1971

Phytoplankton Dynamics of Two Northern Prairie Lakes and Possible Relations to Dissolved Nutrients

Alan B. Hauber

AND POSSIBLE RELATIONS TO DISSOLVED NUTRIENTS

BY

ALAN B. HAUBER

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Wildlife Biology, South Dakota
State University

1971

PHYTOPLANKTON DYNAMICS OF TWO NORTHERN PRAIRIE LAKES
AND POSSIBLE RELATIONS TO DISSOLVED NUTRIENTS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Head, Department of Wildlife and Fisheries Sciences — Date

PHYTOPLANKTON DYNAMICS OF TWO NORTHERN PRAIRIE LAKES AND POSSIBLE RELATIONS TO DISSOLVED NUTRIENTS

Abstract

Phytoplankton populations in Enemy Swim Lake were observed to be quite different. Although these lakes lie within the same geographic area (Coteau des Prairies), major differences in water quality were recorded. The differences in water quality were reflected in the phytoplankton populations and appeared to be influenced by the agricultural practices on the watersheds.

Enemy Swim Lake was basically a diatom lake while Lake Herman contained mostly blue-green algae. Genera of algae found in Enemy Swim Lake were: *Anabaena*, *Aphanizomenon*, *Lyngbya*, *Pediastrum*, *Staurastrum*, *Dinobyron*, *Asterionella*, *Fragilaria*, *Melosira*, *Stephanodiscus*, and *Ceratium*. All the above genera occurred in Lake Herman except *Lyngbya*, *Staurastrum*, *Dinobyron*, and *Melosira*. *Surirella* was the only genus found exclusively in Lake Herman.

Numbers of phytoplankton in Enemy Swim were lower and subject to less variation than those in Lake Herman. The highest total standing crop recorded in Enemy Swim was less than 150,000/liter while Lake Herman had levels over 3,000,000/liter.

ACKNOWLEDGMENTS

I wish to express appreciation to Dr. John G. Nickum for his criticisms and suggestions during the study and preparation of the manuscript. I would also like to thank Dr. Donald R. Progulske for reviewing the manuscript.

I am indebted to Steven Gloss for collecting samples during the first half of the study. I am also indebted to Bill Thorn and Alan Swanson for their assistance in collecting field data.

Financial support was provided by the Office of Water Resources Research, project number B0002-SDAK Matching Grant Agreement number 14-01-001-1546. Equipment and supplies were provided by the Water Resources Research Institute, Department of Wildlife and Fisheries Sciences, and Cooperative Fishery Unit of South Dakota State University. A vehicle was provided by the South Dakota Department of Game, Fish, and Parks.

ABH

LIST OF FIGURES

Figure Page

LIST OF TABLES

TABLE OF CONTENTS

INTRODUCTION

Phytoplankton populations vary considerably from one lake to another, even within a single geographic area, apparently due to differences in water quality. Lake Herman and Enemy Swim Lake are examples of such a situation since they lie within the same geographic area (Coteau des Prairies), but differ in phytoplankton populations, and have large differences in water quality. Much higher levels of algal nutrients in Lake Herman seem associated with more extensive cultivation of its watershed. Differences in numbers, kinds, and dynamics of algae populations were observed in the two lakes over a period of three years.

Algal populations of lakes can be important in many ways, both beneficial and detrimental. The entire lake ecosystem depends upon algae for a majority of the dissolved oxygen necessary for life. Algae are also the base for the food chain upon which the higher animals depend. In winter, a lack of necessary light for photosynthesis can cause the algae to die and decay, thus causing depletion of dissolved oxygen required by aquatic organisms. Certain filamentous blue-greem algae are capable of blocking filtering systems for city water supples. Other nuisance factors of algae are: taste, odor, corrosion, and toxicity.

There appears to have been little study of the phytoplankton populations of northern prairie lakes and their nutrient requirements. Griffith (1916) recorded several genera of algae found in the James River of South Dakota. Ten genera were listed as common representatives of the phytoplankton of Lewis and Clark Reservoir by Sprague (1958). Johnson (1959) found ten genera in an oxbow lake of the Missouri River. A heavy diatom crop was found by Bell (1961) in Lewis and Clark

Reservoir with Asterionella being dominant. Other diatoms present were Melosira, Navicula, and Tabellaria. The only green algae found was Pediastrum. Genera and counts of algae from selected South Dakota farm ponds were reported by Graham (1966). Petri and Larson (1969) reported genera and counts of algae in May and October of 1967 in several South Dakota lakes.

Phytoplankton dynamics and their relation to chemical and physical factors have been studied in other areas, but there has not been complete agreement as to how these factors influence phytoplankton levels. The spring maximum of diatoms was succeeded by Dinobyron in a study by Hamilton (1969). Holland (1969) found light penetration to have no obvious relation to total diatoms. Hutchinson (1967) recorded spring and fall maximum levels of Asterionella and blooms of blue-greens in late summer when combined nitrogen in solution is low and inorganic phosphate undetectable. Large spring and small autumnal maxima of Asterionella formosa were reported by Canter and Lund (1948). Asterionella formosa was found by Jorgensen (1956) to form substances which inhibit the growth of other species and the rate of inhibition was very dependent on the experimental circumstances. Aphanizomenon was found to become dominant after Anabaena in Smith Lake with Ceratium following later in the summer (Billaud, 1966). Temperature, transparency, and pH were not considered to be limiting to algal populations by Wiebe (1930). Prescott (1968) found hard water lakes to be predominately populated by Cyanophyta-diatoms (Microcystis, Aphanothece, Asterionella). According to Lund (1950), the cose of the spring period of increase of Asterionella is not directly due to light or temperature. Diatoms in the English lakes occur when waters are richest in nitrate, phosphate, and silica, while desmids and other green algae occur in summer when nitrate and phosphate are low (Pearsall, 1932). Pearsall (1932) and Tucker (1957) proposed that high organic content was correlated with large Myxophycean populations. Hutchinson (1944) found the opposite to be true. Tubulence was reported by Lund (1950) to be a major factor in the periodicty of Melosira italica.

The specific objectives of this study were to:

a) Identify and estimate levels of dominate genera of phytoplankton present in both lakes.

b) Compare phytoplankton levels and dynamics in the two lakes.

c) Determine possible relationships between the physical and chemical characteristics and phytoplankton populations.

This study was part of a more comprehensive project the objectives of which were to:

a) Determine present conditions, seasonal variations, and possible year to year variation of chemical, physical, and biological characteristics of the two lakes.

b) Compare the chemical, physical, and biological natures of the two lakes.

Although an immense amount of research has been done in other areas, there is an obvious lack of knowledge of the phytoplankton of northern prairie lakes. It was this lack of information that led to the initiation of this study.

THE STUDY LAKES

Lake Herman and Enemy Swim Lake are northern prairie eutrophic lakes with major physical and chemical differences. Lake Herman is shallower, more turbid, and contains higher amounts of inorganic nutrient and organic matter than Enemy Swim Lake (Table 1). Climates of the two lake areas are slightly different with higher moisture levels and temperatures in the Lake Herman area than around Enemy Swim (Tables 2 and 3). Utilization of the watersheds of the two lakes is quite different. Over 50 percent of the watershed of Lake Herman is cultivated while most of that at Enemy Swim is grazed.

Lake Herman is located approximately two miles west of Madison, South Dakota, in Lake County. The entire watershed is on the western side of the Coteau des Prairies in the Western Lake Section of the Central Lowlands Province of South Dakota (Lake Herman Report, 1969). Enemy Swim is seven and one-half miles north of Waubay, South Dakota, in Day County. It lies within a highland which is part of the Coteau des Prairies, an upland dividing the valleys of the Minnesota and James Rivers. The Coteau des Prairies is an extensive, hilly, lake-dotted glacial highland laying along the eastern border of South Dakota within the drainage system of the Big Sioux River. Surface deposits are mainly drift from the late Wisconsin age which were left by the sixth of seven major ice advances in South Dakota. Most of the surface deposits are till of a relatively impervious mixture of boulders, pebbles, sand, clay, and silt. Many small boulder-stream knobs and ridges are on the uplands. Many small lakes and sloughs are found on the watersheds of both lakes with the greatest density occurring around Enemy Swim.

Table 1. Maximum and minimum values (in mg/l) for selected chemical and physical parameters of Enemy Swim Lake and Lake Herman during the study period.

	Enemy Swim		Lake Herman	
	Maximum	Minimum	Maximum	Minimum
Secchi visibility (in cm)	325	115	160	20
Temperature (in C°)	22.8	0.0	26.0	0.0
pH	8.8	7.8	9.05	7.61
phth alkalinity	24	0	30	0
MO alkalinity	242	184	358	124
Conductivity (in micromhos/cm^2)	575	280	1,380	540
Total hardness	281	136	721	400
Ca hardness	151	53	350	92
Chloride	5.5	1.8	11.0	4.2
Sulfate	95	25	630	190
Potassium	9.2	5.0	24.2	8.1
Sodium	10.5	.2	80.0	17.0
Ammonia	.67	.03	2.0	.04
Phosphate	1.32*	.085	3.71	.52
Total organic	26.7	7.5	31.0	11.0
Dissolved organic	17.0	5.6	17.5	9.0
Total residue	34.0	22.0	121.0	69.0
Filtrable residue	25.0	1.5	71.0	3.5

*Two samples in August of 1969 reported only as less than 3.0 ppm.

Table 2. Average monthly air temperatures (C°) for the area around the study lakes, 1967-1969.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Enemy Swim												
1967	- 9.78	-12.4	- .382	6.22	10.9	17.6	20.4	20.1	15.8	7.94	-1.17	-7.28
1968	-10.9	- 9.94	2.94	7.11	11.4	19.3	21.1	21.2	15.6	8.99	- .224	-10.8
1969	-16.1	- 8.45	-7.67	7.67	14.4	15.4	20.4	22.6	16.9	5.28	.224	-7.3
Lake Herman												
1967	- 7.88	-9.10	2.39	7.94	12.4	18.6	21.2	21.0	15.6	8.83	.448	-.392
1968	- 9.22	-7.88	5.06	8.72	11.7	20.3	21.5	22.2	16.2	11.1	1.33	-8.10
1969	-13.9	-7.28	-7.28	8.61	15.5	16.5	22.5	27.7	17.2	6.56	1.33	-6.17

Table 3. Average monthly precipitation (cm) for watersheds of the study lakes, 1967-1969.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Enemy Swim												
1967	2.64	2.79	.61	4.75	1.42	16.9	3.23	1.22	2.01	1.83	.457	1.37
1968	.533	T	1.27	8.94	7.92	9.93	6.17	2.99	7.26	3.30	1.57	3.58
1969	3.84	3.94	.762	4.22	9.14	5.41	11.5	1.17	1.17	5.23	.81	2.67
Lake Herman												
1967	1.75	2.26	.66	4.83	2.16	18.5	2.92	6.76	2.72	2.54	.305	1.04
1968	1.47	.254	2.92	11.8	4.57	12.1	4.39	3.10	7.19	8.97	1.52	11.2
1969	3.51	8.71	1.19	2.44	12.8	5.51	4.60	9.45	4.75	8.54	.991	2.47

Enemy Swim Lake

The watershed of Enemy Swim has not been sharply delineated because of the many lakes and sloughs located within a small area. An estimate of the watershed of Enemy Swim is approximately 77 sq. km. Rothrock (1935) stated that the drainage area is very small considering that the surface area of the lake is confined to the slopes of the hills immediately surrounding the lake. Permanency of the water level, therefore, has to depend largely on water fed into the basin from the surrounding gravels. Enemy Swim was one of the two lakes in eastern South Dakota which did not go dry during the severe drought of 1890-1893.

Soil types surrounding Enemy Swim are mostly moderate to low quality. The more prominent types are Fordville loam, Parnell silty clay loam, Pierce gravelly sandy loam, and Sioux sandy loam. Soils range from medium textured soils with good water holding capacity and good drainage to non-tillable because of poor drainage, droughtiness, excessive stoniness, or steepness of slope (Day County Soil Survey Report).

Enemy Swim is a relatively deep prairie lake having a surface area of 870 ha. and a maximum depth of 7.92 m. The average depth is approximately 3.05 m (Gloss, 1969). Campbell's slough which could be considered a southern arm of the lake has a surface area of 323 ha.

The lake shoreline is exposed sand beach and boulders. Cabins occupy part of the main lake while other areas are part of an Indian Reservation and are not developed. Considerable amounts of submergent and emergent plants are found in Indian and East bays along the shore and in shallow areas.

The climate of the Enemy Swim area is one of extremes, with rapid changes in temperature and hot summers and cold winters. The highest temperature recorded near Webster (approximately twenty miles from Waubay) was 42.2 C and the lowest was -42.8 C. The lake is generally ice covered from November to April.

The average January temperature is -12.68 C while the average in July is 21.18 C. The average yearly temperatures recorded during the study were: 5.65 C in 1967, 6.27 C in 1968, and 5.28 C in 1969 (Table 2).

The annual average precipitation for the Enemy Swim area is 52.88 cm. During the study, average yearly precipitation levels were: 39.18 cm in 1967, 53.47 cm in 1968, and 45.56 cm in 1969 (Table 3).

Lake Herman

The watershed of Lake Herman is approximately 144.98 sq. km. During periods of excessive moisture, an additional 25.89 sq. km. could drain into the lake. Much of the watershed is poorly drained because of many closed depressions which contain sloughs or "potholes." Some artificial drainage of these sloughs has taken place over the years through private efforts. Streams in the area are small and flow during the spring thaw and periods of excessive moisture.

Major soil associations in the watershed are classified as the Egan-Wentworth-Beadle, Egan-Wentworth-Sinai, and Egan-Wentworth-Viborg (Lake Herman Report, 1969). According to the Lake County Soils Survey Report, soils range from deep well drained soils to poorly drained soils on the rolling uplands. The Egan-Wentworth-Sinai Association has moderately fine and fine textured silty soils on the uplands. Both associations are subject to water erosion with the Egan-Wentworth-Sinai Association susceptible to wind and water erosion.

The lake is shallow with a surface area of 546 ha. and a maximum depth of 2.13 m. The average depth is approximately 1.22 m. The depth of Lake Herman has been reduced considerably by siltation with .79-2.56 m of bottom sediments present (Lake Herman Report, 1969).

The shoreline is exposed sand beach or large boulders except near the mouths of streams draining into the lake. Where streams enter, the edge is swampy due to advanced sedimentation. There are approximately 11.248 km of shoreline.

The climate of the Lake Herman area is mid-continental, subhumid, with periods of extreme heat and cold. Temperatures vary considerably with maximums above 37.7 C and minimums below -18.0 C. The lake generally freezes over sometime during November and ice remains until late March or early April. Up to .8 m of ice may form during the winter period.

The average yearly temperature for the Lake Herman area is 7.77 C. During the study, average temperatures were 7.11 C in 1967, 7.44 C in 1968, and 6.29 C in 1969. The highest average monthly temperature recorded in this period was 22.7 C in August of 1969 while the lowest was -13.9 C in January of 1969 (Table 2).

The average annual precipitation in the area as recorded at the Wentworth climatological station is 58.42 cm. During the study, average yearly precipitation levels were 45.89 cm in 1967, 69.49 cm in 1968, and 63.92 cm in 1969 (Table 3).

METHODS

Samples were collected from June 1, 1967, to January 1, 1970. Weekly samples were taken during June 1 to August 30 and monthly from September 1 to May 30. Scheduled samples could not always be obtained during periods of ice formation in the fall and ice thaw in the spring. No sampling was done from January to May, 1969, in Enemy Swim and from February to June in Lake Herman because of the extremely severe winter weather.

Sampling stations were established at mid-lake and in selected bays in both lakes (Figs. 1 & 2). Original sampling in Enemy Swim was conducted at .5 m depth at seven stations and at 1.5, 4.5, and 6.0 m at one mid-lake station. Samples from Lake Herman were taken from .5 m at five stations and .5 and 1.5 m at one mid-lake station. Numbers of sampling stations were later reduced to five in Enemy Swim and three in Lake Herman as sampling variation appeared low. Nine-liter samples were taken with a Kemmerer water bottle from each depth. Water was filtered through a #20 plankton net.

Plankton from nine liters of each sample was preserved with a 5-10% formalin solution. Samples were sufficiently diluted so that individual organisms could be counted and identified. Each sample was thoroughly mixed and one ml placed in a Sedgwick-Rafter counting cell. One strip (approx. 43 fields) was counted across the cell under low power. Dilutions were made so that actual counts ranged from 15-250 units. A unit was considered to be a filament of <u>Aphanizomenon</u>, <u>Anabaena</u>, <u>Lyngbya</u>, or <u>Melosira</u>; a colony of <u>Pediastrum</u> or <u>Dinobyron</u>; a cluster of Asterionella or Fragilaria cells; or single cells of Ceratium, Stephanodiscus, or Surirella. According to Lund and Talling (1957), sufficient accuracy can be obtained if about one hundred individuals are counted; the number shouldn't be less than fifteen. The even distribution of samples was checked by the use of: subsamples, two or more strips, and repetitive subsamples from the same samples. In all cases, dominance and relative abundance of genera remained the same; therefore, it was assumed that samples counted were representative.

Samples for chemical analysis were collected at the same stations and at the same time as plankton samples. Sodium, potassium, sulfate, phosphate, chloride, ammonia, calcium, and total hardness, methyl orange alkalinity, and phenolphthalein alkalinity were then measured in the same samples which were also checked for organic matter and total, non-filtrable, and filtrable residues. All chemical analyses were according to Standard Methods for the Examination of Water and Wastewater (APHA 12th ed.) except as indicated below. Direct Nesslerization was used for the analysis of ammonia. Millipore filters of .45 micron pore size were used for non-filtrable resiude. Total residue was dried at 103-105 C. Filtrable residue was obtained by subtraction of the non-filtrable residue from the total residue. Specific conductance was measured on a Solu-Bridge Conductivity meter. Volumetric titrations described in the Hach Chemical Company catalog No. 10 were used for hardness, alkalinity, and chloride tests. The mercuric nitrate method was used for the analysis of chloride. Sulfate was analyzed according to the method described by Fritz and Yamamura (1955). Analysis for organic matter was done by dichromate oxidation (Maciolek, 1962).

Algae were classified to genera. Species identification were made in some cases, but are not reported. Forms dominant or abundant during the year are emphasized; others were not identified. Keys used for identification were *How to Know the Freshwater Algae* (Prescott, 1964) and *Algae of the Western Great Lakes Area* (Prescott, 1951).

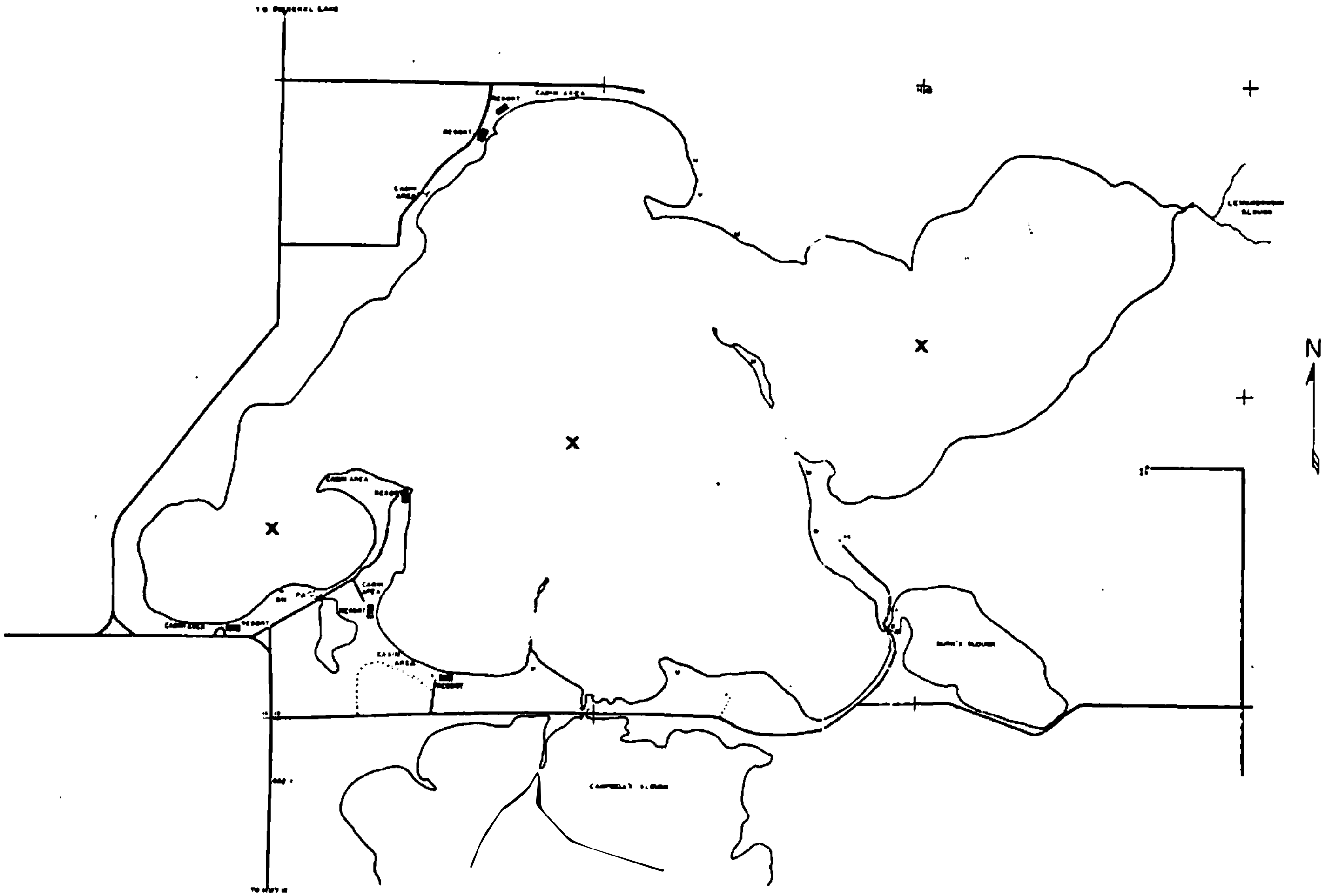


Figure 1. Sampling sites in Enemy Swim Lake. (From South Dakota Dept. of Game, Fish & Parks)

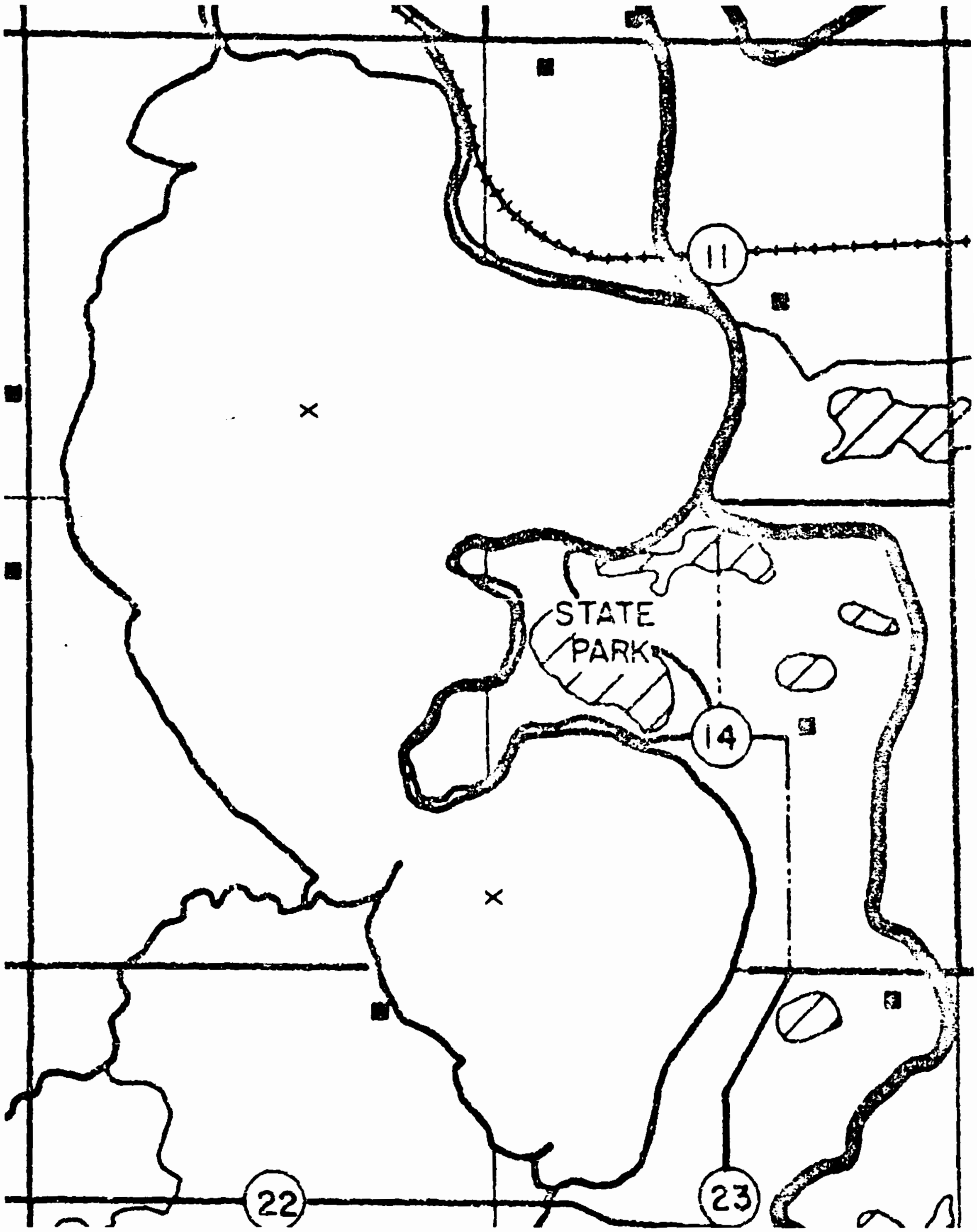


Figure 2. Sampling sites in Lake Herman. (From Lake Herman Report, 1969)

RESULTS AND DISCUSSION

Phytoplankton populations in Enemy Swim Lake and Lake Herman were observed to be distinctly different (Figs. 3-14). Enemy Swim was basically a diatom lake while Lake Herman was mostly dominated by blue-green algae. Numbers of phytoplankton in Enemy Swim were lower and subject to less variation than those in Lake Herman. The highest total standing crop recorded in Enemy Swim was less than 150,000/liter while Lake Herman had levels over 3,000,000/liter (Figs. 3 and 4).

The results and discussion is divided into two areas: a brief description of standing crops and population dynamics, and discussion of specific order: Myxophyceae (blue-greens), Chlorophyceae (greens and desmids), Chrysophyceae, Bacillariophyceae (diatoms), and Dinophyceae. Numbers of organisms reported for a date are mean numbers of all forms in samples from all depths on each date. A pulse is considered to be any rise in population to a peak and subsequent decline. A bloom is artibrarily defined as levels above 25,000/liter in Enemy Swim and 100,000/liter in Lake Herman. Counts of units per liter are presented in the form of 100/liter.

Standing Crop and Population Dynamics

Enemy Swim Lake

The highest sample count in Enemy Swim (141,950/liter) was recorded on November 24, 1967, with the lowest level (5,000/liter) on May 2, 1969. Peak levels reached in 1968 and 1969 were 51,653/liter

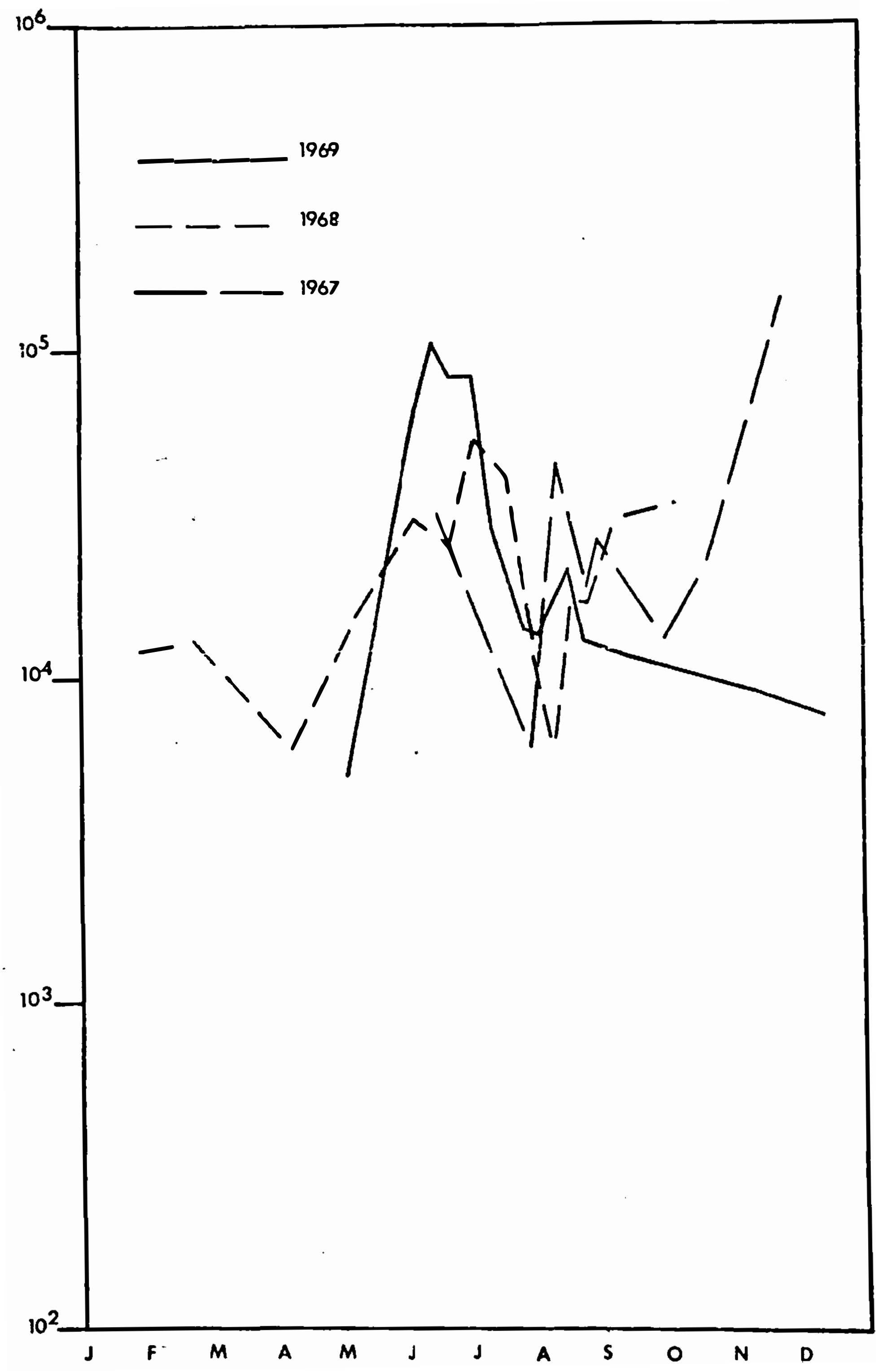


Figure 3. Total algal standing crop (by numbers) in Enemy Swim Lake.

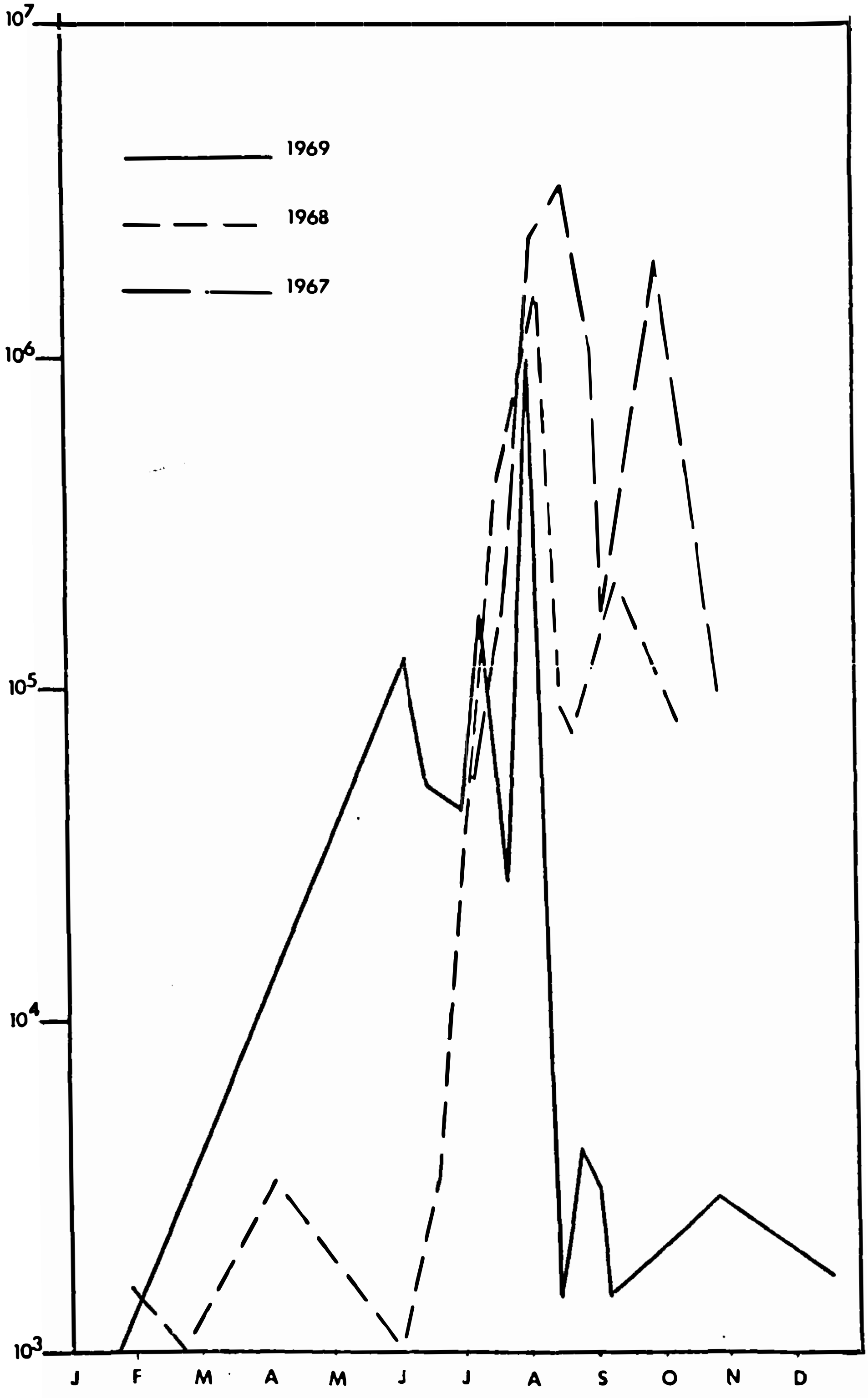


Figure 4. Total algal standing crop (by numbers) in Lake Herman.

and 105,700/liter respectively. The diatoms were the first group to be dominant in the winter and spring. Asterionella became dominant in the winter followed by Stephanodiscus and Fragilaria. After the diatoms, Anabaena became dominant during August and September before Asterionella again was dominant. Exceptions to this pattern were: Dinobyron following Asterionella in 1968, Melosira following Fragilaria in 1967, and Ceratium replacing Fragilaria in 1968. Blooms were observed each June. Smaller increases occurred in mid August of 1967 and 1969. A bloom developed in the fall of 1967 and July of 1968. A bloom also occurred in the fall of 1968 while a decline in numbers was recorded in the fall of 1969.

A spring pulse may have occurred prior to sampling in 1967 as first samples (June 14) had a level of 31,400/liter. By July 26, counts dropped to 6,300/liter. A summer bloom began in late July and peaked at 45,000/liter by August 9. Sample numbers decreased to slightly below 20,000/liter by August 28. After an increase in September, a peak of 141,950/liter was recorded on November 24.

Levels in January and February of 1968 were near 12,500/liter before declining to 6,170/liter by April 6. The standing crop increased and peaked at 30,005/liter by June 3. The summer bloom peaked at 51,000/liter on July 2 before a decline to 6,000/liter was reached by August 7. An autumnal bloom began in mid August with a peak level of 34,000/liter on October 4.

A summer bloom developed in 1969. A level of 5,000/liter was counted on May 2. The standing crop increased to a peak of 105,000/liter by June 13 before declining to a low of 13,500/liter by July 29.

After a brief rise to 21,000/liter by August 15, the standing crop decreased to 7,600/liter by December 12. Samples from Enemy Swim were generally dominated by Diatoms; especially Stephanodiscus, Fragilaria, Asterionella, and Melosira. All late spring pulses were more than 90% in 1969. Only in the fall of 1968 were diatoms in the minority composing 22% of the samples.

Blue-green algae found in Enemy Swim included the following genera: Aphanizomenon, Anabaena, and Lyngbya. The fall bloom of 1968 was more than 71% blue-greens, of which Anabaena was the dominant form.

Ceratium was the only genus of the dinoflagellates found consistently in the samples. The late spring pulse of 1967 was 22% of the samples.

Lake Herman

An extremely large standing crop ranging from 53,000/liter to 3,300,000/liter was found in Lake Herman during the second half of 1967. Peak levels reached in 1968 and 1969 were 1,688,000/liter and 169,134/liter respectively. Levels on all dates in 1967 except July 6 were higher than those recorded in 1968 or 1969. The largest standing crop in Lake Herman was found on August 15, 1967, when 3,300,000/liter were recorded, and one station had nearly 10,000,000/liter. Blue-green algae were dominant in the winter and early spring of 1968 followed by Pediastrum during late spring and early summer. From late June to the end of sampling, blue-greens became dominant. Blue-greens were dominant in 1969 until late July when Surirella gained dominance and remained when sampling was completed.

The first sampling date of the study, July 6, had a level of 53,000/liter. A bloom developed with a peak of 3,300,000/liter reached on August 15 before a decrease occurred reaching 170,000/liter by September 3. The fall bloom peaked at 1,905,000/liter on September 29. The standing crop declined to 91,000/liter by October 26.

Algal levels remained low from January 27 to May 31, 1968. A minor increase to 3,325/liter took place during this period. From May 31 to August 5, numbers of algae increased and peaked at 1,688,000/liter by August 5. The summer bloom then decreased to 88,875/liter by August 13 before a smaller increase to 722,925/liter was found on August 19. A decline followed and 77,000/liter were recorded on October 7.

Because of the severe winter weather in 1969, Lake Herman winter killed and the standing crop was less than 100/liter on January 20. After a break of several months due to the severe weather, sampling began in June. A total of 124,000/liter was recorded on June 4. It appeared that when sampling was resumed the spring bloom was declining. The low count of 43,635/liter was recorded on June 30. The summer bloom had two peaks with the first by July 8 at 169,134/liter and the second by July 30 at 98,525/liter. The standing crop declined rapidly after the second peak to a level of 1,522/liter by August 12. No autumnal pulse appeared as the standing crop was never found to exceed 4,500/liter from August 12 to December 15.

The phytoplankton of Lake Herman was dominated by blue-green algae, Aphanizomenon and Anabaena. Samples in 1967 were over 98% blue-greens. From June 17 to October 7, 1968, 78-99% were blue-greens and during the first half of 1969, more than 88% of the samples were blue-green. *Aphanizomenon* was the dominant blue-green with *Anabaena* less than 10% of the samples except on July 1, August 13, and September 9, 1968. *Aphanizomenon* was 82% or more of all blooms in Lake Herman.

Asterionella, Fragilaria, Stephanodiscus, and *Surirella* were diatoms recorded in Lake Herman. Diatoms were dominant in the fall of 1969 and winter of 1968 composing more than 82% of the samples. *Fragilaria* ranged from 5% to 44% and *Asterionella* up to 63% of the 1968 winter samples. *Surirella* represented over 76% of the 1969 fall samples. *Stephanodiscus* was never found to comprise more than 16% of the samples.

Pediastrum was the only genus of green algae present in sufficient numbers to be considered. In the late spring of 1968, *Pediastrum* comprised 16% to 66% of the samples.

Major Taxa

Phytoplankton levels in Enemy Swim generally ranged from 5,000-150,000/liter while Lake Herman samples contained from 1,000-3,300,000/liter. Highest levels in Enemy Swim and Lake Herman occurred in 1967. Diatoms comprised the greatest portion of phytoplankton samples in Enemy Swim and blue-greens were a majority of the blooms in Lake Herman.

Anabaena

Peak numbers of Anabaena occurred during July or August in Lake Herman and in June or October in Enemy Swim. Anabaena levels were observed to be quite different in the two lakes. A peak during June of all three years was observed in Enemy Swim which was followed by a minimum. Levels indicated an increase in the late summer of 1968, but no decline followed as in 1967 and 1969. Instead 1968 levels of Anabaena continued to rise into a fall bloom. In Lake Herman, a summer pulse appeared during 1967 and 1968. Levels in 1969 never exceeded 600/liter and Anabaena was not recorded during the peak periods of other years.

Anabaena displayed two distinct peaks in Enemy Swim during 1967. Levels of Anabaena appeared to have been high in the spring with 2,800/liter recorded on June 14. No filaments of Anabaena were recorded by July 26. In early August, an increase occurred and peaked at 1,200/liter by August 28. A decline followed until Anabaena disappeared from the November 24 samples.

Anabaena levels in 1968 were erratic. A peak of 2,065/liter was recorded on June 3, but by June 19, only 35/liter were present. Levels of less than 700/liter were found during July. In August, counts indicated an increase and a peak of 4,375/liter was reached by August 14. After a drop to 2,800/liter in late August, a fall peak of 21,140/liter was recorded on October 4.

Anabaena wasn't recorded in May, 1969. A level of 2,450/liter was found on June 13. A summer bloom developed and 25,620/liter were recorded on July 1. After declining to a low of 3,664/liter by July 29, a peak of 14,078/liter was reached in mid August. Anabaena was not found in samples after November 1.

In Lake Herman, 1967 Anabaena levels formed a summer pulse which began in early July at 230/liter and disappeared by late September. The peak level of 30,567/liter was recorded on August 30.

A similar pulse appeared in 1968, but started earlier in late May and ended later in early October. A level of 27/liter was recorded on May 31. Numbers of Anabaena increased into a peak of 66,500/liter by August 19 before disappearing from samples on October 7.

Levels of Anabaena in 1969 were quite different from the two previous years. A level of 700/liter was recorded on June 4. After declining to zero by July 8, Anabaena levels rose to 350/liter by July 22 and remained at this level until the end of sampling.

Petri and Larson (1969) did not record any filaments of Anabaena in May or October of 1967 in either lake. Total standing crop and Anabaena levels in Enemy Swim both dropped to summer minima when temperatures reached 21-21.5 C in all three years. No summer minima appeared in Lake Herman. Summer maxima were formed by Anabaena in Lake Herman and coincided with peaks of the standing crop in 1967 and 1968. Levels in 1969 did not parallel the standing crop. Anabaena peaks in Lake Herman did not appear to be closely related to temperature as maxima occurred at 17-22 C.

Aphanizomenon and Anabaena levels were closely related in both lakes. As Anabaena numbers rose and fell, Aphanizomenon levels reacted conversely (Figs. 5-10). Aphanizomenon was dominant to Anabaena in

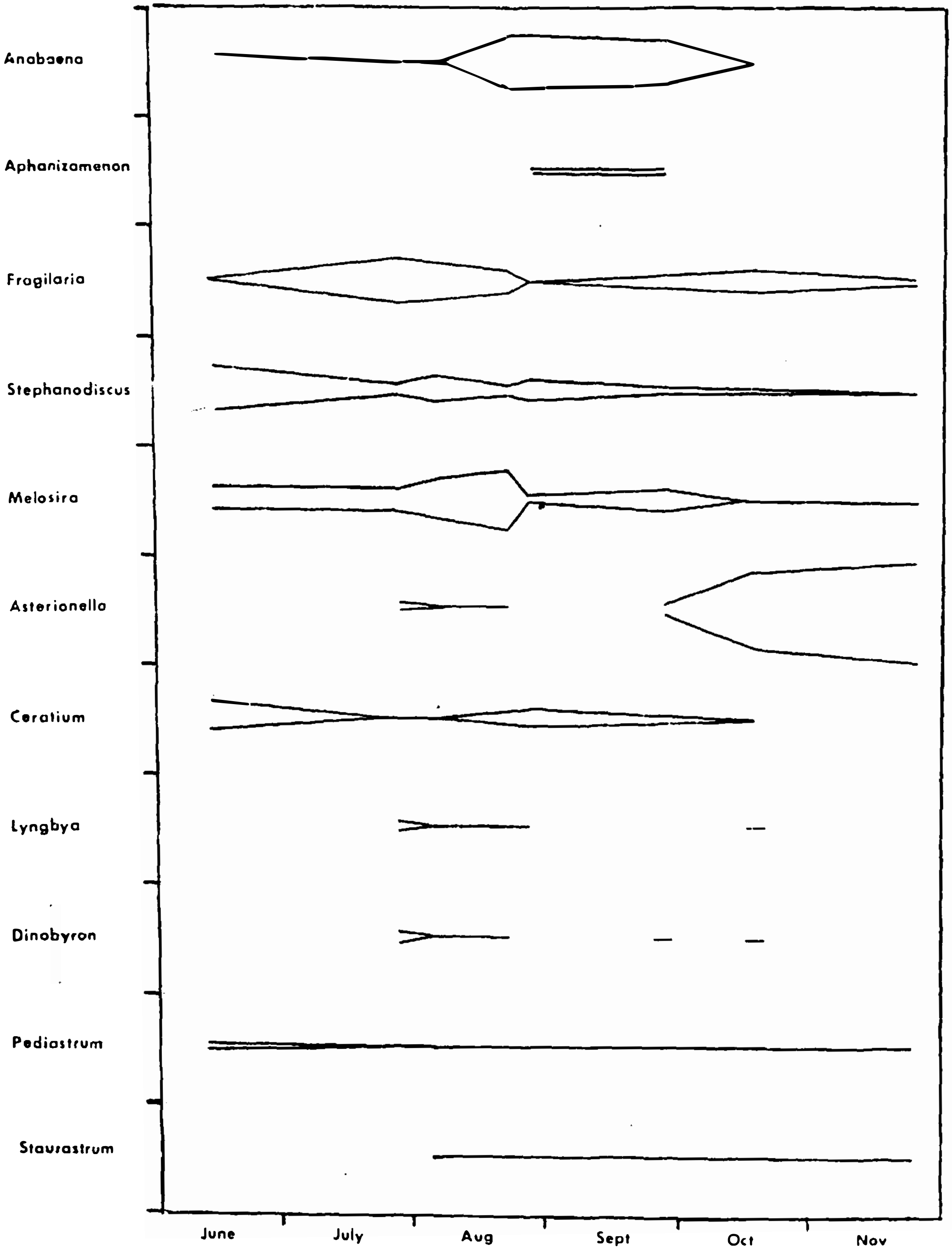


Figure 5. Per cent composition by genera of 1967 algal population in Enemy Swim Lake.

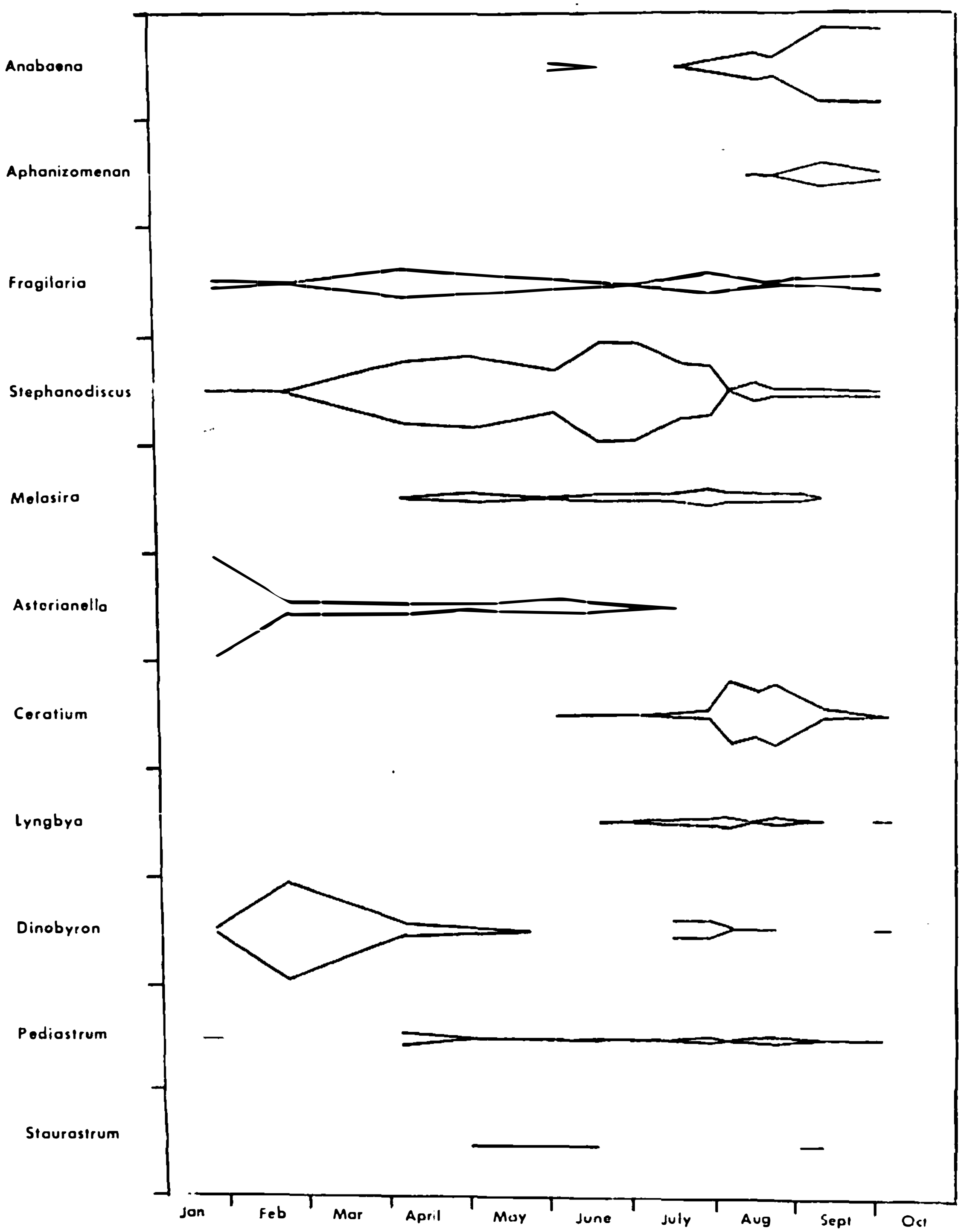


Figure 6. Per cent composition by genera of 1968 algal population in Enemy Swim Lake.

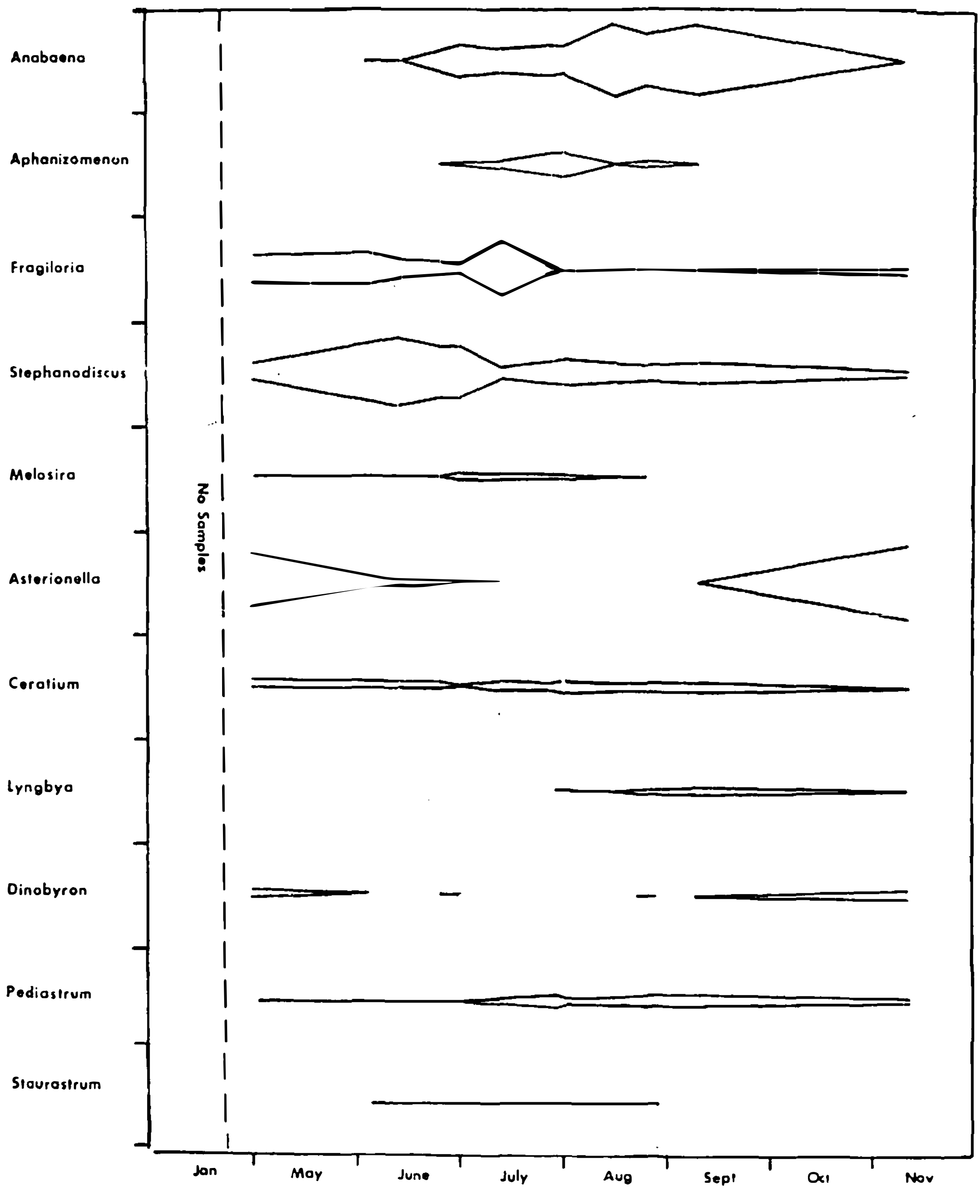


Figure 7. Per cent composition by genera of 1969 algal population in Enemy Swim Lake.

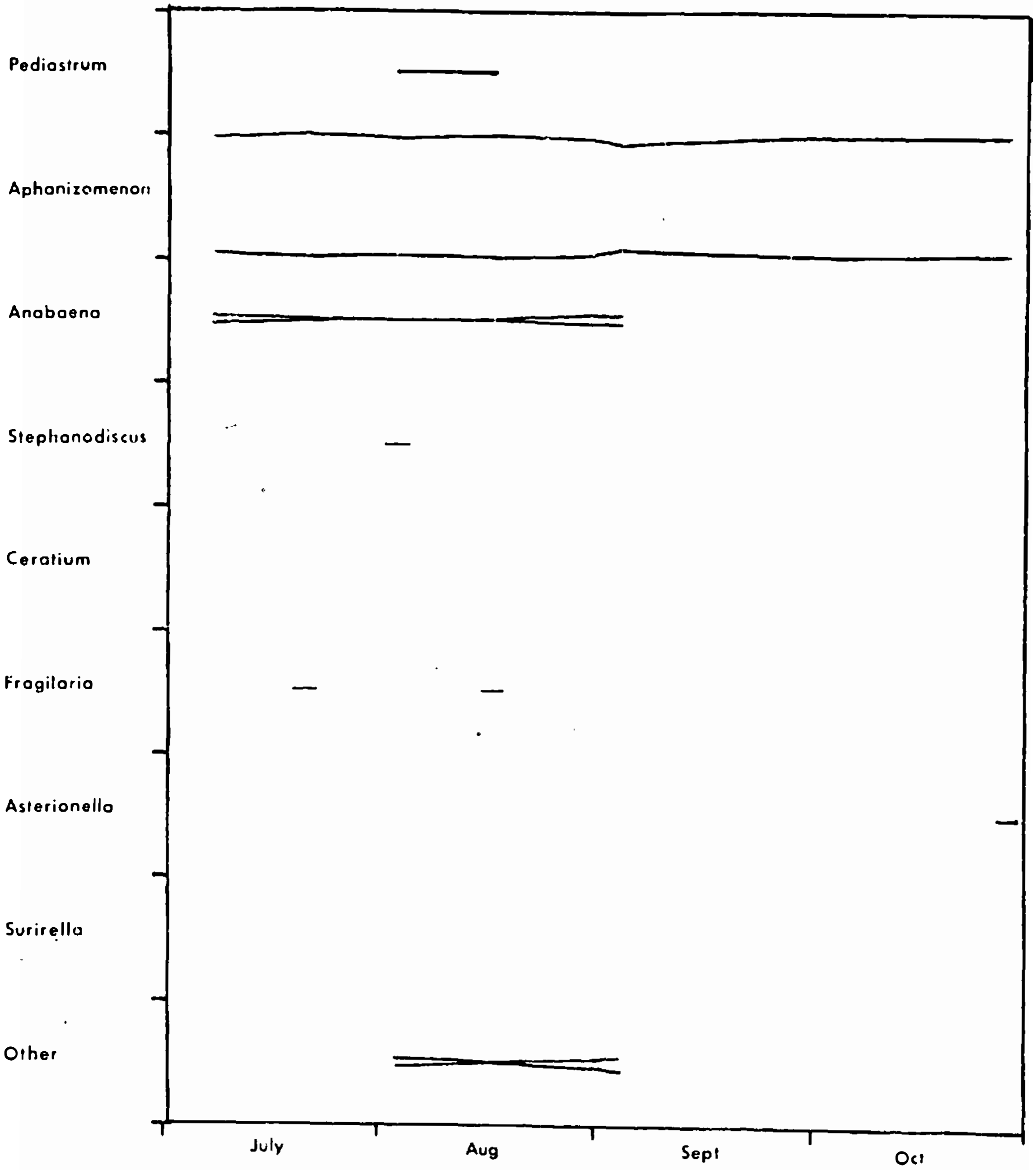


Figure 8. Per cent composition by genera of 1967 algal population in Lake Herman.

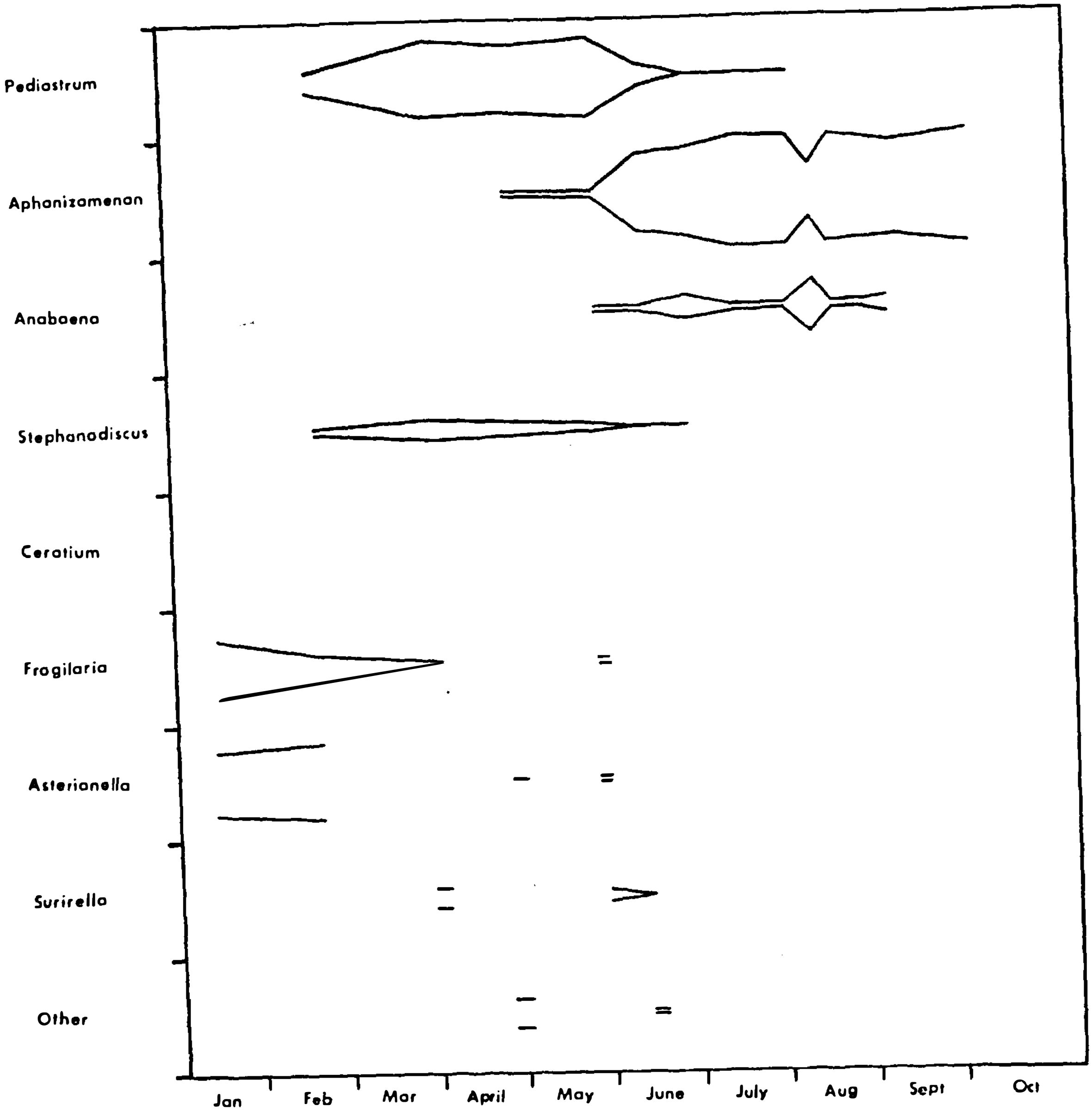


Figure 9. Per cent composition by genera of 1968 algal population in Lake Herman.

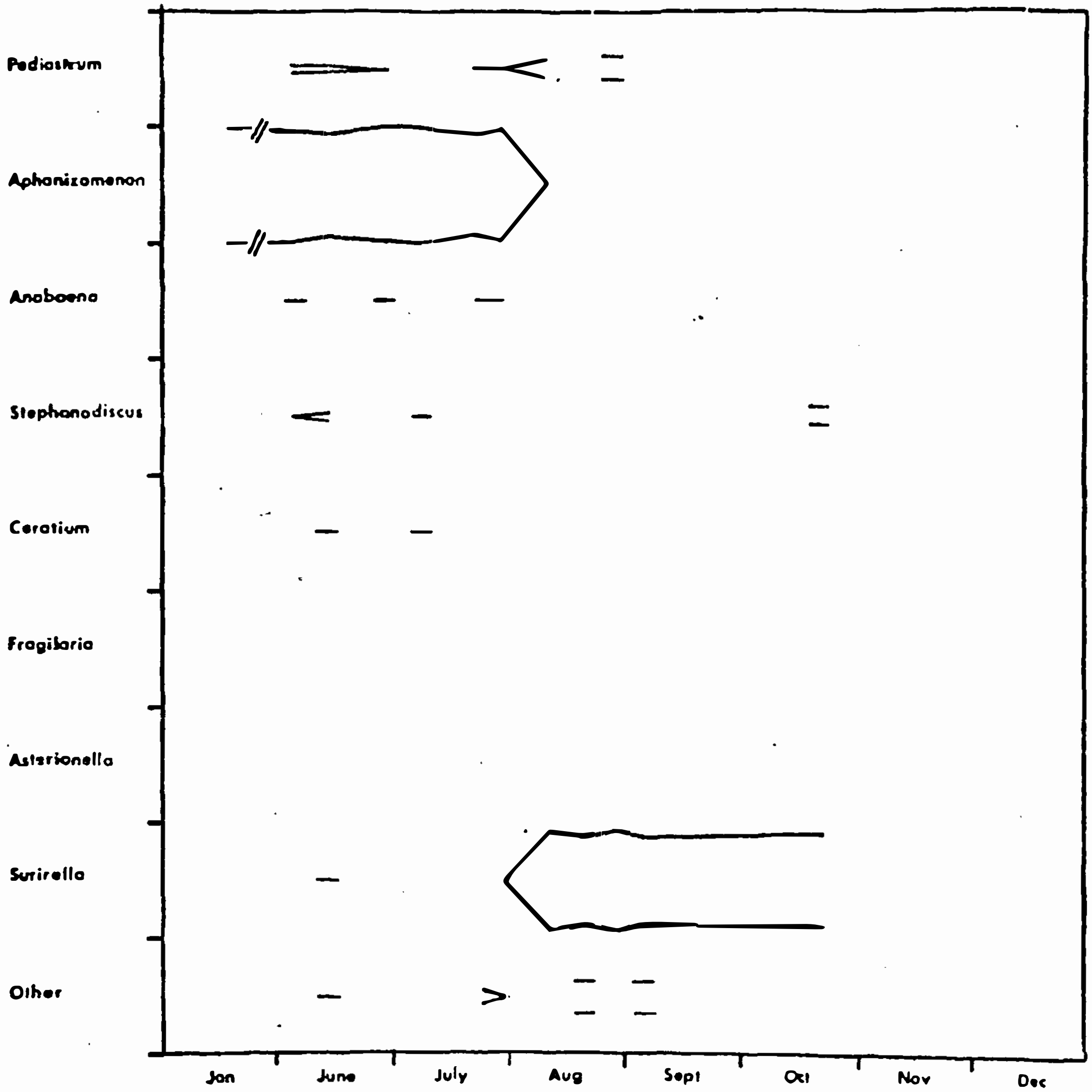


Figure 10. Per cent composition by genera of 1969 algal population in Lake Herman.

Lake Herman, while the opposite occurred in Enemy Swim. Since the two genera were so closely related, their discussion is grouped into a discussion of the Myxophyceae following *Aphanizomenon*.

Aphanizomenon

Aphanizomenon was the dominant genus in Lake Herman while comprising only a small fraction of the Enemy Swim samples. Levels of *Aphanizomenon* in Lake Herman were a thousand times greater than levels recorded in Enemy Swim. Summer blooms appeared during August of 1967 and 1968 in Lake Herman with peak levels over 1,000,000/liter. The maximum of 1969 was recorded in early July with 165,000/liter present. In Enemy Swim, maximum numbers occurred during August of all three years and never exceeded 3,000/liter.

Aphanizomenon was not found in Enemy Swim until the end of August in 1967. A level of 790/liter was found on August 28. By late September, counts of *Aphanizomenon* dropped to 420/liter.

As in 1967, *Aphanizomenon* was not recorded in the samples until August. A level of 87/liter was found on August 14. An increase to 3,675/liter was reached by September 4 with a peak of 6,150/liter by September 11. *Aphanizomenon* levels dropped to slightly above 3,000/liter in early October.

A small summer pulse appeared in 1969 from mid June to early August. A peak of nearly 3,100/liter was recorded on July 24 and 29. In an isolated case, 620/liter were counted on August 20.

Levels of Aphanizomenon in Lake Herman were high when 1967 sampling started as nearly 54,000/liter were found on July 6. Counts indicated an increase into a summer bloom with a peak of 3,231,000/liter recorded by August 15. After decreasing to 160,000/liter by September 3, a fall maximum of 1,905,000/liter was found on September 29. A decline to 90,300/liter by October 26 followed.

In 1968, levels were less than 150/liter until mid June. A count of 2,415/liter was recorded on June 17. As levels of Aphanizomenon increased, a summer bloom developed. The peak level of 1,618,750/liter was recorded on August 5. Sample numbers declined to 51,100/liter by August 13 before rising to a second smaller peak of 653,000/liter by August 19. Aphanizomenon numbers decreased in the fall with 76,650/liter found on October 7.

A level of 117,250/liter was recorded on June 4, 1969. After declining to 42,800/liter by June 30, two peaks were observed with the first by July 8 having 168,400/liter and the second having 97,475/liter by July 30. The low between peaks was 25,800/liter reached on July 22. An isolated count of 13/liter was recorded on August 12.

Hutchinson (1944) found the peak of Myxophyceae to occur in late summer when inorganic nutrients were practically exhausted in Linsley Pond. Maximum levels of blue-greens in Lake Herman did occur in late summer, but nutrients remained quite high (Table 4). In Enemy Swim, 1967 and 1968 blue-green levels decreased in late July or August at the same time as the nutrient low. An increase in blue-green numbers occurred in 1969.

Total numbers of blue-green algae in Lake Herman seemed directly related to levels of total phosphate. Total phosphate levels in Lake Herman were at their highest or just past peak levels when peak blue-green levels were recorded in the late summer. More than 2.4 ppm total phosphate was recorded in August of 1967 and 1968 while only 1.65 ppm was found in 1969. Myxophycean levels in August were more than 3,200,000/liter in 1967 and 1,650,000/liter in 1968. Blue-green numbers in August of 1969 were much lower and were not found to exceed 100,000/liter. In Enemy Swim, blue-green algae levels did not seem related to total phosphate. Myxophycean levels reached highest numbers when total phosphate was less than .23 ppm. The total phosphate reading was thought to be inaccurate as it was approximately four times higher than previously recorded. The blue-green population in Enemy Swim was mostly _Anabaena_ while in Lake Herman, _Aphanizomenon_ made up the majority of the population. For blue-green algae in general, a minimum of 0.03 ppm (ortho-phosphate) is critical, whereas the optimum concentration is around 0.45 ppm (Prescott, 1968). Maximum and minimum levels of total phosphate in both lakes were above those given by Prescott (Table 1). Levels above the optimum were reached only in April and December of 1968 and June and July of 1969 in Enemy Swim. Maximum blue-green levels in Enemy Swim were never found to exceed 30,000/liter. In Lake Herman, total phosphate levels were never found below the optimum level of 0.45 ppm.

Some evidence has been found that high sodium levels may be conducive to large Myxophycean populations (Hutchinson, 1967). Sodium levels in Enemy Swim ranged from .2 to 10.5 ppm while Lake Herman contained from 17.0 to 80.0 ppm. There was approximately a hundred fold increase in blue-green levels from Enemy Swim (Maximum 26,660/ liter) to Lake Herman (maximum 3,300,000/liter). In Enemy Swim, sodium levels ranged from 4.5 to 5.9 ppm in 1968 and 1969 when Anabaena levels were greater than 20,000/liter. In 1967, peak numbers of Anabaena were less than 3,000/liter while sodium concentrations were 6.5 ppm or more. Anabaena levels in Lake Herman were 30,000/liter in 1967 and 65,000/ liter in 1968 when 52.6 and 63.0 ppm sodium respectively were found. In 1969, 25 ppm sodium was recorded at a peak of only 700/liter.

Sodium levels during 1967 and 1968 in Lake Herman ranged from 53 to 55 ppm when peak numbers of Aphanizomenon were 1,650,000/liter or more. Sodium concentrations in 1969 dropped to 27 ppm while peak levels of Aphanizomenon were a tenth of previous years. Sodium levels in Enemy Swim were much lower as were the numbers of Aphanizomenon. Peak levels in 1967 and 1968 were from 600-700/liter when 6.7-7.8 ppm sodium was present. The peak 1969 level increased to 3,000/liter as sodium concentrations dropped to 5.3 ppm.

Pearsall (1932) and Tucker (1957) both reported finding a correlation between high concentrations of organic matter and high Myxophycean populations. In Linsley Pond, Hutchinson (1944) found the opposite to be true. Data for total organic was not available for 1967 in either lake. Highest blue-green levels in Enemy Swim (26,660) occurred at 11 mg C/l or more total organic carbon. In Lake Herman, a level of 1,650,000/liter occurred in 1968 when 23.5 mg C/l was present while 165,000/liter were found in 1969 at an organic level of 9.9 mg C/l.

The 1968 total organic level in Lake Herman rose above 29 mg C/l as Anabaena reached peak levels (65,000/liter). The level reached by Anabaena in 1969 was a tenth of the 1968 numbers, but the total organic content was 31 mg C/l. In Enemy Swim, 1968 numbers peaked in October (24,000/liter) when the organic level was 17.5 mg C/l. The organic level in 1969 dropped from near 27 mg C/l to 10 mg C/l as Anabaena levels rose to a peak of 25,000/liter.

Aphanizomenon levels in Lake Herman of 1,650,000/liter were found when 25.6 mg C/l was present. A peak of 165,000/liter was recorded in 1969 when less than 10 mg C/l was present. This particular situation did not occur in Enemy Swim. Total organic levels in 1968 and 1969 both were near 10 mg C/l while Aphanizomenon numbers were 620/liter in 1968 and 3,100/liter in 1969.

Lyngbya

Lyngbya was found only in Enemy Swim and at levels less than 710/liter. In 1967 and 1968, peaks appeared in early and late summer with a decrease in mid summer. A single pulse occurred in 1969 which peaked in late August at the time of lowest levels in previous years. Lyngbya occurred at approximately the same time as other blue-green algae.

Lyngbya was first recorded in 1967 when a level of 700/liter was found on July 26. Levels of Lyngbya in August ranged from 233 to 534/liter. Lyngbya disappeared from the samples by September 27.

Lyngbya was not recorded in 1968 until mid June when 35 and 53/liter were found on June 19 and July 2 respectively. Mid July samples had no Lyngbya present, but by July 31, counts indicated a rise to 350/liter. A peak of 570/liter was reached by August 7 before a low of 87/liter was recorded on September 4. A week later levels had risen to 630/liter. Lyngbya numbers declined to 140/liter by October 4.

A pulse appeared in 1969 from mid July to mid September. Levels of 140/liter were recorded on both July 24 and 29. A peak of 467/liter was reached by August 20 before a decline to 350/liter occurred in mid September. Lyngbya was not found in the November 8 sample.

Peaks of Myxophyceae occurred in Linsley Pond when inorganic nutrients were practically exhausted in late summer (Hutchinson, 1944). Maximum levels of Lyngbya occurred in July or August when nutrients were still quite high (Table 4). Peak levels of Lyngbya were never found to exceed 700/liter.

Levels of Lyngbya in Enemy Swim were so low that no obvious relationships between the levels and nutrients could be observed. With sodium and phosphate concentrations more than double in Lake Herman and Lyngbya not being found there, it appeared that high sodium and phosphate that favored Aphanizomenon and Anabaena inhibited Lyngbya numbers.

Pediastrum

Pediastrum levels were higher in Lake Herman than in Enemy Swim. In Lake Herman, peaks appeared in early spring, mid summer, and fall. Highest levels generally occurred during the mid summer. Pediastrum levels in Enemy Swim were found to form peaks in late June or early July and late August. Graham (1966) found Pediastrum in one South

Table 4. Maximum and minimum inorganic nutrient levels (in mg/l) at times of peak blue-green algae populations (August), 1967-1969.

Lake Herman

	1967		1968		1969	
	max.	min.	max.	min.	max.	min.
Total phosphate	2.20 ppm	1.48	2.47	1.51	1.65	.820
Sodium	52.9	51.0	65.0	53.3	53.0	14.0
Potassium	17.4	17.0	22.3	20.0	24.2	8.1
Ca hardness	278	245	255	246	266	203
Total hardness	446	422	488	470	351	328
Chloride	6.8	6.0	8.5	6.0	6.9	6.3
Sulfate	320	302	480	450	630	165
Phenolphthalein alk.	30	18	20	14	3.2	0.0
MO alkalinity	260	194	182	176	164	154
Total residue	77	69	95	92	--	--
Filtrable residue	33.5	9.0	59.5	56.0	--	--

Enemy Swim

	1967		1968		1969	
	max.	min.	max.	min.	max.	min.
Total phosphate	.115	.09	.140	.117	.584	.294
Sodium	7.85	5.9	7.1	6.25	6.0	5.3
Potassium	7.4	7.2	8.5	7.40	7.0	6.7
Ca hardness	114	75	139	115	67	58
Total hardness	230	224	250	245	200	194
Chloride	3.8	3.1	3.5	2.2	4.8	4.3
Sulfate	47	38	52	42	50	25.0
Phenolphthalein alk.	11.2	8.2	9.0	8.2	14.8	9.2
MO alkalinity	208	200	212	202	188	184
Total residue	34	23	33	28	--	--
Filtrable residue	12.0	7.0	8.5	5.0	--	--

Dakota pond, with the maximum population occurring in August. Declines took place during late July or early August in Enemy Swim forming summer minima at the time of maxima in Lake Herman. Green algae were never found to be abundant in the Michigan Lakes studied by Tucker (1957), but they were most common in lakes where the blue-greens were most abundant.

A total of 1,750/liter was found in Enemy Swim on June 14, 1967, however by July 26 Pediastrum was absent from the samples. An increase started in early August and peaked at 700/liter by August 23. Pediastrum levels remained fairly steady with a range of 420 to 710/liter through October 18. A level of 234/liter was recorded on November 24.

Less than 25/liter were found during the winter of 1968. A level of 700/liter was recorded by April 6. After a slight decline to 481/liter in May, Pediastrum levels peaked at 1,750/liter by July 2. A summer minimum developed in early August with a level of 117/liter found on August 7. A peak of 1,225/liter was reached by August 21. After a drop to less than 500/liter by September 11, counts indicated an increase to 1,050/liter by October 4.

Levels in the late spring of 1969 were quite low. On May 2, a level of 78/liter was recorded before increasing to 2,800/liter by June 13. After a gradual decline, 588/liter were recorded on July 29. A total of 1,470/liter was present by August 20. Pediastrum levels declined to 420/liter by November 8.

Pediastrum was found in Lake Herman on two dates during 1967. A level of 14,000/liter was recorded on August 2 and 225/liter were found on October 26.

Two pulses appeared in 1968. The first peaked at 2,100/liter by April 3 following a count of 105/liter on February 21. After a decline to 282/liter by June 3, a second pulse began in early June. The peak of 8,750/liter was reached by August 5 and 13. A level of 350/liter was found on September 9.

A high of 5,600/liter was recorded on June 4, 1969. After a steady decline, *Pediastrum* was not found in the July 8 sample. Small summer pulses appeared later with peaks of 350 and 583/liter on July 30 and August 28 respectively. A single occurrence of 224/liter was recorded on October 24.

In other literature, colonial forms of green algae are often related to the desmids (*Staurastrum*). For this reason, the discussion of *Pediastrum* follows the presentation of *Staurastrum*.

Staurastrum

Staurastrum was recorded only in Enemy Swim and was never found to exceed 2,100/liter. It was present in most samples, but never dominant. Petri and Larson (1969) recorded no more than 150 counts/ml in Enemy Swim during May and October of 1967. Tucker (1957) recorded 72,600/liter in Douglas Lake.

Staurastrum was not found in 1967 until August 9 when 306/liter were present. After declining to 167/liter by August 23, an increase to 350/liter was observed on October 18. Sampling ended with the same level present.

Two separate peaks were found in 1968. The first started in April and ended in early July. A high of 455/liter occurred on June 3. The second, smaller increase began in late August and peaked at 140/liter on September 11. Staurastrum was not found in samples after October 4.

Levels indicated an increase to 2,100/liter by June 13, 1969. This level dropped sharply to 88/liter by June 20 before increasing again. Counts ranged from 200-500/liter during July and August. After a decline to zero, 70/liter were recorded on November 8.

Pearsall (1932) associated green algae and desmids with low nitrates and phosphates. He also stated that desmids were favored by lower ratios of nitrate to phosphate, but a higher Ca content of the water disturbs the balance in favor of the other green algae. Hutchinson (1967) found green algae in summer when nutrient content is low (low Ca and low NNO_3:PPO_4 ratio tends to favor desmids). Pearsall (1932) reported that in general the ratio of desmids to green algal colonial forms falls as the N/P ratio rises. Levels of phosphate in Enemy Swim remained fairly low during most of the study. In Lake Herman, total phosphates often exceeded 2.3 ppm. Peaks of Pediastrum and Staurastrum in Enemy Swim were reached in mid June or early July except in 1967 when Staurastrum was not recorded until August. Highest levels of both genera were recorded on June 13, 1969 with 2,100/liter of Staurastrum and 2,800/liter of Pediastrum present. Calcium hardness and total phosphate levels in Enemy Swim were much lower than in Lake Herman (Table 1) where only Pediastrum was recorded. Levels of Pediastrum in

Lake Herman were higher than those in Enemy Swim with several counts over 4,000/liter. Peak levels ranged from 5,600 to 14,000/liter.

Dinobyron

Dinobyron was recorded only from Enemy Swim during the study. Petri and Larson (1969) reported not finding Dinobyron in Enemy Swim or Lake Herman during May or October of 1967. Levels recorded were highest in 1968 (maximum 12,017/liter) and lowest in 1967 (maximum 467/liter). Sample numbers were erratic with several dates having no Dinobyron present.

A pulse appeared from mid June to late August in 1967. The peak of 467/liter was reached by July 27 before declining to zero by August 28. Dinobyron was observed on September 27 and October 18 at 218 and 175/liter respectively.

Winter levels during 1968 were high with 490/liter observed on January 26 before a peak of 12,017/liter was recorded on February 22. Dinobyron levels declined to 570/liter by April 6 and remained less than 1,000/liter until Dinobyron disappeared from the June 19 and July 2 samples. A summer pulse began in early July and peaked at 7,000/liter by July 17. After the peak, 87/liter were found in mid August. A level of 609/liter was recorded on August 21. A single occurrence of 560/liter was found in early October.

Dinobyron levels in 1969 fluctuated greatly from May to late July. After that period, Dinobyron was recorded on only two dates. A level of 254/liter was present on May 2, increasing to 1,050/liter by June 5. Dinobyron was not found in the June 13 samples, but by July 1, a level of 1,120/liter had been reached. This peak was followed by a decline to zero by July 24. Levels of 117 and 425/liter were recorded on august 20 and November 8 respectively.

Dinobyron levels in Enemy Swim characteristically dropped to zero in June and September. The first sample on June 14, 1967, had no Dinobyron present. In 1968 and 1969, Dinobyron was not found on June 18 and 12 respectively. The low in June followed spring maxima occurring in May or early June. Hutchinson (1967) found D. divergens to have a spring maximum followed by an early summer minimum. This is what generally occurred in Enemy Swim. In two of the years, the summer maximum was larger than levels reached in the spring. Spring levels in 1968 were highest for the entire study. The drop to zero in the fall occurred within a ten-day period from August 28 to September 8 and was followed by increases of less than 1,000/liter.

The standing crop in Enemy Swim formed summer minima at water temperatures of 21-21.5 C. Dinobyron summer maxima of 1968 and 1969 took place at 21-21.5 C. The peak in 1967 was at 19.6 C. Hutchinson (1967) reported that Dinobyron populations are suppressed as long as maximal spring populations of other forms can be maintained. A diatom maximum, mostly Asterionella, followed by Dinobyron was reported by Hamilton (1969). Increases in diatom numbers were followed by decreases in Dinobyron levels (Figs. 5, 6, 7) in Enemy Swim.

Hutchinson (1967) found that Dinobyron was actually inhibited by levels of phosphate that were hardly adequate for the diatoms that normally precede it. Total phosphate levels in Lake Herman were more than double those recorded in Enemy Swim. Dinobyron was not in the

Lake Herman samples. In Enemy Swim, highest levels of Dinobyron were found at total phosphate concentrations below .234 ppm. In April of 1968, a count of 831/liter was made when total phosphates were greater than 1.30 ppm.

Asterionella

Asterionella was recorded in the spring and fall when diatoms generally appear. Asterionella was reported at levels less than 150/ml in October and from 2,401-4,800/ml during May in Enemy Swim by Petri and Larson (1969). They did not report Asterionella in Lake Herman during the same period. Levels were much lower in Lake Herman (maximum 900/liter) than in Enemy Swim (maximum 129,000/liter). Asterionella in Enemy Swim was found to occur in the summer when 6,500/liter were found in August of 1967. Asterionella was a dominant component of the phytoplankton of Enemy Swim several times.

A small summer pulse appeared in Enemy Swim during late July of 1967 with a peak of 650/liter on August 9. After a decline to zero by August 28, Asterionella levels bloomed to 129,000/liter by November 24.

Winter levels of 1968 were high with 11,200/liter present on January 26. A low of 390/liter was reached by May 3. An early summer pulse began sometime in May and peaked at 5,400/liter on June 3. Specimens of Asterionella were not found in samples after August 7.

A level of 2,400/liter was reached on May 2, 1969. Counts indicated an increase to a peak of 8,200/liter by June 20. After a steady decline, Asterionella was not present in the July 29 sample. The November 9 sample was the only fall sample to contain Asterionella when 6,800/liter were found.

The years 1967 and 1969 were quite similar in Lake Herman with Asterionella recorded on one date. A level of 233/liter was found on October 26, 1967, while December 15, 1969 had 350/liter present.

A count of 875/liter was recorded on January 26, 1968. Numbers of Asterionella declined to 420/liter by February 21. Less than 20/liter were found in April and May. Asterionella was not recorded in samples after June 1.

Hutchinson (1967) felt that during early spring that light was more important to Asterionella levels than temperature. In Enemy Swim, spring maxima occurred in June and may be related to increased light. There appeared to be no obvious relationship between temperature and spring maxima. In Lake Herman, levels were higher under the ice (875/liter) than in the spring (150/liter). It may be that factors other than light influence Asterionella levels in Lake Herman.

Cantor and Lund (1948) gave several factors besides fungal parasitism that may limit the size of autumnal increases and winter numbers of Asterionella formosa: 1) light duration and intensity, 2) turbulence, 3) floods, 4)ingestion, and 5) competition--Myxophyceae--no inhibition but may compete for nutrients. In Enemy Swim, shorter fall days with less light occurred at the same time as fall maxima. Levels of Asterionella were generally higher in the fall and winter than in the spring. In the summer (July and August) period with much light, Asterionella levels were below 1,000/liter. In Enemy Swim, when

Anabaena levels increased or were high, Asterionella numbers were low or decreasing (Figs. 5, 6, 7). In Lake Herman, blue-green algae reached high levels (maximum 3,300,000/liter) while Asterionella never was found to exceed 875/liter. It appeared that competition occurred between the two genera. The effects of turbulence, floods, and ingestion upon Asterionella levels were not determined.

Hutchinson (1944) found no evidence that Asterionella in Linsley Pond depended upon inorganic nutrient levels. In both lakes, there were no obvious relationships between inorganic nutrients and Asterionella.

Fragilaria

Fragilaria levels in the two lakes were observed to be quite different. Maximum levels recorded in Enemy Swim were near 20,000/liter, but never exceed 700/liter in Lake Herman. Spring pulses were found in 1968 and 1969 in Enemy Swim. Summer pulses occurred in July of 1968 and 1969 and August of 1967. Fall pulses developed in October or November of all three years. Fragilaria was not found in the fall samples from Lake Herman, but did occur in the summer of 1967, spring of 1968, and winter of 1969.

Fragilaria levels in Enemy Swim increased in the summer and fall of 1967. A summer pulse started in mid June. A total of 700/liter was recorded on June 14, followed by an increase to a peak of 15,975/liter by August 9. After declining to 875/liter by August 28, a maximum of 10,850/liter was found on November 24.

A level of 565/liter was counted on January 26, 1968, but in late February, Fragilaria was not found in the samples. A spring pulse developed with a level of 1,400/liter recorded on April 6 before the peak of 3,500/liter was reached by June 3. A level of 394/liter was counted on July 2. A summer pulse started in early July and peaked at 3,989/liter on July 17. The peak fall count of 4,970/liter was recorded on October 4.

Samples taken on May 3, 1969, had 1,271/liter present. This increased to 19,850/liter by June 5. After declining to 6,900/liter by July 2, a second peak of 14,480/liter was recorded on July 9. A low of 140/liter was reached by September 8 before rising to 610/liter by November 8.

Fragilaria in Lake Herman was not found in any fall samples. In the summer of 1967, 70/liter were present on July 14 and 175/liter on August 15.

A level of 700/liter was found on January 26, 1968, before declining to 105/liter by February 21. After a brief rise to 175/liter by April 3, levels below 15/liter were found by May 31. Fragilaria was not recorded after June 17.

Fragilaria was not found in 1969 until December 15 when 350/liter were counted.

Fragilaria capucina was found by Provasoli, McLaughlin, and Pintner (1954) to tolerate total solid concentrations of 700-900 ppm. They thought that lower total solid concentrations were probably as advantageous. Fragilaria was found in the winter of 1969 in Lake Herman when total solids were 920 to 1,050 ppm. Other periods of occurrence were at 900 ppm or below in both lakes.

Hutchinson (1944) found that Anabaena and Fragilaria competed for phosphate with Fragilaria favored when nitrate is relatively abundant; Anabaena when nitrate is scarce. Samples were analyzed for phosphate, but not nitrate in this study. It appeared that competition was taking place in both lakes. In Lake Herman, Fragilaria occurred at minimum levels or was not found when Anabaena was present (Figs. 8, 9, 10). Fragilaria numbers increased as Anabaena levels decreased or as Fragilaria decreased, Anabaena increased in Enemy Swim (Figs. 5, 6, 7).

Melosira

Melosira was found only in Enemy Swim during this study. Hutchinson (1967) described Melosira as being meroplanktonic requiring considerable turbulence to remain suspended and being reproductive in the plankton.

Highest overall levels of Melosira occurred in 1967. Except on July 28, 1967, levels were never found below any recorded in 1968 or 1969. A level of 6,300/liter was found on June 14. A decline to 1,283/liter by July 26 was followed by a summer high of 14,374/liter on August 9. No fall maximum occurred as a low of 583/liter was found on November 24.

During the period of late February to early May in 1968, levels of Melosira rose from less than 10/liter to 1,000/liter. After stabilizing near 1,000/liter, a summer pulse began in late June. A peak of 2,930/liter was reached on July 2, followed by a decline to 210/liter by September 11. A fall increase peaked at 840/liter by October 4.

The summer increase of 1969 appeared earlier than in the two preceding years with 78/liter on May 2. A peak of 2,030/liter was recorded on July 1. A gradual decline to zero by September 9 followed.

Lund (1955) found the autumnal rise in English lakes to be so fast that it could not be explained by cell division. In Enemy Swim, the largest population was 15,000/liter and never increased at an unexplainable rate. The greatest rise between sampling dates was approximately 10,000/liter in a two week period in August. Petri and Larson (1969) found from 600 to 1,200 counts/ml in May and 1 to 150/ml in October when sampling Enemy Swim in 1967. In Lake Herman, they recorded less than 150/ml in May and October.

Levels of Melosira increased after spring ice melt and reached a peak in the late spring. Levels were higher in 1967 than in 1968 or 1969. Highest levels of each year occurred at a water temperature of 19 C. Lund (1955) suggested two causes of Melosira periodicity: 1) turbulence, 2) inflow controls amount suspended in outflow. Neither of these factors could be measured during the study. Rises did occur shortly after the ice left in the spring which could be attributed to turbulence.

Stephanodiscus

Levels above 11,000/liter occurred either in June or July of each year in Enemy Swim. Stephanodiscus levels were less than 2,000/liter in Lake Herman except when 14,000/liter were recorded in 1967.

Samples taken on June 14, 1967, contained 11,800/liter, followed by a decline to 700/liter by July 26. Stephanodiscus levels peaked at 10,281/liter on August 9 before beginning to decline. A count of 1,633/ liter was reached by August 23. After rising to 4,813/liter by August 28, Stephanodiscus numbers decreased to 568/liter by September 27. During October and November, levels ranged from 933 to 1,138/liter.

Samples taken in January and February of 1968 contained 24/liter. On April 6, 2,917/liter were found before increasing steadily to a peak of 45,718/liter by July 2. After the maximum, a decline to 175/ liter by August 7 followed. A small increase to 2,575 liter occurred by August 14 before Stephanodiscus levels decreased. A total of 1,190/ liter was found on October 4.

A spring bloom in 1969 took place from May to early July. A level of 739/liter was found on May 3 before increasing to 70,000/liter by June 13. Samples taken from early July to August remained between 3,180 and 3,900/liter before gradually declining to 630/liter by November 8.

Stephanodiscus in Lake Herman was found only on August 1, 1967 at a level of 14,000/liter.

Levels in 1968 were greatest on April 3, when 525/liter were found. This level was attained after an increase from the 35/liter counted on February 21. Stephanodiscus disappeared from samples after July 1.

Stephanodiscus levels were spotty in 1969. A level of 700/liter was recorded on June 3. The peak of 1,900/liter was reached on June 14.

After declining to zero by June 30, Stephanodiscus was found on three other dates. A count of 467/liter was recorded on both July 8 and 22, while 392/liter were present on October 24.

Tucker (1957) found Michigan lakes to have greatest numbers of Stephanodiscus in the spring and fall although not dominant. Diatoms were dominant in the winter and spring in a study by Davis (1962). Stephanodiscus in Enemy Swim reached peak levels during June or July. Only in 1967, did a peak appear after the end of July. In Lake Herman, Stephanodiscus was recorded in August, 1967, while in 1968 and 1969, the highest numbers were found in the spring. Stephanodiscus was recorded in the fall of 1969. Petri and Larson (1969) reported less than 150/ml in Enemy Swim during May and October of 1967. In Lake Herman, they did not find Stephanodiscus in May, but October samples had 301 to 600/ml.

Surirella

Surirella was found only in Lake Herman. Maximum levels recorded were never above 4,000/liter. Occurrences were only spotted in 1967 and 1968 with less than 550/liter recorded.

Surirella was not recorded during the portion of 1967 sampled. It was first found on April 3, 1968, at a level of 510/liter. After dropping to zero by April 30, levels rose to 48/liter by May 31. From July 1 to the end of sampling, Surirella was not found in the samples.

The first samples of 1969 contained no Surirella. By June 14, 118/liter were present. A general increase followed which peaked at 4,000/liter on August 21. A level of 1,500/liter was reached by September 5 before rising to 2,400/liter by October 24. Surirella was absent from the December 15 samples.

No specific chemical changes appeared related to levels of *Surirella* in Lake Herman. Hutchinson (1967) stated that there is obviously a tendency for some genera, notably *Surirella*, which are strictly benthic in the temperate region, to produce planktonic species in the tropics. All specimens of *Surirella* collected in this study were collected as planktonic individuals. If *Surirella* is strictly benthic in temperate regions, some factor such as agitation due to wind action must be carrying the cells into the plankton.

Ceratium

Ceratium was found in both lakes, but much less often in Lake Herman. Brief appearances were recorded in Lake Herman during August, 1967 and June and July of 1969. In Enemy Swim, *Ceratium* formed spring maxima in 1967 and 1969 with fall maxima in 1967 and 1968. An early summer maximum developed in 1968. Summer minima appeared in all three years. The peak level found in Enemy Swim was 9,363/liter while in Lake Herman a high of 4,375/liter was recorded.

Levels of *Ceratium* in Enemy Swim were high when sampling started in 1967. On June 14, a level of 8,050/liter was present, but decreased to 116/liter by July 26. A fall pulse began in early August and peaked at 4,200/liter on August 28. *Ceratium* was not found in the samples by November 24.

Ceratium was not found in the 1968 samples until a level of 35/liter was recorded on June 3. After an increase, a level of 2,528/liter was found on July 17. After declining to 700/liter by July 31, *Ceratium* numbers rose to a maximum of 9,363/liter by August 21. By early October, a level of 350/liter had been reached.

The highest 1969 level of 3,150/liter was found on June 13, rising from a count of 146/liter on May 2. A decline followed with 630/liter found by June 24. Levels ranged from 800 to 900/liter until Ceratium disappeared from samples by November 8.

Ceratium was recorded in Lake Herman on one date in 1967. A level of 4,400/liter was found on August 15.

Ceratium was not found in any 1968 samples. Ceratium was recorded on two dates in 1969. A level of 117/liter was counted on June 14 while July 8 had 234/liter present.

Graham (1966) found Ceratium in two South Dakota farm ponds with maximum numbers in November. In this study, Ceratium had almost disappeared by November of all three years. Peak levels were recorded in June or August. Tucker (1957) found largest populations in Lake Lansing during August or September. Ceratium was not reported by Petri and Larson (1969) in Enemy Swim or Lake Herman during 1967.

Numbers of Ceratium in both lakes appeared to increase when the water temperature was above 15 C. Ceratium in Lake Herman was found when the water was more than 21 C. In Enemy Swim, Ceratium levels declined in the fall when the water temperature was less than 15 C. In 1969, 146/liter were found on May 2 at 10 C. By the first of June, the water had warmed to 15 C and levels rose to 1,000/liter. In all other cases, the temperature was 15 C or more when Ceratium occurred. Sampling in 1967 was started after the water had warmed to above 15 C. Davis (1962) found Ceratium to occur at 15 C or above in the Cleveland Harbor area of Lake Erie.

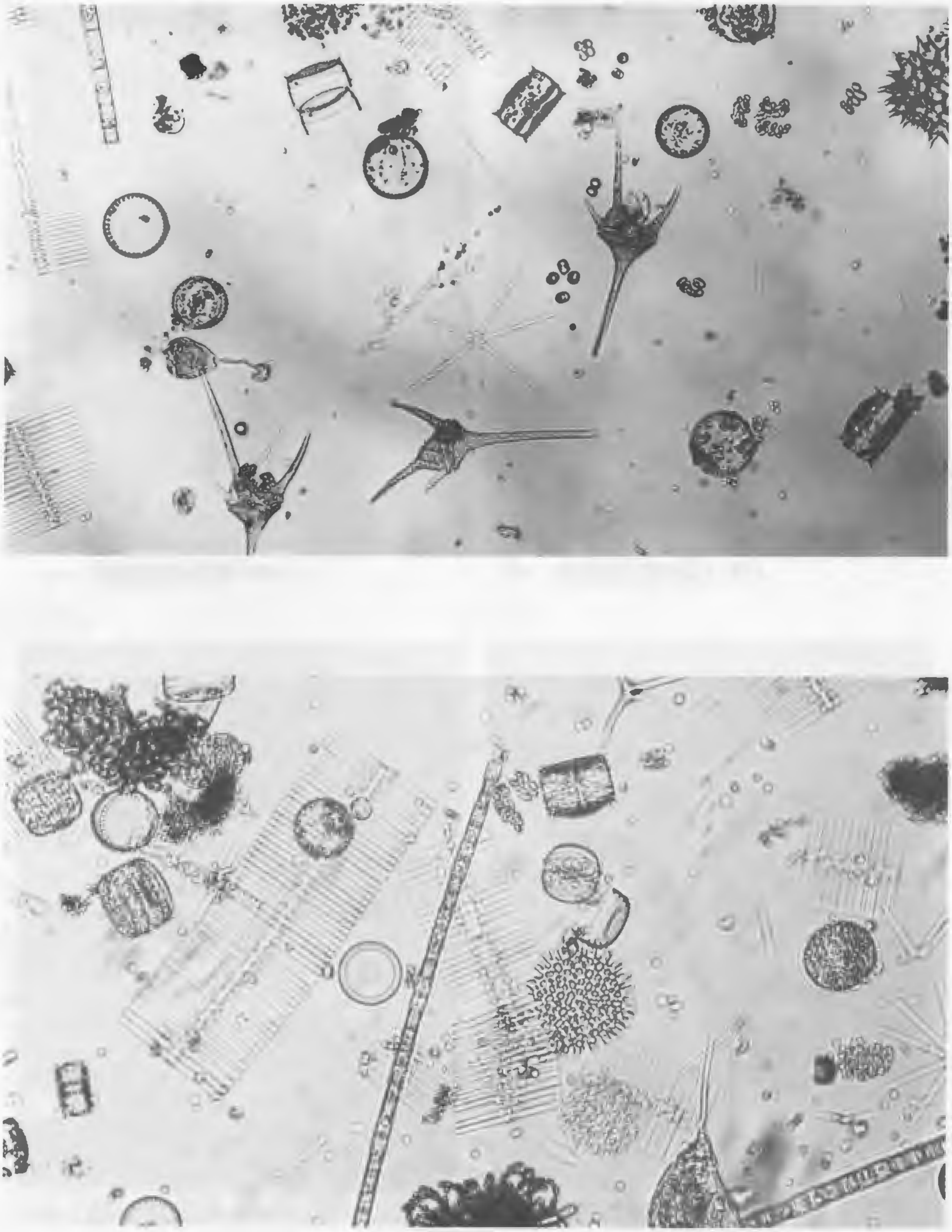
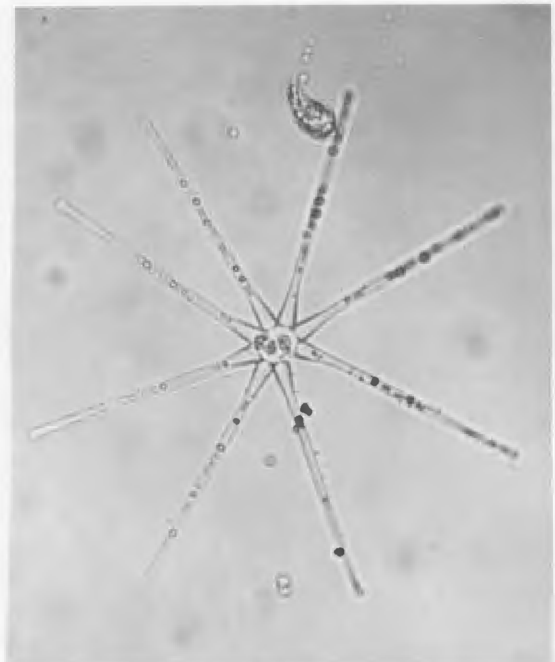
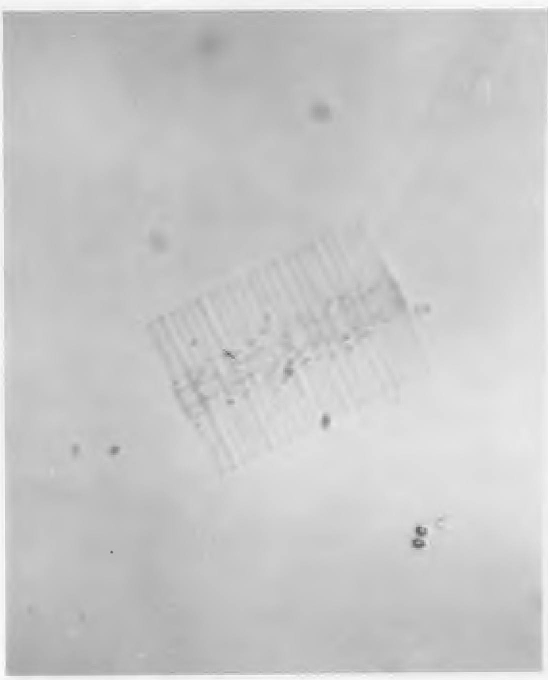


Figure 11. Algal samples from Enemy Swim Lake.

1. Staurastrum sp.



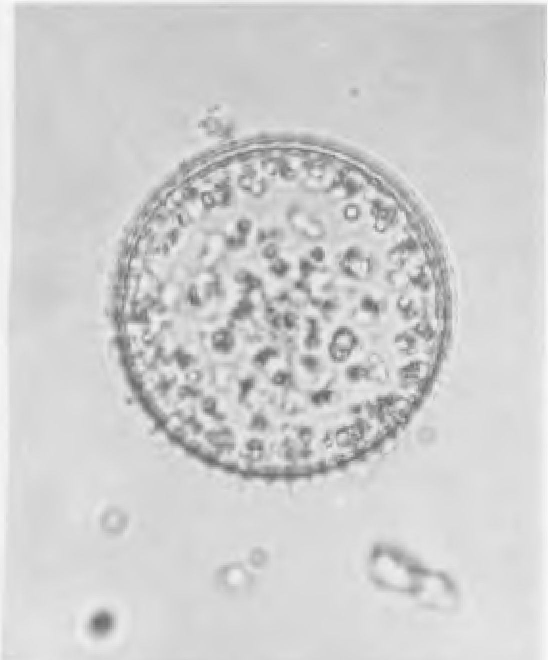
2. Asterionella sp.



3. Fragilaria sp.

4. Anabaena sp.

Figure 12. Common algae found in Enemy Swim Lake (1, 2, 3, and 4) and Lake Herman (2, 3, and 4).



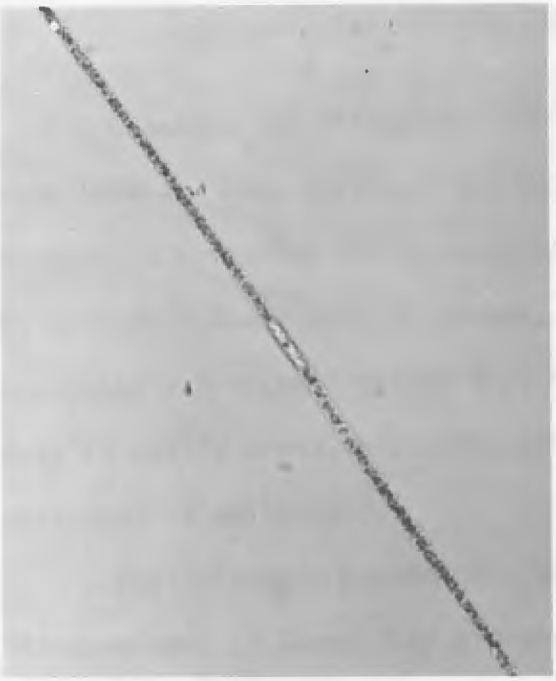
1. Stephanodiscus sp.

2. Ceratium sp.

3. Melosira sp.

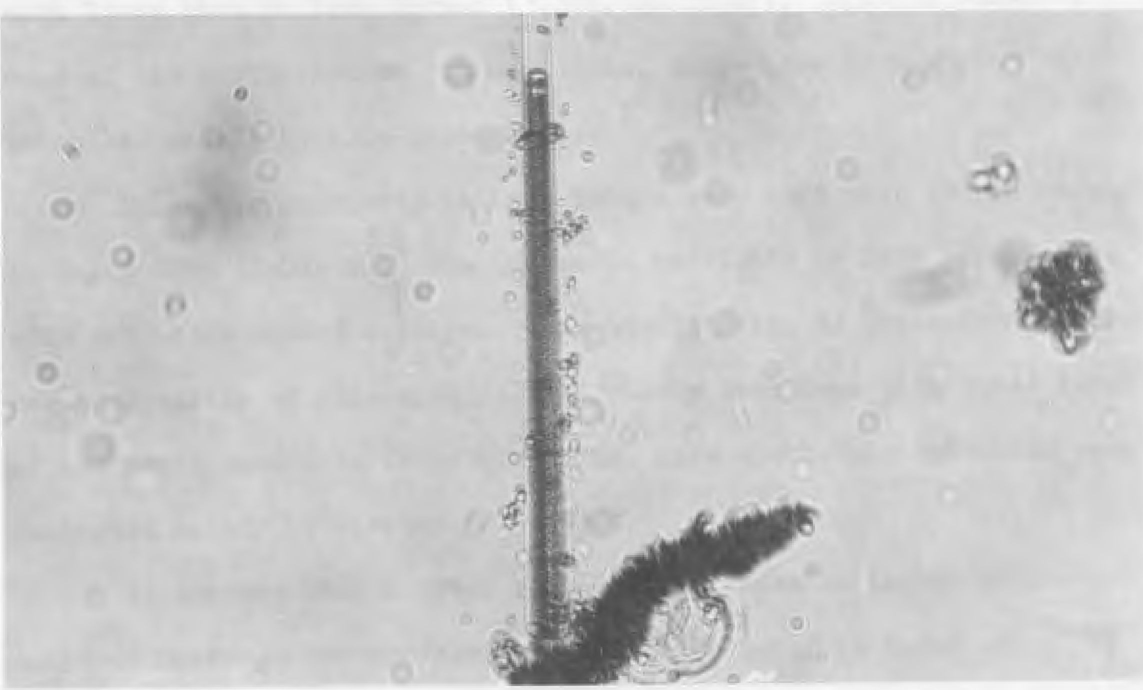
4. Dinobyron sp.

Figure 13. Common algae found in Enemy Swim Lake (1, 2, 3, and 4) and Lake Herman (1 and 2).



1. Aphanizomenon sp.

2. Stephanodiscus sp.



3. Melosira sp.

Figure 14. Common algae found in Enemy Swim Lake (1, 2, and 3) and Lake Herman (1 and 2).

SUMMARY AND CONCLUSIONS

Chemical and biological differences were observed between Enemy Swim Lake and Lake Herman. The two lakes are found within the same geographic area, but differ morphologically and in use of their watersheds. Enemy Swim is deeper, less turbid, and contains less inorganic and organic matter than Lake Herman. The watershed of Enemy Swim is mostly grassland, while over fifty per cent of Lake Herman's watershed is cultivated.

Phytoplankton populations were found to be quite different. The standing crop in Enemy Swim was smaller and more stable than in Lake Herman. The maximum standing crop in Enemy Swim (141,000/liter) was much lower than in Lake Herman (3,300,000/liter). Diatoms composed most of the phytoplankton of Enemy Swim, while Lake Herman was inhabited mainly by blue-green algae.

Dissolved nutrients in Lake Herman were more than double those in Enemy Swim (Table 1). The increased nutrients in Lake Herman were more conducive toward a larger, less stable (Fig. 4) phytoplankton crop composed mostly of blue-green algae. Enemy Swim Lake with lower levels of nutrients seemed to favor a smaller, more stable phytoplankton crop dominated mainly by diatoms (Fig. 3).

It appears that a study of the differences in inorganic nutrients between two northern prairie lakes could be based on relatively few samples taken at two to three month intervals. During the study period, basic differences in nutrient levels between the lakes were maintained.

A study of the phytoplankton in northern prairie lakes would need to be quite extensive with a long sampling period. Major differences in population levels, dominance, and composition were observed from year to year, season to season, and in some cases, from week to week in both lakes.

LITERATURE CITED

American Public Health Association, Inc. 1965. Standard methods for the examination of water and wastewater. APHA. New York. 769 pp.

Bell, Thomas N. 1961. Algal flora of Gavins Point Dam. Proceedings of the S. Dak. Acad. Sci. 40:125-131.

Billaud, Vera. 1966. Aspects of nitrogen nutrition of some blue-green algae. From Environmental requirements of blue-green algae-proceedings of a symposium. U. S. Department of Interior. pp. 35-54.

Canter, H. M. and Lund, J. W. G. 1948. Studies of plankton parasites. I. Fluctuations in the numbers of Asterionella formosa Hass., in relation to fungal epidemics. New Phyt. 47:238-261.

Davis, Charles C. 1962. The Cleveland harbor area of Lake Erie. Ecological Mono. 32(3):209-248.

East Dakota Conservancy Sub-District. 1969. Lake Herman Report. 48 pp.

Fritz, James S. and Yamamura, Stanley S. 1955. Rapid microtitration of sulfate. Anal. Chem. 27:1461-1464.

Gloss, Steven P. 1969. Water quality changes under ice cover in northern prairie lakes. M. S. Thesis, S. Dak. State Univ. (unpublished).

Graham, Larry. 1966. Limnology of three farm ponds in south central South Dakota. M. S. Thesis. S. Dak. State Univ. (unpublished)

Griffith, W. H. 1916. Microorganisms of the James River. Proceedings of the S. Dak. Acad. Sci. 1:73-77.

Hach Chemical Company. 1967. Water and wastewater analysis procedures. Catalog No. 10. Hach Chemical Company, Ames, Iowa. 104 pp.

Hamilton, D. H. Jr. 1969. Nutrient limitation of phytoplankton growth. Limnol. and Oceanogr. 14(4):579-590.

Holland, Ruth E. 1969. Seasonal fluctuations of Lake Michigan diatoms. Limnol. and Oceanogr. 14(3):423-436.

Hutchinson, G. E. 1944. Limnological studies in Connecticut. VII. A critical examination of the supposed relationship between phytoplankton periodicity and chemical changes in lake water. Ecology. 25:2-26.

_______. 1967. A treatise on limnology. Vol. 2. John Wiley and Sons, Inc. New York. 1115 pp.

Johnson, W. M. 1959. The ecology of an oxbow lake in S. E. South Dakota. M. S. Thesis. Univ. of S. Dak. (unpublished).

Jorgensen, Erik G. 1956. Growth inhibiting substances formed by algae. Physiologia Plantarium. 9:712-726.

Lund, J. W. G. 1950. Studies of Asterionella formosa Hass. II. Nutrient depletion and the spring maximum. J. of Ecology. 38:1-35.

_______. 1955. Further observations on the seasonal cycle of Melosira italica (EHR) KUTZ SUBSP Subarctica O. MULL. J. of Ecology. 43:90-102.

_______. and Talling, J. F. 1957. Botanical limnological methods with special reference to the algae. Botanical Review. 23:489-548.

Maciolek, J. A. 1962. Limnological organic analyses by quantitative dichromate oxidation. Research Report 60. USDI, BSFW, D. S. Fish and Wildlife Service. 61 pp.

Pearsall, W. H. 1932. Phytoplankton in the English lakes. II. The composition of the phytoplankton in relation to dissolved substances. J. of Ecology. 20:241-262.

Petri, Lester R. and Larson, L. Rodney. 1969. Quality of water in selected lakes of Eastern South Dakota. U. S. Geological Survey. 44 pp.

Prescott, G. W. 1951. Algae of the Western Great Lakes area. Bull. Cranbrook Inst. Sci., 30 xiii. 946 pp.

_______. 1964. How to know the freshwater algae. Wm C. Brown Co., Dubuque, Iowa. 272 pp.

_______. 1968. The algae: A review. Houghton Mifflin Company, Boston. 282 pp.

Provalsoli, Luige. McLaughlin, John J. A. and Pintner, Irma J. 1954 Relative and limiting concentrations of major mineral constituents for the growth of flagellates. Trans. N. Y. Acad. Sci. Ser. 2 16:412-417.

Rothrock, E. P. 1935. Geology and water resources of Day County. South Dakota. Univ. of S. Dak., Vermillion.

Tucker, Allan. 1957. The relation of phytoplankton periodicity to the nature of the physico-chemical environment with special reference to phosphorous II. Seasonal and vertical distribution of the phytoplankton in relation to the environment. Amer. Mid. Nat. 57:334-370.

Soils of Day County, South Dakota. Agronomy Dept. Ag. Exp. Station. S. Dak. State Univ. 56 pp.

Soils of Lake County, South Dakota. Agronomy Dept. Ag. Exp. Station. S. Dak. State Univ.

Sprague, James W. 1958. Report of fisheries investigations during the fourth year of impoundment of Gavins Point Reservoir, Dept. of Game, Fish, and Parks, South Dakota.

Wiebe, A. H. 1930. Investigation of plankton production in fish ponds. Fisheries Document No. 1082. U. S. Dept. Commerce, Bureau of Fisheries. 137-176.