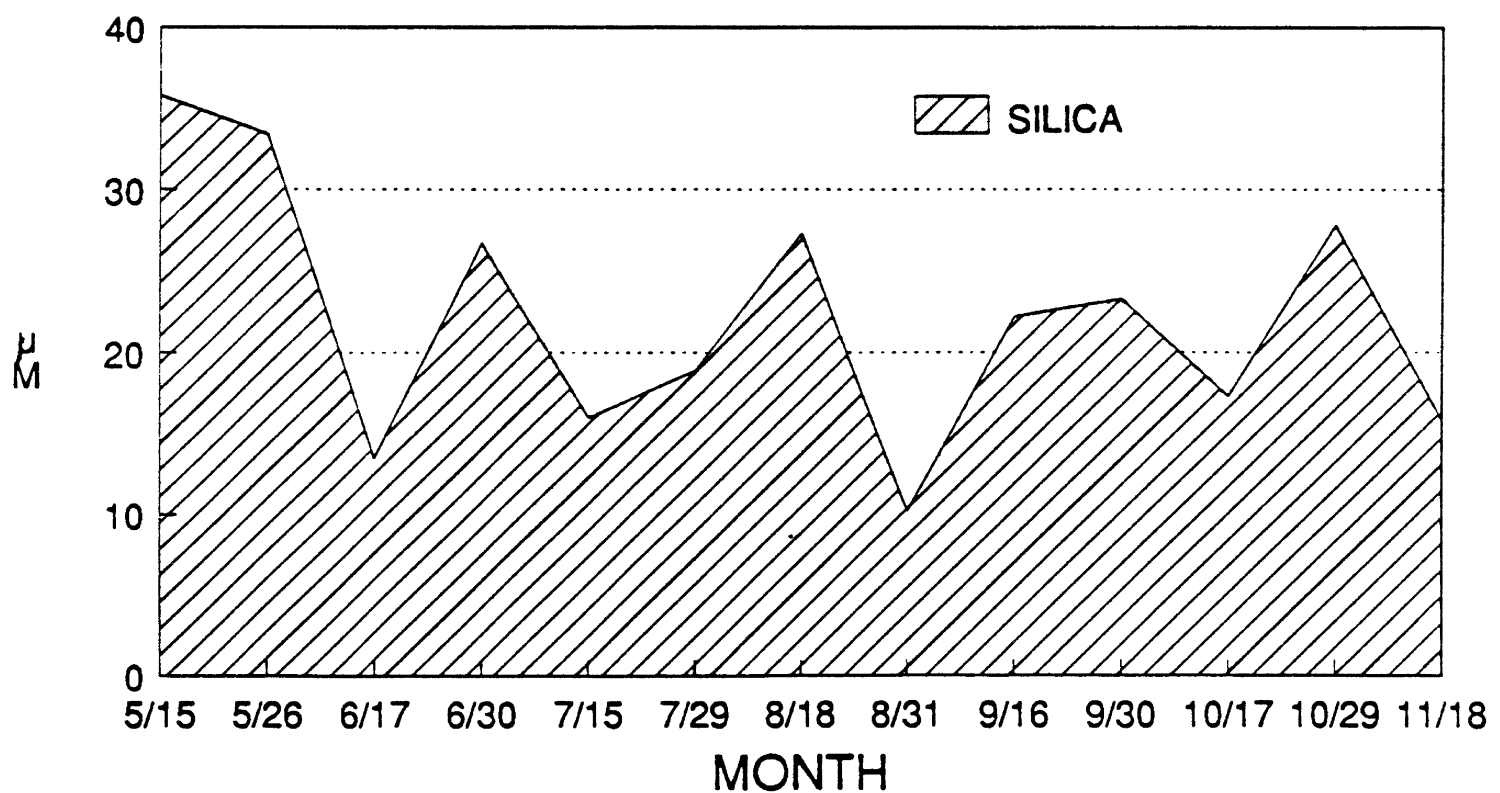
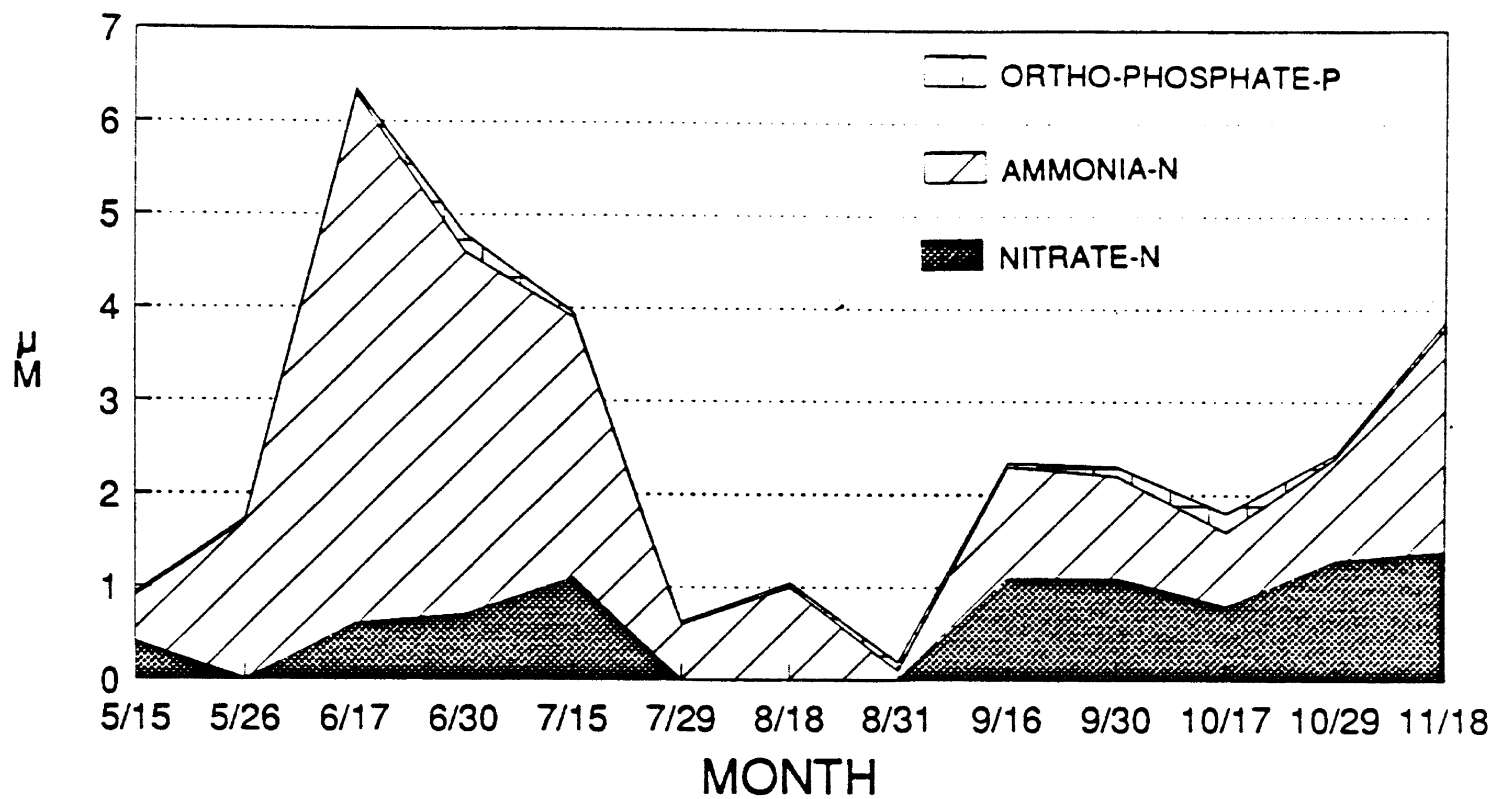


Figure 34. Top. Nitrate-N, ammonia-N, and orthophosphate-P concentrations (μM) from one depth on Mountain Lake, Virginia, during thermal stratification 1987. Bottom. Silica concentration (μM) from one meter depth in Mountain Lake, Virginia, during thermal stratification 1987. Values are means of duplicates.

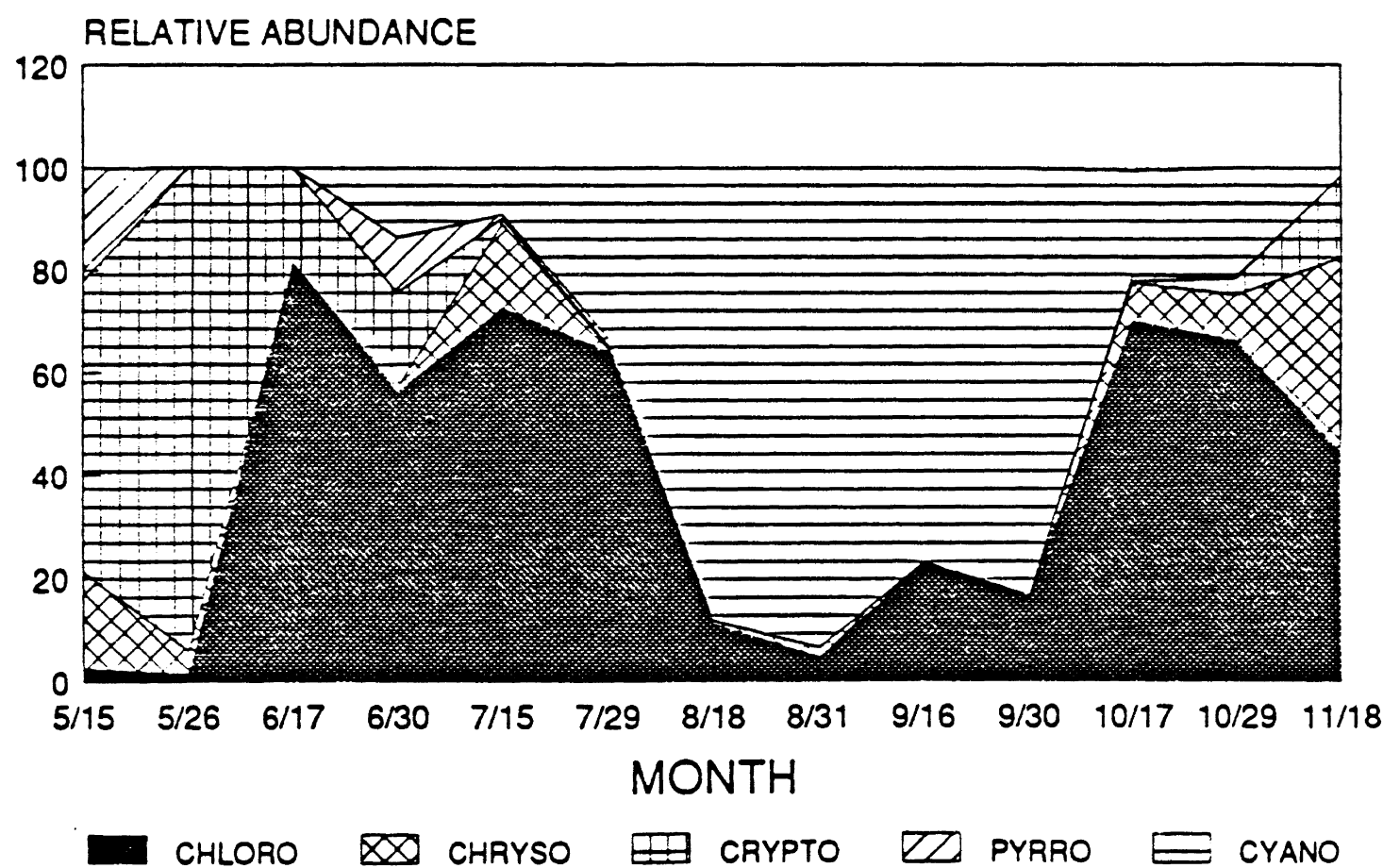


Figure 35. Relative abundance of major classes of phytoplankton from one meter depth in Mountain Lake, Virginia, 1987. Values are means of duplicates.

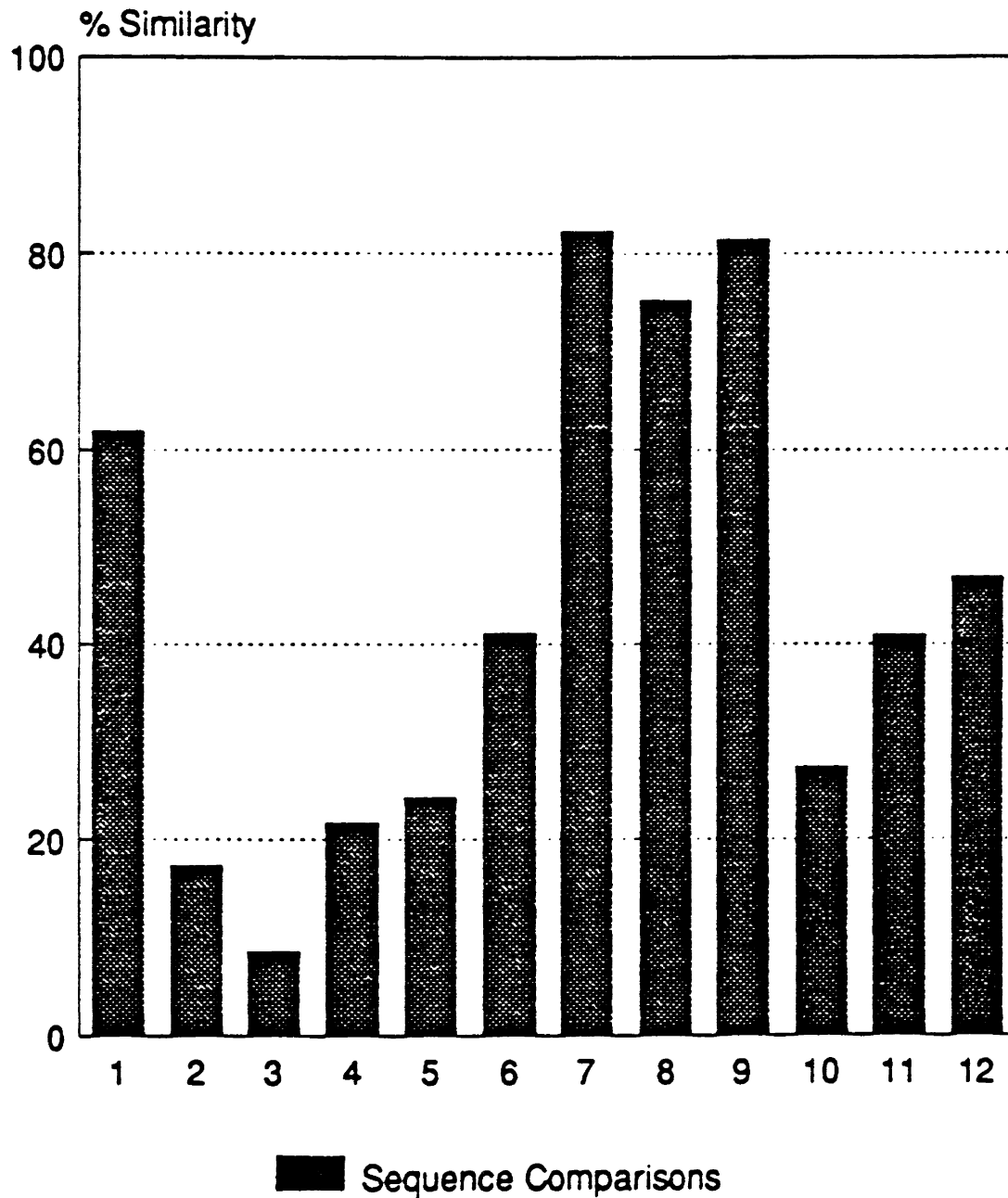


Figure 36. Percent Similarity of sequential phytoplankton communities. 1 = May 15 and May 30; 2 = May 30 and June 18; 3 = June 18 and June 30; 4 = June 30 and July 15; 5 = July 15 and July 29; 6 = July 29 and August 18; 7 = August 18 and August 31; 8 = August 31 and September 16; 9 = September 16 and September 30; 10 = September 30 and October 17; 11 = October 17 and October 29; 12 = October 29 and November 18.

Appendix A

Depth (meters)

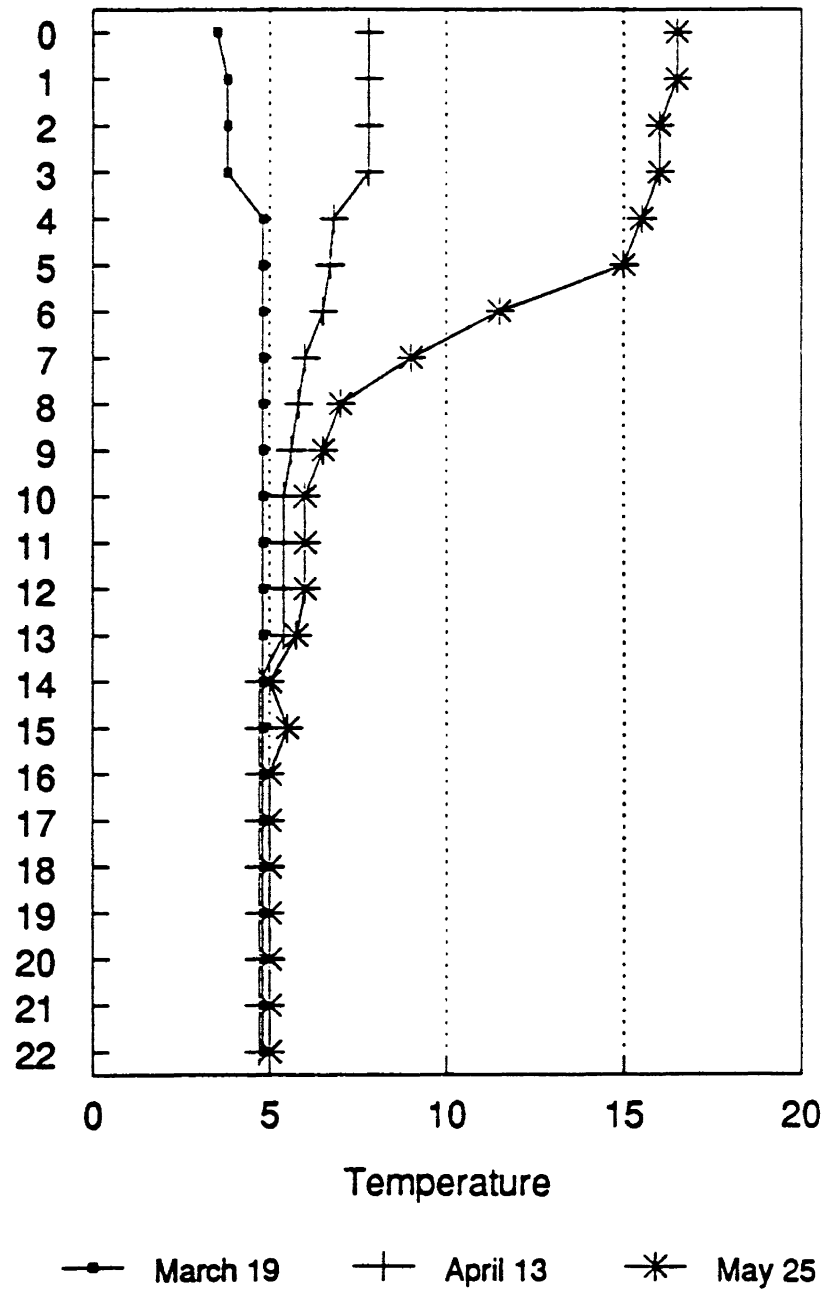


Figure 37. Spring 1985 temperature profiles for Mountain Lake, Virginia

Depth (meters)

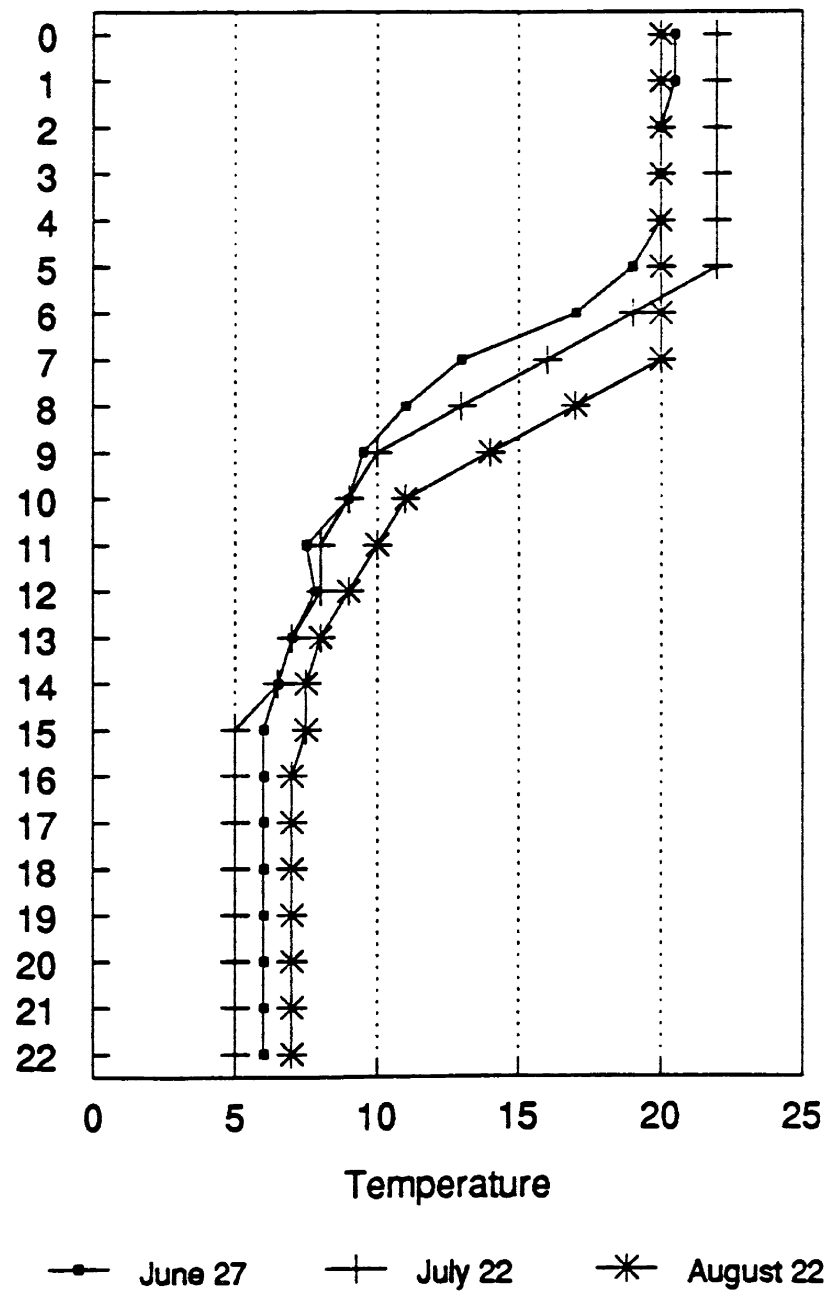


Figure 38. Summer 1985 temperature profiles for Mountain Lake, Virginia.

Depth (meters)

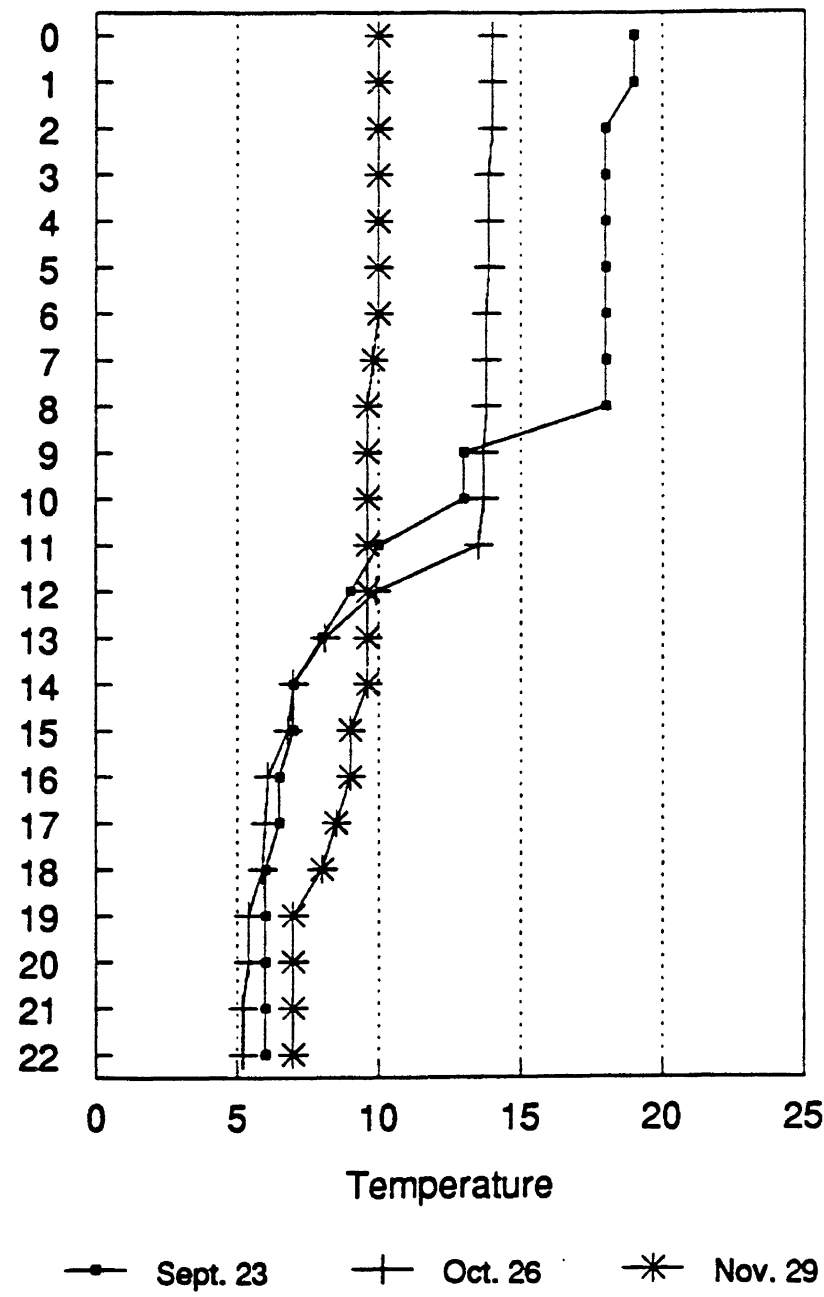


Figure 39. Fall 1985 temperature profiles for Mountain Lake, Virginia.

Depth (meters)

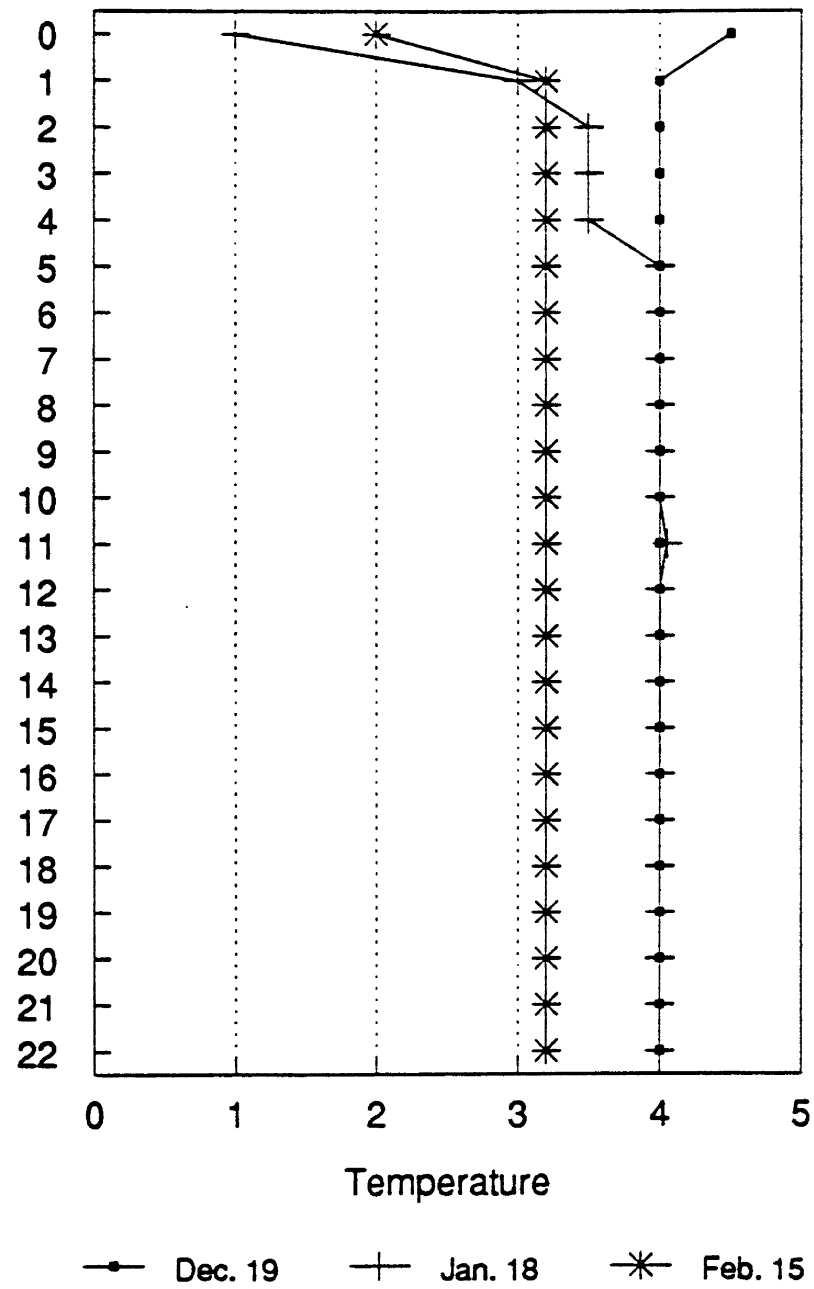


Figure 40. Winter 1985-86 temperature profiles for Mountain Lake, Virginia.

Depth (meters)

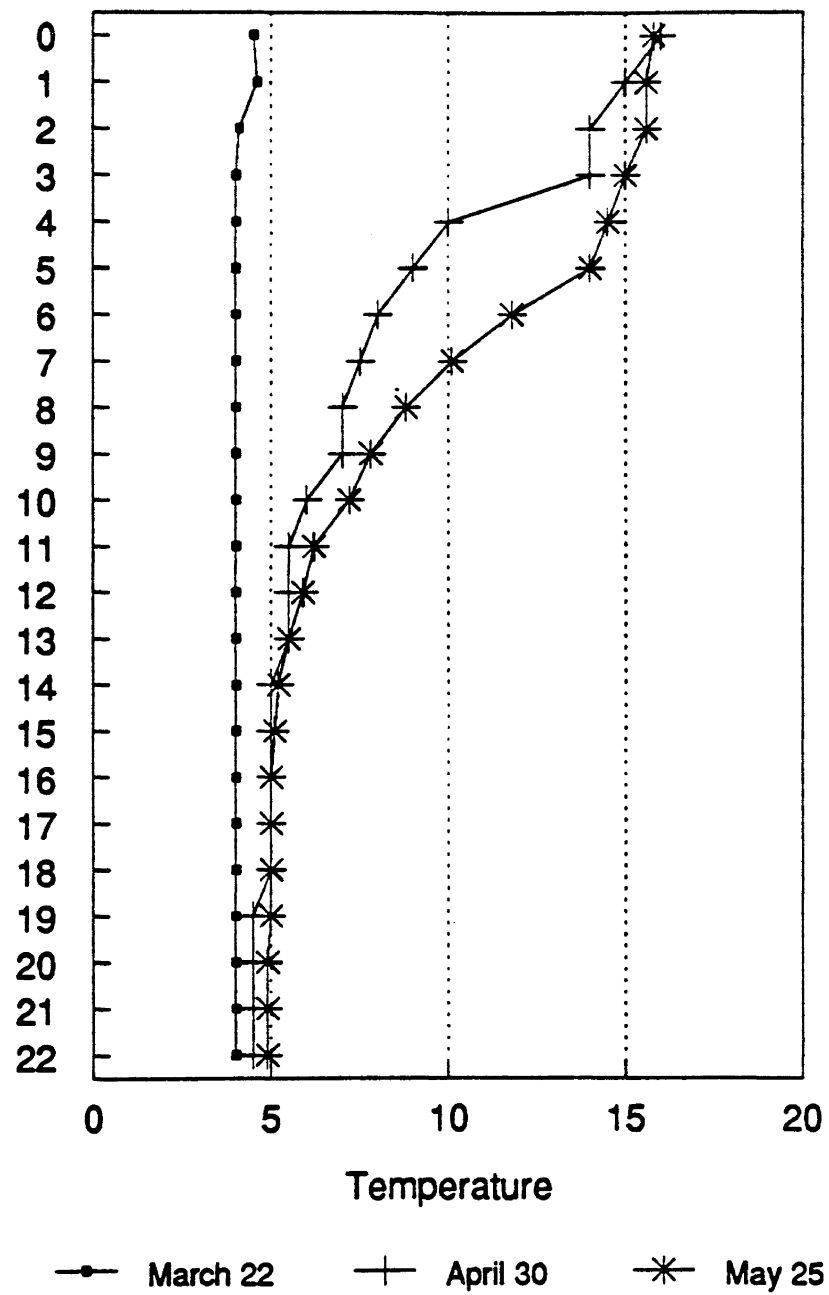


Figure 41. Spring 1986 temperature profiles for Mountain Lake, Virginia.

Depth (meters)

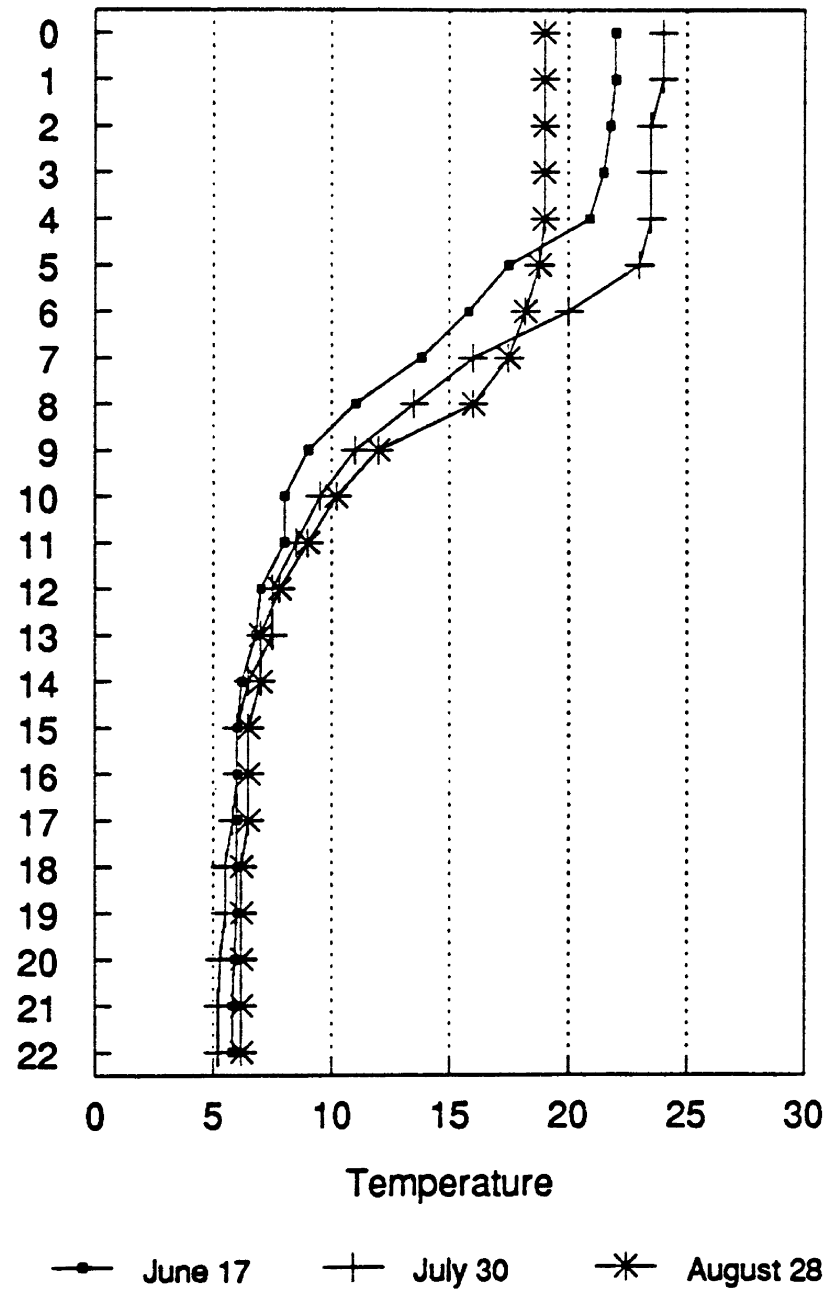


Figure 42. Summer 1986 temperature profiles for Mountain Lake, Virginia.

Depth (meters)

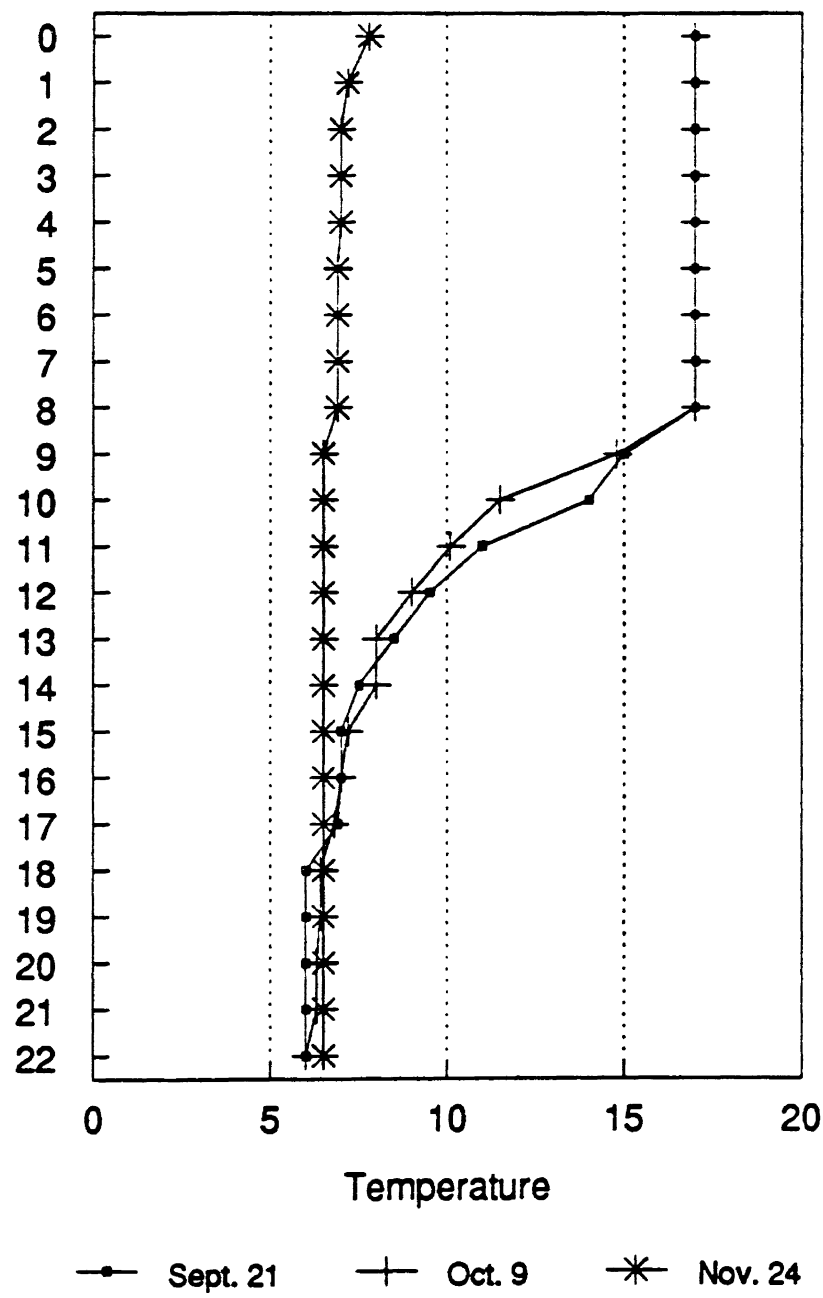


Figure 43. Fall 1986 temperature profiles for Mountain Lake, Virginia.

Depth (meters)

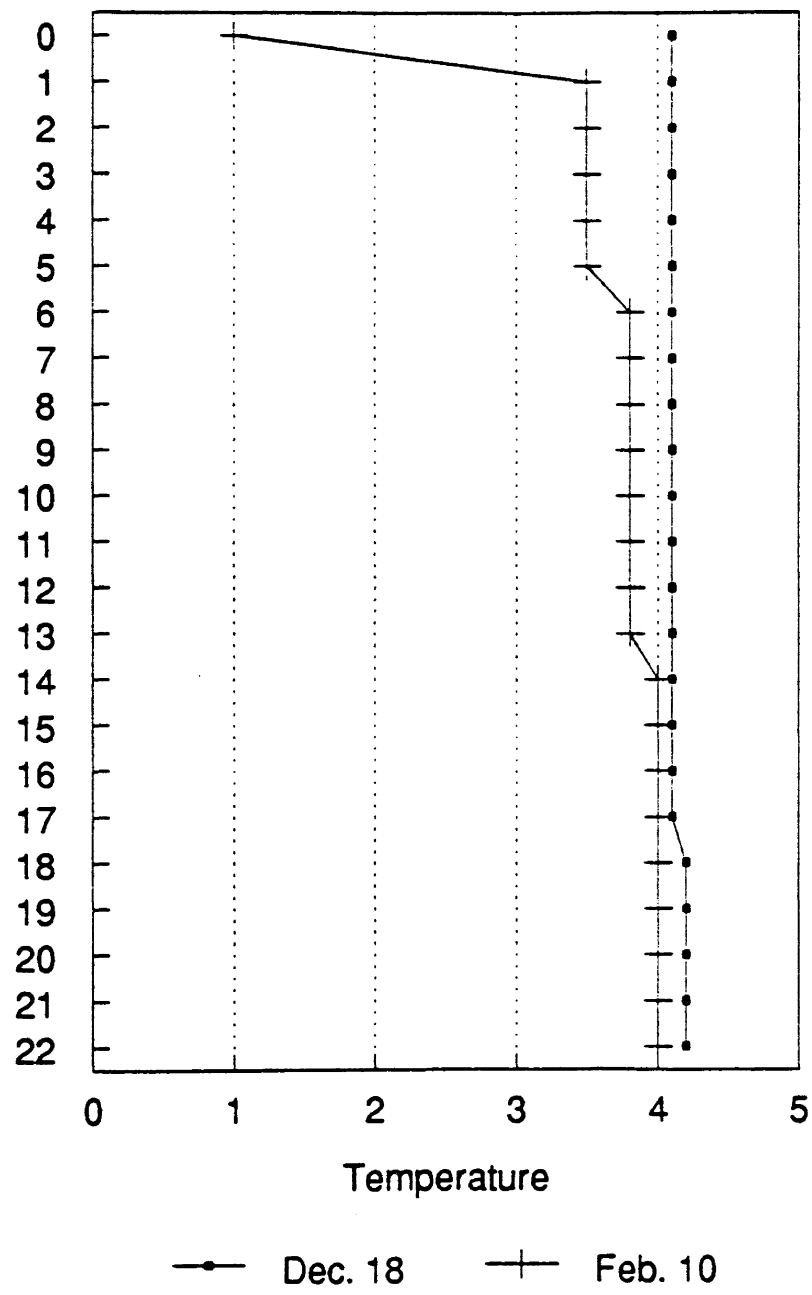


Figure 44. Winter 1986-87 temperature profiles for Mountain Lake, Virginia.

Depth (meters)

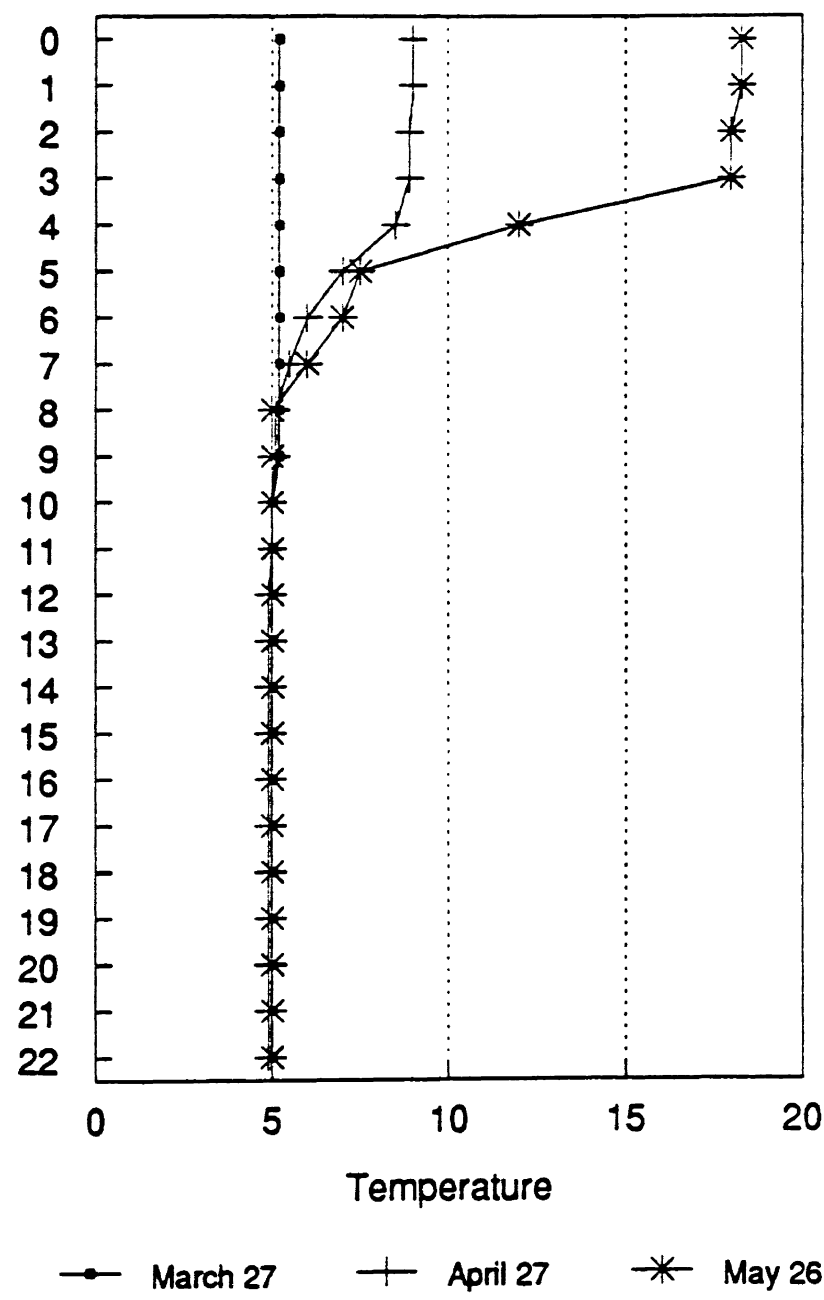


Figure 45. Spring 1987 temperature profiles for Mountain Lake, Virginia.

Depth (meters)

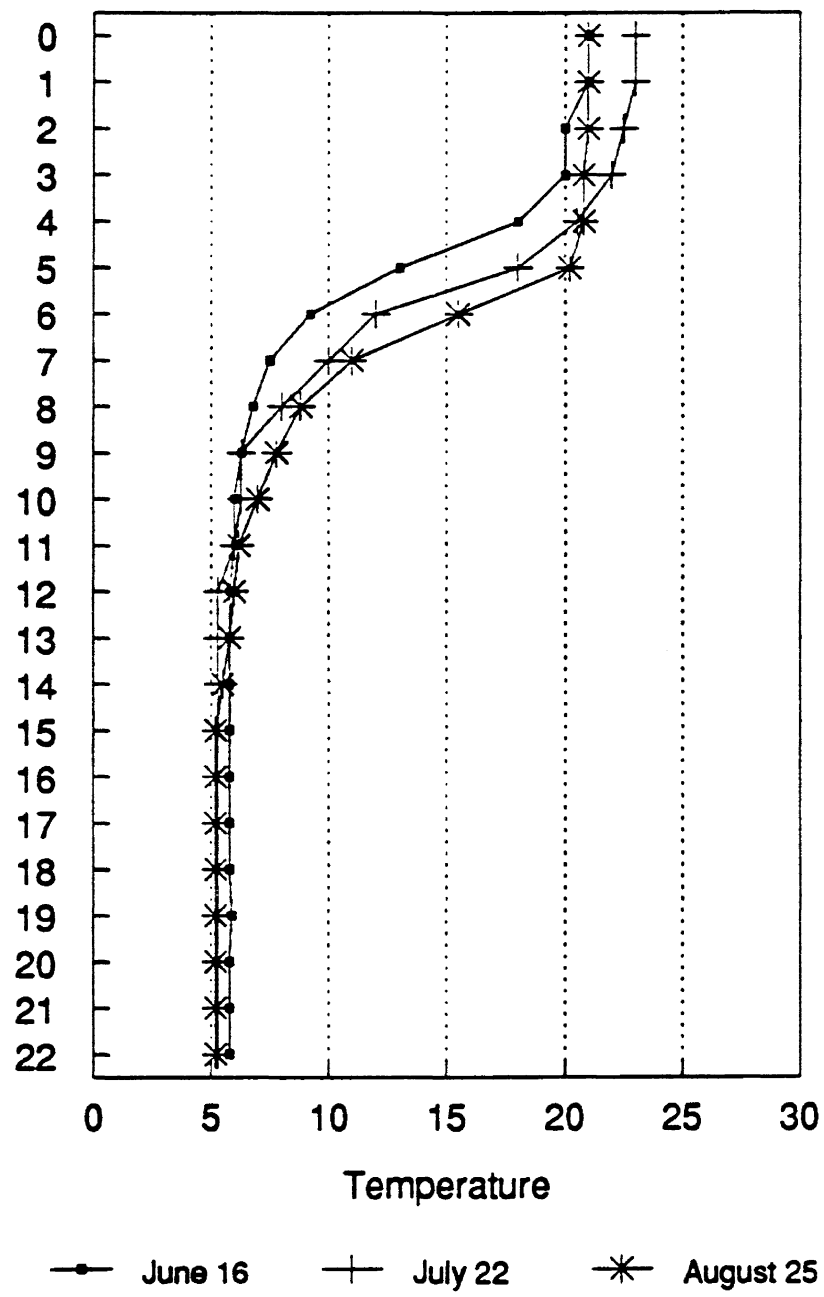


Figure 46. Summer 1987 temperature profiles for Mountain Lake, Virginia.

Depth (meters)

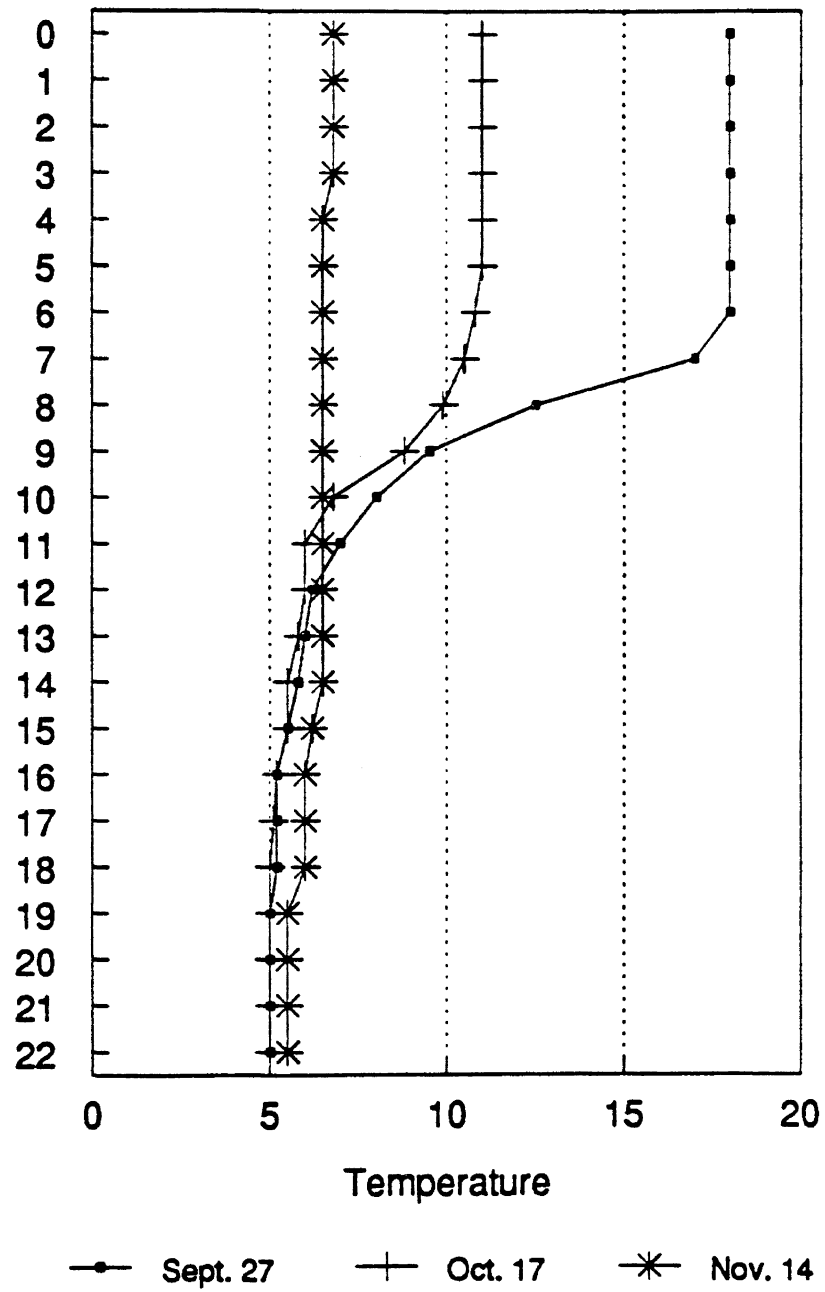


Figure 47. Fall 1987 temperature profiles for Mountain Lake, Virginia.

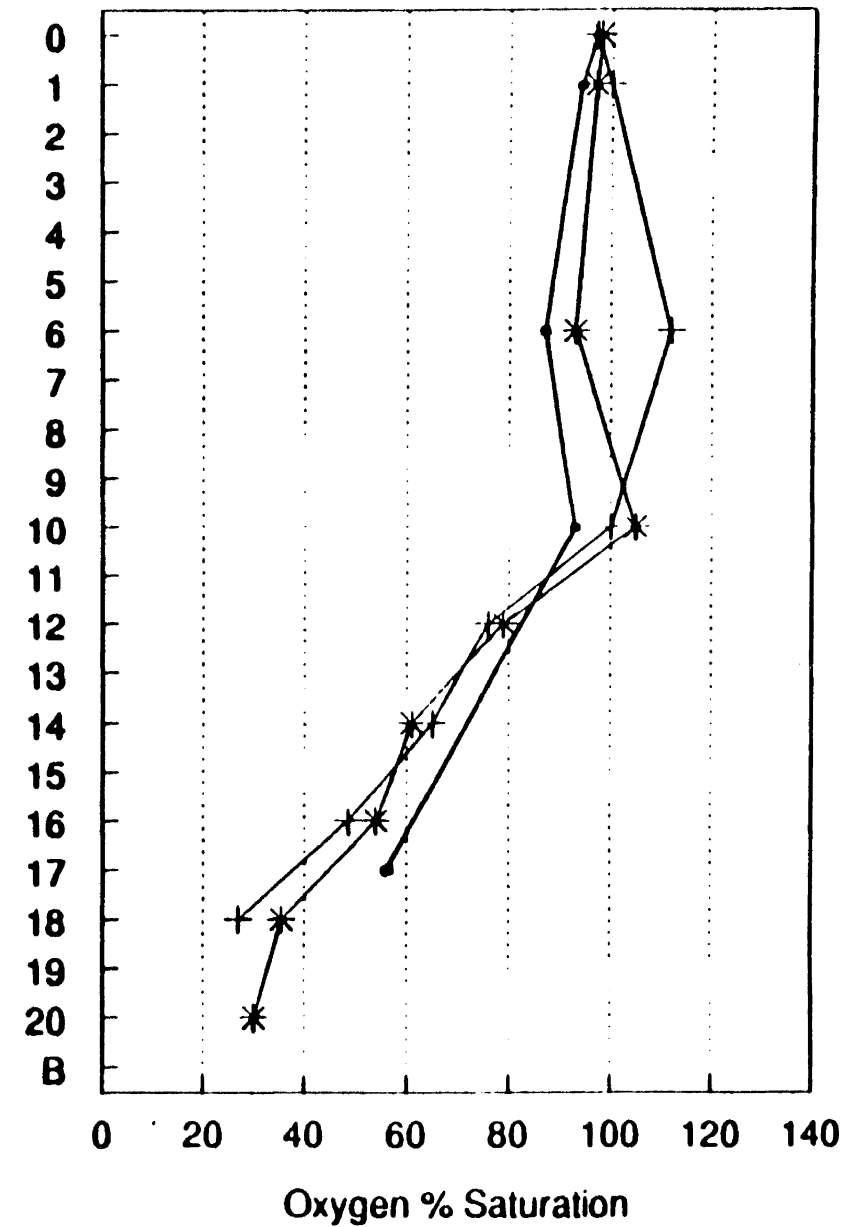
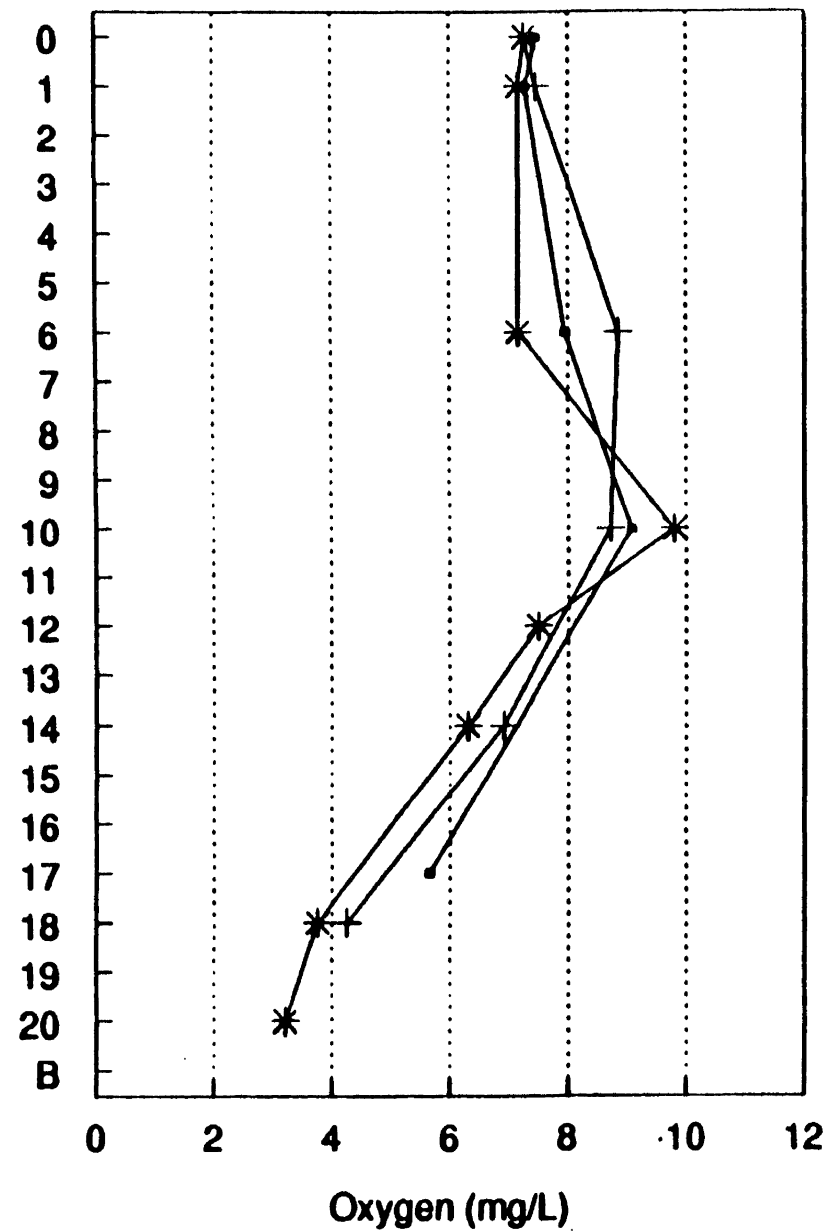
Appendix B

Table 23. Sulfate Levels from Selected Depths in Mountain Lake, Virginia, 1985-86.

Sulfate (mg/L)												
Depth	Month											
	M	A	M	J	J	A	S	O	N	D	J	F
.1 m	5.75	6.20	10.24	4.83	6.45	6.86	2.69	2.43	2.85	3.44	4.36	5.53
1 m	5.75	5.75	10.58	4.71	7.22	7.13	2.97	2.56	3.11	3.30	4.79	5.48
6 m	6.25	5.57	8.88	6.51	6.91	7.05	3.27	2.04	3.04	4.78	3.96	4.57
10 m	6.50	5.89	7.18	6.51	6.31	5.92	3.60	2.06	3.15	5.44	4.36	4.89
17 m	6.50	5.79	6.88	7.23	6.24	5.97	4.19	2.22	4.15	2.63	4.44	5.05
MEAN	6.15	5.80	8.96	5.81	6.67	6.65	3.25	2.27	3.26	3.92	4.38	5.05

Appendix C

Depth (meters)



—•— June 27 —+— July 22 —*— August 22

—•— June 27 —+— July 22 —*— August 9

Figure 48. Summer 1985 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Depth (meters)

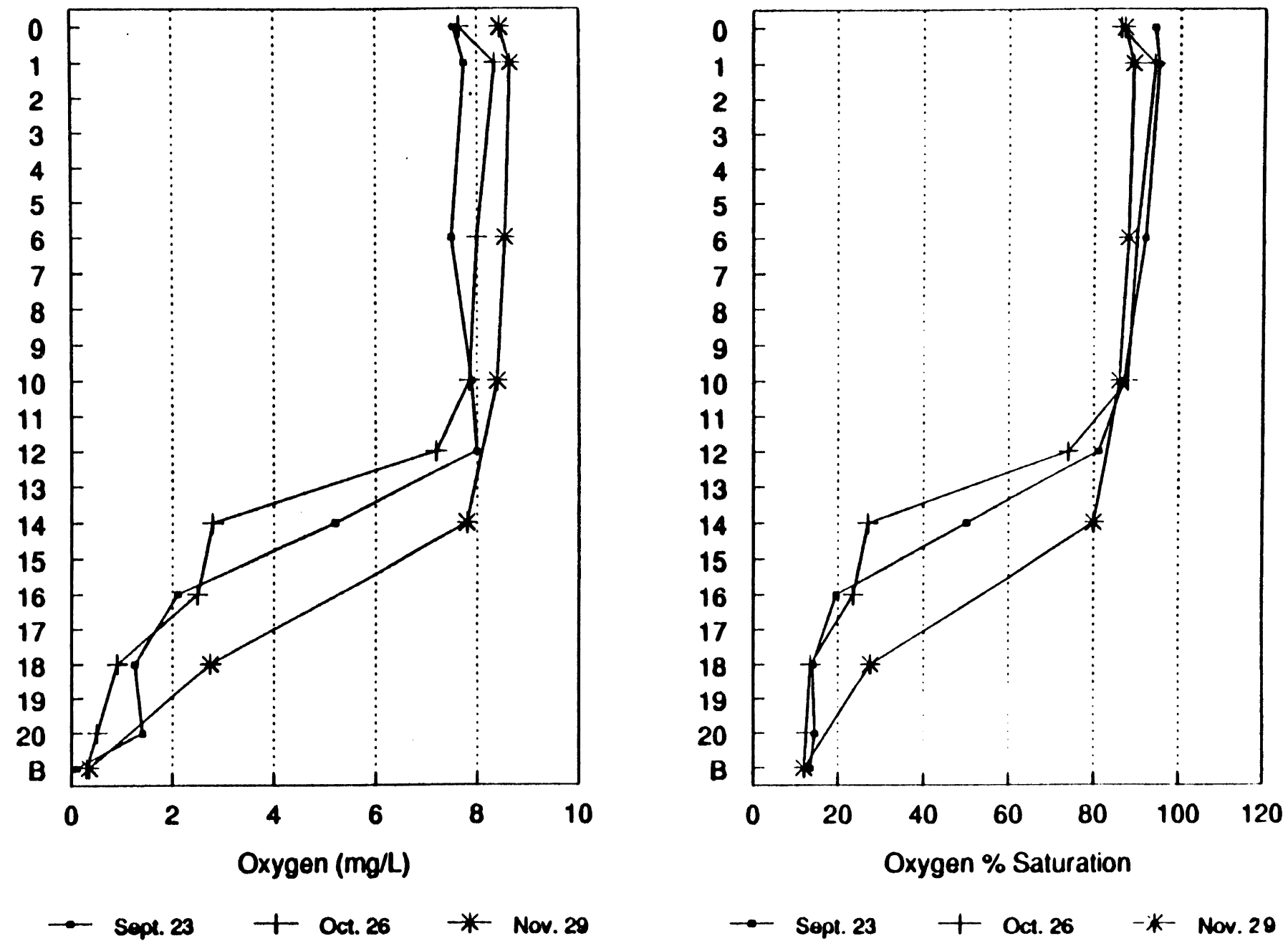


Figure 49. Fall 1985 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Depth (meters)

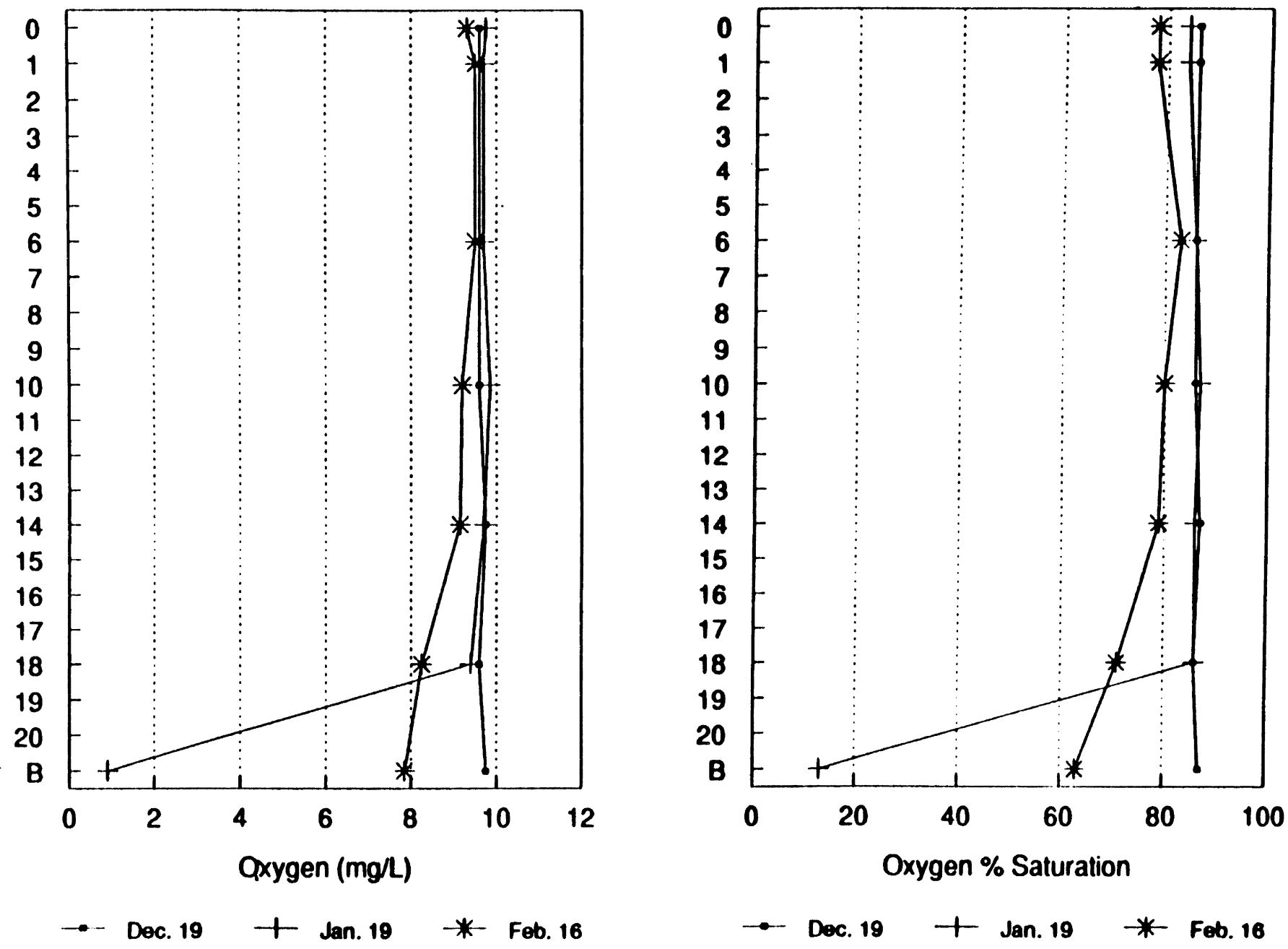


Figure 50. Winter 1985-86 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Depth (meters)

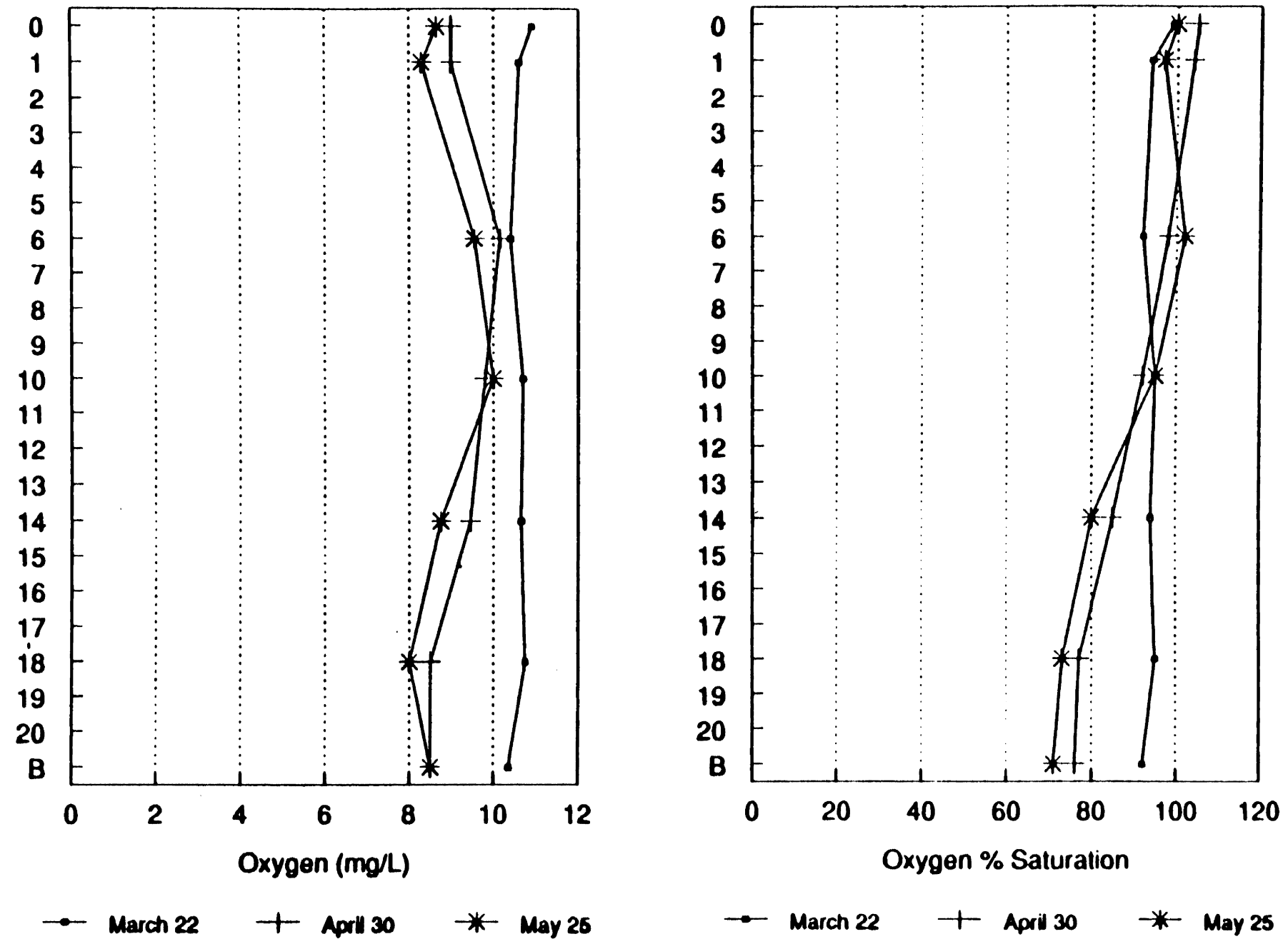


Figure 51. Spring 1986 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Depth (meters)

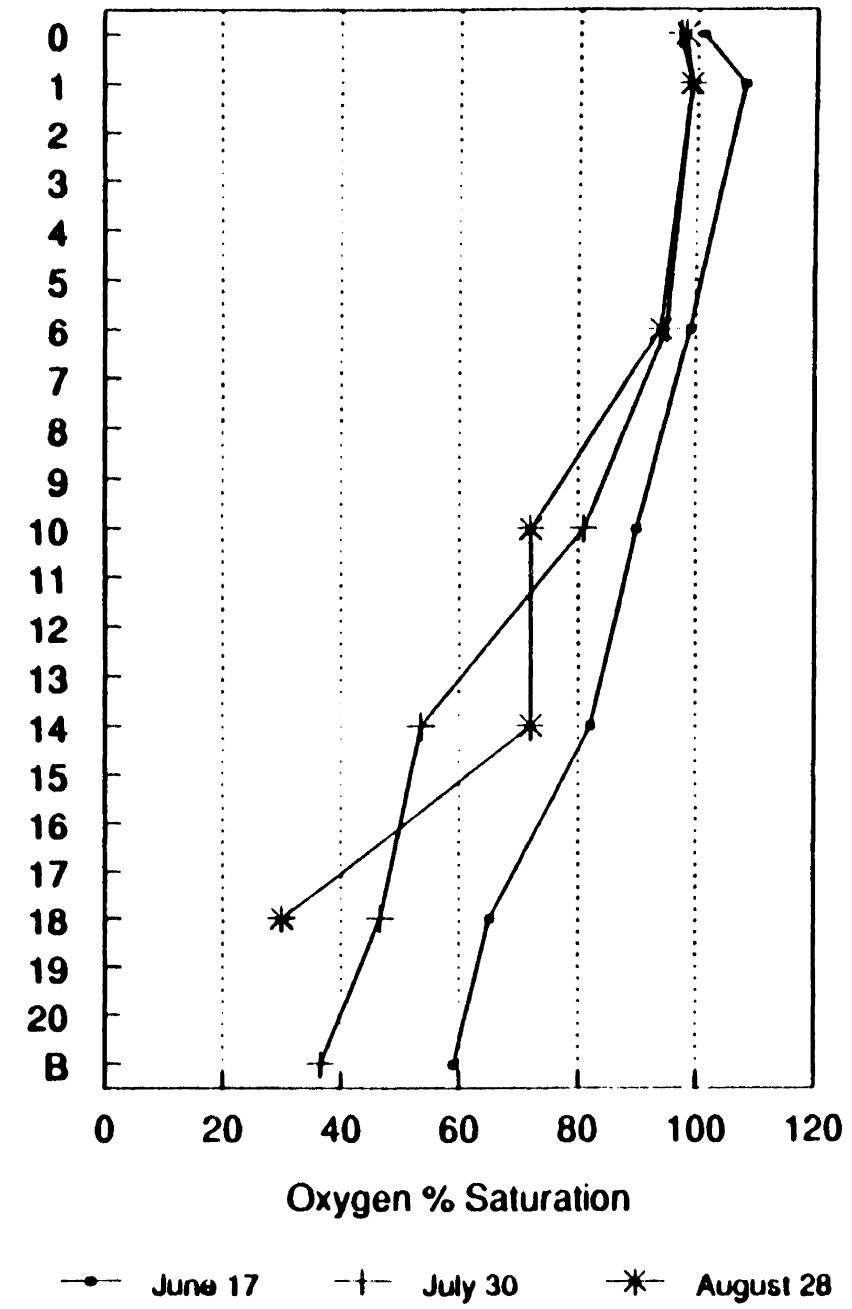
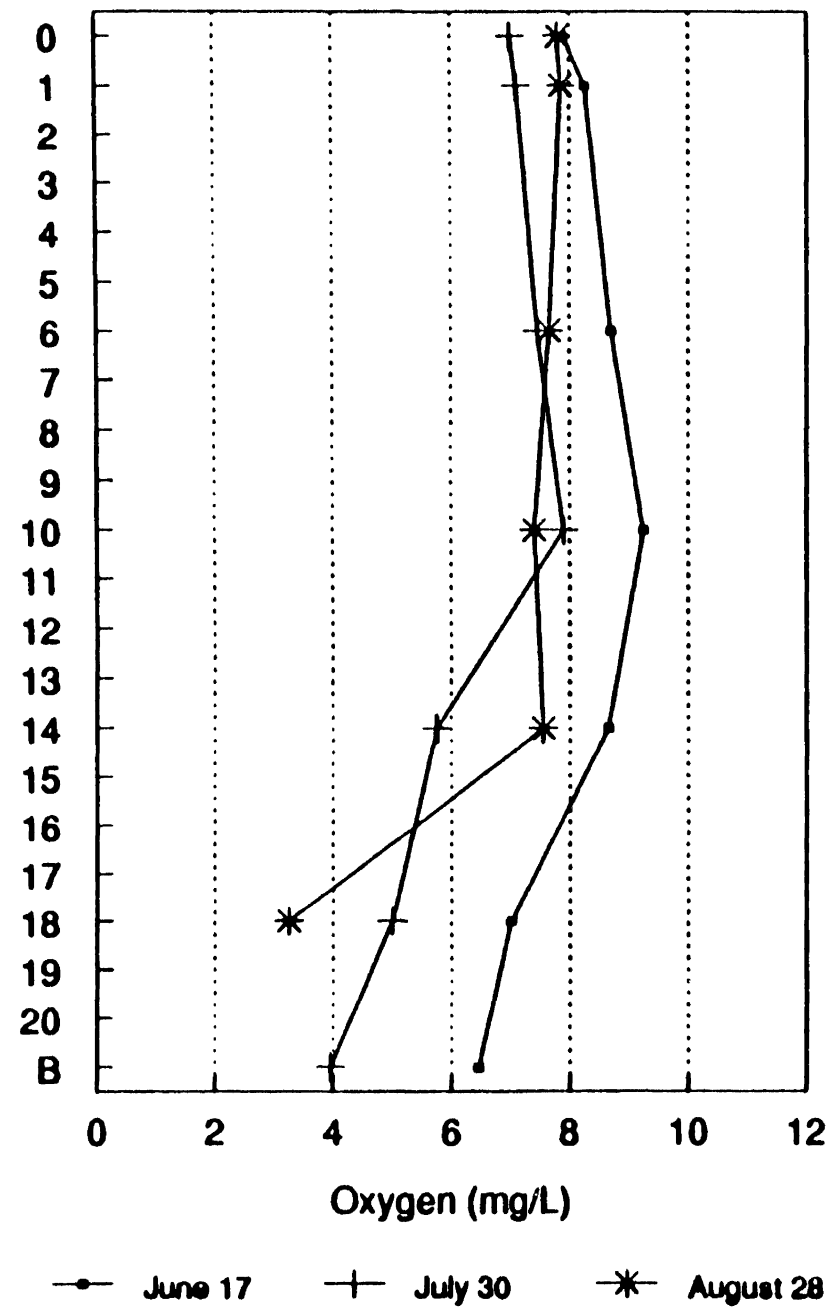


Figure 52. Summer 1986 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Depth (meters)

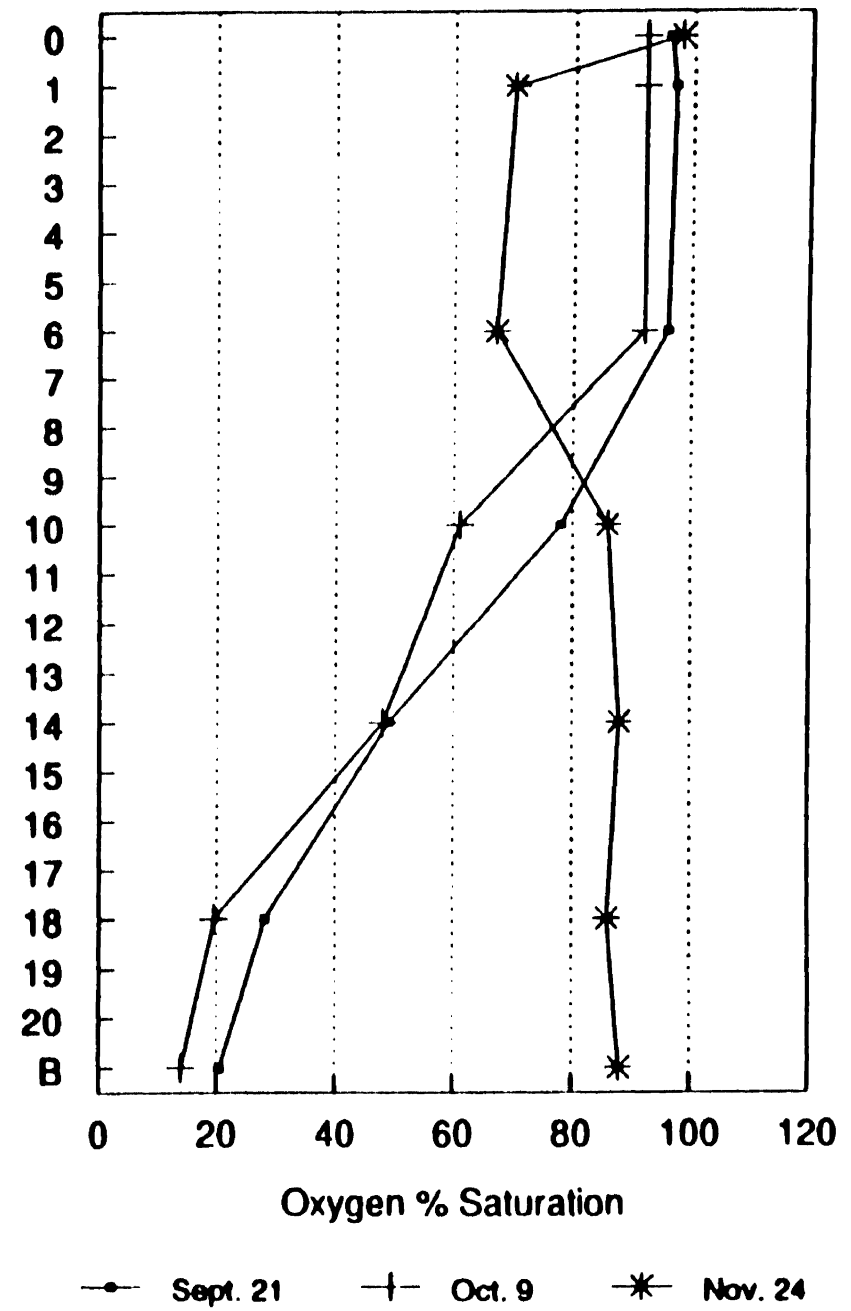
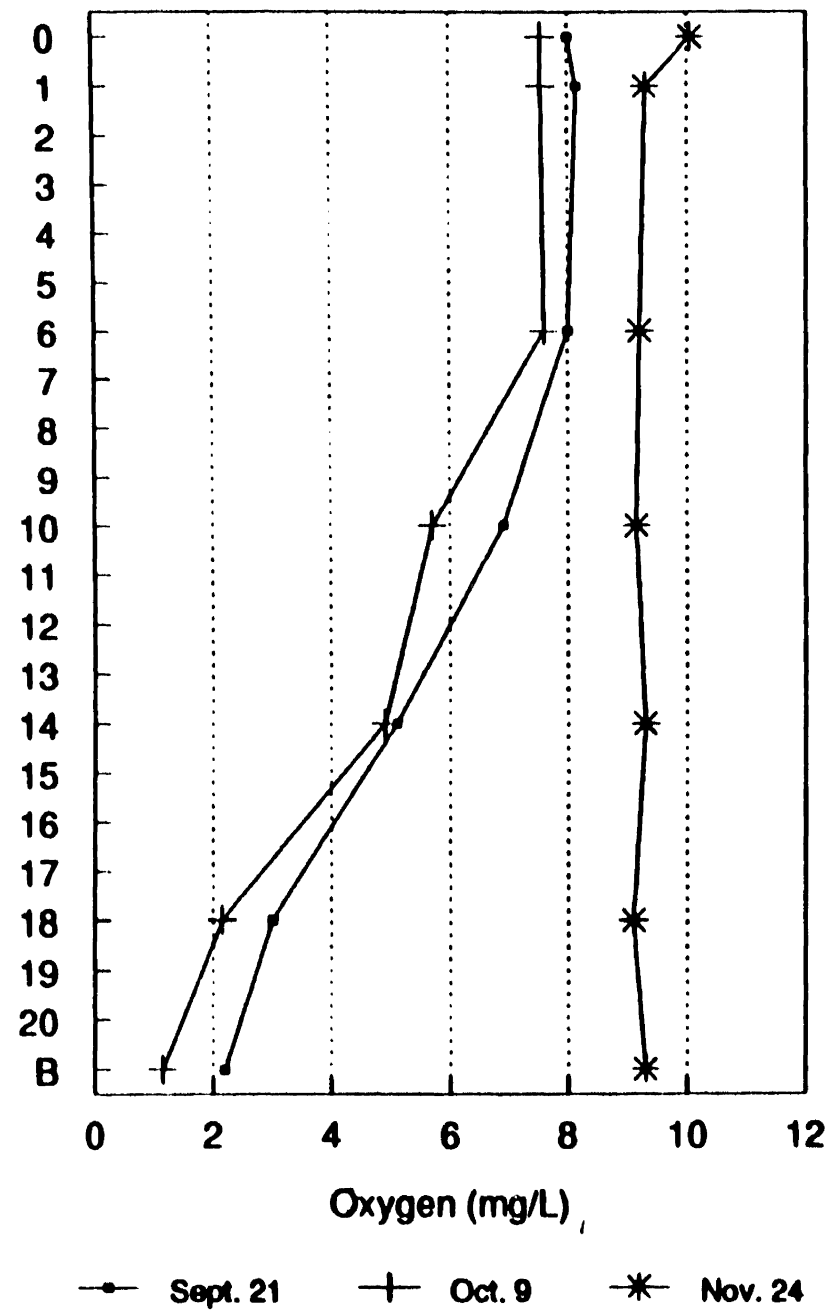
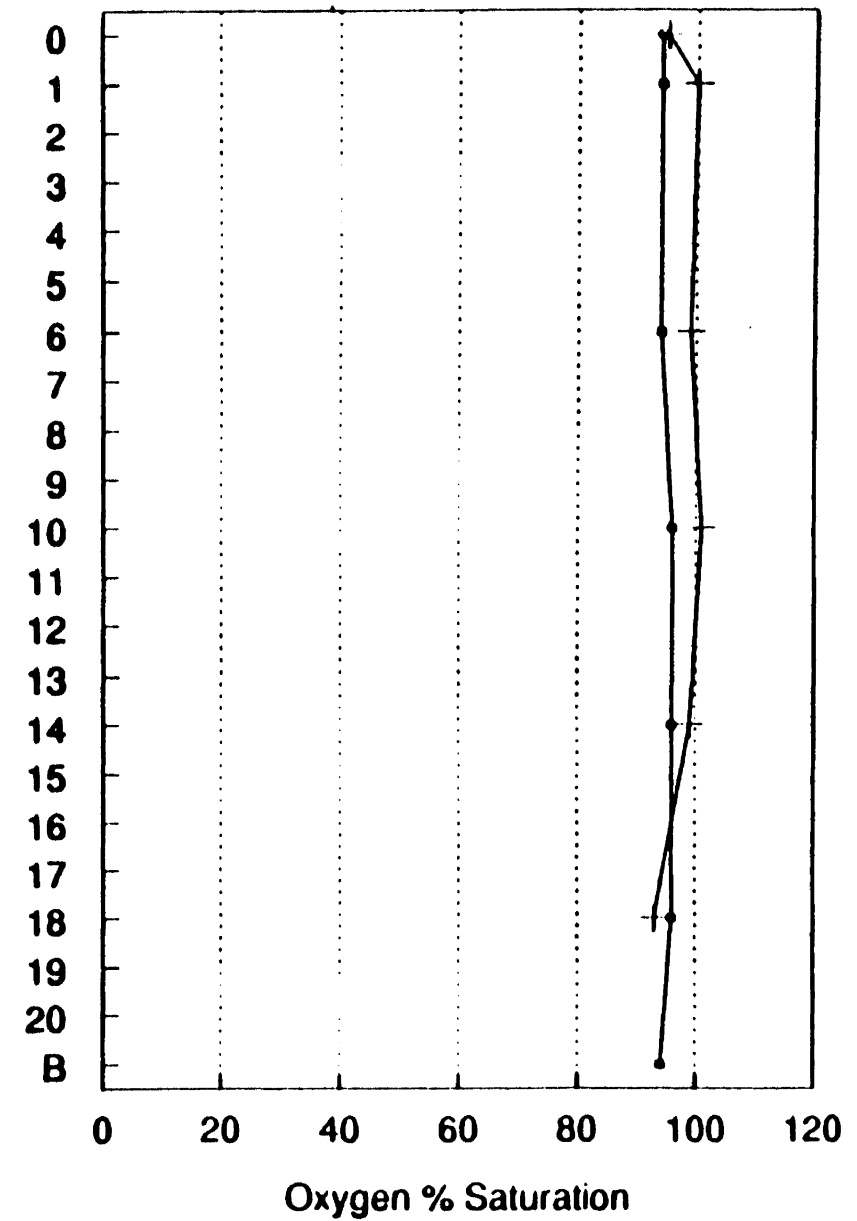
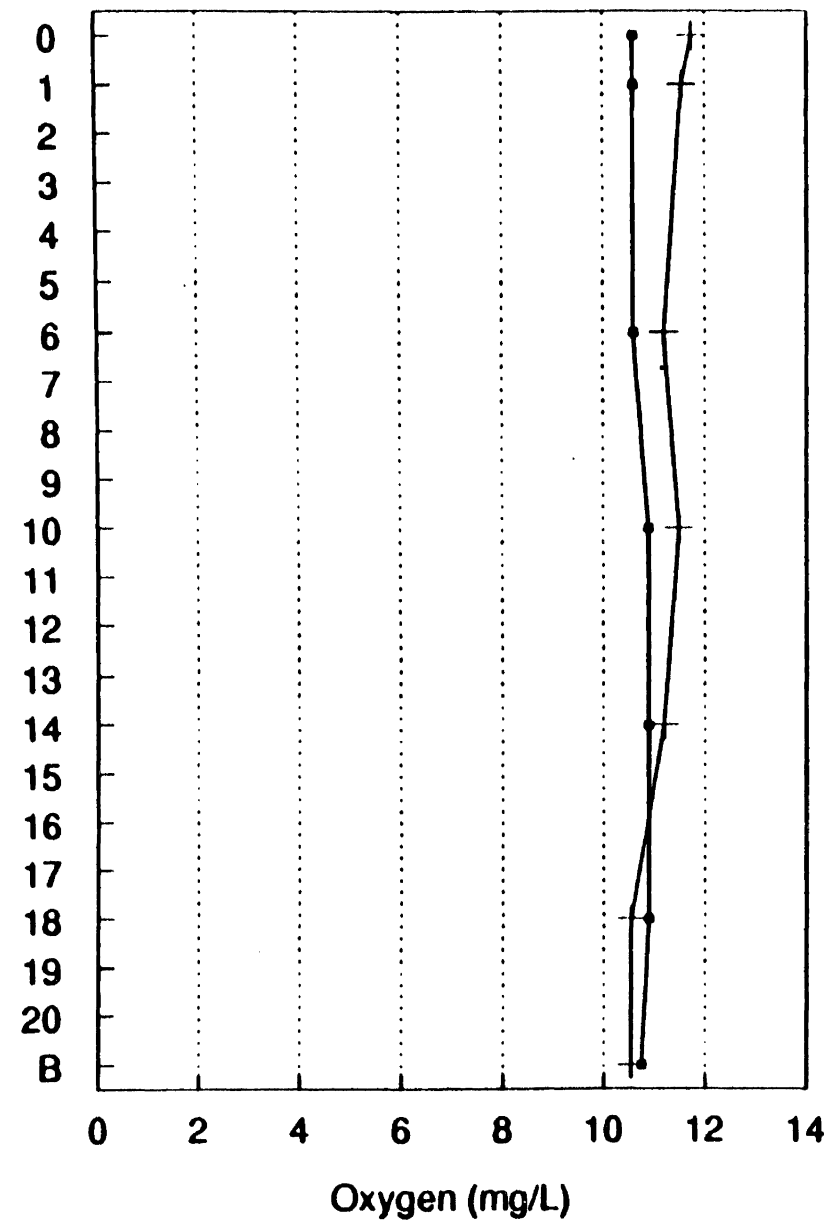


Figure 53. Fall 1986 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Depth (meters)

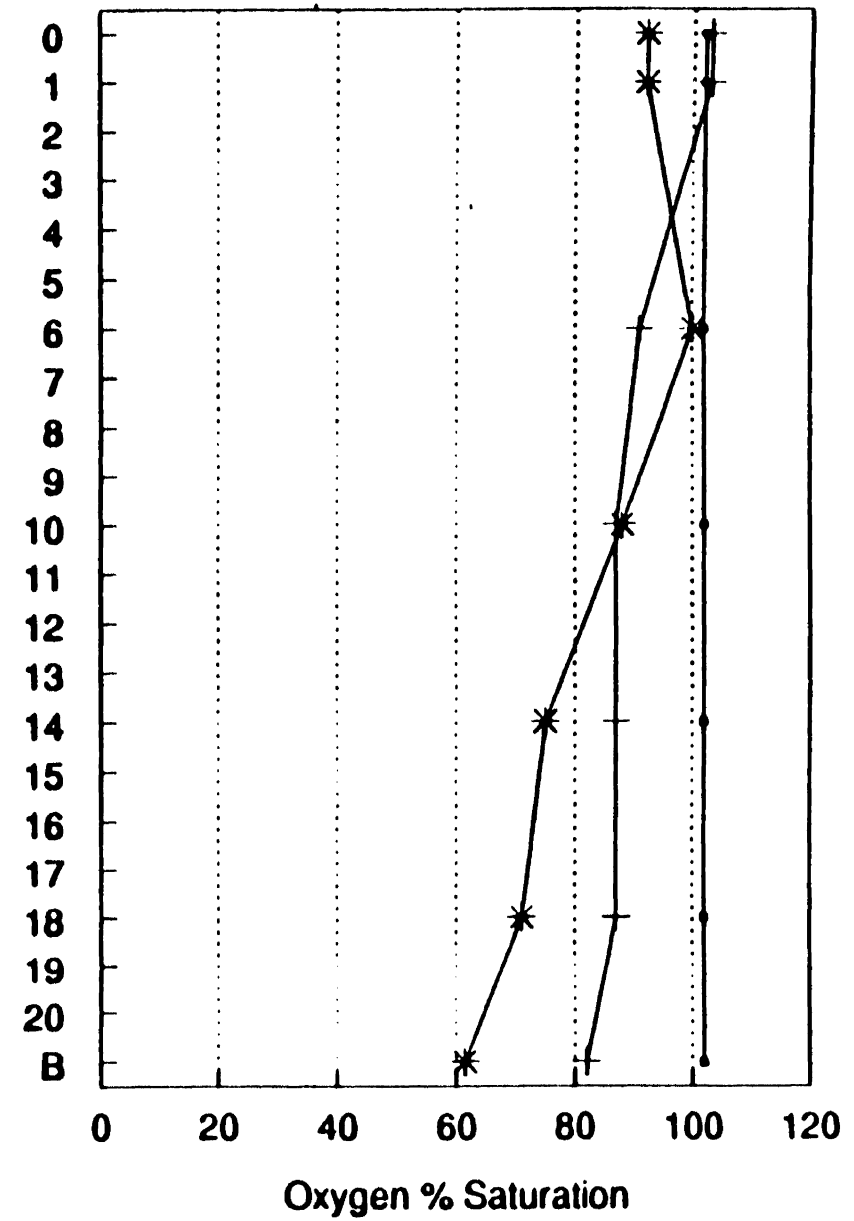
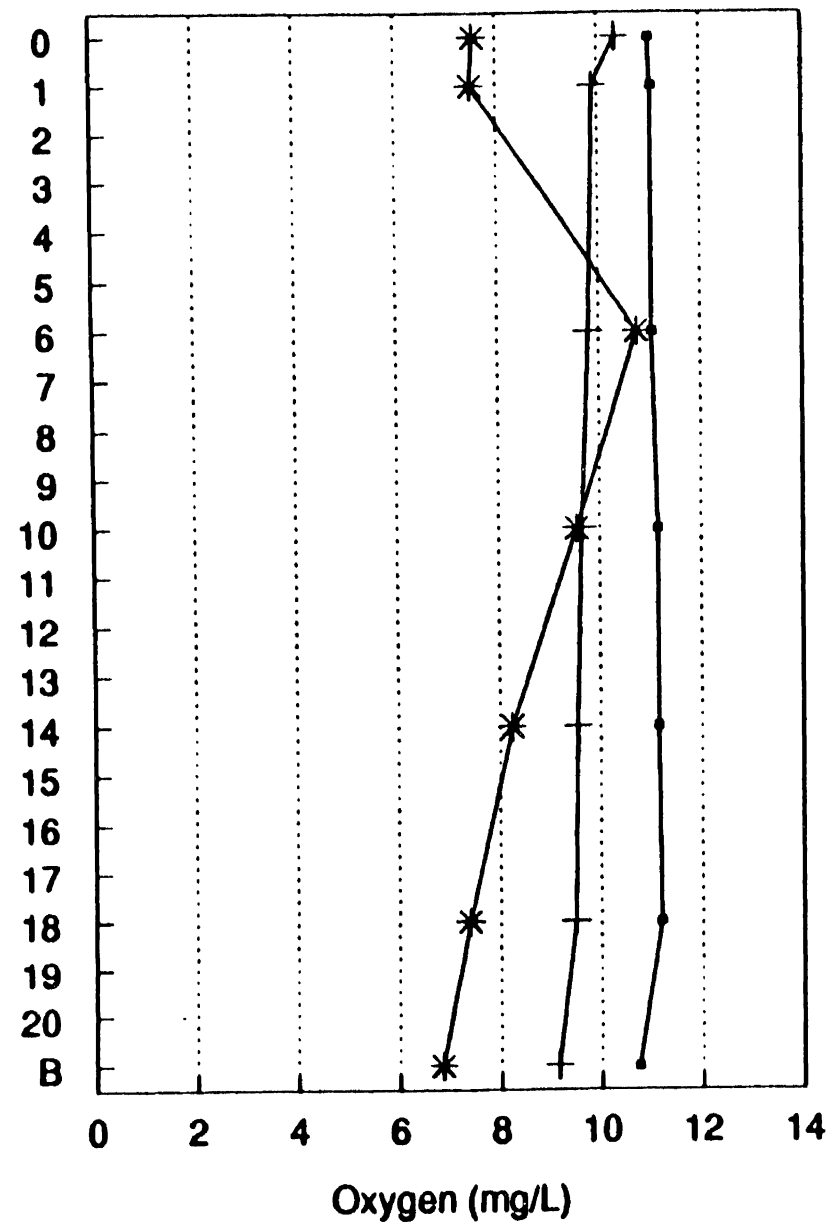


—•— Dec. 18 —+— Feb. 10

—•— Dec. 18 —+— Feb. 10

Figure 54. Winter 1986-87 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Depth (meters)



—•— March 27 —+— April 27 —*— May 26

—•— March 27 —+— April 27 —*— May 26

Figure 55. Spring 1987 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Depth (meters)

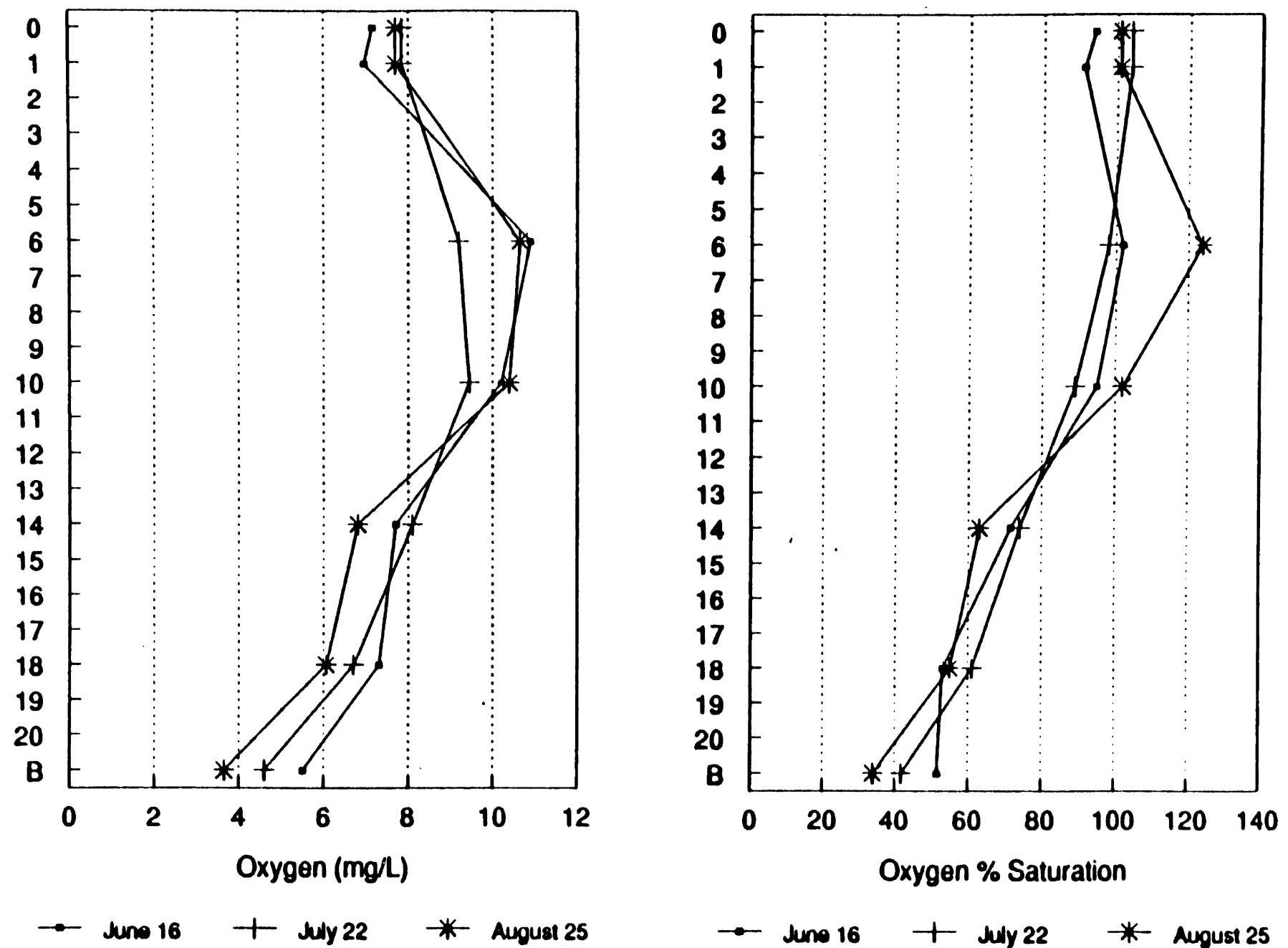


Figure 56. Summer 1987 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Depth (meters)

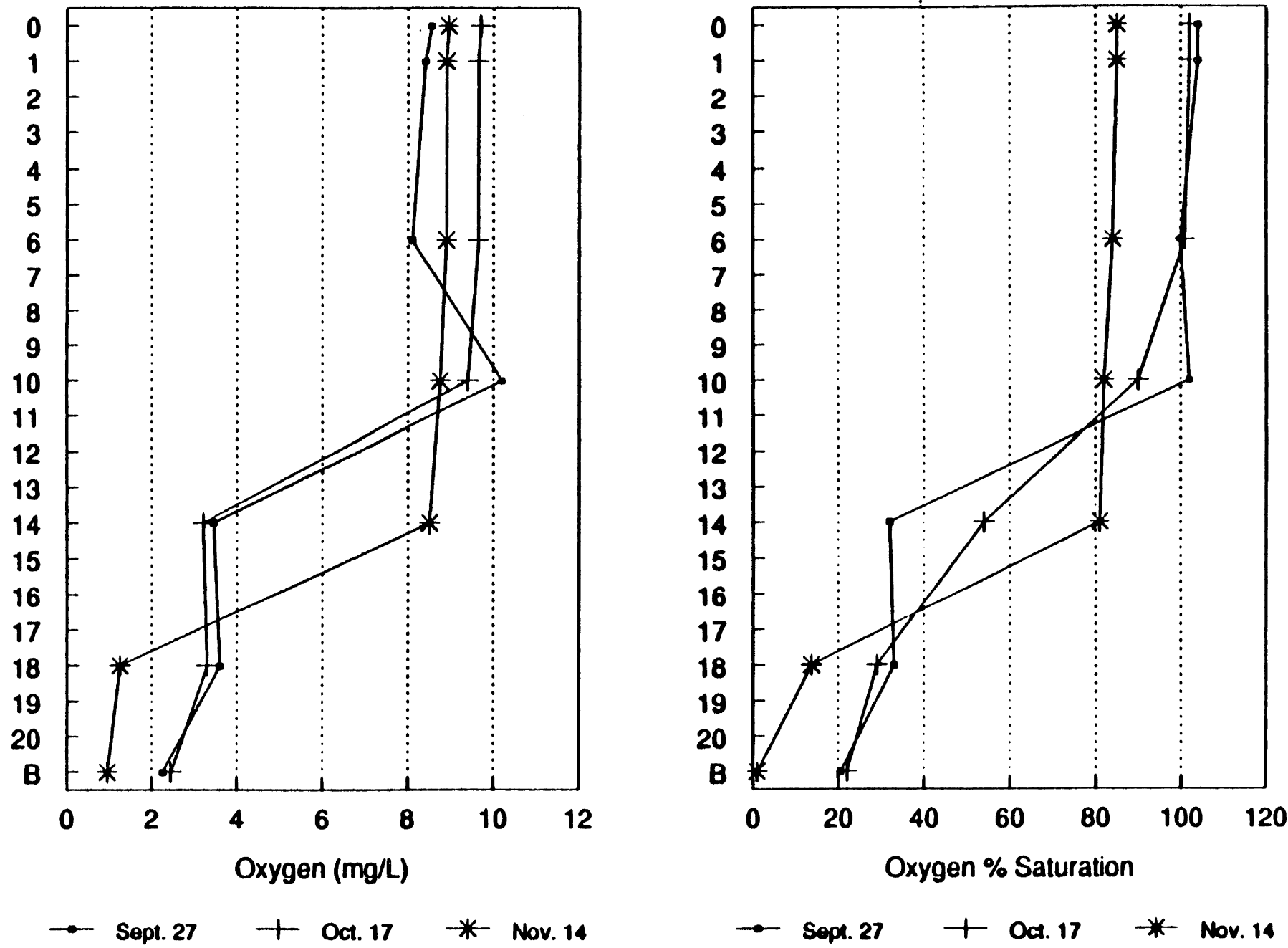


Figure 57. Fall 1987 oxygen profiles (left) and % saturation (right) for Mountain Lake, Virginia.

Appendix D

Table 24. Monthly nutrient levels and N:P ratios for five selected depths in Mountain lake, Virginia, for March 19, 1985-November 14, 1987.

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N* mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
March 19, 1985						
.1 m	0.0170	0.0061	0.0231	0.0014	16.5	1.106
1 m	0.0200	0.0078	0.0278	0.0016	17.4	1.089
6 m	0.0160	0.0055	0.0215	0.0012	17.9	1.172
10 m	0.0190	0.0055	0.0245	0.0017	14.4	1.386
17 m	0.0160	0.0138	0.0298	0.0024	12.4	1.386
Mean	0.0180	0.0066	0.0253	0.0017	14.9	1.227
April 13, 1985						
.1 m	0.0020	0.0045	0.0050	0.0035	1.4	0.949
1 m	0.0220	0.0048	0.0268	0.0035	7.6	0.966
6 m	0.0010	0.0060	0.0070	0.0024	2.9	0.964
10 m	0.0100	0.0056	0.0156	0.0010	15.6	0.982
17 m	0.0300	0.0052	0.0352	0.0011	32.0	1.511
Mean	0.0120	0.0052	0.0179	0.0020	9.0	1.026

*Total-N = nitrate-N plus ammonia-N; nitrate-N was always below detectable levels.

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
May 25, 1985						
.1 m	0.0110	0.0062	0.0172	0.0020	8.6	1.577
1 m	0.0125	0.0062	0.0185	0.0024	7.7	1.610
6 m	0.0093	0.0090	0.0183	0.0024	7.6	1.587
10 m	0.0080	0.0158	0.0238	0.0025	9.5	1.652
17 m	0.0090	0.0246	0.0436	0.0030	14.5	1.696
Mean	0.0101	0.0121	0.0243	0.0022	11.0	1.616
June 15, 1985						
.1 m	0.0100	0.0048	0.0148	0.0015	9.9	0.761
1 m	0.0100	0.0057	0.0157	0.0019	8.3	0.836
6 m	0.0095	0.0091	0.0186	0.0015	12.4	0.802
10 m	0.0090	0.0048	0.0138	0.0016	8.6	0.761
17 m	0.0100	0.0316	0.0416	0.0028	14.8	0.850
Mean	0.0097	0.0121	0.0209	0.0018	11.6	0.796

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
July 22, 1985						
.1 m	0.0067	0.0057	0.0124	0.0017	7.3	1.276
1 m	0.0056	0.0051	0.0107	0.0015	7.1	1.321
6 m	0.0050	0.0092	0.0142	0.0042	3.4	1.461
10 m	0.0051	0.0047	0.0098	0.0018	5.4	1.262
17 m	0.0064	0.0391	0.0455	0.0019	23.9	1.083
Mean	0.0057	0.0098	0.0184	0.0022	8.4	1.302
August 22, 1985						
.1 m	0.0106	0.0115	0.0221	0.0010	22.5	0.979
1 m	0.0092	0.0046	0.0138	0.0008	16.4	0.874
6 m	0.0126	0.0049	0.0175	0.0011	16.1	0.919
10 m	0.0116	0.0056	0.0172	0.0007	23.2	1.050
17 m	0.0078	0.0127	0.0205	0.0014	14.4	0.964
Mean	0.0106	0.0073	0.0182	0.0010	18.0	0.956

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
September 26, 1985						
.1 m	0.0044	0.0078	0.0122	0.0014	8.7	0.762
1 m	0	0.0079	0.0079	0.0016	4.9	0.830
6 m	0.0052	0.0142	0.0194	0.0010	19.4	0.687
10 m	0.0173	0.0087	0.0260	0.0015	17.3	0.806
17 m	0.0091	0.0620	0.0711	0.0017	41.7	0.684
Mean	0.0048	0.0156	0.0204	0.0015	13.6	0.761
October 26, 1985						
.1 m	0	0.0091	0.0091	0.0003	32.6	0.437
1 m	0	0.0092	0.0092	0.0002	46.0	0.606
6 m	0	0.0075	0.0075	0.0005	15.0	0.466
10 m	0	0.0108	0.0108	0.0010	10.8	0.534
17 m	0.0110	0.0627	0.0737	0.0042	17.5	0.743
Mean	0.0010	0.0149	0.0221	0.0009	24.5	0.536

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
November 29, 1985						
.1 m	0.0183	0.0136	0.0319	0.0065	4.9	0.708
1 m	0.0161	0.0132	0.0293	0.0037	7.9	0.624
6 m	0.0138	0.0125	0.0263	0.0028	9.4	0.636
10 m	0.0143	0.0128	0.0271	0.0019	14.3	0.672
17 m	0.0170	0.0247	0.0417	0.0025	16.7	0.648
Mean	0.0159	0.0129	0.0313	0.0035	8.9	0.658
December 19, 1985						
.1 m	0.0258	0.0157	0.0415	0.0022	19.1	0.725
1 m	0.0243	0.0153	0.0396	0.0008	49.5	0.731
6 m	0.0223	0.0157	0.0380	0.0009	42.2	0.725
10 m	0.0158	0.0186	0.0344	0.0008	43.0	0.767
17 m	0.0178	0.0160	0.0338	0.0031	10.9	0.773
Mean	0.0212	0.0163	0.0375	0.0016	23.4	0.744

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
January 19, 1986						
.1 m	0.0083	0.0159	0.0242	0.0007	34.6	0.958
1 m	0.0088	0.0164	0.0252	0.0008	31.5	1.446
6 m	0.0115	0.0138	0.0253	0.0008	31.6	1.250
10 m	0.0133	0.0165	0.0298	0.0007	42.6	0.993
17 m	0.0113	0.0171	0.0284	0.0008	35.5	0.874
Mean	0.0106	0.0158	0.0266	0.0008	35.5	1.104
February 16, 1986						
.1 m	0.0144	0.0162	0.0306	0.0003	102.0	1.333
1 m	0.0151	0.0159	0.0310	0.0009	34.4	1.053
6 m	0.0240	0.0165	0.0405	0.0002	202.5	0.952
10 m	0.0177	0.0169	0.0346	0.0005	69.2	1.017
17 m	0.0084	0.0190	0.0274	0.0011	24.9	1.124
Mean	0.0159	0.0169	0.0328	0.0006	54.7	1.096

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
March 22, 1986						
.1 m	0.0049	0.0250	0.0299	0.0010	29.9	0.530
1 m	0.0074	0.0260	0.0334	0.0006	55.7	0.440
6 m	0.0164	0.0247	0.0411	0.0013	31.6	0.470
10 m	0.0126	0.0262	0.0388	0.0008	48.5	0.639
17 m	0.0169	0.0268	0.0437	0.0007	62.4	0.360
Mean	0.0117	0.0257	0.0374	0.0009	41.5	0.488
April 30, 1986						
.1 m	0.0122	0.0233	0.0355	0.0009	39.4	0.330
1 m	0.0086	0.0097	0.0183	0.0006	30.5	0.430
6 m	0.0407	0.0092	0.0500	0.0009	55.6	0.390
10 m	0.0289	0.0135	0.0424	0.0007	60.6	0.490
17 m	0.0365	0.0392	0.0758	0.0010	75.8	0.370
Mean	0.0240	0.0190	0.0444	0.0008	55.5	0.402

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
May 25, 1986						
.1 m	0.0133	0.0575	0.0708	0.0019	37.3	0.261
1 m	0.0087	0.0132	0.0219	0.0011	19.9	0.370
6 m	0.0036	0.0175	0.0211	0.0007	30.1	0.261
10 m	0.0135	0.0152	0.0287	0.0012	23.9	0.280
17 m	0.0168	0.0452	0.0620	0.0011	56.4	0.210
Mean	0.0112	0.0298	0.0409	0.0012	34.1	0.275
June 17, 1986						
.1 m	0.0038	0.0101	0.0140	0.0008	17.2	0.470
1 m	0.0105	0.0108	0.0213	0.0009	23.8	0.370
6 m	0.0054	0.0197	0.0251	0.0007	38.0	0.440
10 m	0.0158	0.0158	0.0316	0.0009	36.7	0.370
17 m	0.0148	0.0371	0.0519	0.0010	53.5	0.221
Mean	0.0101	0.0187	0.0391	0.0008	48.9	0.374

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
July 30, 1986						
.1 m	0.0093	0.0103	0.0196	0.0005	39.2	0.442
1 m	0.0100	0.0085	0.0185	0.0006	30.8	0.434
6 m	0.0135	0.0136	0.0271	0.0007	38.7	0.442
10 m	0.0104	0.0129	0.0233	0.0008	29.1	0.426
17 m	0.0427	0.0460	0.0887	0.0006	147.8	0.527
Mean	0.0178	0.0183	0.0354	0.0006	59.0	0.454
August 28, 1986						
.1 m	0.0061	0.0092	0.0153	0.0008	19.1	0.496
1 m	0.0062	0.0070	0.0132	0.0001	132.0	0.504
6 m	0.0055	0.0072	0.0127	0.0008	15.9	0.712
10 m	0.0197	0.0123	0.0320	0.0008	40.0	0.457
17 m	0.0498	0.0405	0.0904	0.0009	100.4	0.511
Mean	0.0175	0.0152	0.0327	0.0007	46.7	0.536

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
September 21, 1986						
.1 m	0.0104	0.0171	0.0275	0.0011	25.0	0.728
1 m	0.0101	0.0092	0.0193	0.0010	19.3	0.643
6 m	0.0093	0.0142	0.0235	0.0009	26.1	0.658
10 m	0.0320	0.0296	0.0616	0.0014	44.0	0.473
17 m	0.0533	0.0493	0.1026	0.0017	60.4	0.612
Mean	0.0230	0.0239	0.0469	0.0012	39.1	0.622
October 19, 1986						
.1 m	0.0100	0.0167	0.0267	0.0017	15.4	0.782
1 m	0.0103	0.0061	0.0164	0.0050	3.2	0.789
6 m	0.0133	0.0063	0.0196	0.0017	11.4	0.588
10 m	0.0183	0.0211	0.0394	0.0060	6.6	0.519
17 m	0.0420	0.0298	0.0718	0.0064	11.3	0.674
Mean	0.0188	0.0160	0.0348	0.0042	8.3	0.670

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
November 24, 1986						
.1 m	0.0187	0.0075	0.0262	0.0019	13.7	1.075
1 m	0.0154	0.0056	0.0210	0.0016	13.1	0.905
6 m	0.0159	0.0056	0.0215	0.0017	12.9	1.029
10 m	0.0200	0.0056	0.0256	0.0011	24.2	1.222
17 m	0.0175	0.0052	0.0227	0.0037	6.1	0.836
Mean	0.0175	0.0059	0.0234	0.0020	11.7	1.013
December 18, 1986						
.1 m	0.0236	0.0074	0.0310	0.0011	28.7	0.751
1 m	0.0195	0.0057	0.0252	0.0029	8.7	0.720
6 m	0.0177	0.0057	0.0234	0.0015	15.3	1.036
10 m	0.0154	0.0065	0.0218	0.0020	10.7	0.743
17 m	0.0149	0.0058	0.0207	0.0015	13.4	0.674
Mean	0.0182	0.0062	0.0244	0.0018	13.5	0.785

Table 24 (Cont'd.)

January, 1987 - No Data - Ice Conditions

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
February 11, 1987						
.1 m	0.1078	0.0110	0.1188	0.0008	156.2	1.693
1 m	0.0070	0.0056	0.0126	0.0006	21.7	1.685
6 m	0.0094	0.0092	0.0186	0.0006	30.5	1.515
10 m	0.0068	0.0058	0.0125	0.0008	15.8	1.793
17 m	0.0092	0.0054	0.0146	0.0005	27.4	1.631
Mean	0.0280	0.0074	0.0354	0.0006	54.4	1.664
Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
March 27, 1987						
.1 m	0.0240	0.0058	0.0299	0.0008	35.6	1.176
1 m	0.0104	0.0056	0.0154	0.0008	19.8	1.770
6 m	0.0092	0.0067	0.0159	0	-	1.662
10 m	0.0113	0.0055	0.0168	0.0005	35.0	1.826
17 m	0.0242	0.0058	0.0301	0.0004	69.9	1.770
Mean	0.0158	0.0059	0.0218	0.0005	42.6	1.648

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
April 27, 1987						
.1 m	0.0271	0.0054	0.0325	0.0014	22.7	0.898
1 m	0.0295	0.0062	0.0357	0.0016	22.9	0.959
6 m	0.0108	0.0067	0.0176	0.0013	13.3	1.670
10 m	0.0187	0.0117	0.0304	0.0034	8.8	2.156
17 m	0.0155	0.0086	0.0241	0.0012	20.2	0.658
Mean	0.0203	0.0077	0.0280	0.0018	15.6	1.268
Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
May 26, 1987						
.1 m	0	0.0191	0.0191	0.0013	14.5	0.658
1 m	0	0.0198	0.0198	0.0012	16.4	0.758
6 m	0	0.0076	0.0076	0.0020	3.7	0.882
10 m	0.01062	0.0117	0.0224	0.0046	4.8	0.537
17 m	0.01756	0.0358	0.0534	0	-	0.635
Mean	0.00564	0.0188	0.0245	0.0023	10.6	0.692

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
June 16, 1987						
.1 m	0.0080	0.0874	0.0953	0.0029	32.6	0.836
1 m	0.0083	0.0794	0.0877	0.0018	47.4	0.812
6 m	0.0082	0.0742	0.0824	0.0013	63.9	0.836
10 m	0.0068	0.0281	0.0349	0.0009	37.1	0.720
17 m	0.0223	0.1152	0.1375	0.0015	89.9	0.573
Mean	0.0107	0.0769	0.0876	0.0017	51.5	0.755
July 22, 1987						
.1 m	0	0.0150	0.0150	0.0018	8.2	0.942
1 m	0.0098	0.0116	0.0214	0.0011	19.4	1.284
6 m	0.0121	0.0920	0.1041	0.0007	151.0	0.865
10 m	0.0103	0.0486	0.0589	0.0003	190.0	0.714
17 m	0.0295	0.1717	0.2012	0.0014	144.7	0.478
Mean	0.0123	0.0687	0.0801	0.0011	76.4	0.895

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
August 25, 1987						
.1 m	0	0.0350	0.0350	0.0044	7.9	0.592
1 m	0	0.0064	0.0064	0.0029	2.2	0.614
6 m	0	0.0133	0.0133	0.0044	3.0	0.772
10 m	0	0.0135	0.0135	0.0007	20.1	1.570
17 m	0.0720	0.2083	0.2803	0.0046	61.1	0.692
Mean	0.0030	0.0553	0.0697	0.0034	17.1	0.853
Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
September 27, 1987						
.1 m	0.0155	0.0216	0.0370	0.0020	18.3	0.607
1 m	0.0123	0.0154	0.0277	0.0032	8.6	1.398
6 m	0.0165	0.0129	0.0294	0.0031	9.4	0.649
10 m	0.0160	0.0169	0.0329	0.0019	17.7	0.999
17 m	0.0297	0.1666	0.1963	0.0023	85.0	0.642
Mean	0.0180	0.0467	0.0647	0.0025	25.9	0.859

Table 24 (Cont'd.)

Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
October 17, 1987						
.1 m	0.0157	0.0157	0.0314	0.0046	6.8	0.628
1 m	0.0126	0.0116	0.0242	0.0061	4.0	1.035
6 m	0.0133	0.0116	0.0248	0.0060	4.1	0.806
10 m	0.0165	0.0105	0.0270	0.0161	1.7	0.821
17 m	0.0164	0.1546	0.1711	0.0046	37.1	0.357
Mean	0.0149	0.0408	0.0557	0.0075	7.4	0.729
Depth (meter)	NO ₃ -N mg/L	NH ₄ -N mg/L	Total-N mg/L	PO ₄ -P mg/L	N:P Ratio	SiO ₂ mg/L
November 14, 1987						
.1 m	0.0206	0.0356	0.0562	0.0038	14.8	0.985
1 m	0.0175	0.0347	0.0522	0.0023	22.7	0.949
6 m	0.0188	0.0317	0.0505	0.0031	16.3	1.113
10 m	0.0200	0.0332	0.0532	0.0027	19.7	0.956
17 m	0.0181	0.0484	0.0665	0.0019	35.0	0.749
Mean	0.0190	0.0367	0.0557	0.0028	19.9	0.950

Appendix E

The formula used to determine photosynthetic efficiency (Lind, 1979) is shown below.

$$\text{Photosynthetic Efficiency (\%)} = \text{gC} \cdot \text{m}^{-2} \cdot \frac{\text{day} \times 2 \times 5,500}{\text{Solar energy} \times 0.5} \times 100$$

where

5,500 = Approximate caloric equivalent per gram dry
algal tissue

2 = Approximate conversion of carbon to dry
algal tissue

0.5 = Conversion of total solar energy to portion
of spectrum that is photosynthetically
active (PAR)

and

Solar energy is expressed as

Calories $\cdot \text{m}^{-2} \cdot \text{day}^{-1}$

Appendix F

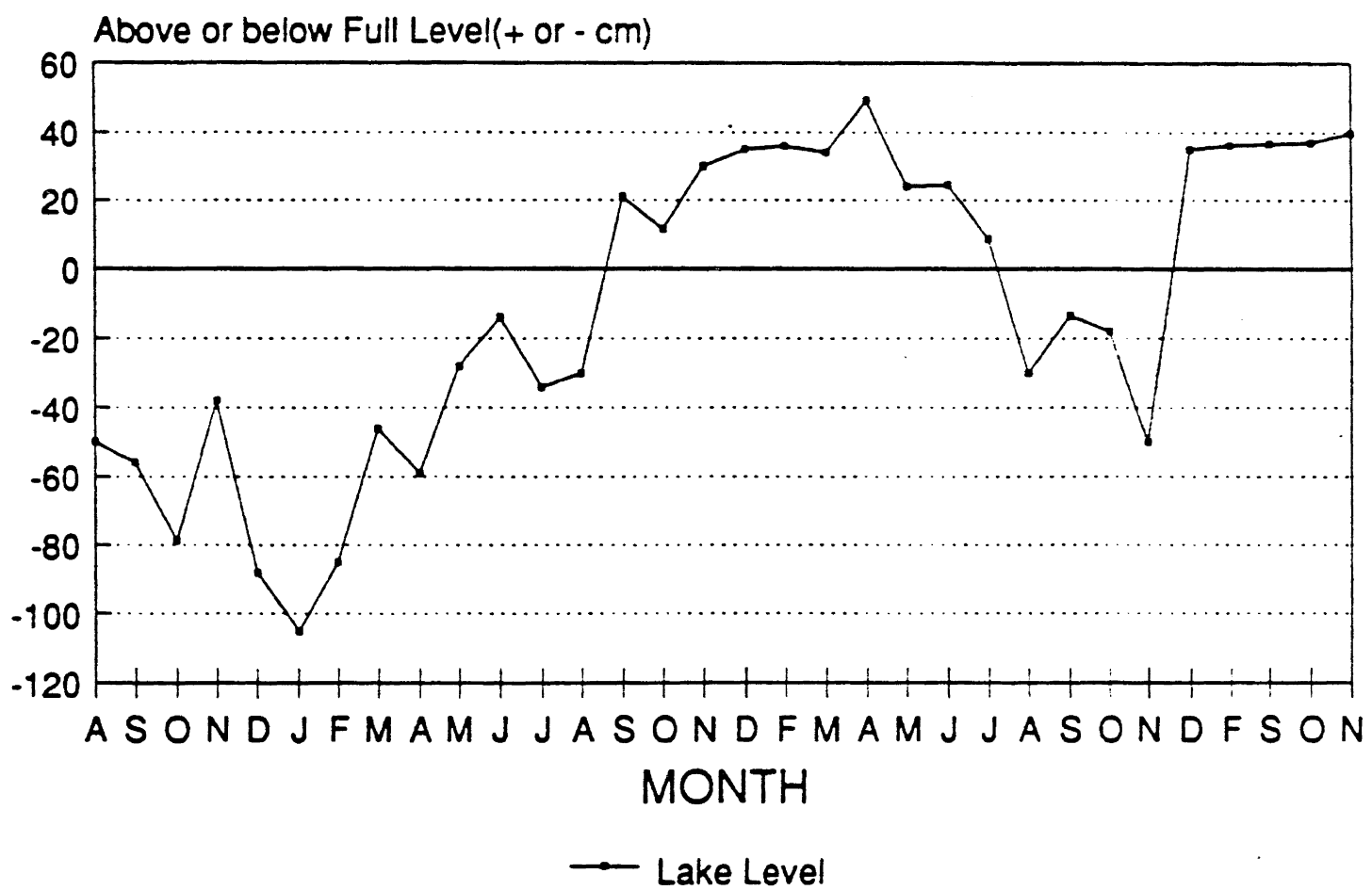


Figure 58. Lake level fluctuations in Mountain Lake, Virginia. 1985-87.

Appendix G

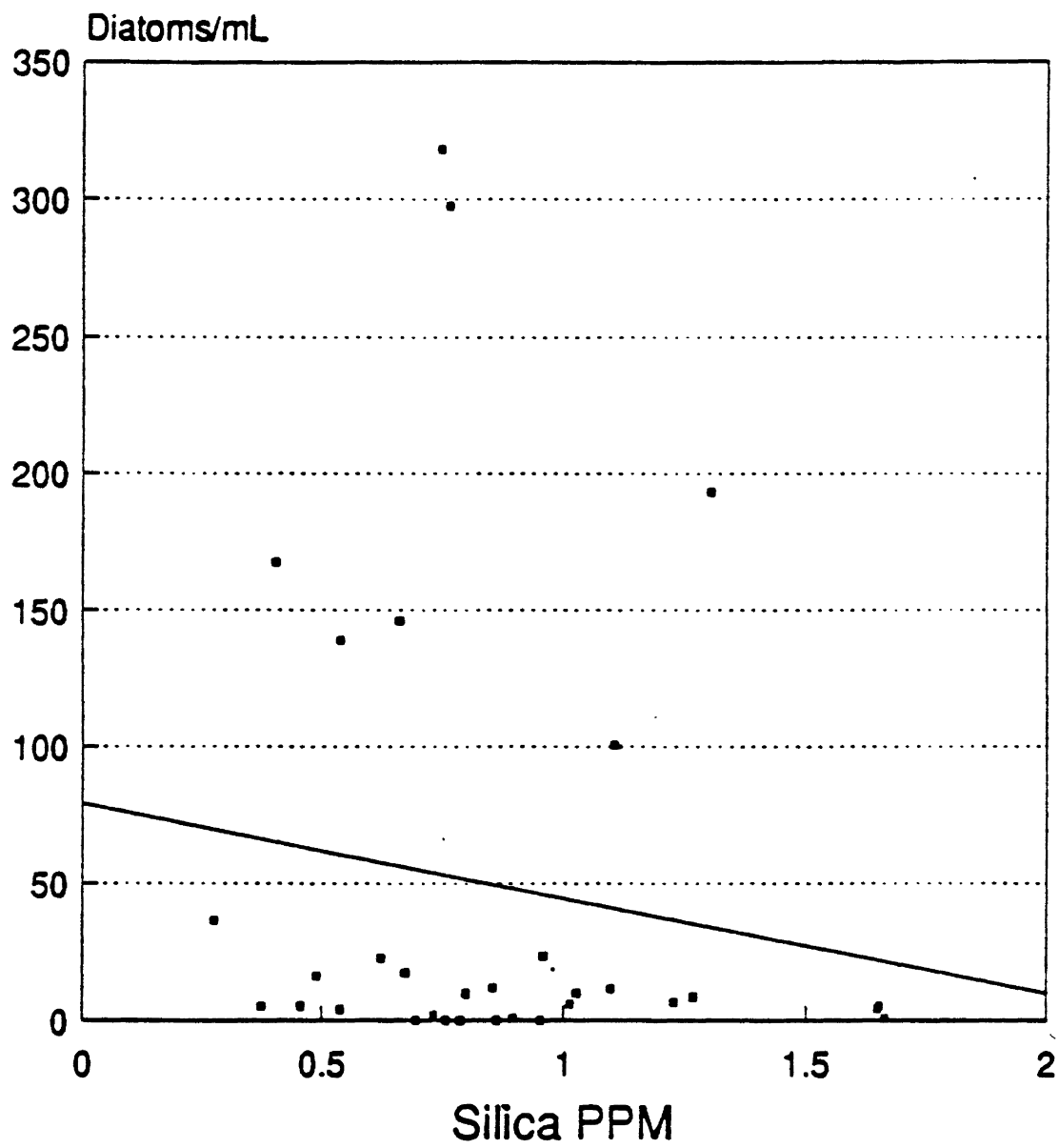


Figure 59. Correlation of diatoms per milliliter and silica concentration in Mountain Lake, Virginia, 1985-87.
($R^2 = -0.012$)

Appendix H

Table 25. Monthly Phytoplankton* Summary

Date: 3/17/85

Rank	Species Name	**Mean no./mL
1	<u>Peridinium inconspicuum</u> Lemmermann	61.5
2	<u>Gymnodinium</u> sp.	31.6
3	<u>Cryptomonas pyrenoidifera</u> Geitler	15.6
4	<u>Asterionella formosa</u> Hassall	5.8
5.5	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	0.9
5.5	<u>Chromulina ovalis</u> Klebs	0.9
7.5	<u>Botyococcus sudeticus</u> Lemmermann	0.4
7.5	<u>Bambusina confervacea</u> West & West	0.4
Total =		117.1

*Number reported is natural unit which refers to one cell, colony, or filament which is single organism.

**Mean based on samples from five depths in Mountain Lake, Virginia.

Table 26. Monthly Phytoplankton Summary

Date: 4/13/85

Rank	Species Name	Mean no./mL
1	<u>Gymnodinium</u> sp.	62.9
2	<u>Cryptomonas pryenoidifera</u> Geitler	33.7
3	<u>Chlorochromonas minuta</u> Lewis	24.4
4	<u>Synedra</u> sp.	6.3
5	<u>Asterionella formosa</u> Hassall	4.3
6	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	3.3
7	<u>Chilomonas paramecium</u> Ehrenberg	2.9
8	<u>Navicula gracilis</u> Ehrenberg	2.3
9	<u>Chromulina ovalis</u> Klebs	0.9
10	<u>Cryptomonas ovata</u> Ehrenberg	0.4
		Total = 141.6

Table 27. Monthly Phytoplankton Summary

Date: 5/25/85

Rank	Species Name	Mean no./mL
1	<u>Gymnodinium</u> sp.	98.9
2	<u>Chromulina ovalis</u> Klebs	86.8
3	<u>Elakatothrix gelatinosa</u> Wille	60.5
4	<u>Cryptomonas pryenoidifera</u> Geitler	44.1
5	<u>Chilomonas paramecium</u> Ehrenberg	37.8
6	<u>Chlorochromonas minuta</u> Lewis	32.6
7	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	16.8
8	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	14.0
9	<u>Dinobryon divergens</u> Imhof	7.3
10	<u>Cryptomonas ovata</u> Ehrenberg	4.3
11	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	2.4
12.5	<u>Asterionella formosa</u> Hassall	2.3
12.5	<u>Crucigenia rectangularis</u> (Naeg.) Gay	2.3
15	<u>Navicula</u> sp.	0.4
15	<u>Aphanocapsa elachista</u> West & West	0.4
15	<u>Arthrodesmus quadrata</u> (Schm.) Teiling	0.4
Total = 411.6		

Table 28. Monthly Phytoplankton Summary

Date: 6/27/85

Rank	Species Name	Mean no./mL
1	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	140.7
2	<u>Gymnodinium</u> sp.	98.0
3	<u>Chilomonas paramecium</u> Ehrenberg	26.6
4	<u>Chromulina ovalis</u> Klebs	20.7
5	<u>Peridinium inconspicuum</u> Lemmermann	10.2
6	<u>Asterionella formosa</u> Hassall	9.4
7	<u>Cryptomonas ovata</u> Ehrenberg	5.1
8	<u>Peridinium wisconsinense</u> Eddy	4.9
9	<u>Elakatothrix gelatinosa</u> Wille	2.9
10	<u>Arthrodesmus subulatus</u> Kuetzing	1.4
11.5	<u>Chlamydomonas</u> sp.	1.0
11.5	<u>Glenodinium palustre</u> (Lemm.) Schiller	1.0
14.5	<u>Cyclotella meneghiniana</u> Kuetzing	0.4
14.5	<u>Arthrodesmus phimus</u> Turner	0.4
14.5	<u>Sphaerocystis schroeteri</u> Chodat	0.4
14.5	<u>Coelastrum microsporum</u> Naegeli	0.4
Total = 323.7		

Table 29. Monthly Phytoplankton Summary

Date: 7/24/85

Rank	Species Name	Mean no./mL
1	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	785.1
2	<u>Asterionella formosa</u> Hassall	150.9
3	<u>Gymnodinium</u> sp.	78.1
4	<u>Cyclotella meneghiniana</u> Kuetzing	32.9
5	<u>Chilomonas paramecium</u> Ehrenberg	21.2
6	<u>Peridinium wisconsinense</u> Eddy	11.7
7	<u>Chroococcus minutus</u> (Kuetz.) Rabenhorst	6.0
8	<u>Spondylosium planum</u> (Wolle) West & West	5.7
9	<u>Chromulina ovalis</u> Klebs	4.8
10	<u>Sphaerellopsis gloeocystiformis</u>	4.4
11	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	3.9
12	<u>Arthrodesmus phimus</u> Turner	3.3
13	<u>Elakatothrix gelatinosa</u> Wille	1.9
14	<u>Cryptomonas ovata</u> Ehrenberg	0.9
16.5	<u>Aphanocapsa rivularia</u> (Carm.) Rabenhorst	0.4
16.5	<u>Navicula gracilis</u> Ehrenberg	0.4
16.5	<u>Nostoc spongiaeforme</u> C. A. Agardh	0.4
16.5	<u>Oocystis pusilla</u> Hansgirg	0.4
Total = 1112.4		

Table 30. Monthly Phytoplankton Summary

Date: 8/22/85

Rank	Species Name	Mean no./mL
1	<u>Peridinium wisconsinense</u> Eddy	97.0
2	<u>Gymnodinium</u> sp.	60.1
3	<u>Cryptomonas pyrenoidifera</u> Geitler	55.7
4	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	43.1
5	<u>Asterionella formosa</u> Hassall	19.7
6	<u>Chlorochromonas minuta</u> Lewis	17.0
7	<u>Chilomonas paramecium</u> Ehrenberg	14.1
8	<u>Chroococcus minutus</u> (Kuetz.) Rabenhorst	7.8
9	<u>Chromulina ovalis</u> Klebs	6.7
10	<u>Elakatothrix gelatinosa</u> Wille	4.2
11	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	3.8
12	<u>Mallomonas acaroides</u> Perty	1.9
13.5	<u>Synura</u> sp.	1.3
13.5	<u>Oocystis</u> sp.	1.3
16	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	1.0
16	<u>Sphaerellopsis gloeocystiformis</u> Dill	1.0
16	<u>Spondylosium planum</u> (Wolle) West & West	1.0
19	<u>Glenodinium cinctum</u> (Muell.) Ehrenberg	0.4
19	<u>Oscillatoria</u> sp.	0.4
19	<u>Aphanocapsa elachista</u> West & West	0.4
		Total = 338.0

Table 31. Monthly Phytoplankton Summary

Date: 9/26/85

Rank	Species Name	Mean no./mL
1	<u>Cyclotella meneghiniana</u> Kuetzing	295.8
2	<u>Chroococcus minutus</u> (Kuetz.) Rabenhorst	115.4
3	<u>Chlorochromonas minutus</u> Lewis	22.3
4	<u>Chromulina ovalis</u> Klebs	16.5
5	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	8.8
6	<u>Cryptomonas pyrenoidifera</u> Geitler	7.8
7	<u>Elakotothrix gelatinosa</u> Wille	4.3
8	<u>Peridinium cinctum</u> (Mueller) Ehrenberg	4.2
9	<u>Chroococcus dispersus</u> (V. Keiss) Lemmermann	2.4
10	<u>Chilomonas paramecium</u> Ehrenberg	1.0
11	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	0.9
12	<u>Asterionella formosa</u> Hassall	0.4
13	<u>Fragilaria</u> sp.	0.4
		Total = 480.4

Table 32. Monthly Phytoplankton Summary

Date: 10/26/85

Rank	Species Name	Mean no./mL
1	<u>Cyclotella meneghiniana</u> Kuetzing	139.0
2	<u>Chroococcus minutus</u> (Kuetz.) Rabenhorst	11.0
3	<u>Chromulina ovalis</u> Klebs	5.9
4	<u>Elakatothrix gelatinosa</u> Wille	3.9
5	<u>Cryptomonas pyrenoidifera</u> Geitler	3.8
6	<u>Peridinium cinctum</u> (Mueller) Ehrenberg	3.2
7	<u>Gonatozygon monotaenium</u> DeBary	2.8
8	<u>Schroederia setigera</u> (Schroed.) Lemmermann	1.8
9	<u>Chroococcus dispersus</u> (V. Keiss) Lemmermann	1.4
10	<u>Chlamydomonas</u> sp.	1.0
11	<u>Aphanothece saxicola</u> Naegeli	0.4
		Total = 174.2

Table 33. Monthly Phytoplankton Summary

Date: 11/29/85

Rank	Species Name	Mean no./mL
1	<u>Cyclotella meneghiniana</u> Kuetzing	145.6
2	<u>Cryptomonas pyrenoidifera</u> Geitler	63.6
3	<u>Chroococcus minutus</u> (Kuetz.) Rabenhorst	16.4
4.5	<u>Chlorochromonas minuta</u> Lewis	7.8
4.5	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	7.8
6	<u>Peridinium cinctum</u> (Mueller) Ehrenberg	6.2
7	<u>Chroococcus dispersus</u> (V. Keiss) Lemmerman	3.6
8	<u>Gonatozygon kinahani</u> (Arch.) Rabenhorst	0.8
		Total = 250.8

Table 34. Monthly Phytoplankton Summary

Date: 12/19/85

Rank	Species Name	Mean no./mL
1	<u>Cyclotella meneghiniana</u> Kuetzing	313.2
2	<u>Cryptomonas pyrenoidifera</u> Geitler	71.2
3	<u>Chlorochromonas minuta</u> Lewis	18.4
4	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	8.6
5	<u>Chroococcus dispersus</u> (V. Keiss) Lemmermann	6.0
6	<u>Navicula</u> sp.	3.6
7	<u>Elakatothrix gelatinosa</u> Wille	2.6
8	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	1.6
		Total = 425.2

Table 35. Monthly Phytoplankton Summary

Date: 1/18/86

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pyrenoidifera</u> Geitler	316.2
2	<u>Cyclotella meneghiniana</u> Kuetzing	100.4
3	<u>Cryptomonas pusilla</u> Bachman	53.2
4	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	32.6
5	<u>Chlorochromonas minuta</u> Lewis	7.6
6	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	0.4

		Total = 510.8

Table 36. Monthly Phytoplankton Summary

Date: 2/16/86

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pyrenoidifera</u> Geitler	563.0
2	<u>Chlorochromonas minuta</u> Lewis	150.0
3	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	15.8
4	<u>Cyclotella meneghiniana</u> Kuetzing	10.4
5	<u>Mesotaenium</u> sp.	10.2
6	<u>Elakatothrix gelatinosa</u> Wille	5.2
7	<u>Fragilaria</u> sp.	0.8
		Total = 755.4

Table 37. Monthly Phytoplankton Summary

Date: 3/22/86

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pusilla</u> Bachman	405.6
2	<u>Cyclotella meneghiniana</u> Kuetzing	8.6
3	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	5.2
4	<u>Navicula</u> sp.	2.6
5	<u>Neidium</u> sp.	1.8
6.5	Unknown chrysophyte	1.6
6.5	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	1.6
9.0	<u>Chlorochromonas minuta</u> Lewis	0.8
9.0	<u>Synedra</u> sp.	0.8
9.0	<u>Fragilaria</u> sp.	0.8
		Total = 429.4

Table 38. Monthly Phytoplankton Summary

Date: 4/30/86

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pusilla</u> Bachman	159.8
2	<u>Cyclotella meneghiniana</u> Kuetzing	149.6
3	Unknown chrysophyte flagellate	9.6
4	<u>Navicula</u> sp.	8.8
5	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	5.2
6.5	<u>Cymbella</u> sp.	1.8
6.5	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	1.8
8	<u>Gomphonema</u> sp.	1.6
12	<u>Cryptomonas pyrenoidifera</u> Geitler	0.8
12	<u>Fragilaria</u> sp.	0.8
12	<u>Synedra</u> sp.	0.8
12	<u>Suriella</u> sp.	0.8
12	<u>Meridion</u> sp.	0.8
12	<u>Stichococcus bacillaris</u> Naegeli	0.8
12	<u>Navicula gracilis</u> Ehrenberg	0.8
Total =		343.8

Table 39. Monthly Phytoplankton Summary

Date: 5/25/86

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pusilla</u> Bachman	115.0
2	<u>Cyclotella meneghiniana</u> Kuetzing	35.6
3	<u>Stichococcus bacillaris</u> Naegeli	18.6
4	<u>Chroococcus dispersus</u> (V. Keiss) Lemmermann	7.0
5	<u>Sphaerocystis Schroeteri</u> Chodat	5.2
6	<u>Oocystis borgei</u> Snow	3.6
7.5	<u>Gloeocystis gigas</u> (Kuetzing) Lagerheim	3.4
7.5	Unknown chrysophyte flagellate	3.4
9.5	<u>Aphanocapsa elachista</u> West & West	0.8
9.5	<u>Fragilaria</u> sp.	0.8
		Total = 193.4

Table 40. Monthly Phytoplankton Summary

Date: 6/17/86

Rank	Species Name	Mean no./mL
1	<u>Stichococcus bacillaris</u> Naegeli	1498.0
2	<u>Cryptomonas pusilla</u> Bachman	165.6
3	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	86.2
4	Unknown cyanophyte (cells in pairs)	31.4
5	<u>Cyclotella meneghiniana</u> Kuetzing	5.0
6.5	<u>Elakatothrix gelatinosa</u> Wille	4.4
6.5	<u>Gloeocystis paroliniana</u> (Menegh.) Naegeli	4.4
8	<u>Gloeocystis vesiculosa</u> Naegeli	4.2
9	<u>Chroococcus dispersus</u> (V. Keiss) Lemmermann	3.4
10.5	<u>Oocystis borgei</u> Snow	2.6
10.5	Unknown chrysophyte flagellate	2.6
12	<u>Mallomonas</u> sp.	1.8
13	<u>Peridinium wisconsinense</u> Eddy	0.8
Total = 1810.4		

Table 41. Monthly Phytoplankton Summary

Date: 7/30/86

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pusilla</u> Bachman	252.2
2	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	103.6
3	<u>Dinobryon elegantissimum</u> Bourrelly	91.0
4	<u>Peridinium wisconsinense</u> Eddy	17.6
5	<u>Tetraspora</u> sp.	12.2
6	<u>Gloeocystis vesiculosa</u> Naegeli	11.4
7.5	<u>Mallomonas</u> sp.	8.6
7.5	<u>Cryptomonas ovata</u> Ehrenberg	8.6
9	<u>Dinobryon divergens</u> Imhof	8.0
10	<u>Cyclotella meneghiniana</u> Kuetzing	5.2
11	<u>Cryptomonas pyrenoidifera</u> Geitler	4.4
12	<u>Peridinium inconspicuum</u> Lemmerman	3.6
13.5	<u>Quadrigula chodatii</u> (Tan-Ful.) G. M. Smith	3.4
13.5	<u>Aphanocapsa elachista</u> West & West	3.4
16.5	<u>Asterionella formosa</u> Hassall	2.6
16.5	<u>Oocystis</u> sp.	2.6
16.5	<u>Gloeocapsa</u> sp.	2.6
16.5	<u>Phacus</u> sp.	2.6

Table 41 (Cont'd.)

Rank	Species Name	Mean no./mL
19	<u>Elakatothrix gelatinosa</u> Wille	1.6
21	<u>Scenedesmus bijuga</u> (Turp.) Brebisson	0.8
21	<u>Micrasterias radiata</u> Hassall	0.8
21	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	0.8
		Total = 547.6

Table 42. Monthly Phytoplankton Summary

Date: 8/28/86

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pusilla</u> Bachman	152.2
2	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	90.8
3	<u>Peridinium wisconsinense</u> Eddy	65.4
4	<u>Crucigenia quadrata</u> Morren	28.8
5	<u>Quadrigula chodatii</u> (Tan-Ful.) G. M. Smith	28.0
6	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	21.8
7	<u>Tetraspora</u> sp.	8.8
8.5	<u>Elakatothrix gelatinosa</u> Wille	6.0
8.5	<u>Cryptomonas ovata</u> Ehrenberg	6.0
10.5	<u>Gloeocapsa</u> sp.	2.6
10.5	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	2.6
12.5	<u>Gymnodinium</u> sp.	1.8
12.5	<u>Micrasterias radiata</u> Hassall	1.8
14.5	<u>Mallomonas</u> sp.	1.6
14.5	<u>Dinobryon divergens</u> Imhof	1.6
19.5	<u>Cyclotella meneghiniana</u> Kuetzing	0.8
19.5	<u>Peridinium inconspicuum</u> Lemmermann	0.8
19.5	<u>Oocystis pusilla</u> Hansgirg	0.8
19.5	<u>Crucigenia rectangularis</u> (Naeg.) Gay	0.8
19.5	<u>Synura</u> sp.	0.8

Table 42 (Cont'd.)

Rank	Species Name	Mean no./mL
19.5	<u>Tabellaria</u> sp.	0.8
19.5	<u>Navicula</u> sp.	0.8
19.5	<u>Phacus</u> sp.	0.8
		Total = 426.2

Table 43. Monthly Phytoplankton Summary

Date: 9/21/86

Rank	Species Name	Mean no./mL
1	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	140.6
2	<u>Cryptomonas ovata</u> Ehrenberg	111.2
3	<u>Cryptomonas pusilla</u> Bachman	53.4
4	<u>Gymnodinium</u> sp.	36.4
5	<u>Quadricula chodatii</u> (Tan-Ful.) G. M. Smith	31.6
6	<u>Asterionella formosa</u> Hassall	19.2
7	<u>Tetraspora</u> sp.	19.0
8	<u>Peridinium wisconsinense</u> Eddy	18.2
9	<u>Oocystis borqi</u> Snow	8.6
10	<u>Elakatothrix gelatinosa</u> Wille	6.0
11	<u>Crucigenia quadrata</u> Morren	5.2
12	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	4.2
13.5	<u>Micrasterias radiata</u> Hassall	3.4
13.5	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	3.4
15.5	<u>Phacus</u> sp.	2.6
15.5	<u>Synedra</u> sp.	2.6
17.5	<u>Dinobryon cylindricum</u> Imhof	1.6
17.5	<u>Chlamydomonas</u> sp.	1.6

Table 43 (Cont'd.)

Rank	Species Name	Mean no./mL
19.5	<u>Chroococcus dispersus</u> (V. Keiss) Lemmermann	0.8
19.5	<u>Cyclotella meneghiniana</u> Kuetzing	0.8
		Total = 470.4

Table 44. Monthly Phytoplankton Summary

Date: 10/9/86

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pusilla</u> Bachman	165.6
2	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	141.2
3	<u>Quadricula chodatii</u> (Tan-Ful.) G. M. Smith	43.6
4	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	32.2
5	<u>Synedra</u> sp.	17.4
6	<u>Gymnodinium</u> sp.	14.6
7	<u>Phacus</u> sp.	6.0
8	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	5.2
9	<u>Oocystis</u> sp.	5.0
11.5	<u>Micrasterias radiata</u> Hassall	2.6
11.5	<u>Mallomonas</u> sp.	2.6
11.5	<u>Chlamydomonas</u> sp.	2.6
11.5	<u>Gloeocystis gigas</u> (Kuetz.) Lagerheim	2.6
14	<u>Dinobryon divergens</u> Imhof	1.6
18	<u>Kirchneriella obesa</u> (W. West) Schmidle	0.8
18	<u>Gloeocystis vesiculosa</u> Naegeli	0.8
18	<u>Spondylosium planum</u> (Wolle) W. & G. S. Smith	0.8
18	<u>Sphaerocystis schroeteri</u> Chodat	0.8

Table 44 (Cont'd.)

Rank	Species Name	Mean no./mL
18	<u>Gloeocystis paroliniana</u> (Menegh.) Naegeli	0.8
18	<u>Dicytosphaerium pulchellum</u> Wood	0.8
18	<u>Dinobryon elegantissimum</u> Bourrelly	0.8
		Total = 448.4

Table 45. Monthly Phytoplankton Summary

Date: 11/24/86

Rank	Species Name	Mean no./mL
1	<u>Gymnodinium</u> sp.	131.6
2	<u>Cryptomonas pusilla</u> Bachman	113.4
3	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	76.8
4	<u>Cryptomonas ovata</u> Ehrenberg	67.2
5	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	14.6
6	<u>Quadricula chodatii</u> (Tan.-Ful.) G. M. Smith	7.8
7	<u>Dinobryon divergens</u> Imhof	5.0
8.5	Unknown chrysophyte flagellate	3.4
8.5	<u>Micrasterias radiata</u> Hassall	3.4
10.5	<u>Synedra</u> sp.	2.6
10.5	<u>Navicula</u> sp.	2.6
12	<u>Mallomonas</u> sp.	2.4
14.5	<u>Melosira</u> sp.	0.8
14.5	<u>Gloeocystis planetonica</u> (West & West) Lemmermann	0.8
14.5	<u>Oocystis</u> sp.	0.8
14.5	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	0.8
		Total = 434.0

Table 46. Monthly Phytoplankton Summary

Date: 12/18/86

Rank	Species Name	Mean no./mL
1	<u>Gymnodinium</u> sp.	105.8
2	<u>Cryptomonas pusilla</u> Bachman	63.0
3	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	46.2
4	<u>Cryptomonas ovata</u> Ehrenberg	15.6
5	Unknown chrysophyte flagellate sp. 1	8.8
6	Unknown chrysophyte flagellate sp. 2	3.6
8	<u>Quadricula chodatii</u> (Tan.-Ful.) G. M. Smith	3.4
8	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	3.4
8	<u>Mallomonas</u> sp.	3.4
10	<u>Glenodinium pulvisculus</u> (Ehrenb.) Stein	1.6
11.5	<u>Scenedesmus quadricauda</u> var. <u>quadrispina</u> (Chod.) G. M. Smith	0.8
11.5	<u>Oocystis borgei</u> Snow	0.8
Total = 256.4		

Table 47. Monthly Phytoplankton Summary

Date: 2/17/87

Rank	Species Name	Mean no./mL
1	<u>Gymnodinium</u> sp.	129.2
2	<u>Cryptomonas pusilla</u> Bachman	123.0
3	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	18.2
4	Unknown chrysophyte flagellate sp. 1	11.4
5	<u>Glenodinium minimum</u> (Lantzsch) Bachman	6.8
6	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	3.6
7.5	<u>Quadrigula chodatii</u> (Tan.-Ful.) G. M. Smith	1.6
7.5	<u>Cryptomonas ovata</u> Ehrenberg	1.6
10	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	0.8
10	<u>Chlamydomonas</u> sp.	0.8
10	<u>Elakatothrix gelatinosa</u> Wille	0.8
		Total = 297.8

Table 48. Monthly Phytoplankton Summary

Date: 3/27/87

Rank	Species Name	Mean no./ml
1	<u>Gymnodinium</u> sp.	57.6
2	<u>Cryptomonas pusilla</u> Bachman	33.2
3	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	27.0
4	<u>Cryptomonas ovata</u> Ehrenberg	8.0
5	<u>Glenodinium minimum</u> (Lantzsch) Bachman	7.0
6.5	Unknown chrysophyte flagellate sp. 1	2.6
6.5	<u>Chlamydomonas</u> sp.	2.6
8	<u>Synedra</u> sp.	1.8
9	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	1.6
10.5	<u>Peridinium inconspicuum</u> Lemmermann	0.8
10.5	<u>Navicula</u> sp.	0.8
		Total = 143.0

Table 49. Monthly Phytoplankton Summary

Date: 4/27/87

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pusilla</u> Bachman	128.2
2	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	89.6
3	<u>Gymnodinium</u> sp.	38.2
4	Unknown chrysophyte flagellate sp. 1	26.2
5	<u>Navicula</u> sp.	6.0
6	<u>Chlamydomonas</u> sp.	4.4
8	<u>Cryptomonas ovata</u> Ehrenberg	2.6
8	<u>Elakatothrix gelatinosa</u> Wille	2.6
8	<u>Tabellaria fenestrata</u> (Lyng.) Kuetzing	2.6
10	<u>Micrasterias radiata</u> Hassall	0.8
		Total = 301.2

Table 50. Monthly Phytoplankton Summary

Date: 5/26/87

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas pusilla</u> Bachman	233.8
2	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	220.8
3	Unknown chrypophyte flagellate sp. 1	162.4
4	<u>Cryptomonas ovata</u> Ehrenberg	17.4
5	<u>Gymnodinium</u> sp.	8.8
6	<u>Chlamydomonas</u> sp.	3.4
8	<u>Gloeocystis gigas</u> (Kuetz.) Lagerheim	2.6
8	<u>Peridinium inconspicuum</u> Lemmermann	2.6
8	<u>Stichococcus bacillaris</u> Naegeli	2.6
10	<u>Spondylosium planum</u> (Wolle) West & West	2.0
11.5	<u>Elakathothrix gelatinosa</u> Wille	0.8
11.5	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	0.8
Total = 657.6		

Table 51. Monthly Phytoplankton Summary

Date: 6/17/87

Rank	Species Name	Mean no./mL
1	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	136.0
2	<u>Cryptomonas pusilla</u> Bachman	63.0
3	<u>Chlorella vulgaris</u> Beyerinck	59.4
4	<u>Gloeocystis vesiculosa</u> Naegeli	31.4
5	<u>Gloeocystis gigas</u> (Kuetz.) Lagerheim	26.2
6	<u>Cryptomonas pyrenoidifera</u> Geitler	21.8
8	<u>Chroococcus dispersus</u> (V. Keiss) Lemmermann	2.6
8	<u>Oocystis borgei</u> Snow	2.6
8	<u>Peridinium inconspicuum</u> Lemmermann	2.6
10	<u>Stichococcus bacillaris</u> Naegeli	1.8
11.5	<u>Micrasterias radiata</u> var. <u>dichotoma</u> (Wolle) Cushmann	0.8
11.5	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	0.8
Total = 349.0		

Table 52. Monthly Phytoplankton Summary

Date: 7/23/87

Rank	Species Name	Mean no./mL
1	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	347.0
2	<u>Quadrigula chodatii</u> (Tan.-Ful.) G. M. Smith	61.0
3	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	39.2
4	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	24.4
5	<u>Gloeocystis gigas</u> (Kuetzing) Lagerheim	21.8
6	<u>Crucigenia rectangularis</u> (A. Braun) Gay	18.2
7	<u>Stichococcus bacillaris</u> Naegeli	17.4
8	<u>Oocystis borgei</u> Snow	16.6
9	<u>Gymnodinium</u> sp.	15.6
10	<u>Elakatothrix gelatinosa</u> Wille	8.8
12	<u>Dinobryon cylindricum</u> Imhof	7.0
12	<u>Peridinium wisconsinense</u> Eddy	7.0
12	<u>Micrasterias radiata</u> Hassall	7.0
14	<u>Oocystis pusilla</u> Hansgirg	6.0
15.5	<u>Cyptomonas pyrenoidifera</u> Geitler	3.4
15.5	<u>Peridinium inconspicuum</u> Lemmermann	3.4
18	<u>Sphaerocystis schroeteri</u> Chodat	0.8
18	<u>Chroococcus dispersus</u> (V. Keiss) Lemmermann	0.8
18	<u>Cyclotella meneghiniana</u> Kuetzing	0.8
Total =		606.2

Table 53. Monthly Phytoplankton Summary

Date: 8/25/87

Rank	Species Name	Mean no./mL
1	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	193.0
2	<u>Quadrigula chodatii</u> (Tan.-Ful.) G. M. Smith	74.4
3	<u>Gloeocystis planctonica</u> (West & West) Lemmermann	29.6
4	<u>Gloeocystis vesiculosa</u> Naegeli	25.4
5	<u>Oocystis borgei</u> Snow	21.8
6	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	19.8
7	<u>Crucigenia rectangularis</u> (A. Braun) Gay	14.8
8	<u>Elakatothrix gelatinosa</u> Wille	11.4
9	<u>Asterionella formosa</u> Hassall	10.6
10	<u>Cryptomonas pusilla</u> Bachman	10.4
11	<u>Gloeocystis gigas</u> (Kuetz.) Lagerheim	7.0
12	<u>Gloeocystis major</u> Gerneck ex Lemmermann	6.0
13.5	<u>Crucigenia irregularis</u> Wille	4.4
13.5	Unknown chrysophyte flagellate sp. 1	4.4
15	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	3.4
16	<u>Chroococcus minimus</u> (Keissl.) Lemmermann	2.6
17	<u>Gymnodinium</u> sp.	2.4
18.5	<u>Peridinium wisconsinense</u> Eddy	1.6
18.5	<u>Spondylosium planum</u> (Wolle) West & West	1.6

Table 53 (Cont'd.)

Rank	Species Name	Mean no./mL
21.5	<u>Peridinium inconspicuum</u> Lemmermann	0.8
21.5	<u>Navicula</u> sp.	0.8
21.5	<u>Dictyosphaerium pulchellum</u> Wood	0.8
21.5	<u>Chlamydomonas</u> sp.	0.8
		Total = 447.6

Table 54. Monthly Phytoplankton Summary

Date: 9/27/87

Rank	Species Name	Mean no./mL
1	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	191.8
2	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	32.2
3	<u>Cryptomonas pusilla</u> Bachman	26.0
4	<u>Sphaerocystis schroeteri</u> Chodat	16.6
5	<u>Quadrigula chodatii</u> (Tan.-Ful.) G. M. Smith	16.4
6	<u>Crucigenia rectangularis</u> (A. Braun) Gay	14.8
7	<u>Oocystis pusilla</u> Hansgirg	9.6
8	<u>Gloeocystis gigas</u> (Kuetz.) Lagerheim	7.8
9	<u>Gloeocystis planctonica</u> (West & West) Lemmermann	6.0
10	<u>Aphanothece microscopica</u> Naegeli	4.2
11	<u>Mallomonas</u> sp.	3.6
12	Unknown green flagellate	2.6
13	<u>Elakathothrix gelatinosa</u> Wille	1.6
15.5	Unknown chrysophyte flagellate sp. 1	0.8
15.5	<u>Dinobryon cylindricum</u> Imhof	0.8
15.5	<u>Pediastrum tetras</u> formak <u>evoluta</u> West	0.8
15.5	<u>Chlamydomonas</u> sp.	0.8
Total = 336.4		

Table 55. Monthly Phytoplankton Summary

Date: 10/17/87

Rank	Species Name	Mean no./mL
1	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	51.6
2	<u>Oocystis pusilla</u> Hansgirg	46.2
3	<u>Cryptomonas pusilla</u> Bachman	35.6
4	<u>Gloeocystis vesiculosa</u> Naegeli	14.8
5	<u>Aphanocapsa elachista</u> var. <u>conferta</u> West & West	9.8
6	<u>Crucigenia irregularis</u> Wille	9.6
7	<u>Aphanothece</u> sp.	7.0
8	<u>Elakatothrix gelatinosa</u> Wille	5.2
9.5	<u>Dinobryon cylindricum</u> Imhof	4.2
9.5	<u>Crucigenia rectangularis</u> (A. Braun) Gay	4.2
11	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	3.4
12.5	<u>Quadrigula chodatii</u> (Tan.-Ful.) G. M. Smith	2.6
12.5	<u>Mallomonas</u> sp.	2.6
15.5	<u>Peridinium wisconsinense</u> Eddy	1.8
15.5	<u>Scenedesmus arcuatus</u> Lemmermann	1.8
15.5	<u>Synedra</u> sp.	1.8
15.5	<u>Phacus</u> sp.	1.8
19	<u>Gymnodinium</u> sp.	1.6
19	<u>Dictyosphaerium pulchellum</u> Wood	1.6
19	Unknown chlorophyte flagellate	1.6
24	<u>Glenodinium minimum</u> (Lantzsch) Bachman	0.8

Table 55 (Cont'd.)

Rank	Species Name	Mean no./mL
24	<u>Pediastrum tetras</u> forma <u>evoluta</u> West	0.8
24	<u>Sphaerocystis schroeteri</u> Chodati	0.8
24	<u>Eucapsis</u> sp.	0.8
24	<u>Chroococcus dispersus</u> (V. Keiss) Lemmermann	0.8
24	<u>Dactylococcopsis musicola</u> Hustedt	0.8
24	<u>Micrasterias radiata</u> Hassall	0.8
		Total = 214.4

Table 56. Monthly Phytoplankton Summary

Date: 11/14/87

Rank	Species Name	Mean no./mL
1	<u>Oocystis pusilla</u> Hansgirg	177.2
2	<u>Cryptomonas pusilla</u> Bachman	132.0
3	<u>Mallomonas</u> sp.	31.2
4	<u>Cryptomonas erosa</u> var. <u>reflexa</u> Marsson	15.6
5	<u>Dinobryon cylindricum</u> Imhof	14.8
6	Unknown chrysophyte flagellate	12.0
7	<u>Elakatothrix gelatinosa</u> Wille	10.4
8	<u>Scenedesmus bijuga</u> (Turp.) Lagerheim	8.8
9	<u>Cryptomonas ovata</u> Ehrenberg	6.2
10	<u>Micrasterias radiata</u> Hassal	5.2
11	<u>Gymnodinium</u> sp.	3.4
12	<u>Gloeocystis vesiculosa</u> Naegeli	2.6
14.5	<u>Sphaerocystis shroeteri</u> Chodat	1.6
14.5	<u>Crucigenia irregularis</u> Wille	1.6
14.5	<u>Crucigenia quadrata</u> Morren	1.6
14.5	<u>Peridinium inconspicuum</u> Lemmermann	1.6
18.5	<u>Cylindrocapsa</u> sp.	0.8
18.5	<u>Aphanothece</u> sp.	0.8
18.5	<u>Quadrigula chodatii</u> (Tan.-Ful.) G. M. Smith	0.8
18.5	<u>Phacus</u> sp.	0.8
Total = 429.0		

Appendix I

The velocity of MeA uptake at each concentration was calculated using the formula:

$$V = \frac{3,784 \text{ times } 10^4 \times a}{b \times c \times d \times e}$$

where a is in counts per minute accumulated by the phytoplankton, corrected for passive adsorption, b is the specific activity of [^{14}C]methylamine (microcuries per micromole), c is the efficiency of the scintillation counter (percentage), d is the volume filtered from the incubation bottle (milliliters), and e is the incubation time in minutes (Vincent, 1979).

The coefficient of 3.784×10^4 incorporates the conversion of disintegrations per minute (dpm) to microcuries, micromoles methylamine to nanograms methylamine nitrogen, uptake per minute to per hour, and uptake per milliliter of sample to liter.

Appendix J

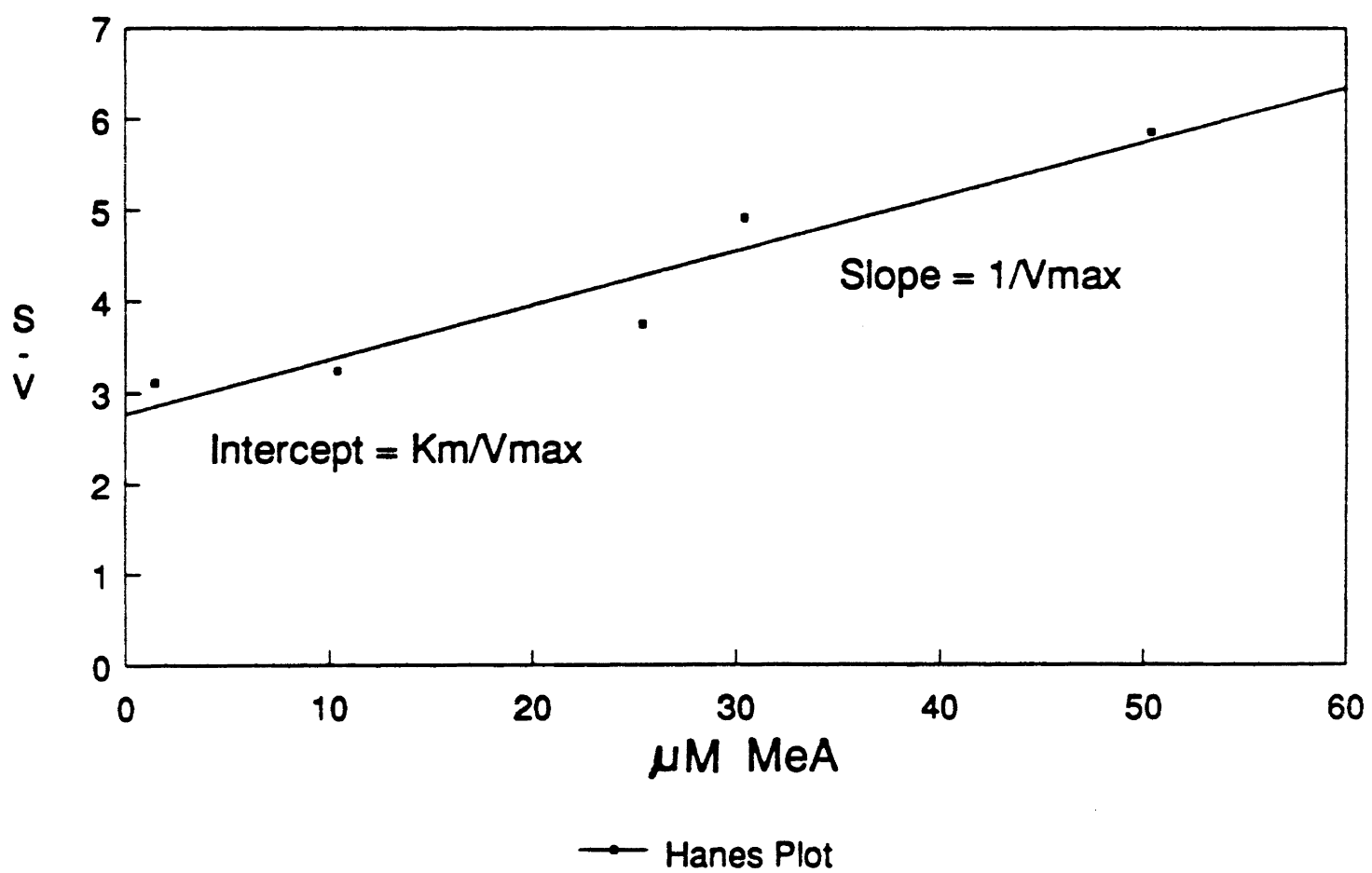


Figure 60. Hanes Plot linear transformation is shown which plots the substrate concentration $[S]$ against $[S]/V$ and where the slope = $1/V_{\text{max}}$ and the intercept = K_m/V_{max} (Palmer, 1981).

Appendix K

A dummy-variable model (Statistical Program for the Social Sciences) was used to compare two straight-line regressions for differences in slope and differences in intercept at the same time.

The model $Y = \beta_0 + \beta_1 X + \beta_2 Z + \beta_3 ZX + E$ yields two models for the two values of Z :

Thus the coefficients for the model are:

$$\beta_{0f} = \beta_0,$$

$$\beta_{0s} = (\beta_0 + \beta_2).$$

$$\beta_{1f} = \beta_1, \text{ and}$$

$$\beta_{1s} = (\beta_1 + \beta_3).$$

The hypothesis being tested then is $H_0: \beta_3 = 0$. When $\beta_3 = 0$, the slope for the second uptake experiment $\beta_{1s} = (\beta_1 + \beta_3)$ is then simply equal to β_1 , which is the slope for the first uptake experiment (i.e., the two lines are parallel). The test statistic concerning $H_0: \beta_3 = 0$ is the partial F test or t test.

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