

A LIMNOLOGICAL INVESTIGATION
OF JORDAN LAKE, MICHIGAN
WITH PARTICULAR REFERENCE
TO THE ALGAE WHICH CAUSE
"WATER BLOOM"

Thesis for the Degree of M. S.
MICHIGAN STATE COLLEGE
Wilbert Ernest Wade
1948

This is to certify that the
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with Particular Reference to the Algae which Cause
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A LIMNOLOGICAL INVESTIGATION OF JORDAN LAKE, MICHIGAN
WITH PARTICULAR REFERENCE TO THE ALGAE WHICH CAUSE
"WATER BLOOM"

By
Wilbert Ernest Wade

A THESIS

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TABLE OF CONTENTS

I. INTRODUCTION	Page
A. History of the Investigation	1
B. Scope of Study	3
C. Acknowledgements	4
II. DESCRIPTION OF JORDAN AND TUPPER LAKES	
A. Location	5
B. Geological History	5
C. General Physical Characteristics	7
D. General Chemical Characteristics	10
E. Phytoplankton	12
F. Other Algal Growths	13
G. Higher Aquatic Plants	13
H. Fish and Fish Food Organisms	15
III. "WATER BLOOMS" AND RELATED FACTORS	
A. History of "Blooms" and Related Literature . .	18
B. Organisms That May Cause "Water Bloom"	22
C. Injurious Effects of "Water Bloom"	24
D. Chemical and Physical Factors Affecting "Water. Blooms"	30
IV. DATA AND MEASUREMENTS	
A. Methods and Procedures	43
B. Data	52
V. DISCUSSION OF RESULTS	78

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VI. TREATMENT AND CONTROL	Page
A. Types of Treatment Other Than Copper Sulphate. .	102
B. Copper Sulphate, Use and Objections To Use . . .	104
C. Treatment of Jordan Lake	113
D. Brighton Lake and Copper Sulphate Treatment. . .	114
VII. CONCLUSIONS	118
VIII. SYSTEMATIC LIST OF ALGAE IN JORDAN LAKE INCLUDING	
PLATE AND PLATE DESCRIPTIONS	122
IX. BIBLIOGRAPHY	166

A Limnological Investigation of Jordan Lake, Michigan With Particular Reference to the Algae Which Cause "Water bloom".

I. INTRODUCTION

A. History of the Investigation

In many Michigan lakes a dense blue-green algal scum, which develops at the surface during summer and early fall, often becomes obnoxious to vacationers, swimmers and others using the lakes for recreational purposes. Operators of municipal water-works may also experience difficulties because of odors and tastes imparted to the water by these algae. Control measures for such superabundant growths, often called "water blooms", have been studied in many states, but available literature fails to show that investigations of this nuisance condition and remedies have been reported in Michigan. Although not all of the 5,000 lakes in Michigan are subjected to this obnoxious condition, many in southern Michigan are, especially those near centers of greatest population. Thus a determination of the causes of such conditions and development of methods for their correction obviously would be of great benefit to the people of Michigan who seek to enjoy the recreational facilities of lakes. Secondly, correction of algal nuisances would help maintain the excellent reputation of Michigan lakes among out-of-state tourists;

thus benefiting Michigan citizens who earn their livelihood by operating beach cottage resorts, boat liveries, bait and sporting goods stores and other recreational enterprises related at least indirectly to lakes.

The occurrence of a "water bloom" condition at Jordan Lake, Lake Odessa, Michigan, first came to the attention of the writer in May, 1947. A group of local lake-front property owners had previously petitioned (October, 1946) the Michigan State Department of Health for a survey of Jordan Lake. This survey was to determine whether pollution was occurring in Jordan Lake from the municipal sewage plant effluent and if so, whether the pollution was a causative factor in the "water bloom" condition. Accordingly Mr. R. G. Foster of the State Stream Control Commission conducted a survey in October, 1946, but detected no pollution from sewage. Mr. Foster suggested to the residents interested in the "water bloom" condition that they confer with Dr. G. W. Prescott, phycologist at Michigan State College, who was familiar with algae problems associated with water supplies. A group of residents, after having organized the Lake Odessa Improvement Association requested Dr. Prescott to make an inspection. Dr. Prescott, Mr. Foster and the writer visited Jordan Lake on May 12, 1947, made some preliminary water collections, and interviewed the officers of the Improvement Association concerning the possibility of the writer conducting a survey of the lake. Subsequently,

arrangements were made for the writer to undertake a study of the biological and limnological conditions of Jordan Lake under the direction of Dr. Prescott. The Improvement Association gladly offered their assistance, including the use of a boat and motor, and a small fund to defray transportation costs.

The State Stream Control Commission continued their investigation of Jordan Lake and officially condemned it because of pollution on July 12, 1947. Their investigation indicated the presence of sewage pollution on and around the municipal beach and determined that the location of the pollution changed according to wind direction, thus creating a continuous threat from pathogenic organisms at the municipal beach and all areas in the northeast one-third of Jordan Lake. (See map). The report also recommended that additions and improvements for the village sewage treatment facilities were necessary to protect the natural waters of Jordan Lake against repeated contamination from untreated sewage.

The Improvement Association realized that additions to the sewage facilities would not necessarily solve the "water bloom" problems, and so were willing to support the writer's survey which had begun June 24th.

B. Scope of Study

The primary purposes of the survey were:

1. To determine what organisms were responsible for the

profuse algal growth and to learn at what time and in what quantity, objectionable organisms occurred in Jordan Lake. This would include also an examination to learn why these organisms formed obnoxious scums.

2. To determine whether there existed a correlation between limnological factors, such as water chemistry, and the "bloom" conditions.

3. To determine by chemical analyses, the sources and quantities of fertilizing substances entering the lake, and the relative fertilizing capacity of the lake itself.

4. To determine effectiveness of methods of algae control by the use of copper sulphate.

5. To record, if possible, a year-around analysis of lake conditions (chemical, physical and biological) so as to determine where the "bloom"-producing organisms wintered over and to learn at what time chemical treatment might be administered to be most effective.

C. Acknowledgements

The writer wishes to thank Dr. G. W. Prescott for his assistance in many ways during the time this study has been in progress. His considerable knowledge, generous advice and helpful criticism have been of great value. Acknowledgements are also due Drs. G. S. Steinbauer and F. L. Wynd and Mr. Herman S. Silva of the Botany Department of Michigan State College for their helpful suggestions. I wish to thank Mr. F. E. Eldridge, recently of the Sanitary Engineering Department of Michigan State College for

• Die Bedeutung der Sprache ist in der Literatur und in der Kunst von zentraler Bedeutung. Die Sprache ist das Medium, durch das wir unsere Gedanken und Gefühle ausdrücken können. Sie ist das Werkzeug, mit dem wir unsere Welt erschaffen und verstehen. In der Literatur wird die Sprache oft als Kunstform betrachtet, die es ermöglicht, die menschliche Erfahrung in einer Weise darzustellen, die über das rein Sachliche hinausgeht. In der Kunst wird die Sprache oft als Mittel zur Darstellung von Bildern und Ideen verwendet, die in Worten nicht fassbar sind. Die Sprache ist also ein zentraler Bestandteil unserer Kultur und unseres Lebens.

• Die Rolle der Literatur ist es, die menschliche Erfahrung in einer Weise darzustellen, die über das rein Sachliche hinausgeht. Sie ermöglicht es uns, die Welt aus der Perspektive anderer zu sehen und zu verstehen. Literatur ist ein Spiegelbild der Gesellschaft, die sie produziert. Sie reflektiert die Werte, Normen und Ideale einer Kultur. Durch Literatur können wir uns mit anderen Menschen verbinden und ihre Erfahrungen teilen. Literatur ist also ein wichtiges Mittel zur Bildung und zur Erhellung der menschlichen Existenz.

• Die Kunst der Sprache ist die Kunst, die Sprache so zu verwenden, dass sie nicht nur Informationen vermittelt, sondern auch Freude und Schönheit bereitet. Die Kunst der Sprache liegt in der Wahl der Worte, in der Satzgestaltung und in der Rhetorik. Ein guter Schriftsteller weiß, wie er die Sprache so einsetzen kann, dass sie seine Gedanken und Gefühle perfekt ausdrückt. Die Kunst der Sprache ist also eine Kunst der Form und der Gestaltung.

• Die Sprache als Werkzeug ist ein Werkzeug, das wir verwenden, um unsere Gedanken und Gefühle auszudrücken. Es ist ein Werkzeug, das wir verwenden, um uns mit anderen Menschen zu verbinden und unsere Welt zu verstehen. Die Sprache ist ein Werkzeug, das wir verwenden, um unsere Existenz zu erschaffen und zu gestalten. Sie ist ein Werkzeug, das wir verwenden, um unsere Welt zu verbessern und zu bereichern. Die Sprache ist also ein zentraler Bestandteil unserer Kultur und unseres Lebens.

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the use of the Sanitary Engineering laboratory facilities and for his generous assistance in chemical analysis procedure. Also, I wish to thank Drs. E. N. Transeau and C. E. Taft of Ohio State University and Dr. F. Drouet of the Chicago Museum of Natural History for reviewing some of my determinations and for the identifications of a number of species. Acknowledgements are also due the Lake Odessa Improvement Association, especially to Messrs. Emmett Blakeslee and Ernest Bertotti for their cooperation during the survey.

II. DESCRIPTION OF JORDAN AND TUPPER LAKES

A. Location

Jordan Lake borders the village of Lake Odessa, and lies in Woodland Township, Barry County (T 4 N., R. 7 W., Sec. 3, 4 and 5) and Odessa Township, Ionia County (Sec. 33 and 34). Tupper Lake is situated in Odessa Township, Ionia County (Sec. 26, 27, 34, 35) and lies approximately one mile northeast of Jordan Lake, being connected to it by a shallow partly artificial channel.

B. Geological History

Jordan and Tupper Lakes are glacial lakes, having been formed contemporary^{ly} with the Arkona Lake stage of the Pleistocene Period. The Lansing moraine was laid down

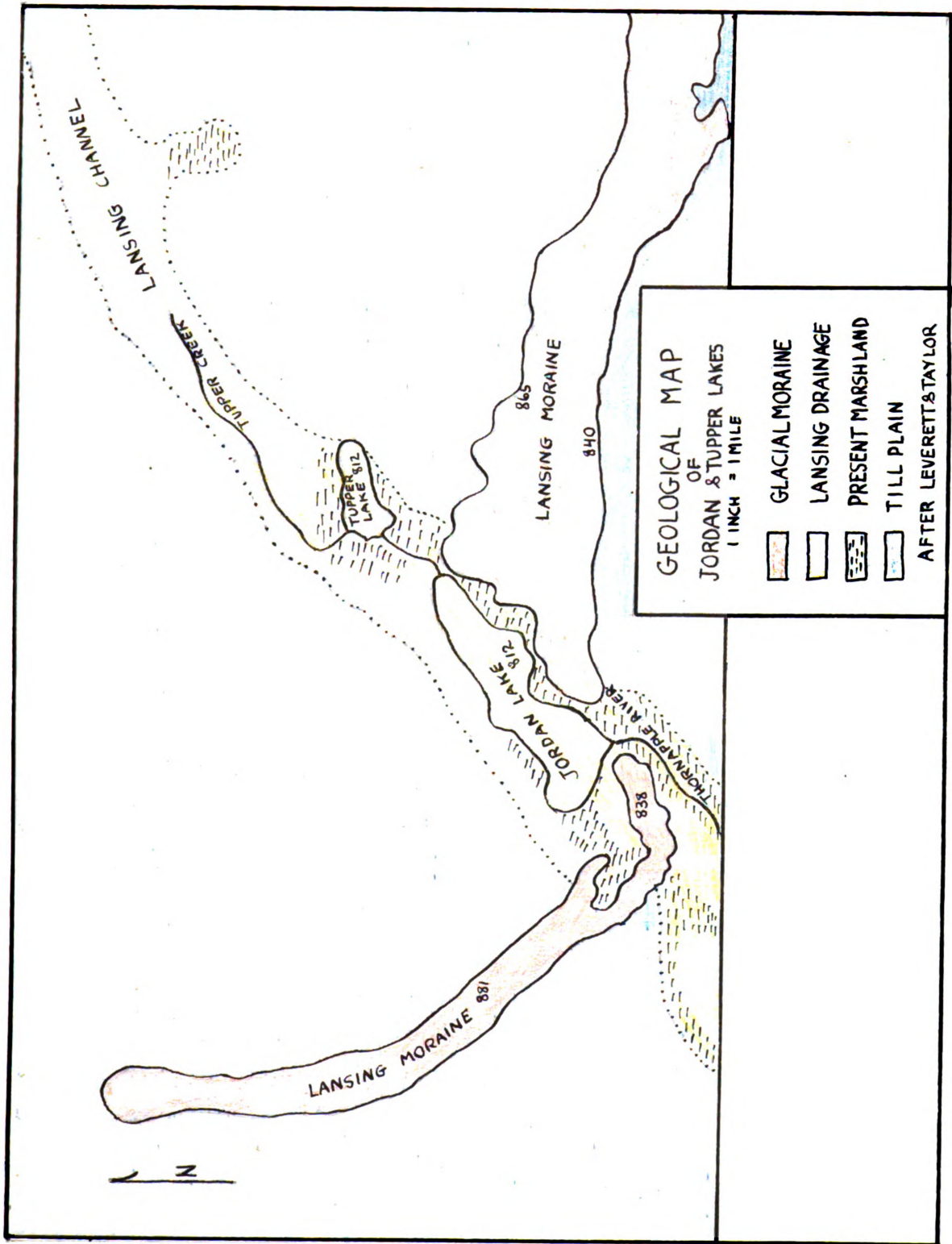
DESCRIPTION OF JORDAN AND UPPER LAKE

referred to as

Upper Lake is situated in Okeechobee Township, (Sec. 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40) and lies approximately 10 miles northeast of Jordan Lake, being connected to it by a small, partly artificial channel.

B. Geological History

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contemporarily with the Annona lake stage of the
The Llanos movement was laid down



along the southern base of the present Jordan Lake (see geological map) during a halt in the retreat of the Saginaw lobe of glacial ice. Drainage water from the glacier ice to the northeast flowed in a southwesterly direction through the Lansing Channel cutting the moraine. As the demands upon this area, a valley train, lessened, the water followed roughly the general area now occupied by Thornapple River, the outlet to Jordan Lake and Tupper Creek, the inlet to Tupper Lake. The area of the present Tupper Lake also lay in the valley train mentioned above. This lake has remained a body of water in the original drainage-way, as has Jordan Lake, because of the greater depth of its basin.

C. General Physical Characteristics

Although Jordan Lake is well-known in southern Michigan for its fine fishing, no attention has been given to its limnological nor biological features. Jordan Lake occupies approximately an area of 1,000 acres. The long axis, $1\frac{1}{2}$ miles long, runs in a general northeast-southwest direction. The width varies from $\frac{5}{16}$ of a mile at the northeast end to $1\frac{1}{16}$ of a mile at the southwestern end. The shoreline circumference is approximately 4 miles. The lake margin is shallow and has a gentle slope completely around the lake as evidenced by growth of both emergent and submerged vegetation. The average depth is estimated at 20 to 25 feet, the northeast end being 0-25 ft. deep and one depression in the southwestern end reaching a depth

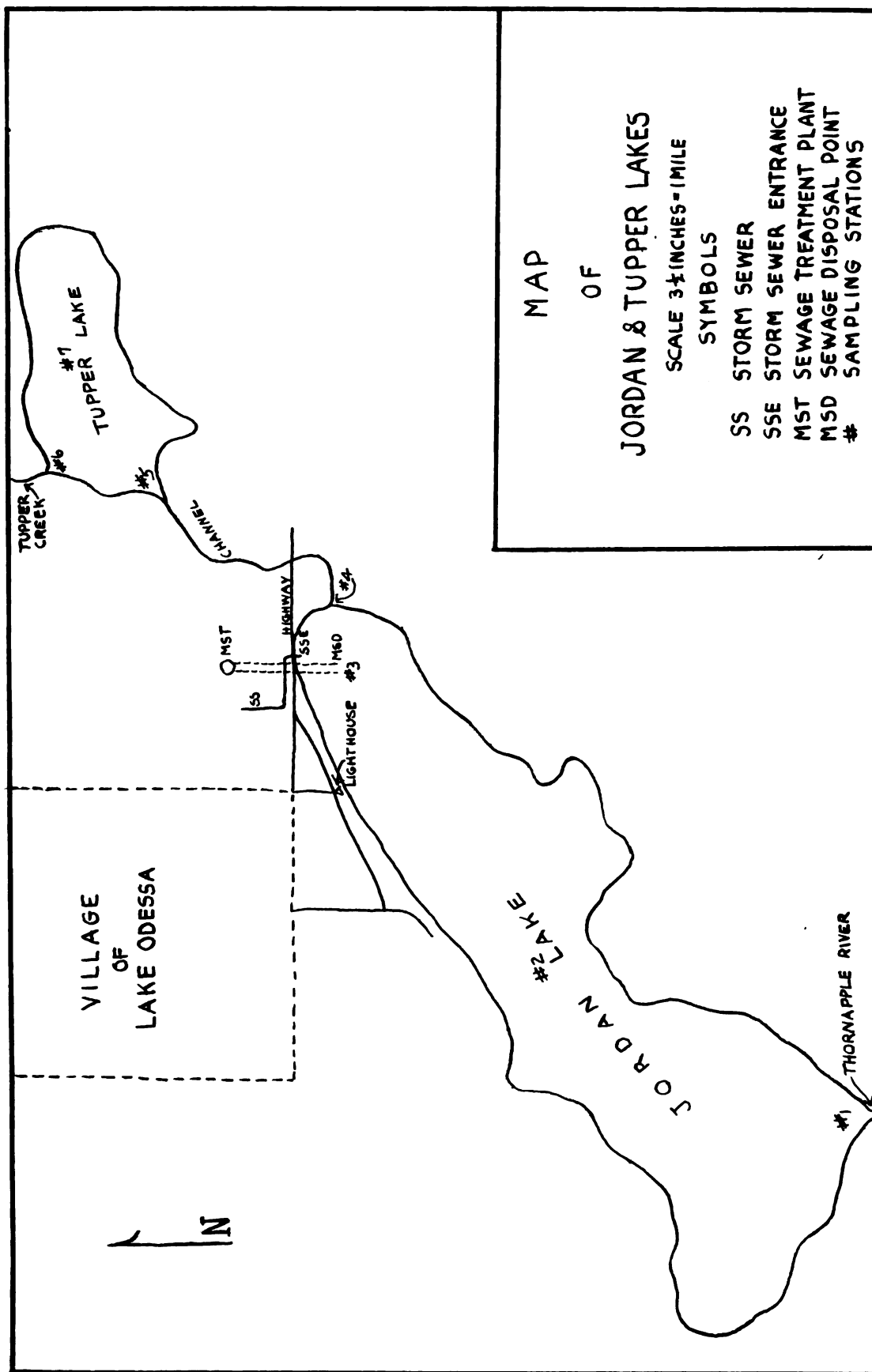
of 75-80 ft. according to local sources of information. Life-long residents of the village claim that a current of spring-fed water enters the lake at the northeastern end and maintains a distinct channel through the lake. This last information has not been verified by the writer.

The Thornapple River is the outlet of Jordan Lake arising at the southern end. The lake is fed at the northeastern end principally by the channel from Tupper Lake. This channel is shallow, supports heavy growths of submerged and emergent vegetation, and during the summer becomes almost stagnant. This condition exists during dry seasons when the Tupper Lake water level becomes low. Inasmuch as both Jordan and Tupper Lakes have a level of 812 feet above sea level, the flow in the channel between them is not great except during rainy seasons.

The storm sewer effluent from the village flows in an open ditch, from a point approximately 100 yards from the highway (map symbol ss), then parallel along the highway for 250 yards to the point (symbol sse) where it enters the lake by a culvert.

The municipal sewage plant effluent enters the center of the northeast arm of the lake by an underground pipe (symbol msd). This plant is composed of 6 septic tanks, each of 15,400 gallons capacity. The domestic sewage entering the plant is detained for 6 to 8 hours to permit settlement of sludge and then is pumped from the tanks and chlorinated before entering the drainage pipe to the lake.

The bottom deposits are in general of a black mucky



material except near the inlet where there is a meager sand deposit.

In addition to the village of Lake Odessa along the northern periphery of Jordan Lake, there are homes and cottages about the lake, occupying approximately one-third of the shoreline. The number of sewers or storm sewers entering from these habitations is unknown.

Tupper Lake is approximately $3/4$ of a mile long and $3/8$ of a mile at its greatest width. Tupper Creek, which drains both swamp areas and farm land to the northeast, enters the lake at the north. The creek is a small stream of very slow moving, muddy-brown water, becoming almost stagnant in summer. Low swampy regions surround the lake on the north, south and southwest sides. No data ~~is~~ are available on the depth of this lake. Marginal waters are shallow and the bottom ~~here~~ has a gentle slope accompanied by a heavy growth of both submerged and emergent aquatic plants. Several private cottages are present on this lake, and a commercial boat livery is operated at the extreme eastern end.

D. General Chemical Characteristics of the Lakes.

Both Jordan and Tupper Lakes are hard-water drainage lakes, having relatively similar water chemistry. Jordan Lake is high in half-bond carbon dioxide, as much as 155 p.p.m. (in May), and has a pH that varies from 7.2 to 9.2 (Feb. to Aug.). Dissolved oxygen is abundant throughout summer months. Total nitrogen ranges from 2.72 to 6.4

p.p.m. Inorganic nitrogen values vary throughout the growing season but are relatively abundant (NO_2 up to .044 p.p.m., NO_3 up to 6 p.p.m.). Inorganic phosphorous was present in .015 p.p.m. in August. In addition to drainage from Tupper Lake, Jordan Lake receives abundant supplies of bicarbonates, nitrogen and phosphorous both organic and inorganic from the sewage effluent and storm sewer. Diatoms are abundant during the cooler months, indicating an ample supply of silica. As previously mentioned bottom deposits are black and oozy, similar to the productive type of lake having a high organic content.

Although Jordan and Tupper Lakes are similar chemically, the channel connecting them has some different characteristics. In the spring when the water level of both lakes is high, the chemistry of the channel water is more like that of Tupper Lake. The plankton organisms are identical thus indicating that Tupper Lake adds both organisms and nutrients to Jordan Lake. However, during the summer season, the water level drops, the resulting current is almost nil, and an abundant growth of aquatic plants almost entirely fills the channel. During this summer period the water entering Jordan Lake from the channel is a dark brown, indicating high humic acid-content, probably derived from swampy areas bordering the channel. The dissolved oxygen content of the channel near its inlet to Jordan Lake falls to 0 p.p.m. during August, although a few submerged aquatic plants are present. A blanket of duckweed (Lemna minor

Linnaeus) covers much of the surface in the channel during the late summer months and the plankton organisms found at this time in the channel are very few in numbers. The great majority of the plankters are found on the surface, having been driven into the channel from Jordan Lake by the prevailing wind, which is toward the northeast. Although the channel is not an important contributor of plankton to Jordan Lake during the summer, it does continue to supply some nutrients (NO_2 up to .007 p.p.m., NO_3 up to .14 p.p.m., total nitrogen up to 3.02 p.p.m.) The inorganic phosphorous content is also high, .014 and .024 p.p.m. on Aug. 5th and 21st, 1948 respectively.

E. Phytoplankton

A systematic study of all algal organisms in Jordan Lake was undertaken, but more emphasis was placed on the euplankton because of their importance in causing the "water bloom" conditions. In general, the lake supports:

- 1) An abundant growth of Diatoms, mainly during cooler months, with maxima in the spring and fall.
- 2) The Cyanophyta (blue-green algae), although represented throughout the year in collections, becoming the dominant flora during the summer months.
- 3) Euplankton of the Chlorophycean type (green algae) present in some abundance at certain times of the year, never becoming the dominant flora.
- 4) Minor pulses of organisms of the Chrysophycean (Synura) and Dinoflagellatae (Peridinium and Ceratium) groups.

F. Other Algal Growths

Another characteristic of algal growth in Jordan Lake is the profuse development of filamentous algae along shallow shorelines, often floating loose as mats in the lake. These mats, usually composed of Hydrodictyon and Cladophora, but sometimes of Tolyoothrix, were abundant throughout the summer months. As the water level dropped these growths were stranded on shore, often creating a disagreeable odor condition.

G. Higher Aquatic Plants

Jordan Lake supports very abundant growths of both submerged and emergent aquatic vegetation. The entire periphery of the lake is shallow and during the summer months many areas along shore became impassable to boats because of the dense growths of aquatic vegetation. A list of species found in the lake (and kindly identified by Dr. G. W. Prescott), is presented below. Classification is from Fassett (1940).

Typhaccae

Typha latifolia Linnaeus

Najadaceae

Potamogeton americanus Chamisso and Schlechtendal

P. amplifolius Linnaeus

P. confervoides Reichenbach

P. filiformis Persoon

The Role of the Teacher

The teacher's role is to create a learning environment where students can learn effectively. This involves setting clear expectations, providing feedback, and encouraging students to take ownership of their learning. The teacher should also be a facilitator, helping students to explore and understand complex concepts through discussion and problem-solving. In addition, the teacher should be a role model, demonstrating the values and attitudes that are expected of students. The teacher should also be a communicator, keeping parents and the school community informed about student progress and needs. Finally, the teacher should be a reflective practitioner, evaluating their own practice and making adjustments as needed to improve student learning.

The Role of the Student

The student's role is to actively engage in the learning process. This involves setting personal goals, taking responsibility for learning, and seeking help when needed. The student should also be a collaborator, working with peers to solve problems and share knowledge. In addition, the student should be a critical thinker, evaluating information and making informed decisions. The student should also be a responsible citizen, following school rules and contributing to the school community. Finally, the student should be a lifelong learner, continuing to learn and grow throughout their life.

The Role of the Parent

The parent's role is to support their child's learning and development. This involves providing a stable and supportive home environment, setting high expectations, and encouraging their child to learn. The parent should also be a communicator, keeping the teacher informed about their child's progress and needs. In addition, the parent should be a role model, demonstrating the values and attitudes that are expected of their child. The parent should also be a reflective practitioner, evaluating their own parenting style and making adjustments as needed to improve their child's learning. Finally, the parent should be a lifelong learner, continuing to learn and grow throughout their life.

- P. gramineus var. graminifolius Fries
P. natans Linnaeus
P. pectinatus Linnaeus
P. praelongus Wulfen
P. Richardsonii (Bennett) Rydberg
P. zosteriformis Fernald
Najas flexilis (Willdenow) Rostkovius and Schmidt

Alismaceae

Sagittaria latifolia Willdenow

Hydrocharitaceae

Anacharis canadensis (Michaux) Planchon
Vallisneria americana Michaux

Cyperaceae

Scirpus americanus Persoon
S. validus Wahlberg

Lemnaceae

Lemna minor Linnaeus
L. trisulca Linnaeus

Pontederiaceae

Pontederia cordata Linnaeus
Heteranthera dubia (Jacquin) MacMillan

Polygonaceae

Polygonum natans forma genuinum Standford

1. The first step in the process of creating a new product is to identify a market need. This involves conducting market research to determine what consumers are looking for and what gaps exist in the current market. Once a need is identified, the next step is to develop a concept that addresses this need. This often involves brainstorming and prototyping to refine the idea.

2. After the concept is developed, the next step is to create a business plan. This document outlines the financial aspects of the product, including the costs of production, distribution, and marketing. It also includes a sales forecast and a timeline for when the product will be launched. The business plan is crucial for securing funding from investors or lenders.

3. Once the business plan is complete, the next step is to secure funding. This can be done through various means, such as crowdfunding, venture capital, or bank loans. Each option has its own requirements and risks, so it's important to choose the one that best fits the product and the entrepreneur's goals.

4. After funding is secured, the next step is to develop a marketing strategy. This involves identifying the target audience, choosing the right channels to reach them, and creating compelling content that highlights the product's benefits. A strong marketing strategy is essential for getting the product noticed and driving sales.

5. Finally, the product is launched. This is a critical moment for the entrepreneur, as it marks the beginning of the product's journey in the market. It's important to monitor sales and customer feedback closely to make any necessary adjustments and ensure the product is meeting the needs of the market.

The process of creating a new product is a complex one, but it's also a rewarding one. By following these steps, entrepreneurs can increase their chances of success and bring their vision to life. It's important to remember that the process is not linear, and there may be setbacks along the way. However, with persistence and a clear plan, the goal is achievable.

In conclusion, the process of creating a new product involves several key steps: identifying a market need, developing a concept, creating a business plan, securing funding, developing a marketing strategy, and launching the product. Each step is crucial for the success of the product, and entrepreneurs must approach each one with care and attention.

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Ceratophyllaceae

Ceratophyllum demersum Linnaeus

Nymphaeaceae

Nymphaea (tuberosa?) Paine

Nuphar advena Aiton

Lythraceae

Decodon verticillatus (Linnaeus) Elliott

Haloragidaceae

Myriophyllum heterophyllum Michaux

M. exalbescens Fernald

H. Fish and Fish Food Organisms

As previously mentioned, Jordan Lake is well-known throughout Michigan as a lake for good fishing, as evidenced by the large number of anglers present on the lake daily. Numerous large catches have been witnessed by the writer during the summer months. Furthermore testimony from local officials and visiting anglers bear out the fact that Jordan Lake supports an abundant fish population, especially pan fishes. Following is a list of some of the common fishes found in Jordan Lake, furnished by Mr. Emmet Blakeslee, a lake side resident and ardent fisherman, which, although not complete, indicates the type of fish association. (Classification after Hubbs and Lagler 1947).

1. Micropterus salmoides (Largemouth bass)

the following table:

Table 1.1

The following table shows the results of the experiment. The first column shows the number of trials, the second column shows the number of correct responses, and the third column shows the percentage of correct responses.

Table 1.2

The following table shows the results of the experiment. The first column shows the number of trials, the second column shows the number of correct responses, and the third column shows the percentage of correct responses.

Table 1.3

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The following table shows the results of the experiment. The first column shows the number of trials, the second column shows the number of correct responses, and the third column shows the percentage of correct responses.

2. Esox lucius (Northern pike)
3. Pomoxis nigro-maculatus (Common Crappie or Calico bass)
4. Lepomis macrochirus (Blue gill)
5. L. gibbosus (Common sunfish)
6. Perca flavescens (Yellow perch)
7. Ameiurus sp. (Catfish)
8. Catostomus commersoni (Common sucker)

The only evidence of a fish-killing occurred in May of 1948. At that time an estimated 500 dead fish were found along shore. The great majority of these were Crappie Bass (Pomoxis nigro-maculatus). Dr. P. I. Tack, of the Zoology Department, Michigan State College, although not having an opportunity to examine specimens, believed that the death followed the spawning season of this species. He stated that the female of the species often became injured and weakened during spawning and thus are susceptible to diseases. Local residents testified that death of these fish is usual in Jordan Lake during the spring.

Fish food organisms (excluding algae) generally can be separated into two groups; insects and zooplankton. No detailed study of insect larvae or nymphs occurring in Jordan Lake was carried out. Frequent observations made at the lake, however, indicate that nymphs of Ephemera (Mayflies) and Odonata (damselflies and dragonflies) were common. Some nymphs of Plecoptera (stoneflies) were also observed. Aquatic and semi-aquatic adults of the Order Hemiptera were observed for families Corixidae, (Water Boatman); Notonecta-

tidae, (Back-swimmers); Belostomatidae, (electric light bugs); Nepidae, (water scorpion); and Gerridae, (water skimmers). Aquatic adults of the Order Coleoptera present were Gyrinidae, the whirl-a-gig beetles; Dytiscidae, the diving beetles, and Hydrophilidae, the scavenger beetles. Caddis fly (Trichoptera) cases were common on submerged reeds and stones. Aquatic larvae of the Orders Diptera (flies), except Chironomidae, Neuroptera (nerve-wing insects), and Lepidoptera (~~S~~caled-wing insects) were not observed nor collected but some representatives of these groups may be present. Non-aquatic adults of dragon flies, damsel flies, may flies, caddis flies were common along shore especially where there were lights at night. The genus Donacia Order Coleoptera, Family Chrysomelidae was collected as an adult although its aquatic larva was not found.

The zooplankton (both eu- and tychoplankton) varied in number and in quality during the season but in general were abundant. Representatives of different phyla appearing commonly at various times during the year were:

Protozoa - Amoeba, Arcella, Diffugia, Vampyrella,
Epistylis, Vorticella.

(The genera Volvox, Euglena, Eudoria, Mallomonas Pandorina, Synura, Ceratum and Peridinium, often classified by zoologists as Protozoa were represented in collections and are listed in a later taxonomic section.

Rotifera - Anuraea (Keratella), Diglena, Notholca,
Polyarthra and Triarthra.

Crustacea (Entomostraca)

Copepoda - Cyclops, Diaptomus

Cladocera - Daphnia, Bosmina

The phylum Mollusca, although not planktonic, but sometimes used for fish food was represented by the following genera: Univalves, Amnicola, Campeloma, Gonio-
basis, Physa and Planorbis; bi-valves Anodonta and Unio.

III. "WATER BLOOMS" AND RELATED FACTORS

The phenomenon of "water bloom" occurs when lakes, ponds, or reservoirs become turbid or colored by abundant growths of algae. This condition is known in European countries under the names of "Wasserblueth" and "fleur d'eau" and in America as "fermenting", "purging", "working of the lake", "breaking of the meres", and "water bloom".

A. History of "Water Blooms" and Related Literature

As early as 1840, William Thompson wrote in the *Annals of Natural History* an article* "on a minute alga which colored Ballydrain Lake, in the county of Antrim". Another early paper on "water blooms" in England by Allman (1852) was entitled "On a Microscopic alga as a

* Not seen.

cause of phenomena of the coloration of a large body of water". Fitch et al (1934) refer to a "water bloom" poisoning in Lake Alexandria, Australia reported by a Mr. G. Francis in 1878. Some of the earliest published articles on similar conditions in America (Minnesota) were by Arthur (1883, 1884, 1889). Porter (1887) also reported on some poisonous algae in Minnesota. Farlow (1883) related certain forms of algae to disagreeable tastes and odors in water. Rafter (1889) discussed the relationships of fresh-water algae to the purity of public water supplies. "The working of Madison Lakes" by Trelease was published in Wisconsin in 1889. Swingle (1896) was probably one of the first investigators of disagreeable algae troubles to use control methods. He worked on Bordeaux mixture; its chemistry, physical properties, and toxic effects on fungi and algae. Odors and tastes in water supplies of Massachusetts were discussed by Jackson and Ellms (1897). Another Minnesota study was by Nelson (1903) who made certain observations on some algae which cause "water bloom". G. T. Moore and colleagues were the first workers to publish on the control of algae in relationship to water supplies. Moore (1902), Moore and Kellerman (1904, 1905), Moore, Jackson, Goodnough and others (1905) and Kellerman (1912), all made important contributions to the control of algal nuisances. G. C. Whipple's book "The Microscopy of Drinking Water", (often a handbook for water-works engineers), was first published in 1899. Other early papers on

the control of algae were those of Caird (1904, 1905), Ellms (1905), Goodnough (1905), Carroll (1904), and Kraemer (1904).

The entire field of aquatic biology began to be studied during the first years of the present century. Birge (1903, 1906, 1907, 1908) was one of the first American researchers to probe at the complex interrelationships that occur in bodies of water. Others in this early period who were interested in the ecology and periodicity of algae were Marsh (1899), Whipple and Parker (1902), Check (1903), Baldwin and Whipple (1906), Kofoid (1908), Chambers (1912), Transeau (1916), Schuette (1918), and Church (1919).

Continued use of copper sulphate for control of algae in water supplies during this period brought forth papers by Huff (1916), Huff and House (1916), Embrey (1917), and Haine (1918), among others. The demand for cleaner and purer water and the use of copper sulphate to provide potable water are reflected by the papers by Brush (1920), Russell and Juday (1920), Huff (1922), Page (1923), Mahlie (1923), Diven (1924). Hale, well-known for his work with the New York City Water Supplies, first published on algal control in 1926. Although control of algal growths remained important in this period other work on the periodicity of algae appeared by Huff (1922, 1923) and Eddy (1925, 1928). British workers publishing on the same problem were Hodgetts (1921), Pearsall (1921, 1922, 1923, 1924, 1929), Griffiths (1923), Fritsch (1931) and Akehurst

(1931). The chemical and physical factors related to lake productivity (and thus to "water bloom") continue to be a problem for many researchers. A group of Wisconsin workers, contemporaries and students of Birge, have published widely in this field, especially Juday (1924 a and b); Juday and Birge (1931, 1932); Juday, Fred, and Wilson (1924); Domogalla and Fred (1926), and Domogalla, Fred and Peterson (1926).

In the last twenty years water-works and sanitary engineers have developed various methods for the control of micro-organisms in reservoirs and other water supplies. Numerous publications have appeared, among them papers by Manguin (1928, 1929 a and b), Jackson (1930), Walton (1930), Kienle (1932), Smith (1934), Arnold (1935, 1936), Purdy (1935, 1936, 1937), Goudey (1936), Gopp (1936), Bailey (1937, 1942), Tressler (1937), Gibbons (1940) and Monie (1946).

The intricate relationship of aquatic organisms to their environment are far from being completely known, although numerous limnologists and aquatic biologists have made important studies in the last 25 years. Some of the more significant contributions have been papers and books on physico-chemical relations, e.g., Hutchinson (1938, et al. 1939, 1941, 1943, 1944), Riley (1939, 1940, 1941), Deevey (1940, 1941, 1944), Changler (1940, 1942, 1944), Allgeier et al. (1941), Welch, (1939); aquatic bacteriology, e.g., Hardman and Henrici (1938), Henrici and McCoy (1939),

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Henrici (1939), Zobel (1940), Zobel and Stadler (1940); bottom deposits, e.g., Eggleton (1931, 1939), Juday et al. (1941), Deevey (1942) and Roelofs (1944); general and miscellaneous aspects, e.g., Welch (1933), Prescott (1939), Pennak (1946), Lindeman (1941, 1942), and Hasler (1947). Much research has also been done in foreign countries. To mention even the important works would result in a long list. It will be possible here to mention only a few notable ones from England: Mortimer (1937, 1939), Rosenberg (1939 a and b), Pennington (1942) and Pearsall et al. (1946).

It is necessary to make note of a few important papers on studies, some quite detailed, conducted on lakes where "water blooms" of blue-green algae have become quite serious. Prescott (1931, 1932, 1938, 1948) and Rose (no date - mimeographed copy) have performed experimental work in Iowa Lakes, and Domogalla (1926, 1935) on Wisconsin lakes. The latter recently (1943, 1944) have been given a very complete and detailed survey by Sawyer, Lackey and Lenz.

B. Organisms That May Cause "Water Bloom"

Many species of algae in different groups may cause this condition. Smith (1924) lists 65 species, representing of the eight phyla of algae, as bloom producers. The majority of these however, are classified in the groups:

1. Chlorophyta
2. Pyrrophyta

3. Chrysophyta (Bacillariophyceae and Chrysophyceae)

4. Cyanophyta

The members of the Chlorophyta seldom produce blooms that become obnoxious to water users. Species of Volvox, Eudorina and Pandorina sometimes become so abundant that they impart a greenish color to the water, but they seldom, if ever, form scums or produce disagreeable odors. Some other representatives of this group responsible for "bloom conditions" are Chlorella vulgaris Beyerinck, Pediastrum Boryanum (Turpin) Meneghini and species of Scenedesmus, Protococcus, Chlamydomonas and Sphaerella.

The Dinophyceae, a sub-class of the Pyrrophyta (yellow-brown algae) include several forms that sometimes produce blooms. Species of Peridinium often impart a clam-like taste to water in reservoirs and Ceratium hirundinella Shrank may give lake water a dark brown coffee color. This latter condition usually appears and disappears rapidly.

The Chrysophyta (yellow-green algae) includes three sub-groups, two of which, the Bacillariophyceae (diatoms) and the Chrysophyceae often are objectionable in many ways. Synura uvella Ehrenberg and Uroglenopsis californica (Calkins) Lemmermann members of the latter group, give disagreeable tastes to impounded water. Diatoms such as species of Melosira, Stephanodiscus, Asterionella, Tabellaria, Diatoma and Synedra often plug filters and impart offensive odors and tastes to water.

The Cyanophyta (blue-green algae) are the most detested

of "bloom" formers. Thirty-eight of the 65 species of algae listed by Smith (1924) are in this phylum. Species of Microcystis, Anabaena, Coelosphaerium, Aphanizomenon, Oscillatoria and Gloeotrichia commonly form superabundant growths in hard-water drainage lakes of this region. The physical characteristics that enable this group to become so obnoxious will be discussed below under injurious effects of "water blooms".

C. Injurious Effects of "Water Blooms"

An extremely important problem to the sanitary engineer is the clogging of sand filters. The algal organisms, mainly diatoms and blue-green algae, are strained out in close proximity to surface of the sand filter and become an integral part of a slimy layer. The continued accumulation of micro-organisms in this clogging layer results in a rapid loss of head. Often the filters become completely closed and must be cleaned. Whipple (1927) lists an additional way by which algae may interfere with filtration. In the presence of sunlight, algal organisms during the course of photosynthesis and respiration liberate O_2 and CO_2 . When growth is vigorous, increased quantities of these gases entrapped in the growth film may float layers of organisms and sand to the surface. This leaves portions of the filter sand bare and thus permits some water to pass through too rapidly for proper filtration. This clogging may occur in sewage treatment as well as in water-purification plants. Furthermore serious trouble

may arise from the clogging of water pipes.

As previously mentioned, certain species of algae have the annoying characteristic of imparting undesirable tastes and odors to drinking water. Water works and sanitary engineering journals contain many references to algal tastes and odors, and methods of control. (Hale 1926; Manguin 1928, 1929; Kienle 1932; Jacobson 1930; Purdy 1935; Goudey 1936; Arnold 1936; Gopp 1936; VanArmin 1936; Bailey 1937; and many others). Whipple (1927) lists and classifies different odors and tastes imparted to water by algae. These odors range from aromatic geranium, nasturtium and candied violets to moldy, pig-pen and fishy odors.

Some evidence has accumulated in the past years which indicates that certain species causing "water bloom" produce toxic substances closely associated either with the growth or decay of the algae, which may cause death to both wild and domestic animals. Fitch et al. (1934) list 9 cases of toxic "water bloom", all but one occurring in the state of Minnesota. Species of blue-green algae were present in all 9 cases cited. Fitch and his colleagues made a detailed clinical study of an outbreak of cattle deaths from toxic algae in McGuire Lake, Grand Rapids, Minnesota in 1933. In this study ^{they} failed to isolate the toxic substance, although it was established that there was neither an alkaloid, a toxalbumin nor a botulinus toxin present. The organisms concerned in this case were Microcystis flos-aquae (Wittrock) Kirchner and Anabaena flos-aquae (Lyngbe) Brebisson, both blue-green algae. Prescott

(1948) reports that he received samples of algae (decomposed Aphanizomenon flos-aquae (Linnaeus) Ralfs) from Bermuda where cattle had died after drinking from pools in which the plants had formed a dense "bloom". Steyn (1945) and Stephens (1948) further confirm the belief that some algal organisms may be toxic to higher animals. In these papers Microcystis toxica Stephens, a blue-green alga, indigenous to South Africa, is stated to secrete a toxin capable of producing pathological conditions and even death in cattle and other animals. Deem and Thorp (1939) also report the death of animals due to poison from Anabaena flos-aquae in Colorado. Dogs were reported killed August 29, 1948 by this same species in Storm Lake, Iowa (Pohl, 1948).

Profuse algal growths also may become objectionable through their ability to kill fish either directly or indirectly. Baldwin and Whipple (1906) report a killing of fish ^{following} sudden dying of algae. Smith (1924) reports another case of fish-kill in New York related to the death of blue-green algae.

Prescott (1932, 1938, 1948) lists several lakes in northwestern Iowa where there were fish-kills after superabundant growths of blue-green algae had undergone sudden decay. Moore (1942) comments on a fish-kill at Wallingford, Connecticut (1935) where over 400,000 fish were killed in a small lake in an area of less than 150 acres. A considerable "water bloom" undergoing decay was present in this instance. All these cases of fish mortality have been explained in one or another of several manners. When

abundant growths of algae undergo sudden decomposition, increased bacterial decomposition utilizes available quantities of dissolved oxygen, sometimes depleting the minimum amount (3 p.p.m.) necessary to support fish life. This depletion occurred in the Iowa lakes (Prescott, l.c.) on hot, still nights when photosynthetic activity, furnishing much of the dissolved oxygen, had ceased. The New York case (referred to above) followed treatment by copper sulphate for a heavy "water bloom" of Anabaena. Smith, (l. c.) emphasizes, however, that the amount of copper sulphate used was below toxic limits for fish and that death was due to depletion of oxygen resulting from the decomposition activity of bacteria. He further quotes Haine (1918) as stating that similar reduction of oxygen occurs in a body of water when the algae are suddenly killed by some natural cause. The report on the Connecticut fish mortality was related to shallow water and a presumably high organic content of the bottom mud as secondary factors in the depletion of oxygen. Winter fish-kills have been reported also as occurring after decay of large numbers of blue-green algae in ice-covered lakes.

The problem of algae being toxic to higher animals has been discussed above. Scarcely any research has been conducted, however, on the ability of algae to kill fish by poisoning.

Many micro-organisms are rich in proteins and other nitrogen-bearing substances. Some of the more prominent bloom formers of the blue-green algae (Microcystis,

Anabaena and Aphanizomenon) have high percentages for dry weight of nitrogen (9.0-10.05) and crude protein (55.6-62.8). Decomposition products of these substances often produce serious tastes and odors in water. Methane gas is one such product causing these conditions. Prescott (1932, 1938, 1948) in his Iowa studies, both in laboratory and field experiments, found that one poisonous protein decomposition product, hydroxylamine, was present in quantities sufficient to kill fish. He also states "that sufficient amounts of hydrogen sulfide to kill fish were found to be given off in decomposing algae". His experiments showed that the toxic material was released upon decomposition of algae in contrast with the toxins reported by Fitch (1934), Steyn (1945) and Deem and Thorp (1939) which were either in the living cells or in the water surrounding the cells. The writer believes that similar or possibly identical substances were present in all cases, and that where the toxins occurred in tests with living material, the actual poison was derived from previous individuals already having undergone decomposition. The potency of the toxins in the majority of the cases reported was reduced by drying or refrigerator storage, but still toxic enough to kill chickens, rabbits, and guinea pigs by intraperitoneal injections. The toxins involved were heat stable. McGonigle (1934) reports an algal growth responsible for fish hatchery mortalities, but does not indicate whether oxygen depletion or poisonous substances were directly responsible.

The need for more research on this problem is obvious. The isolation of ~~(a solution of)~~ the ^{toxic} substances produced by algae and their effects on other algae and aquatic organisms might be an initial step toward an explanation of periodicity of phytoplankton and other aquatic life. Akehurst (1931) discusses the possibility of annual plankton successions being determined by the inhibition and stimulation of growth by auto-toxins (excretion products). Sampaio (1946) reports inhibition of bacterial growths in almost pure laboratory cultures of the desmid Closterium acerosum (Schrank) Ehrenberg.

The popular use of lakes for varied recreational facilities makes their loss for such purposes every year during the summer months because of disagreeable "water bloom" an important problem. Eutrophic lakes (generally high in bi-carbonates and inorganic nitrogen and phosphorous) and common in the midwest region of the United States, often produce superabundant growths of blue-green algae during the hot summer months. Such growths become obnoxious, by the formation of a "pea green" scum upon the surface of the lake. Wind and wave action often drive this material upon beaches and into shallow areas near shore. This great increase of organisms is made possible (provided, other environmental factors are optimum) by the simple yet rapid and efficient rate of multiplication in these organisms. Reproduction is by fission, a splitting process, whereby one cell may become two and these two become four and so on, in a very rapid series of cell

divisions.

Several characteristics of these blue-green algae enable them to form thick surface scums. First, some species contain gas-vacuoles (pseudovacuoles), enabling them to float high in the water and to form masses. Secondly, these organisms are surrounded by gelatinous or mucilaginous sheaths which are very sticky. Thus, their tendency to float at the surface, the habit of adhering together, in addition to their characteristic rapid multiplication result in the formation of thick scums. In a few days, or even hours, direct sunlight causes death and decay of these organisms, often converting a reservoir or small lake, as Prescott (1938) describes it, into a "veritable cesspool".

D. Factors Affecting "Water Blooms"

The factors related to general productivity of lakes apply directly to the occurrence of "water blooms" just as they do to other aquatic biota. Such factors, for consideration, are generally divided into physical, biological and chemical.

1. Physical Factors

The morphology of the lake basin is important, at least indirectly, in the productivity of organisms. Mean depth is significant in determining the types of organisms, although the effects of morphology on productivity are often indirect by influencing secondary factors such as

temperature, oxygen, and the production of nitrogenous material. Lakes having an epilimnion volume greater than the hypolimnion are usually more productive than those having the reverse condition. Although lakes, ponds, and reservoirs in which "water blooms" occur vary in morphology, a large number of bodies of waters in which blue-green algal scums develop are relatively shallow, with broad shoals flat shoreline and beaches. Pennak (1946) states "that large size, regular shape, great depth, high elevation and high latitude are all factors which tend to discourage the development of large plankton populations". Rawson (1939) adds that "while edaphic factors determine the kinds and amounts of primary nutritive materials, the morphology of the basin and climate may to a large extent determine the utilization of these materials".

A strong current is inhibitory to a large plankton production by causing turbidity or by carrying both plankton and nutrient materials from the lake. Rapid streams do not have an abundant plankton, whereas slowly flowing water may support "blooms", other conditions being favorable.

In general, reproduction and the formation of new plants is correlated with photosynthesis, hence light is important. The zone in which food manufacture may take place, the zone of photosynthesis, has been estimated by Birge and Juday (1911) to be the upper ten meters in clear water, and a zone 2 to 3 meters deep in highly colored or turbid lakes. Although light is necessary for algal growth,

very intense sunlight may be unfavorable. The blue-green algae appear able to withstand strong sunlight, because of the screening out of certain light waves by the blue-green pigment, phycocyanin. In general, penetration of light into a water medium depends on many secondary factors, such as light intensity and turbidity, suspended debris and plankton, and color of the water.

The importance of temperature in relation to both quality and quantity of plankton production is not fully known. It may act as a limiting factor in distribution and periodicity. At times, it is not temperature as often appears that effects plankton growth but rather light intensity, fluctuations of which may or may not accompany temperature changes. "Water blooms" of blue-green algae usually occur during the summer months when daily average temperatures are highest.

Temperature is certainly an important factor in the thermal stratification of temperate lakes. The accompanying changes (which are related to productivity) that take place in a stratified lake then are indirectly caused by temperature changes. Pennak (1946) makes the general summary that "plankton populations are undoubtedly determined to a large extent by the temperature characteristics of lakes and streams, which in turn, are primarily dependent upon depth, wind and insolation".

2. Biological Factors

The effect of biotic relationship between zooplankton

the first of these is the fact that the system is not a simple one, but a complex one, in which the various parts are interrelated and interdependent. The second is that the system is not a static one, but a dynamic one, in which the parts are constantly changing and evolving. The third is that the system is not a closed one, but an open one, in which the parts are constantly interacting with the environment. The fourth is that the system is not a linear one, but a non-linear one, in which the parts are constantly interacting with each other in a non-linear fashion. The fifth is that the system is not a deterministic one, but a probabilistic one, in which the parts are constantly interacting with each other in a probabilistic fashion. The sixth is that the system is not a simple one, but a complex one, in which the various parts are interrelated and interdependent. The seventh is that the system is not a static one, but a dynamic one, in which the parts are constantly changing and evolving. The eighth is that the system is not a closed one, but an open one, in which the parts are constantly interacting with the environment. The ninth is that the system is not a linear one, but a non-linear one, in which the parts are constantly interacting with each other in a non-linear fashion. The tenth is that the system is not a deterministic one, but a probabilistic one, in which the parts are constantly interacting with each other in a probabilistic fashion.

and phytoplankton on total productivity is not completely known. Riley (1940) found that "variations in the amount animals (zooplankton) do not have a significant effect on gross production or the size of standing crops of plants (phytoplankton)". Akehurst (1931) discusses the possibility of annual plankton successions being determined by the inhibition and stimulation of growth by auto-toxins (excretion products). Some animals appear to produce materials which facilitate growth, and which, when present in high concentrations inhibit growth of plants. Whether phytoplankton produces such substances is not known. As previously mentioned Sampaio (1946) reports that Closterium acerosum (Schrack) Ehrenberg, a desmid of the phylum Chlorophyta, inhibits bacterial growth in laboratory cultures. Pennak (1946) mentions that dissolved complex organic materials may act as inhibitors or promoters of growth for certain species.

3. Chemical Factors

In general, there is a greater production of plankton organisms (both plant and animal) where there are larger quantities of dissolved nutrient materials. This has been substantially proven by experiments involving use of fertilizers, both commercial and natural, to increase plankton production, (Wiebe 1929, Juday et al. 1938, Roelofs 1944, Ball 1948). Furthermore, great increase in the production of organisms in sewage-polluted lakes and streams is well-known (Sawyer et al. 1942, 1943; Hasler,

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1948).

Pearsall (1922), however, has pointed out that the total mass of plankton is not proportional to the quantity of dissolved substances but to the smallest quantity of an ion or compound which may be a limiting factor for each species. Hutchinson (1944) has noted, "Clear-cut correlations between chemical conditions and the quantitative composition (and zooplankton) are not to be expected and the physiological condition of a population and its relation to the populations of other species are likely to explain many of the apparent inconsistencies observed when different seasons and different lakes are compared". Hutchinson (l.c.) further claims that in small eutrophic (productive) lakes all inorganic substances, except phosphates and combined nitrogen, are usually present in great excess.

Calcium is of direct importance in algal nutrition and also has a bearing on productivity through its interrelations with carbon dioxide. In general, eutrophic lakes are rich in calcium, whereas oligotrophic (low in production) are usually poor, although exceptions have been found in lakes in the Alps and in Germany (Rawson, 1939).

Silica content varies greatly in different bodies of water. This chemical is important to diatom growth, although it seldom constitutes a limiting factor in either fresh or marine waters. Rawson (1939) quotes Meloche (1926) as having observed certain correlations between silica and diatoms in Lake Mendota, although several other

factors were involved.

Prescott (1939) states that the ratio of Na:K to Ca:Mg may determine the qualitative nature of the algal flora. For example, lakes having a low Na:K/Ca:Mg ratio (1.1) support a predominant flora of diatoms and blue-green algae whereas those with a higher ratio (3.2) maintain a distinct Chlorophycean, especially desmid phytoplankton.

Iron plays an important role in phytoplankton physiology of course, although a discussion of it is not possible. Rawson (1939) indicates that iron may act as a catalyst in the formation of chlorophyll and also that it may be involved in respiratory activities. Therefore the quantity of this element possibly may be a limiting factor in phytoplankton growth. Hutchinson, et al. (1938), Allgeier et al. (1941) and Thorpe and Deevey (1942) have shown that ferrous iron (as well as hydrogen sulphide and dissolved oxygen) may affect the value of oxidation-potential in the lower water of some lakes. Iron hydroxide may be important in the deeper waters of some lakes where this substance is able to adsorb and precipitate phosphates, thus removing them from circulation.

Little work appears to have been done on the role of manganese in aquatic habitats. Rawson (1944) suggests that this chemical under certain conditions may serve as a partial substitute for iron.

The carbon dioxide content in bodies of water is very important in connection with phytoplankton production

1. The first step in the process of the scientific method is to make an observation or ask a question. In this case, the observation is that the plant is not growing as well as it should be. The question is, "Why is the plant not growing as well as it should be?"

2. The second step is to do background research. This involves looking up information about the plant and the conditions it is growing in. In this case, the researcher would look up information about the plant's needs for water, light, and soil.

3. The third step is to form a hypothesis. A hypothesis is a statement that can be tested. In this case, the hypothesis might be, "If the plant is not getting enough water, then it will not grow as well as it should be."

4. The fourth step is to test the hypothesis. This involves setting up an experiment to see if the hypothesis is correct. In this case, the researcher would set up two groups of plants. One group would get a lot of water, and the other group would get a little water. The researcher would then observe the plants and see which one grows better.

5. The fifth step is to analyze the data. This involves looking at the results of the experiment and seeing if they support the hypothesis. In this case, the researcher would see if the plants that got a lot of water grew better than the plants that got a little water.

6. The sixth step is to draw a conclusion. This is a statement about what the results of the experiment mean. In this case, the conclusion might be, "The plant is not growing as well as it should be because it is not getting enough water."

7. The seventh step is to communicate the results. This involves sharing the results of the experiment with other people. In this case, the researcher would write a report about the experiment and share it with other people who are interested in the plant.

because of its role in photosynthesis. The amount of free carbon dioxide varies in the surface water of lakes according to the amount of photosynthetic activity. In thermally stratified lakes there is an increase in CO_2 content in the bottom waters. Algae may obtain this gas either in a free, dissolved state or from "half-bound" bicarbonates if other sources are depleted. Some useful carbonates may be lost to plant growth by sinking to the bottom after half-bound carbon dioxide is removed by algae. However, carbonic acid in bottom waters may re-dissolve the monocarbonates, and the resulting bicarbonates may be used as a source of CO_2 for photosynthetic activity if they are returned to upper waters.

The hydrogen ion concentration according to more recent studies (Juday 1935, Pennak 1946) is of greater value in aquatic environments as an indicator of the sum of many physio-chemical complexities than it is in itself a limiting factor. Rawson (1939) claims "that pH must be recognized for what it is, namely the result of a number of underlying chemical conditions, it must therefore be considered also with other physical and chemical conditions in a lake." Pennak (1946) agrees, and goes further to point out that "pH is simply a convenient measure of the sum of a good many chemical complexities and it is the individual members making up the complex which presumably affect and limit the plankton, rather than the total.

Prescott (1939) notes that seasonal variations in conductivity are related to fluctuations in pH and increase

in quantity of phytoplankton. When phytoplankton is low, conductivity is high and pH is low; and "When the phytoplankton increases during the seasonal growth, the conductivity becomes less because of a consumption of electrolytic salts, and the pH rises with the precipitation of carbonates".

The value of dissolved oxygen seems to be important usually in the hypolimnion of lakes, where during stratification, the supplies are lowered or exhausted to the point at which animals must either migrate or die. Oxygen is also important in the aerobic decomposition of organic material. Pennak (1946) remarks that "The dissolved oxygen content is never a limiting factor in unpolluted streams". Rawson (1939) states: "Considering the distribution of dissolved oxygen in the three regions (of a lake) it may be assumed that it is rarely a limiting factor for distribution or production in the epilimnion, that in the hypolimnion, the deficiency of oxygen frequently tends to drive out certain animals". As mentioned previously deficiency of oxygen brought about by decomposition of superabundant growths of blue-green algae is important in fish-kill (and in death of other aquatic animals). There is no complete agreement on the question of whether it is the increased CO_2 tension or the low O_2 that limits kind and quantity of aquatic organisms. The blue-green algae, in general, species of which often form profuse blooms, may live in water that is poorly supplied with oxygen. Prescott (1939) reports that

as a class, the blue-greens are poor oxygenators; thus partly explaining why dense growths often are responsible for unbalanced conditions in bodies of water.

The concentration of total dissolved organic matter varies in different bodies of water. Sources of organic substances may be from within the lake (autochthonous) or they may be introduced from surrounding terrain (allochthonous), mainly by drainage or seepage. What role these materials may play in the metabolism of lakes and streams is unknown. They are substances of complex organic nature, and may originate from many sources, such as excretion products of animals, disintegration products of bacterial action or intermediate metabolic products of the organisms themselves. The additions of organic fertilizers to Weber Lake in Wisconsin increased plankton numbers, whereas inorganic fertilizers were not effective (Juday 1942). Pearsall (1942) also claims that abundant growth of blue-green algae is partially dependent on organic content of water. In any case many lakes producing a "water bloom" have a relatively high content of dissolved organic substances. Other lakes (dystrophic), however, have a larger concentration of dissolved organic materials but strangely are very low in production. An excess concentration of dissolved organic materials, including organic acids, are thought to be inhibiting to algal growth. The higher osmotic gradient in lakes with greater amounts of dissolved organic substances may possibly explain the

discrepancy between the volume of production in different lakes where other factors are the same.

Bottom deposits vary in both quantity and quality in different lakes. In general, lakes having organic deposits rich in nitrogen are more productive. The rate in which these organic deposits are broken down and then synthesized into compounds that are essential to plant growth is important. This overturn involves aquatic bacteria which constitutes a characteristic autochthonous flora in natural unpolluted waters. These chemical transformers and their role in lake metabolism have been studied very little. Important work has been done, however, by Henrici (1938, 1939), Henrici and McCoy (1938), and Zobell (1930), Zobell and Stadler (1940).

Results from these studies show:

1. There is a graded series in quantity of bacteria from oligotrophic (unproductive) to eutrophic (productive) lakes.
2. That dystrophic lakes (unproductive) have high counts of bacteria, but must be considered separately because the kinds of organisms are different from those in other types of lakes.
3. A correlation occurs between the concentration of bacteria in bottom deposits and the bacterial flora in the open water of a particular lake, but no correlation is apparent when different lakes are compared.
4. Numbers of bacteria follow closely the curve for

total plankton. As phytoplankton increases, providing more organic food for bacteria, the bacterial count increases. However, the bacterial flora would only increase in great numbers after the death of the phytoplankton, hence the plankton actually may be declining, as the bacterial population grows.

5. Oxygen tension of lake water influences the multiplication of bacteria; their respiration appears to be independent of oxygen tension.

6. The character and concentration of organic matter influences the rate of consumption.

7. One-third of the organic matter (Lake Mendota, Wisconsin, e.g.) is readily oxidizable, the rest being resistant to bacterial attack.

8. Organic matter in water is more oxidizable than that of bottom deposits.

9. Dissolved organic matter in water is less oxidizable than the particulate remains of plankton organisms (according to Zobell (1940)).

Domogalla et al. (1926) have found that seasonal fluctuations in the ammonia, nitrate, and oxygen content of lake waters is found to be caused almost entirely by the seasonal variation in the bacterial flora of the lakes. These fluctuations are much more marked in bottom waters.

Some work, has been done on the oxidation-reduction potentials of lake waters and of lake sediments (Hutchinson

et al. 1939, Allgeier et al. 1941 and Thorpe and Deevey 1941) and their ecological significance but inconsistencies have appeared. Rawson (1939), after reviewing some of the studies, notes "that the potential might provide a useful index to the hypolimnial and benthic environments".

The role of nitrogen and phosphorous in productivity of phytoplankton has been debated by various authors. It has often been thought that inorganic nitrogen (nitrate, nitrites and ammonia) and phosphorous are limiting factors in plankton production. Prescott (1939) has found positive correlations of phosphorous content with productivity and of nitrogen with plankton quantity, and quotes the work of several English limnologists as accessory corroboration. Rawson (1939) claims that "in more exact studies it has often been impossible to show that either (phosphorous, nitrogen) was limiting". Atkins (1926) finds "a complete absence of any evidence that in the water of the lakes (Wisconsin) a deficiency of nitrogen acts as a factor limiting the plankton". Investigation of a large number of Wisconsin lakes by Juday (1928, 1931) showed that there was no correlation and only a slight reduction of phosphates in the upper waters although an abundance of phytoplankton was produced. Sawyer et al. (1943, 1944) conclude that inorganic nitrogen may be "a limiting factor in regard to the amount of growth which could be produced and that inorganic phosphorous acts largely as a governor upon the rate at which growths occurred". This statement was made after working on the problem of "nuisance blooms" of algae

in certain Wisconsin lakes. Numerous studies such as that by Pennington (1942) have been made upon the nutrient requirements of algal cultures. Various organisms have different nutrient requirements, and the form in which inorganic nitrogen is used varies accordingly. Hutchinson (1944) points out that blue-green blooms usually arise in late summer when inorganic nutrients are practically exhausted. The condition appears to be almost directly related with the rise of Fragilaria crotonensis Kitton, a diatom, and a species of Anabaena, a blue-green algae. He (Hutchinson) suggests the relative numbers of these two species "may be interpreted as due to competition for phosphate, favoring Fragilaria when nitrate is relatively abundant, Anabaena when nitrate is scarce, and although the two species are initially competitors, nitrogen fixation by Anabaena results in a more favorable environment for Fragilaria after Anabaena has declined". Nitrogen-fixation by blue-green algae in laboratory cultures has been demonstrated. (Allison and Morris 1935, Allison et al. 1937, Fritsch and De 1938, De 1939, Fogg 1942). More extensive work appears necessary to show whether this process is a factor in productivity and in "water bloom" development.

The complex interrelationship of many factors in aquatic metabolism is little understood and it is intended that only fundamental aspects be discussed here. Algal organisms that produce "water blooms" are a component of

the aquatic biotype and thus are affected by the maze of complicated internal changes that take place in the metabolism of bodies of water.

IV. DATA AND MEASUREMENTS

A. Methods and Procedures

For the purpose of making both quantitative and qualitative studies of algae, collecting stations at the following locations were established: (See map).

Station 1. This station, at the outlet of the lake, was established in order to obtain data on the kinds of organisms leaving the lake.

Station 2. This station is about mid-point in a line drawn from the outlet to the lighthouse on the beach. It was selected in order to obtain data on the quantity and quality of algal flora in the body of the lake.

Station 3. This station is about 100 yds. off shore at the approximate point where the sewage effluent empties into the lake.

Station 4. This station is just within the inlet from Tupper Lake, selected to learn what organisms were entering through the channel.

Station 5. This station is near the outlet of Tupper Lake, established to determine what kinds of organisms were carried into the channel.

the first of these is the fact that the system is not a simple one, and that the results are not always the same. The second is that the system is not a simple one, and that the results are not always the same.

The third is that the system is not a simple one, and that the results are not always the same.

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The tenth is that the system is not a simple one, and that the results are not always the same.

Station 6. This station, just within Tupper Lake from Tupper Creek inlet, was selected to learn what kind of organisms were entering from this source.

Station 7. This station, about mid-point in Tupper Lake, was established to determine the kinds and quantity of algae in the body of the lake.

1. Quantitative Plankton Analysis

Quantitative plankton samples were collected by the use of a 20 gauge silk bolting cloth net. This net was equipped with a device that measured the quantity of water passing through the net. Samples were concentrated in the laboratory by the addition of an equal volume of a saturated Hg_2Cl_2 solution (mercuric chloride) and then removing the supernatant liquid after 24 hours for settling. The concentrate was then made up to a standard volume with preservative (6 parts water - 3 parts 95% ethyl alcohol - 1 part commercial formalin). The following procedure was then followed for counting the number of organisms.

1. A dropping pipette was calibrated. (One which delivered 20 to 21 drops per cubic centimeter was found to be most satisfactory).

2. The area of a 22 mm. cover slip was computed.

3. The area of the field of both a 16 mm. (100 x) and a 4 mm. (430 x) microscope objective was determined.

4. One drop of concentrated plankton sample (well-mixed) was delivered to a slide and the numbers of organisms in 40 to 160 fields were counted and tabulated.

Then the average number of organisms per field was calculated.

5. The number of organisms per liter of concentrate was next determined by the following equation:

Average number per field x number of fields in cover slip x number of drops per cc. x 1,000 equals the number of organisms per liter of concentrate.

6. The number of organisms per liter of lake water was then determined by dividing the number of organisms per liter of concentrate by the concentration factor.

Calculation revealed areas of 380.16 sq. mm. in a 22 mm. cover slip; .09350 sq. mm. in 4 mm. and 1.837704 sq. mm. in 16 mm. objective fields. Simple division then determined 4,064 fields (430 x) and 212 fields (100 x) in a 22 mm. cover slip.

Sample Computation

4-liter sample concentrated to 80 cc.;

concentration factor is 50;

in 40 fields of 4 mm. objective found 5 organisms;

average number organisms per field = .8;

.8 (average per field) x 4,064 (no. of fields of 4 mm. objective in 22 mm. cover slip) x 20 (no. of drops per cc.) x 1,000 (no. of cc. per liter) = 64,964,000 organisms per liter of concentrate;

$$\frac{64,964,000}{50 \text{ (conc. factor)}} = 1,299,280 \text{ organisms per liter of lake water.}$$

A table of values was prepared to simplify calculations of numbers of organisms per liter of lake water.

– Theorem 1.10 (The Mean Value Theorem): Let f be a function defined on the interval $[a, b]$.

Suppose that f is continuous on $[a, b]$ and differentiable on (a, b) . Then there exists a point c in (a, b) such that

$$f'(c) = \frac{f(b) - f(a)}{b - a}.$$

Geometrically, this means that the tangent line to the graph of f at the point $(c, f(c))$ is parallel to the secant line passing through the points $(a, f(a))$ and $(b, f(b))$.

– Theorem 1.11 (The Intermediate Value Theorem): Let f be a function defined on the interval $[a, b]$. Suppose that f is continuous on $[a, b]$. Then for every value y between $f(a)$ and $f(b)$, there exists a point c in (a, b) such that $f(c) = y$.

Geometrically, this means that if f is continuous on $[a, b]$, then the graph of f must pass through every point on the vertical line segment between $(a, f(a))$ and $(b, f(b))$.

– Theorem 1.12 (The Extreme Value Theorem): Let f be a function defined on the interval $[a, b]$. Suppose that f is continuous on $[a, b]$. Then f attains its maximum and minimum values on $[a, b]$.

Geometrically, this means that if f is continuous on $[a, b]$, then the graph of f must have a highest point and a lowest point on the interval $[a, b]$.

– Theorem 1.13 (The First Derivative Test): Let f be a function defined on the interval $[a, b]$. Suppose that f is differentiable on (a, b) . Then f has a local maximum at c if f' changes from positive to negative at c , and f has a local minimum at c if f' changes from negative to positive at c .

Geometrically, this means that if f is differentiable on (a, b) , then the graph of f must have a local maximum or minimum at c if the slope of the tangent line changes from positive to negative or from negative to positive at c .

– Theorem 1.14 (The Second Derivative Test): Let f be a function defined on the interval $[a, b]$. Suppose that f is differentiable on (a, b) and that $f''(c) \neq 0$. Then f has a local maximum at c if $f''(c) < 0$, and f has a local minimum at c if $f''(c) > 0$.

Geometrically, this means that if f is differentiable on (a, b) and $f''(c) \neq 0$, then the graph of f must have a local maximum or minimum at c if the concavity of the graph changes from concave down to concave up or from concave up to concave down at c .

– Theorem 1.15 (The Third Derivative Test): Let f be a function defined on the interval $[a, b]$. Suppose that f is differentiable on (a, b) and that $f''(c) = 0$ and $f'''(c) \neq 0$. Then f has an inflection point at c .

Geometrically, this means that if f is differentiable on (a, b) and $f''(c) = 0$ and $f'''(c) \neq 0$, then the graph of f must have an inflection point at c if the concavity of the graph changes from concave down to concave up or from concave up to concave down at c .

– Theorem 1.16 (The Fourth Derivative Test): Let f be a function defined on the interval $[a, b]$. Suppose that f is differentiable on (a, b) and that $f''(c) = 0$ and $f'''(c) = 0$ and $f^{(4)}(c) \neq 0$. Then f has a local maximum at c if $f^{(4)}(c) < 0$, and f has a local minimum at c if $f^{(4)}(c) > 0$.

Quantitative samples were collected at least once each month except during September, October and November 1947, and January, 1948. Quantitative samples taken while the lake was ice-covered or in a flooded condition were collected in 2-quart Mason jars, without the aid of the net. However, the same procedure was followed for concentration and determination of the number of organisms.

Difficulty with the plankton net made collections possible only at one station on several dates. When certain species did not occur at least once in 160 fields but found in the qualitative sample their presence was indicated on the Quantitative Plankton Analysis record by the use of a symbol. This method was used to indicate relative numbers of organisms for June 14, 1948 when all quantitative samples were destroyed before counts were made, and also in September, October and November, 1947 when only qualitative samples were taken. The list of symbols used are as follows:

aa, very abundant; a, abundant; cc, very common;
c, common; s, scarce; r, rare.

Weekly samples were made at the seven stations in June and early July of 1947. Collections were discontinued at stations 5, 6, and 7 (in Tupper Lake) after this date when the counts at station 4 (inlet to Jordan Lake) indicated a negligible number of organisms were entering Jordan Lake by the channel from Tupper Lake. Bi-weekly sampling was then instituted at the first three stations in Jordan Lake and continued to August 20, 1947. Monthly samples were

then taken (except January, 1948) until March 28, 1948. Bi-monthly sampling was started at this date and continued until June 28 when weekly collections were made, continuing through August 21.

The choice of a method for collection and counting of organisms samples is of importance in a plankton study. In general, there are two methods for collecting aquatic organisms. One, by collection of water in which organisms are suspended, and the concentration of organisms later in the laboratory by various means; and two, the straining out of organisms by the use of a net passing through the water, thus yielding a concentrated sample. The second method was chosen for this study because of the availability of net calibrated to measure the volume of water passing through the net. This type of net (Clarke) has been used successfully especially in oceanographic plankton studies. Although some concentration in the laboratory was necessary for some samples, the use of this net in general eliminated tedious and time consuming labor required to concentrate large volume of waters and eliminated the necessity of carrying bulky containers for field work. The net method may be objectionable because of the loss of some nanoplankton which passes through the silk mesh and because some organisms may stick to the inner surface of the net unless properly washed at the time each sample is taken. These sources of error are inherent in this method but if the same procedure be followed for each collection, then the error is distributed throughout the whole series of

samplings. Hence such errors interfere but very little in the counting. The method permits relative quantitative analyses to be made which, in many cases, are ~~also~~ significant ~~also~~ precise figures.

The methods used for concentration of samples are numerous. A plankton centrifuge is used by many workers when samples of large volumes of water are collected with water bottles. The chief objection to the use of the centrifuge is that this method packs the organisms together, often breaking colonial and filamentous forms into many parts, and creating in some situations, a considerable source of error. Also many types of organisms are crushed by this method and are missed in the counting cell. Inasmuch as the samples taken in this study were already well concentrated, in the field, it was simple to complete the concentration by adding equal amounts of a saturated mercuric chloride solution.

One of the most common methods for counting plankton organisms is by the Sedgwick-Rafter cell and a microscope equipped with an ocular micrometer. Details of this method may be obtained from a standard textbook on water analysis such as Whipple's "Microscopy of Drinking Water". The use of the drop method employed in the present study (modified after Martin and Nelson), eliminates the use of special counting chambers and of special microscope oculars. Once the calibration of the microscope (as previously described) is completed, only a glass slide and cover slip are necessary for the enumeration of organisms.

the first of these is the fact that the system is not a simple one, but a complex one, in which the various parts are interrelated and interdependent. The second is that the system is not a static one, but a dynamic one, in which the parts are constantly changing and evolving. The third is that the system is not a closed one, but an open one, in which the parts are constantly interacting with the environment. The fourth is that the system is not a linear one, but a non-linear one, in which the parts are constantly interacting with each other in a non-linear fashion. The fifth is that the system is not a deterministic one, but a probabilistic one, in which the parts are constantly interacting with each other in a probabilistic fashion. The sixth is that the system is not a simple one, but a complex one, in which the various parts are interrelated and interdependent. The seventh is that the system is not a static one, but a dynamic one, in which the parts are constantly changing and evolving. The eighth is that the system is not a closed one, but an open one, in which the parts are constantly interacting with the environment. The ninth is that the system is not a linear one, but a non-linear one, in which the parts are constantly interacting with each other in a non-linear fashion. The tenth is that the system is not a deterministic one, but a probabilistic one, in which the parts are constantly interacting with each other in a probabilistic fashion.

Littleford et al. (1940) are of the opinion "That precision obtained in plankton counts is largely a function of population density and the volume counted". Thus, no one particular method is demanded for quantitative analyses, provided the organisms are present in sufficient numbers to be counted by whatever method is chosen and assuming of course, that proper technique is used.

Two sources of error in any quantitative study of plankton are found in random sampling and in the clumping of organisms. The latter source of error appears to be more prevalent in methods where centrifuging of collections is involved. Very little difficulty in counting because of clumping was experienced during this survey except in those samples in which the numbers of organisms were very great. A slight dilution and thorough mixing of the sample eliminated this difficulty.

The error of random sampling is inherent in any method. In this study an attempt to reduce this to a minimum was made, especially if organisms were sparse, by counting 40 fields from one drop, and then mixing the sample thoroughly and removing another drop to be counted, sometimes selecting as many as 160 fields.

2. Qualitative Analyses of Algae

Over 100 qualitative collections were made in Jordan Lake during the entire period of study (May 12, 1947 to August 21, 1948). The collections were made from the plankton and from growths along shore and in beach pools

connected with the lake proper. These samples were preserved in 6-3-1 solution and analyzed later in the laboratory. A systematic list of these algae and illustrations of them will be found in a subsequent section.

3. Chemical Analysis of Water and Sewage

Determinations of pH were made in the field with the aid of a portable La Motte colorⁱmetric kit.

Dissolved oxygen samples were collected at Station 2 (near center of the lake) with the use of an oxygen sampling apparatus. The Winkler method for oxygen determination (as outlined in Analysis of Water and Sewage by Theroux, Eldridge and Mallman) was used. In the summer of 1948 it was decided not to make dissolved oxygen determinations unless a critical need arose.

Temperature readings were made at all stations during the summer of 1947 but only at station 2 (middle of lake) throughout the remainder of the study.

Other chemical analyses were made for Methyl Orange Alkalinity, Nitrates, Nitrites and Total Nitrogen. Methods used are those specified in "Analysis of Water and Sewage" by Theroux, Eldridge and Mallman (1936). Stations for these determinations were the lake water proper, inlet, storm sewer and sewage effluent. A single analysis for these chemicals was made in the summer of 1947, but a bi-monthly series of analyses were carried out for the period February 28 through August 21, 1948.

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Inorganic phosphorous content was also determined on samples from the four stations (listed above) on August 5th and 21st.

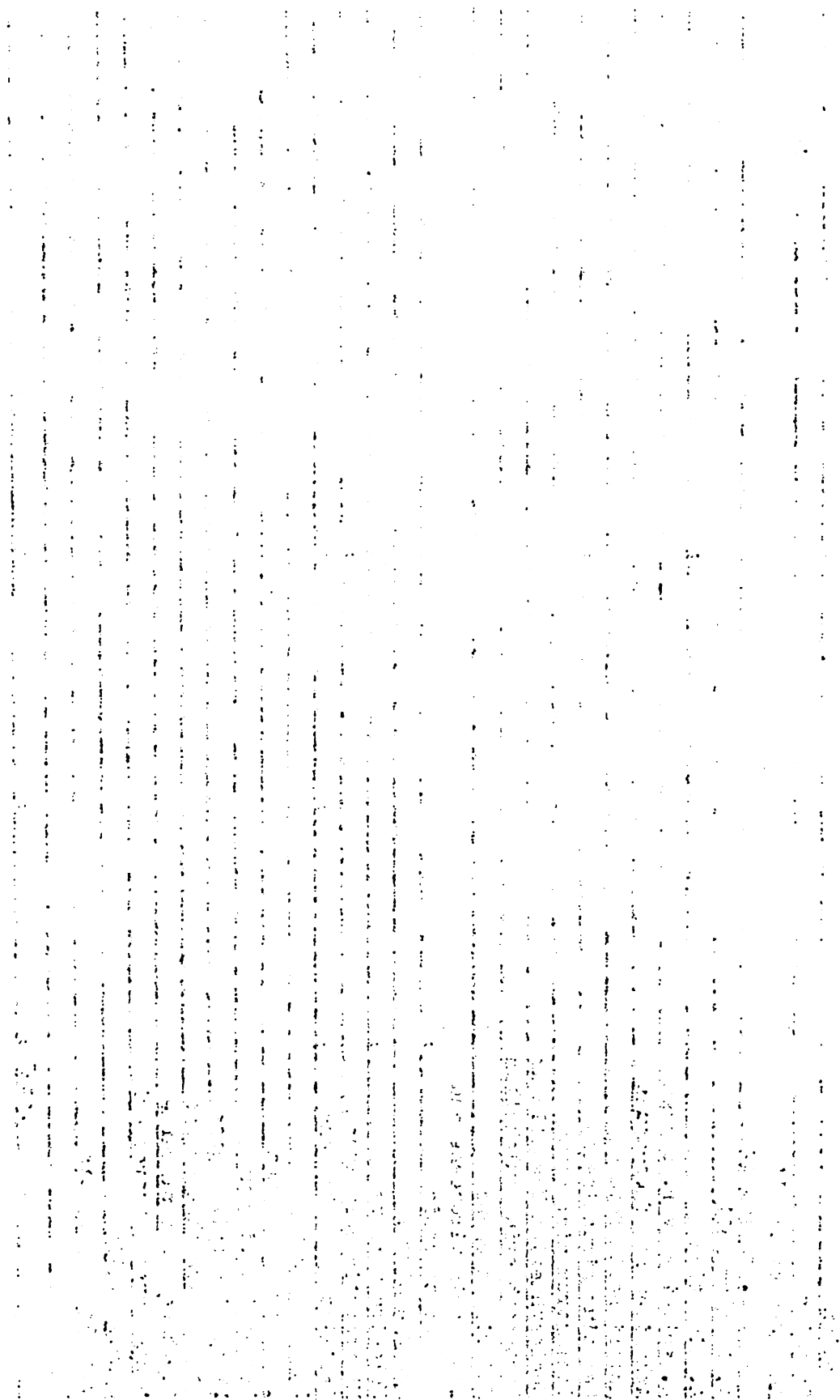
B. Data

1. Quantitative Plankton Counts

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 1	1947	June 24	July 1	July 9	July 19	July 23	July 26*	July 30	Aug. 2
Organism									
Anabaena circinalis var. macrospora	325	58	367	293	588			22	13
A. Lemmermannii									
A. limnetica		29	122	390	1,777			180	220
A. spiroides var. crassa									
Aphanizomenon flos-aquae	325	29	122	586	883			293	73
Asterionella formosa	325								
Ceratium hirundinella	325	58	244	97	1,472				73
Coelastrum microporum									
Coelosphaerium Naegelianum	975	29		97	294			22	73
Dictyosphaerium pulchellum									
Eudorina elegans									
Fragilaria virescens and crotonensis	10,403	58						22	
Lyngbya Birgei									
Melosira varians	12,679							22	
Microcystis aeruginosa	325				1,177				
Oscillatoria rubescens	16,581	322	1,591	976	2,650			45	
Pandorina morum									
Pediastrum Boryanum									
Peridinium cinctum									
Pleodorina californica									
Staurastrum chaetoceras									
Stephanodiscus niagarae	325								
Sphaerocystis Schroeteri	650								
Synura uvella									
Tabellaria fenestra									
Volvox sp.									
Total	43,238	583	2,324	2,439	7,841			606	512

* no sample



Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station	1	1947	Aug. 6	Aug. 9	Aug. 13	Aug. 15	Aug. 20	Sept. *	Oct. *	Nov. Dec
Organism										
Anabaena circinalis var. macrospora	294	244	31	29	183			a	c	
A. Lemmermannii	294	244	46	29	96			a	c	
A. limnetica								aa	a	c
A. spiroides var. crassa	294	244	31	29	96					80
Aphanizomenon flos-aquae										
Asterionella formosa										
Ceratium hirundinella		244							c	
Coelastrum microporum								cc	cc	a
Coelosphaerium Naegelianum										p
Dictyosphaerium pulchellum										
Eudorina elegans										
Fragilaria virescens and crotonensis										40
Lyngbya Birgei										s
Melosira varians										s
Microcystis aeruginosa		489	31	29	183			ccc	cc	53
Oscillatoria rubescens										s
Pandorina morum										
Pediastrum Boryanum										
Peridinium cinctum										
Pleodorina californica										
Staurastrum chaetoceras										s
Stephanodiscus niagarae										
Sphaerocystis Schroeteri										r
Synura uvella										
Tabellaria fenestra										
Volvox sp.										
Total	882	1,465	139	116	558					199

* only one collection station

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station	1	1948	Feb. 28*	Mar. 28*Apr. 16*	May 2 *	May 16* (Flood)	May 31*June 14**	June 28*
Organism								
Anabaena circinalis var. macrospora							r	9
A. Lemmermannii						1	aa	
A. limnetica							r	7
A. spiroides var. crassa							r	4
Aphanizomenon flos-aquae	43	5	10	c		4	c	236
Asterionella formosa								
Ceratium hirundinella						s	s	
Coelastrum microporum				r	s	1		
Coelosphaerium Naegelianum	3		20	10	2	2	cc	9
Dictyosphaerium pulchellum					s			
Eudorina elegans					s	s	s	
Fragilaria virescens and crotonensis	56	85	20	20	5			
Lyngbya Birgei								
Melosira varians			20	20				
Microcystis aeruginosa			r	10	1	1	s	9
Oscillatoria rubescens	14	85						
Pandorina morum			r	r				
Pediastrum Boryanum					2	s	s	
Peridinium cinctum		r						
Pleodorina californica								
Staurastrum chaetoceras			r		s			
Stephanodiscus niagarae			s	c	5	1		
Sphaerocystis Schroeteri				r	10			
Synura uvella								
Tabellaria fenestra	56							
Volvox sp.								
Total	172	175	70	60	25	10		1,274

* only one collection station

** quantitative sample destroyed

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station	1	1948	Jul. 2*	Jul. 8*	Jul. 15*	Jul. 22	Jul. 27	Aug. 5	Aug. 12	Aug. 21
Organism										
Anabaena circinalis var. macrospora	110	20	274	27	274	274		66		
A. Lemmermannii			13	33						
A. limnetica	165	41	109	27	183	183		66		
A. spiroides var. crassa	10	20	73	27	91	91		133		
Aphanizomenon flos-aquae	1,377	416	201	83	640	640		401	38	43
Asterionella formosa										
Ceratium hirundinella		c	73					33	38	108
Coelastrum microporum										
Coelosphaerium Naegelianum	110	145	237	109	183	183		468	339	639
Dictyosphaerium pulchellum			r							
Eudorina elegans										
Fragilaria virescens and crotonensis										
Lyngbya Birgei										s
Melosira varians									19	216
Microcystis aeruginosa	331	124	256	137	732	732		334	350	432
Oscillatoria rubescens	110	c								
Pandorina morum										
Pediastrum Boryanum										
Peridinium cinctum										21
Pleodorina californica										s
Staurestrum chaetoceras		s								
Stephanodiscus niagarae										
Sphaerocystis Schroeteri										
Symura uvella										
Tabellaria fenestra										
Volvox sp.			r							
Total	2,987	766	1,241	448	2,103	2,103		1,504	834	1,459

* one collection station

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 2 1947	June 24	July 1	July 9	July 19	July 23	July 26	July 30*	Aug. 2
<i>Anabaena circinalis</i> var. <i>macrospora</i>	225	58	66	979	366	61		390
<i>A. Lemmermannii</i>								
<i>A. limnetica</i>		29	266	612	183	61		293
<i>A. spiroides</i> var. <i>crassa</i>								
<i>Aphanizomenon flos-aquae</i>	112	29	199	367	183	61		390
<i>Asterionella formosa</i>	112							
<i>Ceratium hirundinella</i>	112	58	66	122	183	122		97
<i>Coelastrum microporum</i>								
<i>Coelosphaerium Naegelianum</i>		29	66	122	91	61		97
<i>Dictyosphaerium pulchellum</i>		29						
<i>Eudorina elegans</i>								
<i>Fragilaria virescens</i> and <i>crotonensis</i>	3,155	58						
<i>Lyngbya Birgei</i>								
<i>Melosira varians</i>	4,628							
<i>Microcystis aeruginosa</i>	112			122	183			97
<i>Oscillatoria rubescens</i>	5,413	322	1,665	1,346	549	61		
<i>Pandorina morum</i>								
<i>Pediastrum Boryanum</i>								
<i>Peridinium cinctum</i>								
<i>Pleodorina californica</i>								
<i>Staurastrum chaetoceras</i>								
<i>Stephanodiscus niagarae</i>	112							
<i>Sphaerocystis Schroeteri</i>	338							
<i>Synura uvella</i>								
<i>Tabellaria fenestra</i>								
<i>Volvox</i> sp.								
Total	14,319	583	2,328	3,670	1,738	427		1,364

* no sample, see stations 1 and 3.

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 2	1947	* #									
Organism	Aug. 6	Aug. 9	Aug. 13	Aug. 15	Aug. 20	Sept. *	Oct. *	Nov. & Dec.			
Anabaena circinalis var. macrospora	1,647	1,047	39	104	96	a	c				
A. Lemmermannii	183										
A. limnetica		418	156	52	183	a	c				
A. spiroides var. crassa											
Aphanizomenon flos-aquae	183	418	39	157	96	aa	a	c	86		
Asterionella formosa											
Ceratium hirundinella		290		52			c				
Coelastrum microporum											
Coelosphaerium Naegelianum					96	cc	cc	a	26	p	
Dictyosphaerium pulchellum											
Eudorina elegans											
Fragilaria virescens and crotonensis									40		
Lyngbya Birgei											
Melosira varians									s	s	
Microcystis aeruginosa		290	111	52	96	ccc	cc	cc	53	s	
Oscillatoria rubescens									s	s	
Pandorina morum											
Pediastrum Boryanum											
Peridinium cinctum											
Pleodorina californica											
Staurastrum chaetoceras									s		
Stephanodiscus niagarae											
Sphaerocystis Schroeteri											
Synura uvella									r	r	
Tabellaria fenestra											
Volvox sp.											
Total	2,013	2,463	345	417	567				199		

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 2	1948	Feb. 28*	Mar. 28*	Apr. 16*	May 2*	May 16*	May 31	*June 14**	June 28*
Organism		(Flood)				(Flood)			
Anabaena circinalis								r	9
var. macrospora							1	aa	
A. Lemmermannii								r	7
A. limnetica								r	4
A. spiroides var. crassa							4	c	236
Aphanizomenon flos-aquae	43	5	10	c					
Asterionella formosa							s	s	
Ceratium hirundinella							1		
Coelastrum microporum				r	10	2	2	cc	9
Coelosphaerium Naegelianum	3		20			s			
Dictyosphaerium pulchellum						s	s	s	
Eudorina elegans									
Fragilaria virescens and crotonensis	56	85	20	20	5				
Lyngbya Birgei									
Melosira varians			20	20					
Microcystis aeruginosa			r	10	1		1	s	9
Oscillatoria rubescens	14	85							
Pandorina morum			r	r					
Pediastrum Boryanum					2		s	s	
Peridinium cinctum		r							
Pleodorina californica									
Staurastrum chaetoceras			r		s				
Stephanodiscus niagarae				c	5		1		
Sphaerocystis Schroeteri			s	r	10				
Synura uvella									
Tabellaria fenestra	56							r	
Volvox sp.									
Total	172	175	70	60	25+		10+		274

* only one collection station
** quantitative sample destroyed

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 2 1948	Jul. 3*	Jul. 8*	Jul. 15*	Jul. 22	Jul. 27	Aug. 5	Aug. 12	Aug. 21
Organism								
Anabaena circinalis var. macrospora	110	20	274	42	274	57		
A. Lemmermannii			18	42				
A. limnetica	165	41	109	42	274	57		
A. spiroides var. crassa	10	20	73	170	137	57		
Aphanizomenon fles-aquae	1,877	416	201	297	823	516	109	84
Asterionella formosa								
Ceratium hirundinella		c	73	28		43	36	508
Coelastrum microporum								
Coelosphaerium Naegelianum	110	145	237	297	686	516	549	762
Dictyosphaerium pulchellum								
Eudorina elegans			r					
Fragilaria virescens and crotonensis								
Lyngbya Birgei								
Melosira varians							18	254
Microcystis aeruginosa	331	124	256	170	823	275	175	254
Oscillatoria rubescens								
Pandorina morum								84
Pediastrum Boryanum								
Peridinium cinctum								
Pleodorina californica								
Staurastrum chaetoceras		s						
Stephanodiscus niagarae								
Sphaerocystis Schroeteri								
Synura uvella								
Tabellaria fenestra								
Volvox sp.								
Total	2,987	766	1,241	1,131	3,017	1,521	887	1,946

* only one collection station

Station 3 1947

61

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 3	1947	Aug. 6	Aug. 9	Aug. 13	Aug. 15	Aug. 20	Sept. *	Oct. *	Nov. #	Dec.
Organism										
Anabaena circinalis var. macrospora	611	418	33	69	144		a	c		
A. Lemmermannii										
A. limnetica	1,770	1,047	33	69	144		a	c		
A. spiroides var. crassa										
Aphanizomenon flos-aquae	244	418	33	69	144		aa	a	c	80
Asterionella formosa										
Ceratium hirundinella		110	33	46				c		
Coelastrum microporum										
Coelosphaerium Naegelianum					144		cc	cc	a	26
Dictyosphaerium pulchellum										
Eudorina elegans										
Fragilaria virescens and crotonensis										40
Lyngbya Birgei										
Melosira varians									s	s
Microcystis aeruginosa		110	66	46	144		ccc	cc	cc	53
Oscillatoria rubescens									s	s
Pandorina morum										
Pediastrum Boryanum										
Peridinium cinctum										
Fleodorina californica										
Staurestrum chaetoceras										
Stephanodiscus niagarae									s	
Sphaerocystis Schroeteri										
Synura uvella									r	r
Tabellaria fenestra										
Volvox sp.										
Total	2,625	2,103	198	299	720					199

* only one collection station

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 3	1948	Feb. 28*	Mar. 28*	Apr. 16*	May 2 *	May 16	*May 31	*June 14**	June 28*
Organism									
Anabaena circinalis var. macrospora							1	r	9
A. Lemmermannii								aa	
A. limnetica								r	7
A. spiroides var. crassa								r	4
Aphanizomenon flos-aquae	43	5	10	c			4	c	236
Asterionella formosa							s	s	
Ceratium hirundinella				r			1		
Coelastrum microporum				10		s	2	cc	9
Coelosphaerium Naegelianum	3		20			s			
Dictyosphaerium pulchellum						s	s	s	
Eudorina elegans									
Fragilaria virescens and crotonensis	56	85	20	20		5			
Lyngbya Birgei									
Melosira varians			20	20					
Microcystis aeruginosa			r	10		1	1	s	9
Oscillatoria rubescens	14	85							
Pandorina morum			r	r					
Pediastrum Boryanum						2	s	s	
Peridinium cinctum									
Pleodorina californica									
Staurastrum chaetoceras									
Stephanodiscus niagarae			r			s			
Sphaerocystis Schroeteri				c		5	1		
Synura uvella			s	r		10			
Tabellaria fenestra	56								
Volvox sp.								r	
Total	172	175	70	60		25+	10+		274

* Only one collection station
** Quantitative sample destroyed

2. The second part of the document focuses on the implementation of the proposed changes. It details the steps involved in the transition process, from the initial planning phase to the final execution. This section also addresses the potential challenges that may arise during the implementation and provides strategies to overcome them.

3. The third part of the document discusses the impact of the proposed changes on the organization's overall performance. It highlights the expected benefits, such as increased efficiency and cost savings, and provides a detailed analysis of the potential risks. This section also includes a comparison of the current state of the organization with the proposed changes, illustrating the expected improvements.

4. The fourth part of the document provides a summary of the key findings and conclusions. It reiterates the importance of the proposed changes and the need for continued monitoring and evaluation. This section also includes a list of recommendations for future actions, ensuring that the organization remains committed to the principles of transparency and accountability.

Page 10

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 3 1948	Jul. 3*	Jul. 8*	Jul. 15*	Jul. 22	Jul. 27	Aug. 5	Aug. 12	Aug. 21
Organism								
Anabaena circinalis var. macrospora	110	20	274	72	290	197	43	
A. Lemmermannii			18	24				
A. limnetica	165	41	109	329	145	197		
A. spiroides var. crassa	10	20	73	36	145	197		
Aphanizomenon flos-aquae	1887	416	201	323	370	591		560
Asterionella formosa								
Ceratium hirundinella		c	73	18		50	131	243
Coelastrum microporum								
Coelosphaerium Naegelianum	110	145	237	108	530	591	436	834
Dictyosphaerium pulchellum								
Eudorina elegans			r					
Fragilaria virescens and crotonensis								
Lyngbya Birgei								
Melosira varians								243
Microcystis aeruginosa	331	124	256	252	1,302	789	170	486
Oscillatoria rubescens	110	c						
Pandorina morum								
Pediastrum Boryanum								
Peridinium cinctum								
Pleodorina californica								
Staurastrum chaetoceras								
Stephanodiscus niagarae								
Sphaerocystis Schroeteri								
Synura uvella								
Tabellaria fenestra								
Volvox sp.								
Total	2,987	7,666	1,241	1,154	3,332	2,612	780	2,390

* one collection station

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 4 - 1947	June 24	Jul. 1	Jul. 9*
Organism			
Anabaena circinalis var. macrospora	81		
A. Lemmermannii			
A. limnetica			
A. spiroides var. crassa			
Aphanizomenon flos-aquae	162		
Asterionella formosa	40	19	
Ceratium hirundinella			
Coelastrum microporum			
Coelosphaerium Naegelianum	81		
Dictyosphaerium pulchellum		9	
Eudorina elegans			
Fragilaria virescens and crotonensis	381		
Lyngbya Birgei			
Melosira varians	534	7	
Microcystis aeruginosa			
Oscillatoria rubescens	179	19	
Pandorina morum			
Pediastrum Boryanum			
Peridinium cinctum			
Pleodorina californica			
Staurostrum chaetoceras	40		
Stephanodiscus niagarae	81		
Sphaerocystis Schroeteri			
Synura uvella			
Tabellaria fenestra			
Volvox sp.			
Total	1,629	54	

* quantitative study after July 1, negligible

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 5 Tupper Lake 1947				Station 6 Tupper Lake 1947			
Organism	June 28	July 5	July 11	June 28	July 5	July 11	
Anabaena circinalis var. macrospora			209			97	
A. Lemmermannii							
A. limnetica	1,038	1,466	1,885	7,916	4,067	1,563	
A. spiroides var. crassa							
Aphanizomenon flos-aquae	2,033	2,034	1,675	11,142	6,224	1,953	
Asterionella formosa							
Ceratium hirundinella	44	104	209			97	
Coelastrum microporum							
Coelosphaerium Naegelianum							
Dictyosphaerium pulchellum	44			293			
Eudorina elegans	130			1,460			
Fragilaria virescens and crotonensis	1,211	209		7,623	366		
Lyngbya Birgei							
Melosira varians	44			293			
Microcystis aeruginosa							
Oscillatoria rubescens	44	314		1,272	366	97	
Pandorina morum	130			879			
Pediastrum Boryanum				293			
Peridinium cinctum							
Pleodorina californica							
Staurastrum chaetoceras							
Stephanodiscus niagarae							
Sphaerocystis Schroeteri							
Synura uvella							
Tabellaria fenestra							
Volvox sp.	44			293	366		
Total	4,760	4,127	3,978	31,464	1,389	3,827	

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station 7 Turner Lake 1947	June 28	July 5	July 11		
Organism					
Anabaena circinalis var. macrospora					
A. Lemmermannii					
A. limnetica	1,758	732	1,300		
A. spiroides var. crassa					
Aphanizomenon flos-aquae	4,005	1,399	4,226		
Asterionella formosa					
Ceratium hirundinella	97		162		
Coelastrum microporum					
Coelosphaerium Naegelianum					
Dictyosphaerium pulchellum	97				
Eudorina elegans	97				
Fragilaria virescens and crotonensis	1,953				
Lyngbya Birgei					
Melosira varians	97				
Microcystis aeruginosa			162		
Oscillatoria rubescens	195		162		
Pandorina morum	195				
Pediastrum Boryanum	97				
Peridinium cinctum					
Fleodorina californica					
Staurastrum chaetoceras					
Stephanodiscus niagarae					
Sphaerocystis Schroeteri	97				
Synura uvella					
Tabellaria fenestra					
Volvox sp.	97				
Total	8,785	2,264	6,012		

Quantitative Plankton Analysis
(Organisms in thousands per liter)

Station: Brighton	1948	May 24	Ju 13	Ju 24	Ju 29	Jul 7	Jul 21	Jul 28	Aug 11
Organism									
Anabaena circinalis var. macrospora				691	347				
A. Lemmermannii	5		1,314						s
A. limnetica			379	138 48					s
A. spiroides var. crassa	15								
Ankistrodesmus falcatus									
Aphanizomenon flos-aquae	15		1,214	9,261 s	487				
Asterionella formosa				s					
Ceratium hirundinella				s		2	s	s	s
Dictyosphaerium pulchellum	5								
Dinobryon sertularia	10								
Eudorina elegans							s	s	r
Fragilaria				s			s		
Melosira sp.	30			s			3	206	s
Microcystis aeruginosa				s				s	
Microactinium pusillum								r	
Pandorina morum				8			s	r	r
Pediastrum Boryanum	5								
Scenedesmus arcuatus	5								
S. quadricauda	5								
Sphaerocystis Schroeteri								s	
Stephanodiscus sp.	5								
Tabellaria sp.	10								
Volvox sp.				r					
Total	110		2,907	10,146	834	2	3	206	

2. Chemical Analysis of Water and Sewage

Chemical Analysis of Water and Sewage

(in parts per million)

Station - Inlet

Methyl Orange Alk

	OH	CO ₃	HCO ₃	NO ₂	NO ₃	TOT N
July 19, 47	0	0	183	.001	.06	1.848
Feb. 28, 48	0	0	170	.01	.3	5.44
Mar. 28, 48	-	-	---	----	--	----
Apr. 16, 48	0	0	150	.024	.12	3.04
May 2, 48	0	0	169	.028	.5	----
May 16, 48	0	0	150	.028	.8	3.2
May 31, 48	0	0	174	.014	.14	3.2
June 14, 48	0	0	172	.007	.14	2.88
June 27, 48	0	0	182	.007	.06	2.88
July 8, 48	0	0	171	.002	.08	3.04
July 22, 48	0	0	171	tr	.04	2.8
Aug. 5, 48	0	0	182	.002	.06	2.78
Aug. 21, 48	0	0	178	tr	.1	2.56

[illegible]

1. *Journal of the American Medical Association*, 1997; 278: 1039-1044.

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1. The first group of variables, *demographics*, includes age, sex, and marital status. The second group, *education*, includes years of schooling, high school graduation, and college graduation. The third group, *employment*, includes employment status, occupation, and industry. The fourth group, *income*, includes household income and personal income. The fifth group, *health*, includes self-rated health, physical health, and mental health. The sixth group, *social capital*, includes social network, social support, and social trust. The seventh group, *life satisfaction*, includes life satisfaction, happiness, and well-being. The eighth group, *quality of life*, includes quality of life, health-related quality of life, and life satisfaction. The ninth group, *subjective well-being*, includes subjective well-being, happiness, and life satisfaction. The tenth group, *life satisfaction*, includes life satisfaction, happiness, and well-being.

Chemical Analysis of Water and Sewage

(in parts per million)

Station - Storm Sewer

Methyl Orange Alk

| | OH | CO ₃ | HCO ₃ | NO ₂ | NO ₃ | TOT N |
|-------------|----|-----------------|------------------|-----------------|-----------------|-------|
| July 19, 47 | 0 | 0 | 322 | .034 | .03 | 1.4 |
| Feb. 28, 48 | 0 | 0 | 159 | .08 | .07 | 5.44 |
| Mar. 28, 48 | 0 | 0 | 220 | .168 | .3 | 6.08 |
| Apr. 16, 48 | 0 | 0 | 249 | .240 | .4 | 13.6 |
| May 2, 48 | 0 | 0 | 343 | .2 | .8 | 12.8 |
| May 16, 48 | 0 | 0 | 245 | .15 | 2.4 | 12.8 |
| May 31, 48 | 0 | 0 | 348 | .15 | .12 | 14.4 |
| June 14, 48 | 0 | 0 | 357 | .1 | .26 | 13.6 |
| June 27, 48 | 0 | 0 | 365 | .028 | .017 | 12.4 |
| July 8, 48 | 0 | 0 | 330 | .088 | .06 | 14.4 |
| July 22, 48 | 0 | 0 | 132 | .088 | .12 | 7.6 |
| Aug. 5, 48 | 0 | 0 | 396 | .045 | .08 | 9.28 |
| Aug. 21, 48 | 0 | 0 | 393 | .01 | .03 | 14.0 |

Chemical Analysis of Water and Sewage
(in parts per million)
Station - Sewer Effluent

Methyl Orange Alk.

| | OH | CO ₃ | HCO ₃ | NO ₂ | NO ₃ | TOT N |
|------------|----|-----------------|------------------|-----------------|-----------------|-------|
| July 19,47 | 0 | 0 | 450 | .034 | .04 | 17.6 |
| Feb. 28,48 | 0 | 0 | 371 | .5 | .7 | 24.8 |
| Mar. 28,48 | 0 | 0 | 318 | .5 | .8 | 24. |
| Apr. 16,48 | 0 | 0 | 314 | .24 | .4 | 25.6 |
| May 2,48 | 0 | 0 | 386 | .17 | .28 | 28.8 |
| May 6,48 | 0 | 0 | 334 | .12 | 3.2 | 15.2 |
| May 31,48 | 0 | 0 | 382 | .04 | .1 | 25.6 |
| June 14,48 | 0 | 0 | 392 | .034 | .1 | 27.2 |
| June 27,48 | 0 | 0 | 397 | .034 | .017 | 30.4 |
| July 8,48 | 0 | 0 | 285 | .014 | .2 | 28.8 |
| July 22,48 | 0 | 0 | 242 | .02 | .4 | 9.6 |
| Aug. 5,48 | 0 | 0 | 348 | .02 | .06 | 28.0 |
| Aug. 21,48 | 0 | 0 | 354 | .01 | .03 | 32.0 |

Chemical Analysis of Water and Sewage

(in parts per million)

Station - Lake

Methyl Orange Alk.

| | OH | CO ₃ | HCO ₃ | NO ₂ | NO ₃ | TOT N |
|------------|----|-----------------|------------------|-----------------|-----------------|-------|
| July 19,47 | 0 | 20 | 116 | .002 | .03 | 4.8 |
| Feb. 28,48 | 0 | 0 | 60 | .014 | .01 | 6.4 |
| Mar. 28,48 | 0 | 0 | 123 | .014 | .02 | 5.76 |
| Apr. 16,48 | 0 | 0 | 155 | .034 | .13 | 3.08 |
| May 2,48 | 0 | 22 | 139 | .028 | .15 | 3.36 |
| May 16,48 | 0 | 0 | 153 | .028 | .6 | 2.96 |
| May 31,48 | 0 | 42 | 153 | .044 | .12 | 3.84 |
| June 14,48 | 0 | 56 | 88 | .007 | .05 | 2.88 |
| June 27,48 | 0 | 58 | 82 | .001 | .03 | 2.96 |
| July 8,48 | 0 | 60 | 35 | .014 | .04 | 3.28 |
| July 22,48 | 0 | 64 | 65 | tr | .04 | 3.84 |
| Aug. 5,48 | 0 | 26 | 11 | .001 | .02 | 3.4 |
| Aug. 21,48 | 0 | 46 | 88 | tr | .08 | 2.72 |

Chemical Analysis of Water and Sewage
(in parts per million)
Inorganic Phosphorous

| | Inlet | Storm Sewer | Sewage Effluent | Lake |
|-------------|-------|-------------|-----------------|-------|
| Aug. 5, 48 | .014 | .028 | .06 | .015 |
| Aug. 21, 48 | .024 | .032 | .032 | .0084 |

3. Other Determinations and Measurements

DISSOLVED OXYGEN---pH---TEMPERATURE READING

| DATE | D.O..
p.p.m. | TEMPERATURE | | | | | pH | | | |
|---------|-----------------|--------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| | | Degrees Centigrade | | | | | | | | |
| 1947 | | Sta.2 | Sta.1 | Sta.2 | Sta.3 | Sta.4 | Sta.1 | Sta.2 | Sta.3 | Sta.4 |
| June 24 | 11.2 | 20 | | 20 | 20 | 20 | 8.5 | 8.6 | 8.5 | 6.4 |
| July 1 | 10.0 | 22 | | 22 | 22 | 21 | 8.5 | --- | --- | 6.7 |
| July 9 | 7.6 | 22 | | 22 | 22 | 21 | 8.5 | 8.2 | 8.5 | 6.8 |
| July 19 | 9.6 | 21 | | 21 | 21 | 19 | 8.7 | 8.7 | 8.7 | 6.8 |
| July 23 | 8.4 | 23 | | 22 | 22 | 19 | 8.5 | 8.5 | 8.5 | 6.8 |
| July 26 | 5.4 | 24.5 | | 23 | 23 | 21 | 8.7 | 8.8 | 8.6 | 6.8 |
| July 30 | 4.7 | 22. | | 24.5 | 24.5 | 23 | 8.7 | 8.6 | 8.6 | 6.8 |
| Aug. 2 | 7.6 | 22 | | 23 | 23 | 20 | 8.5 | 8.6 | 8.6 | 6.8 |
| Aug. 6 | 9.0 | 28 | | 30 | 31 | 27 | 8.8 | 8.7 | 8.8 | 7.0 |
| Aug. 9 | 1.0 | 25 | | 25 | 24 | 22 | 8.9 | 8.9 | 8.8 | 7.2 |
| Aug. 13 | 7.6 | 27 | | 27 | 28 | 26 | 8.8 | 8.9 | 8.8 | 7.2 |
| Aug. 15 | 6.9 | 25 | | 25 | 26 | 24 | 8.2 | 8.6 | 8.7 | 7.2 |
| Aug. 20 | 9.0 | 30 | | 30 | 30 | 27 | 8.8 | 9.0 | 8.9 | 7.2 |
| Aug. 23 | 7.6 | 29 | | 29 | 29 | 28 | 8.7 | 8.8 | 8.9 | 7.2 |

Sta. 4

| | |
|---------|-----|
| Aug. 9 | 0.0 |
| Aug. 13 | 0.0 |
| Aug. 15 | 0.0 |
| Aug. 20 | 0.7 |
| Aug. 23 | 0.7 |

pH --- TEMPERATURE READINGS

| DATE | Station 2 | |
|----------|-----------|----------|
| 1948 | pH | TEMP. °C |
| Mar. 28 | 7.2 | 5 |
| April 15 | 7.8 | 12 |
| May 2 | 8.0 | 19 |
| May 16 | 7.6 | 20 |
| May 31 | 8.2 | 22 |
| June 14 | 8.6 | 25 |
| June 28 | 8.6 | 22 |
| July 3 | 8.8 | 25 |
| July 8 | 9.0 | 23 |
| July 15 | 9.2 | 24 |
| July 22 | 9.2 | 26 |
| July 27 | 9.2 | 25 |
| Aug. 5 | 9.0 | 23 |
| Aug. 12 | 9.2 | 23 |
| Aug. 21 | 9.2 | 26 |

V. DISCUSSION OF RESULTS

During the summer of 1947 the primary purpose of the survey was to determine the kinds of organisms present, and their quantity. Also general observations on limnological conditions of the lake water and the effluents draining into the lake were made. (pH, temperature, dissolved oxygen). One series of samples of the lake water, inlet water, storm sewer effluent and sewage effluent was also analyzed to determine their relative content of bicarbonates, carbonates, nitrates, nitrites and total nitrogen. During 1948, however, emphasis was placed on an attempt to determine whether a correlation existed between the quantity of organisms present and the chemistry of the water, especially in respect to two of the inorganic forms of nitrogen, nitrates and nitrites.

The chemical study will be considered in a subsequent section together with an analysis of phytoplankton correlation.

1. Organisms causing "water blooms" in Jordan Lake.

If the arbitrary standard of 500,000 organisms per liter set by Sawyer et al. (1943, 1944) is used, Jordan and Tupper Lakes are in almost continuous "bloom" condition for approximately 4 months of the year. Although great increases in number of organisms are usually referred to as "pulses" or "blooms", in the following discussion the term "bloom" will be used only for reference to conditions in which the phytoplankton became so abundant as to make

the water quite turbid and somewhat colored, or when a heavy blue-green scum was present on the surface waters.

Six species of blue-green algae are the main components of the "bloom" condition during the summer and early fall in Jordan and Tupper Lakes; Anabaena limnetica G. M. Smith, Anabaena spiroides var. crassa Lemmermann, Anabaena circinalis var. macrospora (Wittrock) de Toni, Aphanizomenon flos-aquae (L.) Ralfs, Microcystis aeruginosa Kuetzing and Coelosphaerium Naegelianum Unger.

The periodicity of the different species of Anabaena vary in certain respects. A. limnetica and A. circinalis var. macrospora appeared in June and remained through summer or early fall, showing a periodicity characteristic of these species. In 1947 these two species appeared in collections as late as October 15th, whereas in 1948 they were not found after August 5th. The third species, A. spiroides var. crassa appeared rarely in 1947 but was very abundant beginning June 14, 1948; disappearing in August. A fourth species, A. Lemmermannii P. Richter also was not observed in 1947 but was found in collections during May, 1948, created a dense bloom on June 14th, and then disappeared, only to reappear in small numbers in samples taken July 15th and July 22nd.

Aphanizomenon flos-aquae appeared in all samples from June 24, 1947 until August 21, 1948 with the exception of a two week period in May, 1948.

Coelosphaerium Naegelianum appeared in most samples during the entire survey. This species first appeared in

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July, 1947, but became reduced in numbers or was lacking for several weeks in August, 1948 and also in March, 1948. The latter collection was taken during a flooded condition of the lake.

Microcystis aeruginosa was somewhat erratic in its periodicity. During the summer of 1947, this organism was absent for a few weeks at several intervals. Collections in February and March, 1948 showed less than 3,000 organisms per liter of lake water.

Other organisms which appeared in great abundance periodically during the study but which did not create a disagreeable condition were: Oscillatoria rubescens De Candolle, (another blue-green alga); Fragilaria virescens Ralfs; Fragilaria crotonensis Kitton; Asterionella formosa Hassall; Melosira varians Agardh and Stephanodiscus niagarae Ehrenberg (diatoms); Ceratium hirundinella (O. F. Mueller) Dujardin.

Plankton samples from a southern Michigan lake containing almost pure growths of Oscillatoria rubescens were collected by Dr. R. C. Ball of the Michigan State College Zoology Department in the spring of 1948. This organism, identical with a species in Jordan Lake, gave the water a reddish purple color because of light refraction due to the great number of pseudovacuoles occurring in the cells. In Jordan and Tupper Lakes at certain intervals this species occurred in great abundance, but the color phenomenon did not appear, although specimens examined revealed presence of pseudovacuoles in the cells.

Diatom species listed above, present in great abundance in the June of 1947 but decidedly reduced in number the following spring, did not produce any objectionable conditions other than that their presence gave the lake water a muddy appearance.

Ceratium hirundinella, a dinoflagellate, appeared sporadically in collections throughout the year. In general, this species was an important component of the summer phytoplankton, often appearing in great numbers. When other algae decline, and this species becomes very abundant, the water takes on a muddy brown appearance, due to the tremendous number of organisms which contain yellow-brown chromatophores.

In general, fewer organisms were present during the summer of 1948 than in the previous summer. The most serious condition arising from the abundance of algae occurred on August 6, 1947. At this time, the surface scum of blue-green algae was blown upon the municipal beach and the shoreline most densely populated. The gelatinous blue-green scum became entangled with heavy mats of Cladophora, and when they began to decompose, they turned a cream color and produced an obnoxious odor. Local residents were generally accustomed to the foetid odor arising from the shallow weed beds, algal mats, a few dead fish, and other disagreeable debris that collected behind boat docks and in shallow coves. Nevertheless they were quick to note this added obnoxious condition and promptly started a rumor that the writer had been

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seen "dumping" some chemical in "their" lake causing this new phenomenon. However, no treatment had been given to the lake.

Reliable local sources reported that this condition was not new to the lake and that the previous summer (1946) many tourists abruptly cancelled their stay when a similar but more serious condition occurred. In both years during July and August surface scum was intermittently present. Although not a serious offender while in the middle of the lake, such masses of vegetation served as poor advertisement for a resort area when washed ashore by wind and wave action, especially in the northeast end.

Quantitative values for the four stations varied on the same date. Mention has been made previously of the almost complete lack of organisms entering Jordan Lake from the channel in the summer months. Dense weed beds at the mouth of the outlet of Jordan Lake (Thornapple River) made sampling in the outlet impossible during the summer months. Thus, values for Station 1 do not show the number of organisms leaving Jordan Lake, but the number of organisms in the area within the lake closest to the outlet. The importance of these weed beds, blocking the outlet, causing the phytoplankton to become concentrated and thus interfering with the determination of the quantity of organisms at Station 1 cannot be fully estimated. This may be the explanation for the high count (43,238,000 organisms per liter) on June 24, 1947.

Variations in quantity at other stations also may be accounted for by the variations in current and prevailing wind direction. An example is the large count (31,464,000 organisms per liter) found at Station 6 (within Tupper Lake from Tupper Creek inlet) on June 28, 1947. At this time wind action had caused organisms to accumulate in this region of the lake.

There are several points of caution to be considered when interpreting the following graphs.

1. It was possible to make chemical analysis for NO_2 , NO_3 , total nitrogen and Methyl orange alkalinity at two-week intervals only (except in February and March). The possible variations in amounts of these substances present between samplings are therefore unknown. Such additional data might influence the configuration of the curves.

2. The samples for March 28 and May 16 were taken while the lake was in a flooded condition. The effect of such a condition on the water chemistry and phytoplankton quantity, both at the time of flood and for the succeeding weeks is difficult if not impossible to measure. The two samples, then merely show values for the time they were collected and only inferences may be drawn as to the effects of the flooded condition on water chemistry and plankton.

3. Temperature readings of surface lake water were usually made at about 10:00 A.M. in the morning, and thus are not indicative of temperature values throughout the

day. (It is well known of course that water temperatures vary but little within a twenty four hour period).

4. All quantitative determinations are indices only for the time they were taken.

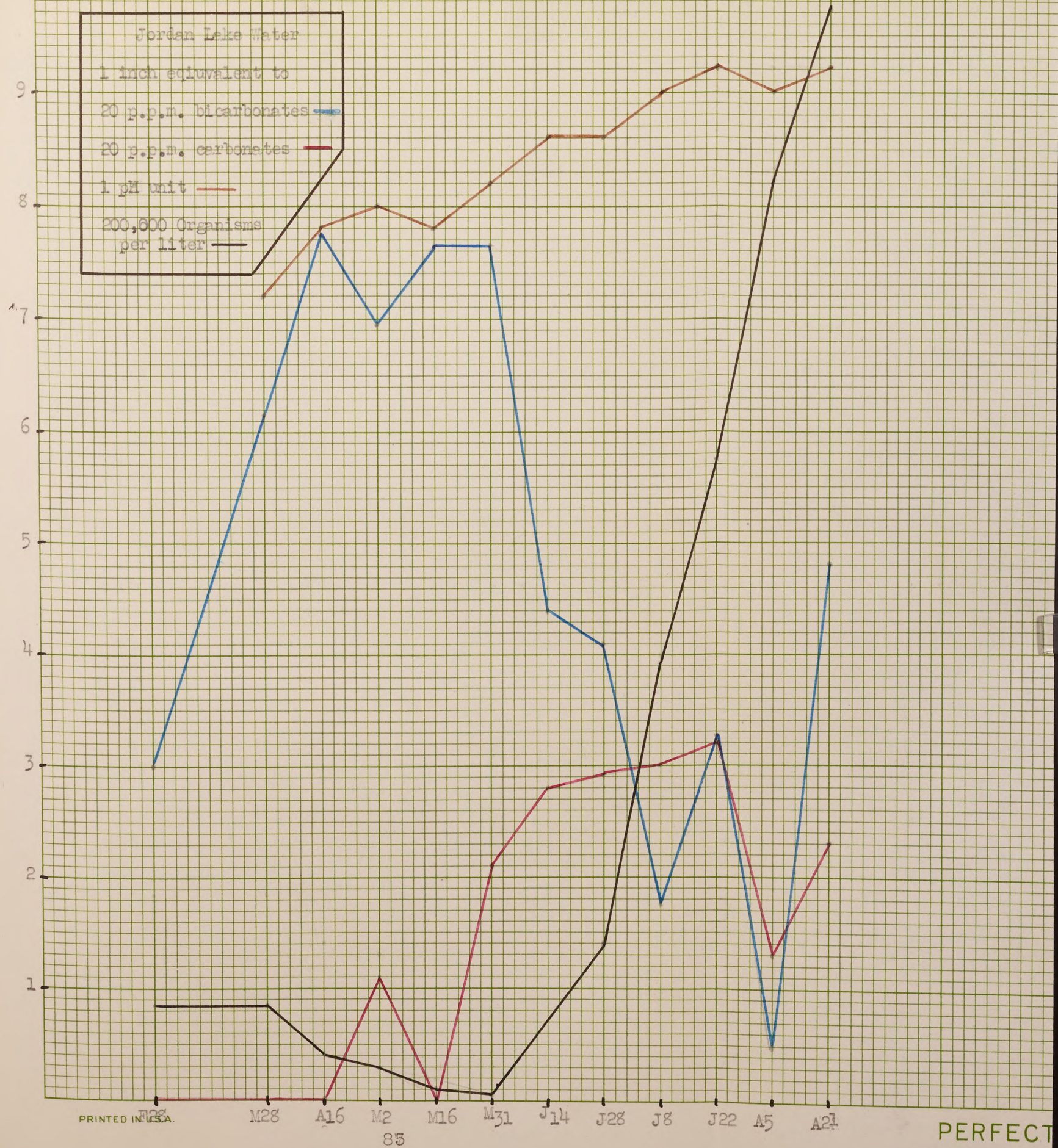
Several significant facts may be noted although a strict correlation between the quantity of phytoplankton and the water chemistry was not found.

Chemical analysis of lake water disclose the following:

1. There is a gradual increase in pH (7.2-9.2) in the lake water as the phytoplankton increases during the summer growth (see Graph). This agrees with Prescott's (1939) contention that when phytoplankton is low, pH is low and conductivity is high. "When phytoplankton increases during the season, conductivity becomes less due to the consumption of electrolytic salts and the pH rises with the precipitation of carbonates".

2. There is an increase in carbonates and a decrease in bicarbonates during the seasonal increase of phytoplankton (see Graph). This is caused by the gradual increase in bicarbonates as a source of CO_2 for the more abundant phytoplankton, resulting in a greater precipitation of carbonates.

3. Total nitrogen content, highest in February and March, varies considerably during the summer months. (See Graph). This variation possibly may be accounted for not only by the fluctuations in nitrate and nitrite content, but also by the loss of NH_3 as a gas through decomposition of organic material. Mortimer (1939) reports that certain

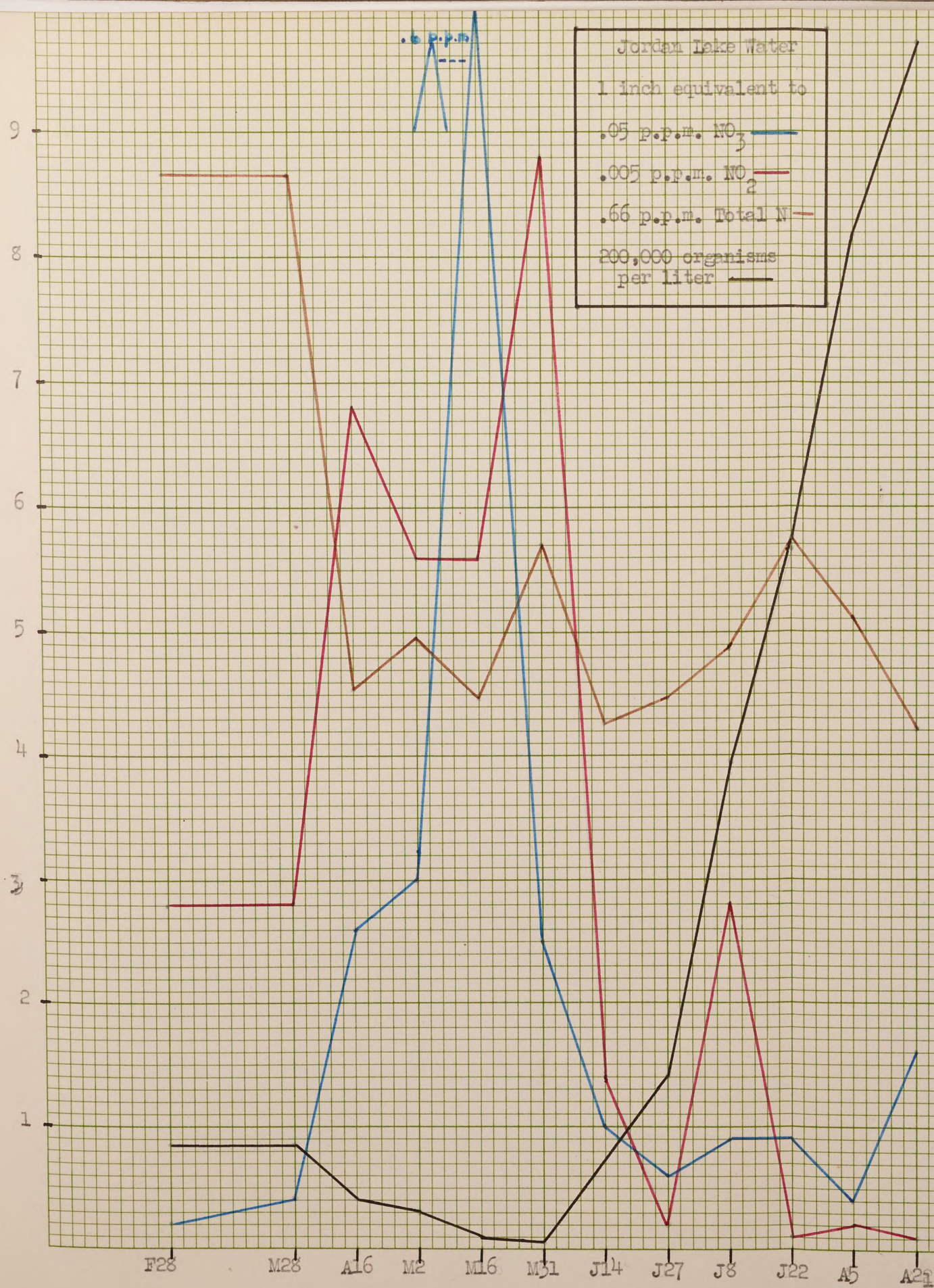


productive lakes in England in the summer of 1938 showed less total nitrogen in the outflow than in the inflow waters, that the difference was in excess of that stored in bottom mud, and therefore represented nitrogen loss. Pennington (1942) also has showed that there was a marked loss of nitrogen from cultures of algae and bacteria, apparently indicating liberation of gaseous nitrogen. This loss may be related to the fluctuations in total nitrogen content during the summer in Jordan Lake.

4. Temperature readings of surface water showed a gradual increase from February through August. Ten readings as high as 30°C were made in August of 1947.

5. Dissolved oxygen content varies from sample to sample because of many factors such as temperature of water, amount of photosynthetic activity and wind action. However, values were high enough throughout the summer to support aquatic animals. One determination, that of 1.0 p.p.m. on August 9, 1947 would indicate a critical condition for fish life. Inasmuch as there was no apparent fish-kill at this date the low oxygen content was obviously local and peculiar to the particular area of water from which the sample was taken.

6. A general inverse correlation between the amounts of nitrites and nitrates and the quantity of phytoplankton makes its appearance, although a strict correlation cannot be drawn (see Graph). It is to be noted, however, that plankton organisms were present in the lowest quantity on May 16 and 31st, when nitrates and nitrites respectively



were most abundant. And conversely, the greatest quantities of organisms were present May 31 to August 21 when nitrates and nitrites were lowest. From this it may be correctly inferred that nitrogenous materials serve as nutrients for phytoplankton, and that their profuse growth had reduced the values of nitrates and nitrites accordingly. This is in keeping with the findings of Sawyer et al. (1943, 1944) who found that inorganic nitrogen in Waubesa Lake was reduced from 0.95 to 0.3 p.p.m. after a "bloom" condition.

Several important factors should be considered before such an inference may be established as valid. Some workers, such as Pennington (1942), for example, have shown by the use of mixed algae and bacteria laboratory cultures and simulated field conditions that algal organisms do not use nitrite but do use nitrate and ammonia, the latter much more rapidly. His experiments also showed that nitrite was produced from both ammonia and nitrate: ammonia from nitrate and nitrate from ammonia. Hence some reduction in nitrates noted in Jordan Lake might be related to nitrite formation and not necessarily to consumption by plankton. It is difficult to apply his results, however, to the conditions at Jordan Lake for several reasons.

In the first place blue-green algae make up the great majority of organisms in the plankton of Jordan Lake during the summer months, whereas the cultures that Pennington worked with were mainly species of Scenedesmus and

Chlorella (green algae which are present in very negligible numbers in Jordan Lake plankton). The physiology of these groups differ radically inasmuch as studies of Pennington (1942) and Chu (1942) have shown nutrient requirements vary greatly not only in different groups of algae but also between two species of the same genus.

The increase of organisms in Jordan Lake occurred two weeks after a decrease in nitrate content and approximately at the same time the nitrite decreased. This latter substance is not used directly by plankton algae (Pennington 1942, Chu 1942) and thus the rate of nitrification and ammonification appears important. The formation of nitrite from nitrate further appears probable in the May 16 to 31 period when there was a decrease in nitrate and a corresponding rise in nitrites, (accompanied by a continued low number of organisms). The rise in quantity of organisms beginning May 31st and the corresponding decrease in nitrite however poses a problem and may indicate the unknown value of NH_3 . Ammonia cannot be derived directly from nitrite (Pennington 1942) and therefore the nitrite decreased because of the formation of nitrate (and possibly the transfer of nitrate to NH_3 which is unknown here) which was immediately utilized by phytoplankton, thereby increasing the number of organisms present. This explanation is reasonable but definite proof is not available from such limited data.

Another factor present, which has no relationship to the inorganic nitrogen content, is that of nitrogen

fixation. As previously mentioned, studies have shown that certain blue-green species (dominant organisms in "water bloom" conditions in Jordan Lake), are able to fix atmospheric nitrogen. Sawyer et al. (1944) also indicate that there is accumulating evidence that nitrogen fixation is of importance in "water bloom" conditions. The importance of this factor in the Jordan Lake "water bloom" and its effect on the chemical correlation presented is not known.

Inorganic phosphorous may be the limiting factor in phytoplankton "blooms". Here, the variation in nutrient requirements by different species of algae are again important. The quantity of a nutrient present may be insufficient and limiting for one species but optimum for another. Only two series of inorganic phosphorous determinations were made of the water in Jordan Lake and thus the relationship, if any, between this chemical and the quantity of phytoplankton is not established. Sawyer et al. (1943, 1944) have shown that inorganic nitrogen and phosphorous are critical in the productivity of lakes, with the inorganic nitrogen limiting the amount of growth which could be produced while inorganic phosphorous controlled the rate at which growths occurred. Thus it is possible that the inorganic phosphorous/inorganic nitrogen ratio may be the critical factor limiting phytoplankton abundance.

In general the chemistry of Jordan Lake water compares rather favorably to similar measurements in lakes in Wisconsin and Iowa where "water blooms" have occurred.

(Table 1.)

When only a few of the many factors that may have an effect upon algal "blooms" are compared a complete picture is not presented and therefore no definite conclusions can be drawn. An analysis shows these facts however: Jordan Lake is lower in nitrates, bicarbonates and inorganic phosphorous (partly) and the pH is within a close range at a similar time of the year. The average number of organisms in July and August is abundant but lower than in two of the Iowa Lakes.

Sawyer et al. (1944) set a fertilizer threshold for the production of "blooms" by reporting "in general, it may be concluded that lakes showing average annual concentrations of inorganic nitrogen and phosphorous, in excess of 0.30 and .015 p.p.m., respectively, will produce frequent nuisance "blooms". It is not possible to state whether the chemical conditions in Jordan Lake water permit the application of this hypothesis. The lack of NH_3 nitrogen determinations prohibits the calculations of the total inorganic value. Furthermore, the two determinations only of inorganic phosphorous although significant do not permit conclusions to be drawn.

The important fact is however, that Jordan Lake supports a heavy "bloom" of algal organisms during the summer months whether or not its water chemistry agrees with such fertilizer thresholds as set by Sawyer et al.

7. Data for Station 4 (inlet) indicates that the inlet does add nutrient materials and other important

Table 1

COMPARISON OF IOWA AND WISCONSIN LAKES

| | Iowa (in July and August) | | | | Wisconsin (ave. of 2 samples July & Aug.) | | | | Ave.
Jul. & Aug. | |
|-----------------------|---------------------------|-----------|---------|---------|---|-----------------------------|-----------------------------|---------|---------------------|-----------|
| | Storm | Center | Diamond | Spint | Mendota | Monona | Waubesa | Kegonsa | Wingra | Jordan |
| NO ₃ | 0.1 | 0.3 | 0.1 | 0.0 | 0.095 | 0.08 | 0.32 | 0.105 | 1.95 | .043 |
| Inorganic phosphorous | 0.08 | 0.1 | 0.08 | 0.01 | 0.01 | .01 | .50 | .45 | .015 | .0115 |
| pH | 8.7 | 9.5 | 9.1 | 8.7 | (7.4-8.6) | ---- | ---- | ---- | (7.8-8.9) | 9.1 |
| Alk | 195 | 220 | 190 | 204 | ---- | ---- | ---- | ---- | ---- | 61.5 |
| Organisms / liter | 3,000,000 | 2,000,000 | 600,000 | 909,000 | 2 | 10 | 12 | 7 | 15 | 1,687,000 |
| | | | | | blue-green blooms in 2 yrs. | blue-green blooms in 2 yrs. | blue-green blooms in 2 yrs. | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|-----|------|----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 | 138 | 139 | 140 | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 | 205 | 206 | 207 | 208 | 209 | 210 | 211 | 212 | 213 | 214 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 | 224 | 225 | 226 | 227 | 228 | 229 | 230 | 231 | 232 | 233 | 234 | 235 | 236 | 237 | 238 | 239 | 240 | 241 | 242 | 243 | 244 | 245 | 246 | 247 | 248 | 249 | 250 | 251 | 252 | 253 | 254 | 255 | 256 | 257 | 258 | 259 | 260 | 261 | 262 | 263 | 264 | 265 | 266 | 267 | 268 | 269 | 270 | 271 | 272 | 273 | 274 | 275 | 276 | 277 | 278 | 279 | 280 | 281 | 282 | 283 | 284 | 285 | 286 | 287 | 288 | 289 | 290 | 291 | 292 | 293 | 294 | 295 | 296 | 297 | 298 | 299 | 300 | 301 | 302 | 303 | 304 | 305 | 306 | 307 | 308 | 309 | 310 | 311 | 312 | 313 | 314 | 315 | 316 | 317 | 318 | 319 | 320 | 321 | 322 | 323 | 324 | 325 | 326 | 327 | 328 | 329 | 330 | 331 | 332 | 333 | 334 | 335 | 336 | 337 | 338 | 339 | 340 | 341 | 342 | 343 | 344 | 345 | 346 | 347 | 348 | 349 | 350 | 351 | 352 | 353 | 354 | 355 | 356 | 357 | 358 | 359 | 360 | 361 | 362 | 363 | 364 | 365 | 366 | 367 | 368 | 369 | 370 | 371 | 372 | 373 | 374 | 375 | 376 | 377 | 378 | 379 | 380 | 381 | 382 | 383 | 384 | 385 | 386 | 387 | 388 | 389 | 390 | 391 | 392 | 393 | 394 | 395 | 396 | 397 | 398 | 399 | 400 | 401 | 402 | 403 | 404 | 405 | 406 | 407 | 408 | 409 | 410 | 411 | 412 | 413 | 414 | 415 | 416 | 417 | 418 | 419 | 420 | 421 | 422 | 423 | 424 | 425 | 426 | 427 | 428 | 429 | 430 | 431 | 432 | 433 | 434 | 435 | 436 | 437 | 438 | 439 | 440 | 441 | 442 | 443 | 444 | 445 | 446 | 447 | 448 | 449 | 450 | 451 | 452 | 453 | 454 | 455 | 456 | 457 | 458 | 459 | 460 | 461 | 462 | 463 | 464 | 465 | 466 | 467 | 468 | 469 | 470 | 471 | 472 | 473 | 474 | 475 | 476 | 477 | 478 | 479 | 480 | 481 | 482 | 483 | 484 | 485 | 486 | 487 | 488 | 489 | 490 | 491 | 492 | 493 | 494 | 495 | 496 | 497 | 498 | 499 | 500 | 501 | 502 | 503 | 504 | 505 | 506 | 507 | 508 | 509 | 510 | 511 | 512 | 513 | 514 | 515 | 516 | 517 | 518 | 519 | 520 | 521 | 522 | 523 | 524 | 525 | 526 | 527 | 528 | 529 | 530 | 531 | 532 | 533 | 534 | 535 | 536 | 537 | 538 | 539 | 540 | 541 | 542 | 543 | 544 | 545 | 546 | 547 | 548 | 549 | 550 | 551 | 552 | 553 | 554 | 555 | 556 | 557 | 558 | 559 | 560 | 561 | 562 | 563 | 564 | 565 | 566 | 567 | 568 | 569 | 570 | 571 | 572 | 573 | 574 | 575 | 576 | 577 | 578 | 579 | 580 | 581 | 582 | 583 | 584 | 585 | 586 | 587 | 588 | 589 | 590 | 591 | 592 | 593 | 594 | 595 | 596 | 597 | 598 | 599 | 600 | 601 | 602 | 603 | 604 | 605 | 606 | 607 | 608 | 609 | 610 | 611 | 612 | 613 | 614 | 615 | 616 | 617 | 618 | 619 | 620 | 621 | 622 | 623 | 624 | 625 | 626 | 627 | 628 | 629 | 630 | 631 | 632 | 633 | 634 | 635 | 636 | 637 | 638 | 639 | 640 | 641 | 642 | 643 | 644 | 645 | 646 | 647 | 648 | 649 | 650 | 651 | 652 | 653 | 654 | 655 | 656 | 657 | 658 | 659 | 660 | 661 | 662 | 663 | 664 | 665 | 666 | 667 | 668 | 669 | 670 | 671 | 672 | 673 | 674 | 675 | 676 | 677 | 678 | 679 | 680 | 681 | 682 | 683 | 684 | 685 | 686 | 687 | 688 | 689 | 690 | 691 | 692 | 693 | 694 | 695 | 696 | 697 | 698 | 699 | 700 | 701 | 702 | 703 | 704 | 705 | 706 | 707 | 708 | 709 | 710 | 711 | 712 | 713 | 714 | 715 | 716 | 717 | 718 | 719 | 720 | 721 | 722 | 723 | 724 | 725 | 726 | 727 | 728 | 729 | 730 | 731 | 732 | 733 | 734 | 735 | 736 | 737 | 738 | 739 | 740 | 741 | 742 | 743 | 744 | 745 | 746 | 747 | 748 | 749 | 750 | 751 | 752 | 753 | 754 | 755 | 756 | 757 | 758 | 759 | 760 | 761 | 762 | 763 | 764 | 765 | 766 | 767 | 768 | 769 | 770 | 771 | 772 | 773 | 774 | 775 | 776 | 777 | 778 | 779 | 780 | 781 | 782 | 783 | 784 | 785 | 786 | 787 | 788 | 789 | 790 | 791 | 792 | 793 | 794 | 795 | 796 | 797 | 798 | 799 | 800 | 801 | 802 | 803 | 804 | 805 | 806 | 807 | 808 | 809 | 810 | 811 | 812 | 813 | 814 | 815 | 816 | 817 | 818 | 819 | 820 | 821 | 822 | 823 | 824 | 825 | 826 | 827 | 828 | 829 | 830 | 831 | 832 | 833 | 834 | 835 | 836 | 837 | 838 | 839 | 840 | 841 | 842 | 843 | 844 | 845 | 846 | 847 | 848 | 849 | 850 | 851 | 852 | 853 | 854 | 855 | 856 | 857 | 858 | 859 | 860 | 861 | 862 | 863 | 864 | 865 | 866 | 867 | 868 | 869 | 870 | 871 | 872 | 873 | 874 | 875 | 876 | 877 | 878 | 879 | 880 | 881 | 882 | 883 | 884 | 885 | 886 | 887 | 888 | 889 | 890 | 891 | 892 | 893 | 894 | 895 | 896 | 897 | 898 | 899 | 900 | 901 | 902 | 903 | 904 | 905 | 906 | 907 | 908 | 909 | 910 | 911 | 912 | 913 | 914 | 915 | 916 | 917 | 918 | 919 | 920 | 921 | 922 | 923 | 924 | 925 | 926 | 927 | 928 | 929 | 930 | 931 | 932 | 933 | 934 | 935 | 936 | 937 | 938 | 939 | 940 | 941 | 942 | 943 | 944 | 945 | 946 | 947 | 948 | 949 | 950 | 951 | 952 | 953 | 954 | 955 | 956 | 957 | 958 | 959 | 960 | 961 | 962 | 963 | 964 | 965 | 966 | 967 | 968 | 969 | 970 | 971 | 972 | 973 | 974 | 975 | 976 | 977 | 978 | 979 | 980 | 981 | 982 | 983 | 984 | 985 | 986 | 987 | 988 | 989 | 990 | 991 | 992 | 993 | 994 | 995 | 996 | 997 | 998 | 999 | 1000 | 1001 | 1002 | 1003 | 1004 | 1005 | 1006 | 1007 | 1008 | 1009 | 1010 | 1011 | 1012 | 1013 | 1014 | 1015 | 1016 | 1017 | 1018 | 1019 | 1020 | 1021 | 1022 | 1023 | 1024 | 1025 | 1026 | 1027 | 1028 | 1029 | 1030 | 1031 | 1032 | 1033 | 1034 | 1035 | 1036 | 1037 | 1038 | 1039 | 1040 | 1041 | 1042 | 1043 | 1044 | 1045 | 1046 | 1047 | 1048 | 1049 | 1050 | 1051 | 1052 | 1053 | 1054 | 1055 | 1056 | 1057 | 1058 | 1059 | 1060 | 1061 | 1062 | 1063 | 1064 | 1065 | 1066 | 1067 | 1068 | 1069 | 1070 | 1071 | 1072 | 1073 | 1074 | 1075 | 1076 | 1077 | 1078 | 1079 | 1080 | 1081 | 1082 | 1083 | 1084 | 1085 | 1086 | 1087 | 1088 | 1089 | 1090 | 1091 | 1092 | 1093 | 1094 | 1095 | 1096 | 1097 | 1098 | 1099 | 1100 | 1101 | 1102 | 1103 | 1104 | 1105 | 1106 | 1107 | 1108 | 1109 | 1110 | 1111 | 1112 | 1113 | 1114 | 1115 | 1116 | 1117 | 1118 | 1119 | 1120 | 1121 | 1122 | 1123 | 1124 | 1125 | 1126 | 1127 | 1128 | 1129 | 1130 | 1131 | 1132 | 1133 | 1134 | 1135 | 1136 | 1137 | 1138 | 1139 | 1140 | 1141 | 1142 | 1143 | 1144 | 1145 | 1146 | 1147 | 1148 | 1149 | 1150 | 1151 | 1152 | 1153 | 1154 | 1155 | 1156 | 1157 | 1158 | 1159 | 1160 | 1161 | 1162 | 1163 | 1164 | 1165 | 1166 | 1167 | 1168 | 1169 | 1170 | 1171 | 1172 | 1173 | 1174 | 1175 | 1176 | 1177 | 1178 | 1179 | 1180 | 1181 | 1182 | 1183 | 1184 | 1185 | 1186 | 1187 | 1188 | 1189 | 1190 | 1191 | 1192 | 1193 | 1194 | 1195 | 1196 | 1197 | 1198 | 1199 | 1200 | 1201 | 1202 | 1203 | 1204 | 1205 | 1206 | 1207 | 1208 | 1209 | 1210 | 1211 | 1212 | 1213 | 1214 | 1215 | 1216 | 1217 | 1218 | 1219 | 1220 | 1221 | 1222 | 1223 | 1224 | 1225 | 1226 | 1227 | 1228 | 1229 | 1230 | 1231 | 1232 | 1233 | 1234 | 1235 | 1236 | 1237 | 1238 | 1239 | 1240 | 1241 | 1242 | 1243 | 1244 | 1245 | 1246 | 1247 | 1248 | 1249 | 1250 | 1251 | 1252 | 1253 | 1254 | 1255 | 1256 | 1257 | 1258 | 1259 | 1260 | 1261 | 1262 | 1263 | 1264 | 1265 | 1266 | 1267 | 1268 | 1269 | 1270 | 1271 | 1272 | 1273 | 1274 | 1275 | 1276 | 1277 | 1278 | 1279 | 1280 | 1281 | 1282 | 1283 | 1284 | 1285 | 1286 | 1287 | 1288 | 1289 | 1290 | 1291 | 1292 | 1293 | 1294 | 1295 | 1296 | 1297 | 1298 | 1299 | 1300 | 1301 | 1302 | 1303 | 1304 | 1305 | 1306 | 1307 | 1308 | 1309 | 1310 | 1311 | 1312 | 1313 | 1314 | 1315 | 1316 | 1317 | 1318 | 1319 | 1320 | 1321 | 1322 | 1323 | 1324 | 1325 | 1326 | 1327 | 1328 | 1329 | 1330 | 1331 | 1332 | 1333 | 1334 | 1335 | 1336 | 1337 | 1338 | 1339 | 1340 | 1341 | 1342 | 1343 | 1344 | 1345 | 1346 | 1347 | 1348 | 1349 | 1350 | 1351 | 1352 | 1353 | 1354 | 1355 | 1356 | 1357 | 1358 | 1359 | 1360 | 1361 | 1362 | 1363 | 1364 | 1365 | 1366 | 1367 | 1368 | 1369 | 1370 | 1371 | 1372 | 1373 | 1374 | 1375 | 1376 | 1377 | 1378 | 1379 | 1380 | 1381 | 1382 | 1383 | 1384 | 1385 | 1386 | 1387 | 1388 | 1389 | 1390 | 1391 | 1392 | 1393 | 1394 | 1395 | 1396 | 1397 | 1398 | 1399 | 1400 | 1401 | 1402 | 1403 | 1404 | 1405 | 1406 | 1407 | 1408 | 1409 | 1410 | 1411 | 1412 | 1413 | 1414 | 1415 | 1416 | 1417 | 1418 | 1419 | 1420 | 1421 | 1422 | 1423 | 1424 | 1425 | 1426 | 1427 | 1428 | 1429 | 1430 | 1431 | 1432 | 1433 | 1434 | 1435 | 1436 | 1437 | 1438 | 1439 | 1440 | 1441 | 1442 | 1443 | 1444 | 1445 | 1446 | 1447 | 1448 | 1449 | 1450 | 1451 | 1452 | 1453 | 1454 | 1455 | 1456 | 1457 | 1458 | 1459 | 1460 | 1461 | 1462 | 1463 | 1464 | 1465 | 1466 | 1467 | 1468 | 1469 | 1470 | 1471 | 1472 | 1473 | 1474 | 1475 | 1476 | 1477 | 1478 | 1479 | 1480 | 1481 | 1482 | 1483 | 1484 | 1485 | 1486 | 1487 | 1488 | 1489 | 1490 | 1491 | 1492 | 1493 | 1494 | 1495 | 14 |
|---|---|---|---|---|---|---|---|---|-----|------|----|

chemicals to Jordan Lake. Bicarbonates and total nitrogen values are abundant throughout most of the year at this station, whereas nitrates and nitrites become reduced in the July-August period.

It is believed that although the inlet furnishes nutrients in limited amounts to Jordan Lake at certain times of the year, it is a relatively minor source of fertilizing material when compared with the storm sewer and the municipal sewage effluent.

8. The volume of flow entering Jordan Lake from the storm sewer is usually low. A large portion of the water used by the Lake Odessa Canning Company is discharged into the storm sewer. The volume and the quality varies considerably from day to day, as well as within a 24-hour period, depending on the volume and type of packing in process. The number of homes which empty their waste into this sewer is not known. The water that does enter the lake from this source however, is generally rich in bicarbonates (up to 396 p.p.m.) and total nitrogen (up to 14.4 p.p.m.). The values of nitrates and nitrites (see Graph) are usually higher than those of the lake water. Although not of major importance as a source of fertilizing materials for phytoplankton, this storm sewer, because it enters the shallow northeast end of the lake, may have an important effect on growth of aquatic plants which are very abundant in this portion of the lake.

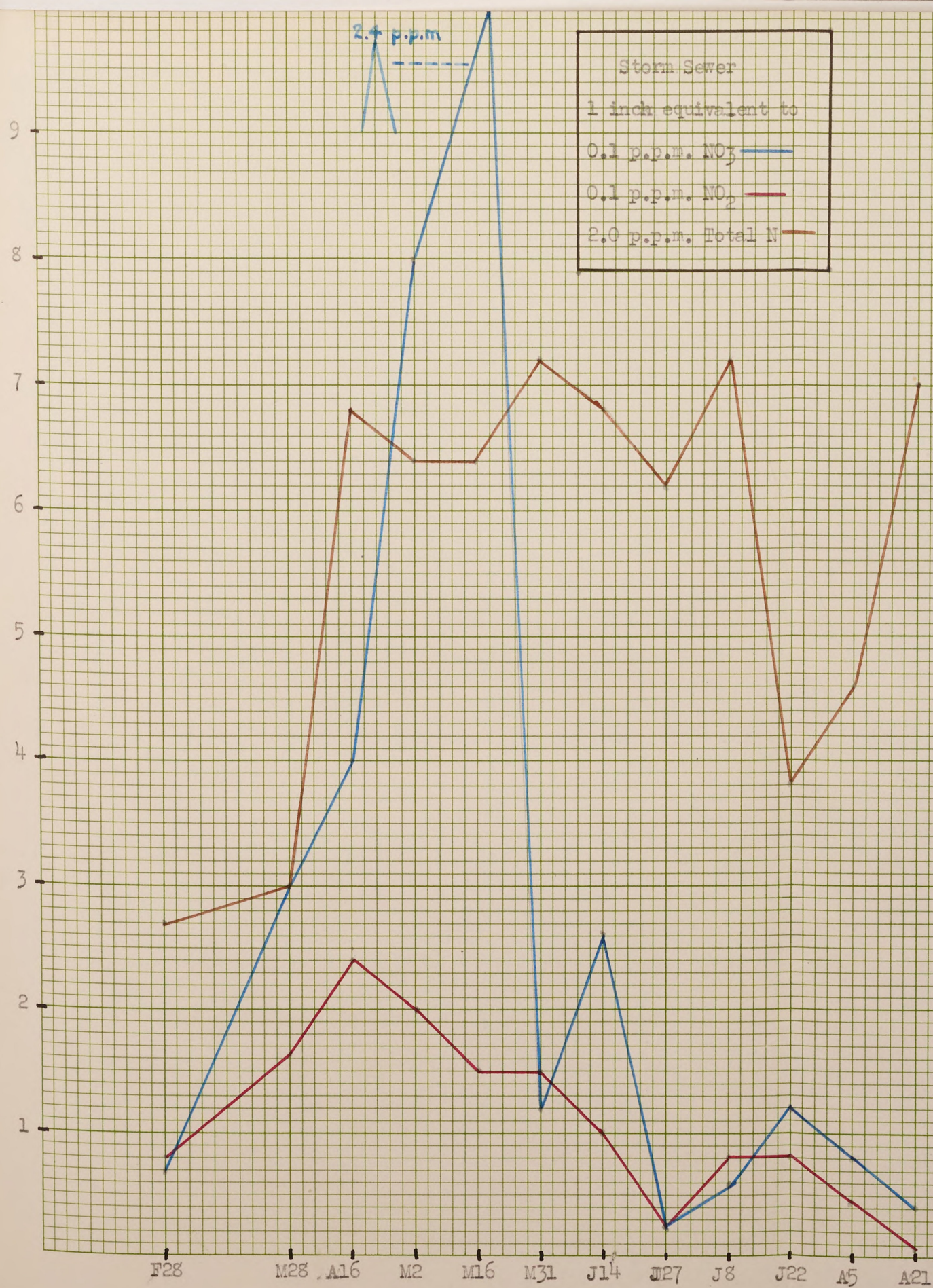
9. The municipal sewage effluent (see Graph) is probably the major contributor of fertilizing substances

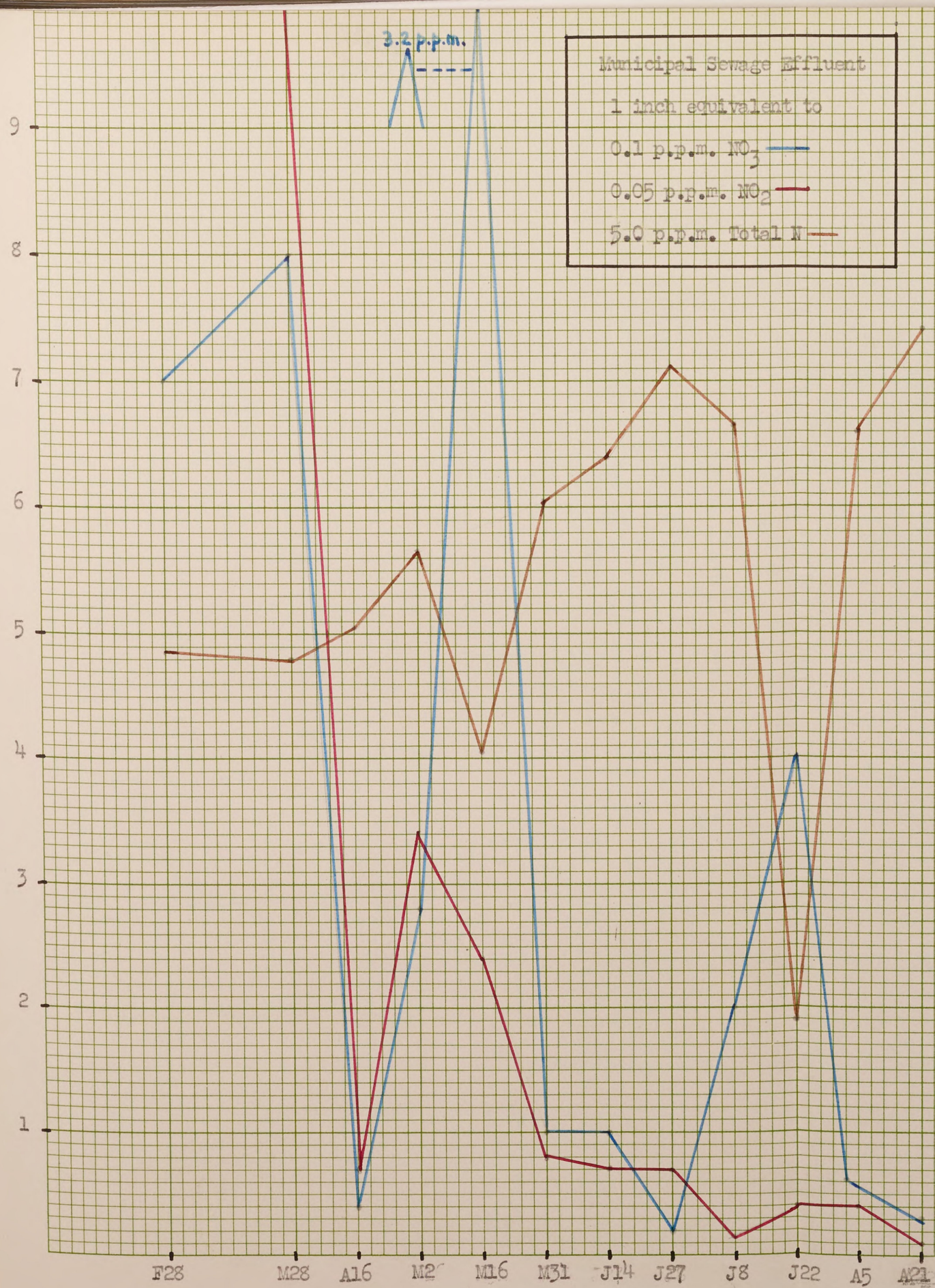
the first of these is the fact that the
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to Jordan Lake. The chemical content varies constantly because of the many substances entering from the village sewers. The total nitrogen value is usually 25-30 p.p.m. and the bicarbonate content is high (250-400 p.p.m.). Inorganic nitrogen content (nitrates and nitrites) is low, although higher than some values for these substances in lake water, because of the lack of aerobic bacterial action in the type of treatment plant. Despite some sludge removal, the effluent adds many tons of organic substances to the lake which eventually may be used as phytoplankton nutrients. New additions to the municipal treatment plant are now, at the time of writing, in the planning stage. However, the inefficiency of the plant may have been responsible for additional nutrient material being added to the lake and thus have had some bearing on the abundance of organisms in the lake.

Data from a survey conducted by Mr. R. G. Foster of the State Stream Control on July 9, 1947 indicate several reasons why the sewage effluent may have important bearing on the "bloom" conditions. These data show that for a 12 hour period on July 9, 1947 the effluent from the plant was 144,000 gallons containing 1,715 pounds of total solids. Additional data are presented below in Table 2.

Table 2

Raw and Final Wastes from Municipal Treatment Plant

| | Wastes at the Sewage Plant | | Removal by
plant |
|--------------|----------------------------|--------------------|---------------------|
| | Influent
p.p.m. | Effluent
p.p.m. | |
| Total Solids | 1,301 | 1,440 | -10.7% |

Table 2 cont.

| | Wastes at the Sewage Plant | | Removal
by plant |
|------------------------------|----------------------------|--------------------|---------------------|
| | Influent
p.p.m. | Effluent
p.p.m. | |
| Total Volatile Solids | 281 | 332 | -18.2% |
| Suspended Solids | 84 | 56 | 33.4% |
| Suspended volatile
solids | 82 | 28 | 30.0% |
| B. O. D. | 265 | 285 | - 7.5% |

These data indicate that although 35% of the total suspended solids were removed by the treatment plant, the total solids were higher in the treated than in the raw sewage. It is apparent that this plant has been contributing a large volume of material to the lake unnecessarily and that this material may form a large part of the bottom deposits which eventually contribute nutrients for phytoplankton use.

10. No chemical determinations were made of bottom mud samples. Jordan Lake has a thick layer of black organic bottom deposits and their importance in furnishing nutrients for phytoplankton growth cannot be over estimated. The organic matter on the bottom, derived from sources both within the lake (dead bodies of plants and animals) and from without (effluents and drainage of all types), varies in different lakes. It is here that reductions of complex organic compounds and the subsequent oxidation of these resulting chemicals into nutrient inorganic substances occur. The rate at which this transformation takes place is dependent on many factors such as the amount and type of

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bacteria and the content of dissolved oxygen, ferrous iron, hydrogen sulphide, ammonia and other oxidizing and reducing materials. Mortimer (1939) in England has shown that the surface layer of mud is richer in nitrates than the surface water above it, whereas in the lower mud there is active reduction and large amounts of ammonia but no nitrate. This in addition to the fact that nitrification tests are negative for the lake studied (Lake Windemere) leads him to suppose that the mud surface is the seat of nitrification.

Sawyer et al. (1944) state "that consolidated lake bottom muds which are capable of being sampled with an Ekman dredge do not appear to be significant sources of nutrient elements. However, the slurry of rapidly decomposing organic matter which exists just above the consolidated muds may be vitally important. This slurry that Sawyer et al. refer to is of recent formation and the quantity present is reflected in recent productivity of organisms.

The same Wisconsin studies also showed that lake bottom muds are much more stabilized than the solid matter leaving the sewage treatment plants and that sewage sludges, whether digested or not may be 10 to 90 times as productive of nitrogen and phosphorous as bottom muds. If this information can be correctly applied to the situation at Jordan Lake, then the importance of the sewage effluent even when properly treated, has a great fertilizing effect on the water of Jordan Lake, reflected in the abundant number of organisms.

The data collected from the various sources indicates a significant increase in the number of people participating in the community programs over the past year. This suggests that the programs are effective in reaching their target audience and providing valuable services. The findings also highlight the need for continued support and resources to ensure the long-term success of these initiatives. The study concludes that the community programs have a positive impact on the lives of the participants and contribute to the overall well-being of the community.

In conclusion, the study has shown that the community programs are effective in achieving their goals and providing valuable services to the community. The findings suggest that the programs should be continued and supported by the relevant authorities. The study also highlights the need for further research to explore the long-term effects of these programs and to identify ways to improve their effectiveness. The final recommendation is that the community programs should be expanded to reach more people and provide even more services.

The question of whether "water blooms" would continue to occur on Jordan Lake with a diversion of the storm sewer and sewage effluent into the outlet is problematical. Tupper Lake receives no sewage effluent and yet supports as great a number of the same types of organisms in early summer as Jordan Lake does. The only inlet entering Tupper Lake is that of Tupper Creek which drains farm land and swamp areas to the northeast. The only other source of fertilizing substances entering Tupper Lake would be sewers from only several cottages and run-off from the agricultural land surrounding the lake. If these latter sources of fertilizing substances are considered minor, then the inlet or bottom deposits are instrumental in furnishing nutrients to the lake. A previously mentioned inlet (Tupper Creek) has a very reduced current, becoming almost stagnant in the summer months. Although no chemical determination of its waters are available, it seems impossible to compare the small flow of Tupper Creek and its contribution of nutrients to Tupper Lake with that of the sewage effluent (over 10,000 gals. per hr.) on Jordan Lake. Thus it might be inferred that although both sources add nutrients to the two lakes, the role of the bottom deposits is also important in producing similar quantitative plankton (at least in early summer).

Both lakes can be classified as eutrophic (productive). Among some of the characteristics of this type of lake, are a high quantity of phytoplankton with blue-green algae and diatoms predominating and usually a bottom deposit of

1. The first part of the document is a letter from the President of the United States to the Congress.

2. The second part is a report from the Secretary of the Treasury on the state of the Union.

3. The third part is a report from the Secretary of the Navy.

4. The fourth part is a report from the Secretary of the War.

5. The fifth part is a report from the Secretary of the Interior.

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30. The thirtieth part is a report from the Secretary of the Public Labor.

organic matter in which a vigorous putrefaction takes place. Hasler (1948) has shown that domestic drainage and sewage have changed many lakes (both in Europe and America) into eutrophic types. This is accompanied by the building up of rich organic deposits on the bottom. A similar condition of eutrophication in Jordan and Tupper Lakes may have occurred where sewage and other drainage have built up bottom deposits and the accessory high production.

The abundance of organisms in Tupper Lake is no doubt related to its sources of fertilizing substances which are:

1. Tupper Creek.
2. Wash-off from surrounding farm land and swamps.
3. Organic matter in bottom deposits and in suspension in lake water.
4. Minor contributions from few cottages and inhabitants.

The great amount of phytoplankton in Jordan Lake is related to the following sources of fertilizing substances:

1. Inlet (channel from Tupper Lake)
2. Storm sewer.
3. Sewage Effluent.
4. Organic matter in bottom deposits and in suspension in lake water.
5. Drainage from surrounding terrain.
6. Possible sewer connections from homes and cottages.
7. Debris and wastes contributed by the many people who use the lake for recreational purposes.

This study has been limited of necessity to a general

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consideration of a complex problem, with special emphasis on the relationship of nitrate, nitrite and total nitrogen to "water bloom" conditions at Jordan Lake. It has been impossible to take into account all the factors related to "bloom" conditions. Many other factors (listed below) such as those advanced by Hutchinson (1944) have been little studied.

- a. Inorganic nutrients other than P, N and Si.
- b. Specific organic substances.
- c. The physiological condition of plankton organisms at different stages of their cycles of growth.
- d. Competitive relation between different species of phytoplankters.

These are only a few of the many other aspects of phytoplankton periodicity that may be important and readily indicate the need for continued and diversified research before a complete solution is possible.

It is appropriate to summarize this discussion of data with a quotation from Hutchinson (1944). "We should expect, from the results of laboratory experiments, to find that conditions in nature are extremely complex and difficult to analyze, and this is indeed the experience of every investigator of phytoplankton of lakes."

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VI. TREATMENT AND CONTROL

A. Types of Treatment Other Than Copper Sulphate

Previous mention has been made to several papers and publications relating to control of algae and to harmful effects produced by them in lakes and reservoirs. Since the early nineteen-hundreds water-works engineers, faced with the important problem of furnishing clean and pure water to the public, have treated water reservoirs and other sources of public water supplies for algae control, using both physical and chemical methods.

Physical methods include:

1. Dredging back shorelines to deepen the water and to maintain steep sides.
2. Artificial aeration.
3. Inlets to promote circulation.
4. By-passing water when objectionable algal growths are present.
5. Removal of mud by periodical cleaning of reservoirs.
6. Building reservoirs so long axis may benefit from prevailing wind action.
7. Removing nitrogen and phosphorous from inflowing waters.
8. Stocking with fish to reduce plankton.
9. Building covered reservoirs.

Some of the above procedures have been applied with

the first of these is the fact that the system is not a simple one, but a complex one, in which the various parts are interrelated and interdependent. The second is that the system is not a static one, but a dynamic one, in which the parts are constantly changing and evolving. The third is that the system is not a closed one, but an open one, in which the parts are constantly interacting with the environment. The fourth is that the system is not a linear one, but a non-linear one, in which the parts are constantly interacting with each other in a non-linear fashion. The fifth is that the system is not a deterministic one, but a probabilistic one, in which the parts are constantly interacting with each other in a probabilistic fashion. The sixth is that the system is not a simple one, but a complex one, in which the parts are interrelated and interdependent. The seventh is that the system is not a static one, but a dynamic one, in which the parts are constantly changing and evolving. The eighth is that the system is not a closed one, but an open one, in which the parts are constantly interacting with the environment. The ninth is that the system is not a linear one, but a non-linear one, in which the parts are constantly interacting with each other in a non-linear fashion. The tenth is that the system is not a deterministic one, but a probabilistic one, in which the parts are constantly interacting with each other in a probabilistic fashion.

success in certain places, but the vast majority of water-works engineers use some type of chemical treatment.

Reports such as Manguin (1928, 1930) report successful algal control by chlorination up to 1.0 p.p.m. Whipple (1927) reports use of chlorine as an algacide in England by Houston and by Hale in 1921 in New York. Chlorine, whether added in excess of the quantity demanded to kill organisms or not, may serve as an additional purpose by eliminating tastes and odors. Some reservoirs are treated with CuSO_4 for killing the organisms, and then with chlorine to remove odors and tastes. In turn, the chlorinous taste sometimes has to be removed by dechlorination with such chemicals as sulphur dioxide, sodium sulphite, bisulphite and thiosulphate and activated carbon. Arnold (1936) reports that chlorine is a fairly effective algacide and has proved effective as long as a chlorine residual was maintained. Being a gas of low solubility, chlorine is difficult to apply without expensive equipment and must be handled in heavy containers. Chloramine is used sometimes with success at certain localities but often CuSO_4 in combination is needed (Bailey, 1937). The use of chloramine results in a more persistent residual chlorine but leaves free NH_3 for plant growth. Arnold (1936) indicates that this combination of chlorine and NH_3 is used in California waters for eradication of Corophium, a fairy shrimp, but not for algae control. Another chemical combination of chlorine, "bleaching powder" or calcium hypochlorite, a solid compound with

30 percent available chlorine when dissolved, is sometimes used. Kienle (1932) reports the successful use of dry calcium hypochlorite in Boston, Massachusetts and Wilmington, Delaware. Other chemicals have been used as a algicide or for taste and odor removal, or for both purposes. Whipple (1927) indicates that potassium permanganate may be used for eradication of tastes and odors. It does not retard chlorine action, but assists in sterilization. This chemical is one of the constituents of a product used by one of the commercial companies for elimination of algae in swimming pools (Perkins, 1946). The chief objections to potassium permanganate are the tendency to render chlorinous tastes more pronounced and the persistence of a pink or even brown color if ground or colored waters are treated.

Use of commercial products such as Perkins CM-21 usually has been restricted to swimming pools. Other algicides such as Benoclor-3 have been reported to be successful in reducing algal and other aquatic plant growth. This chemical, however, imparts a noticeable taste to the water which may last as long as 33 days (Gibbons, 1940).

B. Copper Sulphate, Its Use and Objections to Use.

Copper sulphate has been the most economical and one of the most efficient chemicals used by the sanitary engineer in water supplies. In most cases, this chemical has been employed successfully, sometimes in conjunction with chlorine or some other taste remover. One of the reasons why copper sulphate is chosen over some other effective

chemicals, is the ease with which it can be applied.

Several methods are used for application. The main ones are as follows:

1. Dragging burlap bags containing crystals behind boats.
2. Spreading finely powdered CuSO_4 on ice or on water by hand or by special equipment.
3. Continuous dry feeding in situations where there is a narrow and controlled inlet to a reservoir or aqueduct.
4. Spraying the desired percentage concentration in solution from a tank mounted on a barge or boat. This appears to be one of the most popular and effective methods, as it insures more even distribution of the solution. This method also has an added advantage in that the solution diffuses as it sinks, and thus comes in contact with the maximum amount of vegetation. This is especially good for Aphanizomenon and Microcystis which float on or near the surface. Although demonstrated to be effective and economical (some lakes have been treated for as low as \$0.63 an acre), the chief objections raised to the use of copper sulphate as an algacide are as follows:

1. Possible injurious effect of copper sulphate in water supplies for commercial and domestic consumption. Hale and Muer (1926) however found that no copper of sanitary significance could be found in the New York City water distribution system after watershed treatment with copper sulphate. Hale (1930) reports that copper salts have no effect on the health of individuals using water from public

supplies which have been treated with copper sulphate.

2. The effect of copper sulphate on fish life and fish-food organisms. Numerous articles report fish-kill after copper sulphate treatment. Smith (1924) discusses one case and lists 18 fish-kills out of 38 treatments. M. W. Smith (1936) reports the use of copper sulphate for eradicating predatory fish populations of a lake. In this case a concentration of 3 p.p.m. was used. After 1 hour, the copper content was 1 p.p.m. but later it was 2.4 p.p.m. and 9 months later bottom waters contained 2 p.p.m. The phytoplankton was almost entirely destroyed and growth was low for a year. Zooplankton was also almost completely destroyed. Leeches lived, but most of the fish and even eels were destroyed. Titcomb (1914) also discusses the use of copper sulphate for the destruction of obnoxious fish in ponds and lakes. Schoenfeld (1947) notes that Lake Monona near Madison, Wisconsin has almost a sterile bottom condition after 20 years of treatment with this chemical. He further says that there are only 700 bottom organisms per square yard in Lake Mendota, a connected lake nearby that has never had copper sulphate treatment. Lake Monona also has 605 units of copper on the bottom, whereas in nature Lake Mendota has 85 units.

Thorpe (1942) claims that copper sulphate treatments destroy some of the intermediate organisms composing the food chain and the fact that such treatments usually do not kill fish is irrelevant. He examined a lake treated

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for control of algae, (for 16 years) in which, despite heavy stocking and other management efforts, there had been a reported general decline in fishing success. Basic fertilizers in this lake were average in amount but bottom organisms were very reduced in numbers. He also notes that continued treatment had changed the quality of algae annually present and that those now present are more resistant to treatment but equally obnoxious.

There are many proponents of copper treatment in natural waters where the problem of fish life is involved. Domo-galla (1935) reports that lakes may be treated without injury to weed beds, zooplankton and fish-life. Prescott (1932, 1938, 1948) maintains that when applied correctly copper sulphate can be used in such minute concentrations that it is not injurious to fish life. Aitken (1933) while trying to eliminate certain fish (Black bullhead, black striped shiner, and green sunfish) used concentrations of as much as 7,500 parts per million gallons of water and failed to kill these fish even after 48 hours. Eventually chlorinated lime (1 lb. per 2,000 gallons) was successful in 29 minutes. Rushton et al. (1924) report that treatments of .05 p.p.m. sprayed on three successive days for a total of 0.15 p.p.m. were able to reduce Coelastrum from 4,576 to 68 per cc. in 7 days but "neither were adult trout, trout fry, nor the crustacea, Daphnia, staple food of the young trout affected by treatments". As previously mentioned Smith (1924) notes that many fish-kills were due to the depletion of oxygen by the decomposition of algae killed by copper sulphate and

not by copper sulphate itself.

The basic contention of those who favor this type of treatment is that copper sulphate when used judiciously can be effective in treatment of algal nuisances and yet be harmless to the fish life of a lake or reservoir. In regard to killing of fish food, the opinion is that when used carefully, CuSO_4 will control the algal nuisance but will destroy only such a small portion of the available fish food organisms, thus there are no damaging effects to fish productivity. Table 3 shows concentrations of copper sulphate recommended for treatment of algae. Table 4 shows concentrations of copper sulphate used and found to be safe for different types of fish. It will be seen that some of the concentrations required for the destruction of certain algae are close to those which have been found deadly to fish, thus extreme caution should be used.

Because each lake or reservoir has its own individual characteristics, it is necessary before copper sulphate treatment is administered, that the following factors be taken into consideration:

1. The type or types of algae present and their quantity. This is very important because certain algae can be eliminated by specific dosage. Quantitative examination of algal life in a lake will indicate when organisms approach a nuisance condition and indicate when treatment must be given to be the most effective. Many treatments have been unsatisfactory because they were not given at the proper time.

TABLE 3

Concentrations of copper sulphate recommended for treatment of algae in lakes and reservoirs.

| ORGANISMS | COPPER SULPHATE
(parts per million) | ORGANISMS | COPPER SULPHATE
(parts per million) |
|----------------------|--|----------------------|--|
| Myxophyceae | | Xanthophyceae | |
| Aphenizomenon | 0.2-0.4 | Botryococcus | 0.22 |
| Anabaena | 0.2-0.4 | Tribonema | 2.0-0.4 |
| Microcystis | 0.2-0.4 | | |
| Rivularia | 0.1 | Cryptophyceae | |
| Chlorophyceae | | Synura | 0.33 |
| Hydrodictyon | 0.1 | Uroglena | 0.08-0.25 |
| Eudorina | 10.0 | Mallomonas | 0.5 |
| Pandorina | 10.0 | | |
| Scenedesmus | 0.1 | Diatomaceae | |
| | | Melosira | 0.2 |
| | | Stephanodiscus | 0.33 |
| | | Synedra | 0.36 |

(after Prescott (1938))

TABLE 4

Concentrations of copper sulphate that have been used safely for fish.

| FISH | COPPER SULPHATE
(parts per million) | REFERENCES |
|--------------------|--|-------------------------|
| Trout | 1.0 | Anonymous (1904) |
| Trout (fry) | 2.0 | Marsh & Robinson (1910) |
| Trout (brook) | 0.6-0.8 | " " |
| Trout (brook, fry) | 1.0 | " " |
| Trout (brown) | 0.6-0.8 | " " |
| Trout (rainbow) | 0.6-0.8 | " " |
| Sunfish | 1.2 | Kellerman (1912) |
| Sucker | 0.3 | " |
| Pickereel | 0.4 | " |
| Perch (yellow) | 0.5 | Marsh & Robinson (1910) |
| Perch | 0.75 | Kellerman (1912) |
| Black bass (small) | 2.1 | " |
| Black bass (large) | 5.0 | Marsh & Robinson (1910) |
| Carp | 0.3 | Kellerman (1912) |
| Gar Pike | 0.46 | Prescott (1938) |
| Sheepshead | 0.46 | " |
| Catfish | 0.58 | " |
| Blue-gill | 0.46 | " |
| Bass (silver) | 0.46 | " |

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2. The volume of water must be calculated so that the amount of copper sulphate required to produce the proper concentration for an effective dosage can be determined.

3. Temperature. More copper sulphate is necessary in colder water. Dosages recommended are usually for 15 degrees Centigrade (59 degrees F) and several authors (Goudey 1936, Gopp 1936) suggest adding or decreasing 2.5 percent of copper sulphate for every degree of variation from 15° C.

4. The alkalinity of the water must be determined because the more alkaline the water the greater the amount of copper sulphate required. A 0.5 to 5.6% increase for each 10 p.p.m. alkalinity is recommended. This is due to the fact that copper sulphate dissociates into Cu and SO which reacts with carbonates to form copper carbonate and calcium sulphate with some liberation of carbonic acid. Copper carbonate then breaks down and forms ^{copper}(~~calcium~~)hydrate (by union with OH ions) which is insoluble and precipitates out. The greater the alkalinity, the greater the amount and more quickly does the copper hydrate settle out.

5. Technique of treatment. The most effective and safest method is by spraying. Not only does this method insure more copper coming in contact with the growth, but it also makes possible a better control over the concentration used. The drag method (that in which the crystals in a burlap bag are towed through the water) has been responsible for the death of fish in many treatments

because of the heavy concentration of copper sulphate created in a narrow zone through which the bag passed. Many of the older treatments were made this way and may be responsible for the fish deaths in the cases listed by Smith (1924). Six of the 18 cases of death involved a concentration of 10 p.p.m. or over of copper sulphate.

The control of algal nuisances by copper sulphate in waters containing fish continues to be a problem to the various workers in the fields of aquatic biology. Such control should serve a two-fold purpose:

1. To produce no objectionable affect on fish production.
2. To control obnoxious conditions, to benefit water supplies and to provide enjoyable recreational sites.

If the opponents of the copper sulphate treatment can successfully prove their contention that this method severely interferes with fish production, then other means of control are necessary.

Other suggested methods of control are:

1. Plantings of species of fish (such as the golden shiner and gizzard shad) which use considerable algae in their diet. This method may be of some use although a completely satisfactory solution is doubtful. The blue-green algae that produce some of the most severe "water blooms" appear to be a very minor source of food to any type of fish.

2. Planting of water plants with broad floating leaves which shade the water and restrict the growth of

algae. This method may be somewhat successful along shallow margins of lakes but such plants do not survive in deeper water where phytoplankton may be abundant.

3. Introducing of crayfish which inhibit growth of vegetation by ^o rilling of water thus reducing light penetration. This does not appear practical in a large body of water.

4. Removal of nutrients entering bodies of water. This possibly could be done for small lakes where household sewage, barnyard drainage and a small amount of wash-off from agricultural land occurred, but not practical for large drainage ~~lakes~~ where rivers or other large effluents contribute nutrients. This also ignores the role of bottom deposits which may be important contributors of nutrients to "water bloom" organisms. Some work has been done on the removal of nutrients from sewage effluents entering lakes. Sawyer et al. (1944) have shown ferric chloride when used as a coagulant removes the majority of phosphorous and organic nitrogen but not inorganic nitrogen from effluents.

It was also shown that glucose reduces a large proportion of inorganic phosphorous and nitrogen but not total nitrogen in effluents. Whether an economical and practical application of these methods can be employed where sewage plays a dominant role as a fertilizing substance in "water blooms" is not known. Complete diversion or elimination of sewage effluents entering lakes and other bodies of water may also aid.

5. Thorpe (1942) believes that it may be possible to control types of algal organisms by adjusting basic fertilizers in lakes so as to inhibit the growth of objectionable forms and at the same time promote less bothersome ones. This is only theoretical and no research of this nature has been done.

6. The discovery of a chemical, which could be used for specific elimination of objectionable forms of algae without being injurious to all other aquatic life.

C. Treatment of Jordan Lake

Although original plans provided for copper sulphate treatment in Jordan Lake applications of this chemical were not made for the following reasons:

1. The only condition severe enough to justify treatment occurred on August 6, 1947. The algal growth made a sudden appearance and by the time arrangements for treatment were made, conditions were beginning to clear up.

2. Fear of fish loss by resort owners. This was in part engendered by the appearance in a current popular sportsman's magazine of an article condemning the use of copper sulphate in lakes, and in part to the fear that results of the treatment might deprive them of business.

3. The thought held by local people that the bacterial pollution problem was related to the "water bloom" and that additions to the municipal sewage plant, required by the State Stream Control Commission, would eliminate the great number of organisms when installed.

4. The majority of people who use the lake, do so for fishing and the scum condition is not too objectionable to them. Relatively few people used the lake for swimming purposes in the summer of 1947 because of the pollution condemnation hence there was little demand for a clean lake. In any case during the summer of 1948, the condition was not as serious as previous years.

D. Brighton Lake and Copper Sulphate Treatment

Although the effect of treatment could not be studied at Jordan Lake, a similar "water bloom" condition on a lake near Brighton, Michigan permitted observations on the use of copper sulphate. This treatment (supervised by Dr. G. W. Prescott) was made during the summer of 1948.

This lake, not known by a formal name, is situated almost entirely on land owned by Howell Memorial Boy Scout Reservation about one mile southeast of Brighton, Michigan.

This lake is in part an artificial body of water, the result of damming of a small drainage stream approximately 20 years ago. The circumference of the lake is just under 2 miles and the area occupies nearly 10 million cubic feet, of which over half is water from 0-3 feet in depth. The margins are shallow, supporting a large growth of submerged aquatic vegetation. The inlet is at the northwest, and carries the municipal sewage effluent from the city of Brighton. The southwest bay of the lake covers a "pot hole" about 30 feet deep which existed as a pond separate from the creek before it was dammed.

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This body of water is used for fishing, boating but primarily for swimming by about 500 Scouts on the reservation during the summer. In the summer of 1947 (and previously) a severe "water bloom" made swimming impossible.

R. C. Rusby, Director of Camping and Activities Service for the Detroit Council of the Boy Scouts of America arranged with Dr. G. W. Prescott in May 1948, that the lake be given copper sulphate treatment.

Examination of plankton tows taken May 24th showed the presence of organisms (mainly diatoms similar to those occurring in Jordan Lake at the same time). An exception was Dinobyon sertularia Ehrenberg, a member of the Chrysophyta, the presence of which in large quantities imparts a light brown muddy appearance to the water. The total number of organisms on this date was 110,000 per liter.

A heavy "bloom" developed on June 13th and a sampling revealed an entirely different picture. The quantity of organisms had increased to 2,907,000 organisms per liter and consisted of three identical species of blue-green algae that produce "bloom" conditions in Jordan Lake. They were Anabaena limnetica G. M. Smith, Anabaena circinalis var. macrospora (Wittrock) De Toni and Aphanizomenon flos-aquae (L.) Ralfs. Their abundance imparted a bluish-green color to the water in sharp contrast to muddy appearance of the water three weeks previously.

A 5% solution of copper sulphate (calculated to give a concentration of 1 p.p.m.), was administered in the northwestern part of the lake, by spraying from a tank mounted

on a barge. This area is the most shallow and was clogged at that time with masses of submerged aquatic plants.

Adding to the disagreeable conditions caused by the blue-green algae were floating mats of Hydrodictyon reliculatum (L.) Lagerheim which covered a large portion of the water.

This treatment proved ineffective as samples, taken two days later on June 24th, showed a great increase in algal organisms. The total count was 10,146,000 per liter and was composed almost entirely of Aphanizomenon, with lower numbers of Anabaena. At this time another treatment of the same concentration (1.0 p.p.m.) was administered to the northeastern portion of the lake.

Examination of quantitative samples five days later (June 29th) showed a great decrease in organisms. Aphanizomenon had declined from 9,261,490 to 487,120 per liter and the filaments of this species which were present occurred as short broken and partly deteriorated segments. Anabaena decreased from 691,150 to 347,040 per liter and were in similar broken condition.

The effectiveness of the treatment was further shown, as the sample on July 7 was very clear, with very small numbers of organisms, the count being below 2,000 per liter. A qualitative sample on July 21 showed a slight increase in growth of diatoms and motile Chlorophyceae but no blue-green algae were present.

A quantitative sample seven days later (July 28) indicated continued increase of diatoms, especially Melosira which occurred 206,000 per liter. This same sample also

revealed the presence of a great number of Daphnia, a Cladoceran, indicating that the treatment had reduced the blue-green algae, but had not completely destroyed the zooplankton.

A final examination of the water on August 11th showed one species of Anabaena had reappeared in limited number and that the rest of the phytoplankton was composed mainly of diatoms.

The treatments of the lake permitted complete use of the swimming beach on the southeastern shore of the lake throughout the period studied. After the general treatment on June 24th only local portions of the lake such as the bathing beach area were sprayed, several administrations, using the same concentration of copper sulphate, being necessary. There were no fish killed at any time during the period of treatment in the lake at Brighton.

VII. CONCLUSIONS

1. Six species of blue-green algae are the major components of the "water bloom" occurring in Jordan Lake during the summer months. They are: Anabaena circinalis var. macrospora (Wittrock) De Toni, Anabaena spiroides var. crassa Lemmermann, Anabaena limnetica G. M. Smith, Aphanizomenon flos-aquae (Linnaeus) Ralfs, Microcystis aeruginosa Kuetzing, Coelosphaerium Naegelianum Unger.

These organisms form obnoxious scums because of their ability to multiply rapidly, their tendency to float on or near the surface of the water because of the presence of pseudovacuoles, and the tendency to adhere together in clots or scums resulting from the presence of sticky gelatinous or mucilaginous sheaths.

2. A general correlation seems evident between the number of organisms present and several factors in water chemistry, although a strict correlation does not exist.

a. A general inverse correlation exists between the total number of organisms and the amounts of nitrates and nitrites present in lake water indicating the use of these substances as nutrients either directly or indirectly by the algae.

b. There is a gradual decrease of bicarbonate and an increase in monocarbonate content of the water because of the utilization by algae of bicarbonates as a source of carbon dioxide during the summer. There is a corresponding

rise in pH as a result of the precipitation of carbonates.

3. The inlet to Jordan Lake, the storm sewer and the municipal sewage effluent are the major sources of fertilizing substances entering the lake. The rich productivity of Jordan Lake may be explained (at least in part) by the great amount of organic matter in the bottom deposits. Minor sources of fertilizing substances are the disposed-of household sewage directly into the lake and the depositing of waste materials by the persons who use the lake for recreational facilities.

4. The use of copper sulphate for control of the algal nuisance at Jordan Lake was withheld because of reluctance of local inhabitants. Treatment of a similar condition at a lake near Brighton, Michigan showed that the obnoxious growths of blue-green algae could be controlled without any apparent injury to fish-life.

5. Physical, chemical and biological data and their analyses are presented for the period of June 24, 1947 through August 21, 1948.

6. The place and mode of wintering over is not completely known. Aphanizomenon flos-aquae (L.) Ralfs in vegetative condition is present throughout most of the year although resting spores (gonidia) are produced by this species. Anabaena species also produce resting spores which are thought to winter over in the mud and debris of aquatic vegetation near shore. Microcystis aeruginosa Kuetzing and Coelosphaerium Naegelianum Unger are thought to winter over

as dormant single cells in mud and debris.

7. The "bloom" conditions in Jordan Lake could be controlled temporarily by treatment of copper sulphate with the spray method. Microscopical examination by an experienced aquatic biologist would indicate the time for proper treatment. Permanent measures which would alleviate and possibly reduce "water blooms" would include:

a. Diversion of the municipal sewage effluent.

In order to eliminate the major source of fertilizing substances entering the lake, the effluent should be discharged into the outlet. The lake has a very deep bottom in the southwestern area of the lake, according to local information. The effluent could be discharged into this deep part of the lake (50-60 feet). This would place the nutrient bearing water of the effluent in a cold zone where overturn would be slow or negligible. This does not mean that none of the fertilizing substances would ever get back into circulation and into a condition usable by plants, but it would detract enormously from the fertilizing influence of the sewage effluent. It should be emphasized that anything at all that can be done to eliminate fertilizers in the lake would contribute to a lessening of the algal nuisance.

b. Improvements and additions to the sewage treatment plant. The present facilities permit the entrance of a greater amount of solids to the lake than is necessary.

c. Removal of all other sewage lines (if present)

from storm sewer connections.

d. Removal of all sewage lines emptying directly into the lake from lakeside homes and cottages.

e. Elimination of the practice of dumping garbage and other wastes into the lake.

f. Dredging back shallows and beaches where algae become especially objectionable.

8. A systematic list of the algae in Jordan Lake and illustrations of them are presented.

VIII. SYSTEMATIC LIST OF ALGAE IN JORDAN LAKE

Phylum CYANOPHYTA

Class CYANOPHYCEAE

Sub-class A. CHROOCOCCEAE

Order I. CHROOCOCCALES

Family Chroococcaceae

Chroococcus Naegeli 1849

1. Chroococcus dispersus (v. Keissler) Lemmermann
Smith, 1920, p. 28, Pl. 1, Fig. 2.
Diameter of cells 3-4 u. Pl. 1, Fig. 1. Plankton tow.
May.
2. Chroococcus limneticus var. carneus (Chodat) Lemmermann
Smith, 1920, p. 30, Pl. 1, Fig. 6.
Diameter of cells (without sheath) 7 u; with sheath 9 u.
Pl. 1, Fig. 2. Plankton tow. May.
3. Chroococcus minutus (Kuetzing) Naegeli
Smith, 1920, p. 28. Pl. 1, Fig. 1.
Diameter of cells without sheath 6.45 u; with sheath
8 u. Pl. 1, Fig. 3. Plankton tow. May.

Merismopedia Meyen 1839

1. Merismopedia tenuissima Lemmermann
Smith, 1920, p. 33, Pl. 2, Fig. 2.
Diameter of cells without sheath 2 u. Pl. 1, Fig. 4.
Scrapings from stem of aquatic plant. August.

Microcystis Kuetzing 1833

1. Microcystis aeruginosa Kuetzing

Smith, 1920, p. 39, Pl. 5, Figs. 2-3.

Diameter of cells 4-4.3 u. Pl. 1, Figs. 5-6. Common in summer plankton, often forming a heavy growth.

2. Microcystis aeruginosa var. major (Wittrock) G.M. Smith

Smith, 1920, p. 40, Pl. 4, Fig. 6.

Diameter of cells 5-6 u. Pl. 1, Fig. 7. Summer plankton.

Aphanothece Naegeli 1849

1. Aphanothece stagnina (Sprengel) A. Braun

Smith, 1920, p. 45, Pl. 6, Fig. 2.

Diameter of cells 4 u; length 3-6 u. Pl. 1, Fig. 9. Common in summer plankton.

Sub-class B. HORMOGONEAE

Order HORMOGONALES

Sub-order HOMOCYSTINEAE

Family Oscillatoriaceae

Spirulina Turpin 1827

1. Spirulina major Kuetzing

Smith, 1920, p. 50, Pl. 7, Fig. 1.

Trichomes 1-2 u. in diameter. Pl. 1, Fig. 10. Plankton. May.

Arthrospira Stizenberger 1852

1. Arthrospira Jenneri (Kuetzing) Stizenberger

Tilden, 1910, p. 85, Pl. 4, Fig. 44.

Trichome 6.45 u. wide; cells 7-8 u long. Pl. 1, Fig. 11.

Plankton tow. June.

Oscillatoria Vaucher 1803

1. Oscillatoria Agardhii Gomont

Geitler and Pascher, 1925, p. 369, Figs. 455-456.

Tilden, 1910, p. 62, Pl. 4, Fig. 2.

Trichome 4.3 u wide; cells 3-3.5 u long. Pl. 1, Fig. 12.

Mixed in filamentous mat along shore. August.

2. Oscillatoria amphibia Agardh

Geitler and Pascher, 1925, p. 364, Fig. 431.

Trichome 3 u wide; cells 4 u long. Pl. 1, Fig. 13.

Blue-green film on bottom. August.

3. Oscillatoria chlorina Kuetzing

Geitler and Pascher, 1925, p. 361.

Tilden, J. 1910, p. 75, Pl. 4, Fig. 22.

Trichome 4 u wide; cells 5 u long. Pl. 1, Fig. 14.

Plankton. February.

4. Oscillatoria formosa Bory

Geitler, and Pascher, 1925, p. 372, Fig. 464.

Tilden, 1910, p. 80, Pl. 4, Fig. 33.

Trichome 8.6 u wide; cells 2.5-3 u long. Pl. 1, Fig. 15.

Blue-green growth on bottom. August.

5. Oscillatoria limnetica Lemmerman

Geitler and Pascher, 1925, P. 365. Prescott, 1949,

p. 753, Pl. 109, Fig. 17.

Trichome 1.5-1.8 u wide; Pl. 1, Fig. 16. Blue-green film on bottom. August.

6. Oscillatoria limosa Agardh

Tilden, 1910, p. 65, Pl. 4, Fig. 6.

Trichome 12-14 u wide; cells 4-4.3 u long. Pl. 1, Fig. 17. Filamentous mass along shore. August.

7. Oscillatoria princeps Vaucher

Tilden, 1910, p. 62, Pl. 4, Fig. 3.

Trichome 3-4 u wide; cells 3.5-7 u long. Pl. 1, Fig.

20. Plankton tow. May.

8. Oscillatoria rubescens De Candolle

Geitler and Pascher, 1925, p. 36, Fig. 447.

Cells 6.5 u broad, 3-4 u long. Pl. 1, Fig. 18. Common in plankton. Winter and spring.

9. Oscillatoria sancta Kuetzing

Tilden, 1910, p. 64, Pl. 4, Fig. 5.

Trichome 10.75 u wide; cells 2 u long. Pl. 1, Fig. 19.

In mat of filaments attached on bottom. August.

10. Oscillatoria splendida Greville

Tilden, 1910, p. 76, Pl. 4, Figs. 23-25.

Trichome 3 u wide; cells 5 u long. In blue-green mat on bottom. August.

11. Oscillatoria tenuis Agardh

Tilden, 1910, p. 1, Pl. 4, Figs. 17-18.

Trichome 6-7 u wide; cells 2-3 u long. Pl. 1, Fig. 21. Plankton. May.

Phormidium Kuetzing 1843

1. Phormidium mucicola Nauman and Huber-Pestalozzi

Nauman and Huber-Pestalozzi, 1929, p. 67; Prescott (manuscript), pl. 111, figs. 4-5.

Cells 1.3-2 u in diameter, 1.8-3 u long. Endophytic in Microcystis aeruginosa Kuetzing. Common in summer.

2. Phormidium Retzii (Agardh) Gomont

Tilden, 1910, p. 102, Pl. 5, Figs. 1-4.

Trichome 4-5 u wide; cells 5-6 u long. Pl. 1, Fig. 22. Scrapings from concrete culvert at storm sewer entrance to lake. October.

Lyngbya Agardh 1824

1. Lyngbya aerugineo-caerulea (Kuetzing) Gomont

Tilden, 1910, p. 116, Pl. 5, Figs. 32-33.

Trichome 6.6 u wide; cells 3-6 u long. Pl. 1, Fig. 23. Scrapings from stem of aquatic plant. August.

2. Lyngbya aestuarii Gomont

Tilden, 1910, p. 120, Pl. 5, Figs. 40-41.

Trichome 8-11 u wide; filament 12-15 u wide; cells 3-6 u long. Pl. 1, Fig. 24. Washings along shore and mixed in floating mats. August.

3. Lyngbya Birgei G. M. Smith

Smith, 1920, p. 54, Pl. 7, Figs. 14-15.

Trichome 21 u wide; cells 2-5 u long. pl. 1, Fig. 25.
Summer plankton. Not common.

4. Lyngbya epiphytica Hieronymus

Geitler and Pascher, 1925, p. 397; Prescott, (manuscript), Pl. 112, Figs. 2-3.

Trichome 1-1.5 u wide; cells 1-2 u long. Pl. 1, Fig.

28. Epiphytic on Tolypothrix lanata (Desvaux) Wartmann.
August.

5. Lyngbya Hieronymusii Lemmermann

Fremy, 1930, p. 197, Fig. 192.

Trichome 15-17.2 u wide; sheath 1 u wide; cells 2.5-3.4 u long. Pl. 1, Fig. 26. In washings along shore. Aug.

6. Lyngbya penicillata Kuetzing

Tilden, 1910, p. 115.

Trichome 4.5-5 u wide; cells 6-11 u long. Pl. 1, Fig. 27, Scrapings along shore. June.

Microcoleus Desmazieres 1823

1. Microcoleus paludosus (Kuetzing) Gomont

Tilden, 1910, p. 158, Pl. 6, Fig. 30.

Trichome 5 u broad. Pl. 1, Fig. 29. Mixed in filamentous mass along shore. June.

Sub-order HETEROCYSTINEAE

Family Nostocaceae

Anabaena Bory 1822

1. Anabaena circinalis var. macrospora (Wittrock) De Toni.

Smith, 1920, p. 60, Pl. 9, Fig. 6, Pl. 10, Fig. 1.

Cells 8-10 u broad; heterocysts 8-10 u broad; spores 12 u broad, 20 u long. Pl. 1, Fig. 30. Common in summer plankton. A component of surface scum in Aug. and Sept.

2. Anabaena cylindrica Lemmermann

Geitler, and Pascher, 1925, p. 328.

Cells 3-4.5 u broad; heterocysts 4-6.45 u broad, 6-10 u long; spores 4 u broad, 15-17 u long. Pl. 1, Fig. 31. Beach pool. May.

3. Anabaena Lemmermannii P. Richter

Smith, 1920, p. 61, Pl. 10, Fig. 8, Pl. 11, Fig. 1.

Cells 5-6.45 u broad, 5-6 u long; heterocysts 7 u long; spores 13 u broad, 28-32 u long. Pl. 2, Fig. 1. Common in plankton. May.

4. Anabaena limnetica G. M. Smith

Smith, 1920, p. 57, Pl. 8, Fig. 8.

Cells 8-9 u broad; heterocysts 10 u broad; spores 17 u broad, 24 u long. Pl. 1, Fig. 32. Common in summer plankton. A component of surface scum in July, Aug. and Sept.

5. Anabaena oscillarioides Bory

Geitler, and Pascher, 1925, p. 326. Prescott, (manuscript) Pl. 117, Figs. 8-10.

Cells 6.5 u broad, 3.5 u long; heterocyst 7.9 u broad, 8-9 u long; spores 10-11 u broad, 23-24 u long. Pl. 1, Fig. 33. In debris, beach pool. May.

6. Anabaena spiroides var. crassa Lemmermann

Smith, 1920, p. 59, Pl. 9, Figs. 103.

Cells 9-10 μ broad; heterocysts 12-14 μ broad. Pl. 1, Fig. 34. Common in summer plankton. A component of surface scum in July, August and September.

Nostoc Vaucher 1903

1. Nostoc microscopicum Carmichael

Tilden, 1910, p. 176, Pl. 8, Fig. 5.

Cells 4.3 μ broad; heterocysts 6 μ broad. Pl. 2, Fig.

2. Among washings along shore near inlet. June.

2. Nostoc paludosum Kuetzing

Tilden, 1910, p. 165, Pl. 6, Fig. 38.

Cells 3 μ broad; heterocysts 3.5 μ broad. Pl. 2, Fig.

4. Mixed with other filamentous algae in beach pool. May.

Aphanizomenon Morren, 1838

1. Aphanizomenon flos-aquae (L) Ralfs

Smith, 1920, p. 61, Pl. 11, Figs. 2-4.

Cells 4-6 μ broad; 6-14 μ long; heterocysts 5-7 μ broad, 6-18 μ long; spores 6-8 μ broad, 30-80 μ long. Pl. 2, Figs. 3 and 4. Common in summer plankton. An important constituent of "water bloom".

Cylindrospermum Kuetzing 1843

1. Cylindrospermum stagnale (Kuetzing) Bornet and Flahault

Tilden, 1910, p. 198, Pl. 10, Fig. 2.

Cells 3.3-4 μ broad, 4-8 μ long; heterocysts 5 μ broad, 8.6 μ long; spores 10-16 μ broad, 32-40 μ long. Pl. II.,

Fig. 6. Attached to grass and leaves in shallow beach pool. June.

Family Scytonemataceae

Tolypothrix Kuetzing 1843

1. Tolypothrix lanata (Desvaux) Wartmann

Tilden, 1910, p. 230, Pl. 14, Fig. 1.

Filaments 10-15 u broad; trichomes 9-10 u broad; heterocyst 10-11 u broad. Pl. II., Fig. 7. Attached and floating masses along shore. August.

Plectonema Thuret 1875

1. Plectonema Wollei Farlow

Tilden 1910, p. 208, Pl. 11, Figs. 4-5.

Filaments 55-75 u broad; trichomes 43-53 u broad; cells 4-9 u long. Pl. 2, Fig. 9. In mass of filaments along shore. October. Our specimens may be forma robusta which Drouet reports as only a growth form.

Microchaete Thuret 1875

1. Microchate tenera Thuret

Tilden 1910, p. 203, Pl. 10, Fig. 11.

Filaments 15-16 u broad; trichomes 10-12 u broad; cells 8-12 u long; heterocysts 10-15 u wide, 11-19 u long. Pl. 2, Fig. 1. Attached to Nymphaea leaf. August.

2. Microchaete tenuissima W. and G. S. West

Tilden 1910, p. 203, Pl. 10, Fig. 10.

Filaments 3.5-4 u broad; heterocysts 2.5-4 u broad. Cells 5-16 u in length. Pl. 2, Fig. 10.

Family Stigonemataceae

Stigonema Agardh 1824

1. Stigonema ocellatum (Dillwyn) Thuret

Tilden 1910, p. 246, Pl. 15, Figs. 15-17.

Filaments 15-18 u broad; trichomes 10-14 u broad. Pl. 2, Fig. 11. Collected in plankton in May. This is not a euplanktonic species and only a small secondary portion was collected. The measurements are under the typical measurements.

Family Rivulariaceae

Calothrix Agardh 1824

1. Calothrix fusca (Kuetzing) Bornet and Flahault

Tilden 1910, p. 265, Pl. 17, Figs. 10-11.

Filament 13 u at base; trichomes 10-6 u at base; heterocysts 9 u broad, 6.45 u long. Pl. 2, Fig. 12. Attached to Cladophora in filamentous mass along shore. October.

2. Calbthrix juliana (Meneghini) Bornet and Flahault

Tilden 1910, p. 566, Pl. 16, Fig. 5.

Filament 10-15 u at base; trichomes 9-12 u at base. Pl. 2, Fig. 13, Attached to Cladophora in filamentous mass along shore. October.

3. Calothrix stagnalis Gomont

Tilden 1910, p. 265, Pl. 17, Figs. 8-9.

Filaments 8-10 u broad; cells 6-10 u broad; heterocysts 10-11 u broad. Pl. 2, Figs. 15-16. Attached to filamentous algae. August.

Gloeotrichia Agardh 1842

1. Gloeotrichia pisum (Agardh) Thuret

Tilden 1910, p. 284, Pl. 13, Fig. 5. (Rivularia pisum Ag.) Filaments 5-7 u broad; heterocysts 9 u broad, 9 u long. Pl. 2, Fig. 14. Attached to aquatic plant on stem. Aug.

Phylum CHRYSOPHYTA

Class 1. XANTHOPHYCEAE

Order I. HETEROCOCCALES

Family Ophiocytaceae

Ophiocytium Naegeli 1849

1. Ophiocytium cochleare (Eichwald) A. Braun

Collins, 1909, p. 94; Pascher, A. 1925, p. 77, Fig. 60

Cells 8-10 u in diameter. Pl. 3, Figs. 2-3. Beach pool. May and June.

2. Ophiocytium parvulum (Perty) A. Braun

Smith, 1920, p. 86, Pl. 15, Fig. 11.

Cells 3 u broad. Pl. 3, Fig. 4. Beach pool. May.

Order HETEROTRICHIALES

Family Tribonemataceae

Tribonema Derbes and Solier 1856

1. Tribonema bombycinum (Agardh) Derbes and Solier

Prescott, 1931, p. 47, Pl. 7, Figs. 9-10

Cells 8-10.75 u broad; 2-4 diameters long. Pl. 3, Fig. 5
Floating mass among reeds and grass in inlet. April and May.

2. Tribonema minus (Wolle) Hazen

Prescott, 1931, p. 47, Pl. 7, Figs. 11-12

Cells 4 u broad, 3-6 diameters long. Pl. 3, Fig. 6.

In filamentous mass in beach pool. May.

Class 2. CHRYSOPHYCEAE

Order CHLOROMONADALES

Sub-order CHROMOLINIACEAE

Family Mallomonadaceae

Mallomonas Perty 1852

1. Mallomonas caudata Iwanoff

Smith, 1920, p. 69, Pl. 12, Fig. 6

Cells 12-30 u broad, 40-85 u long. Pl. 3, Fig. 8.

Plankton. November.

Sub-order ISOCHRYSIDINACEAE

Family Synuraceae

Synura Ehrenberg 1838

1. Synura uvella Ehrenberg

Smith, 1920, p. 70, Pl. 12, Figs. 9-10

Cells 8-17 u broad, 20-35 u long. Colonies up to 350 u in diameter. Pl. 3, Fig. 7. Plankton. April and May.

Phylum CHLOROPHYTA

Class CHLOROPHYCEAE

Order VOLVOCALES

Family Volvocaceae

Pandorina Fory 1824

1. Pandorina morum Bory

Smith, 1920, p. 95, Pl. 16, Figs. 16-17

Cells 7-8 u broad; colonies 22-37 u broad. Pl. 3, Fig. 9. Plankton. April through June.

Eudorina Ehrenberg 1832

1. Eudorina elegans Ehrenberg

Smith, 1920, p. 96, Pl. 19, Fig. 1

Cells 14-18 u in diameter; colonies 78-150 u in diameter. Pl. 3, Fig. 10. Plankton. April through July.

2. Eudorina unicocca G. M. Smith

Smith, 1933, p. 335, Fig. 225.

Cells 13-15 u in diameter; colonies 85-120 u in diameter. Pl. 3, Fig. 11. Plankton. April through June.

Pleodorina Shaw 1894

1. Pleodorina californica Shaw

Smith, 1920, p. 97, Pl. 17, Figs. 1-3

Vegetative cells 9-11 u in diameter; reproductive cells 14-19 u in diameter. Colonies 175-245 u in diameter. Pl. 3, Fig. 12. Plankton. July.

Volvox Linnaeus, 1758

1. Volvox aureus Ehrenberg

Smith, 1920, p. 98, Pl. 18, Fig. 2

Cells 5-9 u in diameter; colonies 300-509 u in diameter. Pl. 3, Fig. 13. Plankton. May through July.

Order TETRASPORALES

Family Palmellaceae

Sphaerocystis Chodat 1897

1. Sphaerocystis Schroeteri Chodat

Smith, 1920, p. 101, Pl. 19, Figs. 3-4

Cells 4.3 u in diameter; colony 54-78 u in diameter.

Pl. 4, Fig. 1. Plankton. May through July.

Gloeocystis Naegeli 1849

1. Gloeocystis ampla Kuetzing

Smith, 1933, p. 353, Fig. 236 B

Cells 6.45 u broad, 8.6 u long. Pl. 4, Fig. 3. In filamentous mass along shore near inlet. June.

2. Gloeocystis gigas (Kuetzing) Lagerheim

Smith, 1920, p. 101, Pl. 19, Fig. 2

Cells 6 u in diameter; colony 38-44 u in diameter.

Pl. 4, Fig. 2. Plankton. May.

Family Tetrasporaceae

Tetraspora Link 1809

1. Tetraspora gelatinosa (Vaucher) Desvaux

Prescott, 1931, p. 52. Prescott (manuscript), Pl. 5, Figs. 3-4.

Cells 6.45-8.6 u in diameter. Pl. 4, Figs. 4-5.

Attached to concrete dock. May.

Order ULOTRICHALES

Family Ulotrichaceae

Ulothrix Kuetzing 1833

1. *Ulothrix tenuissima* Kuetzing

Heering, 1914, p. 32, Fig. 31.

Cells 15-17.2 u broad; 10-13 u long. Pl. 4, Fig. 6.

Scrapings from bark of submerged limb. April.

2. *Ulothrix variabilis* Kuetzing

Prescott, 1931, p. 81. Prescott (manuscript), Pl. 6, Fig. 13.

Cells 22 u broad; 15-23 u long. Pl. 4, Fig. 8.

Attached to weeds and submerged wood. April.

3. *Ulothrix zonata* (Weber and Mohr) Kuetzing

Prescott, 1931, p. 81, Pl. 17, Fig. 22.

Cells 22 u broad, 15-23 u long. Pl. 4, Fig. 8

Attached to weeds and submerged wood. April.

Uronema Lagerheim 1887

1. *Uronema elongatum* Hodgetts

Smith, 1933, p. 381, Fig. 254.

Cells 4.5 u broad, 10.75-21.5 u long. Pl. 4, Fig. 9.

Attached to filaments of *Phormidium* from concrete culvert at storm sewer entrance. April.

Family Microsporaceae

Microspora Thuret 1850; emend. Lagerheim 1888

1. *Microspora stagnorum* (Kuetzing) Lagerheim

Prescott, 1931, p. 82. Prescott, (manuscript), Pl. 8, Figs. 6-7.

Cells 8.6 u broad, 10.75-19 u long. Pl. 4, Fig. 10. Floating masses among submerged reeds and grasses. April.

2. *Microspora tumidula* Hazen

Prescott, 1931, p. 82, Pl. 18, Fig. 4.

Cells 6-8 u in diameter. Pl. 4, Fig. 11. Filamentous mass along shore. April.

Family Chaetophoraceae

Stigeoclonium Kuetzing 1843

1. *Stigeoclonium lubricum* (Dillwyn) Kuetzing

Prescott, 1931, p. 86, Prescott, (manuscript), Pl. 10, Figs. 1-2.

Cells 9-11 u in diameter. Pl. 4, Fig. 12. Among reeds and grasses near shore. April and May.

2. *Stigeoclonium tenue* (Agardh) Kuetzing

Prescott, 1931, p. 86; Hazen, 1902, p. 202, Pl. 32, Figs. 1-3.

Cells 6-8 u in diameter. Pl. 4, Fig. 13. Attached to submerged rock at storm sewer entrance. October.

Chaetophora Schrank 1813

1. *Chaetophora elegans* (Roth) Agardh

Prescott, 1931, p. 84, Pl. 19, Figs. 1-2.

Cells 4 u broad; 14-19 u long. Pl. 5, Fig. 1. Attached to aquatic stem. October.

Draparnaldia Bory 1808

1. *Draparnaldia glomerata* (Vaucher) Agardh

Collins, 1909, p. 303, Fig. 89.

Main axis of cells 4 u wide; 2 times diameter in length. Cells in fascicles 6-9 u broad. Pl. 5, Fig. 2. Filamentous growth among reeds and grass in inlet.

Family Coleochaetaceae

Coleochaete Brébisson 1844

1. *Coleochaete orbicularis* Pringsheim

Prescott, 1931, p. 88, Pl. 22, Fig. 3.

Cells 6-18 u broad, 16-32 u long. Pl. 5, Fig. 3.

Attached to submerged plant stems. August.

2. *Coleochaete scutata* Brébisson

Prescott, 1931, p. 88, Pl. 22, Fig. 5.

Cells 24-45 u in diameter. Pl. 5, Fig. 4. Attached to submerged plants. August.

Family Trentepohliaceae

Gomontia Bornet and Flahault 1888

1. *Gomontia Holdenii* Collins

Smith, 1933, p. 417, Fig. 282.

Cells 17-19 u broad, 23-28 u long. Pl. 5, Fig. 5.

Attached to *Nymphaea* stem. August.

Family Cladophoraceae

Cladophora Kuetzing 1843

1. Cladophora callicoma Kuetzing

Collins, 1909, p. 352

Cells in primary branches 75-90 u broad, 250-360 u long;
cells in secondary branches 45 u broad, 180-200 u long.

Pl. 5, Fig. 6. Washings on shore near inlet. October.

2. Cladophora fracta (Dillwyn) Kuetzing

Prescott, 1931, p. 89, Pl. 23, Fig. 2.

Cells in primary branches 80-118 u broad, 245-272 u
long; cells in secondary branches 38-45 u broad, 90-122 u
long. Pl. 5, Figs. 7-8. Washings on shore near inlet.

October.

Rhizoclonium Kuetzing 1843

1. Rhizoclonium hieroglyphicum (Agardh) Kuetzing

Prescott, 1931, p. 91, Pl. 25, Fig. 4.

Cells 25 u broad, 182-247 u long. Pl. 6, Fig. 2.

Beach pool. May.

Pithophora Wittrock 1877

1. Pithophora varia Wille

Prescott, 1931, p. 91, Pl. 24, Figs. 7-8.

Filaments 60-78 u broad; akinetes 90-98 u broad, 290-
454 u long. Pl. 6, Fig. 1. Intermingled with floating
Cladophora near shore. October.

Order OEDOGONIALES

Family Oedogoniaceae

Oedogonium Link 1820

1. Oedogonium crispum (Hassall) Wittrock
Tiffany, 1937, p. 52, Pl. 22, Figs. 336-337.
Vegetative cell 11-12 u broad, 43-56 u long; antheridia 10.75 u broad, 6.45 u long. Pl. 6, Fig. 1. Beach pool. May.
2. Oedogonium hystericinum Transeau and Tiffany
Tiffany, 1937, p. 55, Pl. 30, Figs. 481-482.
Suffultory cell 21 u broad, 53 u long; oogonium 38 u broad, 40 u long; oospore 34.4 u broad, 38.7 u long; antheridia 8.6 u broad, 8 u long. Pl. 7, Fig. 2. Beach pool. June.
3. Oedogonium globosum Nordstedt
Tiffany, 1937, p. 32, Pl. 9, Fig. 120.
Vegetative cell 11 u broad, 81-114 u long; oogonium 38 u broad, 35 u long; oospore 41 u broad, 38 u long. Pl. 7, Fig. 3. Beach pool. June.
4. Oedogonium grande Kuetzing
Tiffany, 1937, p. 38, Pl. 13, Fig. 172-174
Vegetative cell 38-40 u broad; oogonium 60 u broad, 97 u long; oospore 56 u broad, 73 u long. Pl. 7, Fig. 4. Beach pool. June.
5. Oedogonium princeps (Hassall) Wittrock
Tiffany, 1937, p. 36, Pl. 11, Figs. 147-150.

Vegetative cells 43 u broad; oogonium 53 u broad, 81 u long; oospore 51 u broad, 51 u long; antheridium 43 u broad, 8 u long. Pl. 7, Figs. 5-6. Beach pool. June.

6. Oedogonium upsaliense Wittrock

Tiffany, 1937, p. 34, Pl. 10, Fig. 133.

Vegetative cells 15 u broad; suffultory cell 23 u broad; oogonium 53 u broad, 96 u long; oospore 50 u broad, 86 u long; antheridium 15 u broad, 7 u long. Pl. 7, Fig. 7. Beach pool. May.

Order ULVALES

Family Schizomeridaceae

Schizomeris Kuetzing 1843

1. Schizomeris Leibleinii Kuetzing

Prescott, 1931, p. 81, Pl. 18, Figs. 1-2.

Cells 15-53 u in diameter; holdfast 13 u in diameter. Pl. 6, Figs. 3-4. Attached to submerged rock at storm sewer entrance to lake. October.

Order CHLOROCOCCALES

Family Hydrodictyaceae

Pediastrum Meyen 1829

1. Pediastrum Boryanum (Turpin) Meneghini

Smith, 1920, p. 169, Pl. 46, Figs. 2-7.

Diameter cells 12 u. Diameter 16-celled colony 64 u. Pl. 8, Fig. 1. Common in plankton. Spring.

2. Pediastrum duplex Meyen

Smith, 1920, p. 171, Pl. 46, Figs. 14-16.

Diameter of cells 13-18 u; diameter of colony 110 u.

Pl. 8, Fig. 2. Plankton. July.

3. Pediastrum duplex var. clathratum (A. Braun) Lagerheim

Smith, 1920, p. 171, Pl. 47, Figs. 1-3.

Diameter of cells 22 u. Pl. 8, Fig. 3. Plankton. July.

4. Pediastrum tetras var. tetraodon (Corda) Hansgirg

Smith, 1920, p. 174, Pl. 48, Figs. 13-14; Pl. 49,

Figs. 1-2.

Diameter of cells 8 u. Pl. 8, Fig. 4. Scrapings from aquatic plant stems. August.

Sorastrum Kuetzing, 1845

1. Sorastrum americanum var. undulatum G. M. Smith

Smith, 1920; p. 163, Pl. 44, Figs. 2-3.

Cells 7-10 u broad. Pl. 8, Fig. 5. Mixed in a filamentous mat along shore. June.

Hydrodictyon Roth 1800

1. Hydrodictyon reticulatum (Lund) Lagerheim

Smith, 1920, p. 166, Pl. 44, Fig. 6, Pl. 43, Fig. 1.

Cells 5-42 u broad. Pl. 8, Fig. 14. Forming heavy mats along shore. Summer.

Family Coelastraceae

Coelastrum Naegeli 1849

1. Coelastrum microporum Naegeli

Smith, p. 160, Pl. 41, Figs. 12-13, Pl. 42, Fig. 11.

Diameter of cells 11 u (without sheath), 13 u (with sheath). Diameter of coenobe 56 u. Pl. 8, Fig. 6.

Common in plankton. May and June.

Family Oocystaceae

Dictyosphaerium Naegeli 1849

1. *Dictyosphaerium pulchellum* Wood

Smith, 1920, p. 105, Pl. 20, Fig. 13, Pl. 21, Fig. 1.

Cells 4.3 u in diameter. Pl. 8, Fig. 9. Plankton. May.

Oocystis Naegeli 1843

1. *Oocystis Borgei* Snow

Smith, 1920, p. 111, Pl. 22, Fig. 4.

Cells 8.6 u broad, 10 u long; colony 19 u in diameter.

Pl. 8, Fig. 7. Mixed with filamentous algae along shore. June.

2. *Oocystis elliptica* W. West

Smith, 1920, p. 111, Pl. 22, Fig. 5.

Cells 15 u broad, 21 u long; colony 60 u broad. Pl. 8,

Fig. 12. Mixed with filaments of *Zygnema* along shore. June.

3. *Oocystis lacustris* Chodat

Smith, 1920, p. 112, Pl. 22, Figs. 8-9.

Cells 10 u broad, 21 u long. Pl. 8, Fig. 10. Mixed with other algae along shore. June.

4. *Oocystis parva* W. & G. S. West

Smith, 1920, p. 112, Pl. 22, Fig. 6.

Cells 7 u broad, 12 u long; coenobe 19 u broad, 22 u long.

Pl. 8, Fig. 8. Mixed with other algae. Beach pool. June.

Gloeotaenium Hansgirg 1890

1. *Gloeotaenium Loitlesbergerianum* Hansgirg

Smith, 1920, p. 115, Pl. 23, Figs. 8-9.

Cells 23 μ in diameter. Pl. 8, Fig. 11. Mixed with *Oscillatoria* attached to bottom. August.

Kirchneriella Schmidle 1893

1. *Kirchneriella obesa* var. *major* (Bernard) G. M. Smith

Smith, 1920, p. 142, Pl. 35, Fig. 4.

Cells 3-5 μ broad, 8-12 μ long. Pl. 8, Fig. 13. In filamentous mixture along shore. November.

Family Scenedesmaceae

Scenedesmus Meyen 1829

1. *Scenedesmus armatus* (Chodat) G. M. Smith

Smith, 1920, p. 154, Pl. 39, Figs. 7-10.

Cells 5.5 μ broad, 15 μ long; 8-celled coenobe (without spines) 15 μ broad, 44 μ long. Spines 6 μ long, Pl. 9, Fig. 1. Plankton. June.

2. *Scenedesmus bifuga* (Turpin) Lagerheim

Smith, 1920, p. 152, Pl. 37, Figs. 18-20.

Cells 4 μ broad, 10-12 μ long; 4-celled coenobe 10-12 μ broad, 43 μ long. Pl. 9, Fig. 2. Mixed with *Spirogyra* in inlet. May.

3. *Scenedesmus dimorphus* (Turpin) Kuetzing

Smith, 1920, p. 151, Pl. 37, Figs. 15-17.

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Cells 3 u broad, 10 u long; 4-celled coenobe 10 u broad, 14 u long. Pl. 9, Fig. 3. Scrapings from aquatic plant stem. August.

4. Scenedesmus obliquus (Turpin) Kuetzing

Smith, 1920, p. 151, Pl. 37, Figs. 12-14.

Cells 4.3 u broad, 15 u long. 4-celled coenobe 15 u broad, 18 u long. Pl. 9, Fig. 4. Scrapings from aquatic plant stem. August.

5. Scenedesmus quadricauda (Turpin) Brebisson

Smith, 1920, p. 158, Pl. 40, Figs. 9-11.

Cells 4.3 u broad, 15 u long. 4-celled coenobe without spines, 14 u broad, 19.3 u long; spines 8-10 u long. Pl. 9 Fig. 5. Scrapings from aquatic plant stem. August.

6. Scenedesmus quadricauda var. quadrispina (Chodat)

G. M. Smith.

Smith, 1920, p. 158, Pl. 40, Figs. 15-16.

Cells 6 u broad, 17 u long. 4-celled coenobe without spines, 17 u broad, 25.8 u long; spines 5-6 u long. Pl. 9, Fig. 6. Mixed with filamentous algae along shore. June.

Crucigenia Morren 1830

1. Crucigenia irregularis Wille

Smith, 1920, p. 143, Pl. 36, Figs. 4-5.

Cells 4.3-5 u broad, 8.6 u long. 4-celled coenobia. 8 u broad, 26 u long. Pl. 9, Figs. 7-8. Scrapings from aquatic plant stems. August.

Family Botryococcaceae

Botryococcus Kuetzing 1849

1. Botryococcus Braunii Kuetzing

Smith, 1920, p. 84, Pl. 15, Fig. 5.

Cells 5 u broad, 10.5 u long. Colony $3\frac{1}{4}$ u in diameter.

Pl. 3, Fig. 1. Beach pool. May.

Order SIPHONALES

Family Vaucheriaceae

Vaucheria De Caudolle 1803

1. Vaucheria geminata var. racemosa (Vaucher) Walz.

Prescott, 1931, p. 92, Pl. 26, Fig. 3.

Filament 81-99 u broad; stalk of reproductive organs 43 u broad at base; antheridia 28 u wide; oogonia 75 u broad, 86 u long. Pl. 6, Fig. 5. Beach pool. May.

2. Vaucheria sessilis (Vaucher) De Caudolle

Prescott, 1931, p. 93, Pl. 27, Fig. 5.

Filament 43 u broad; antheridia 32 u broad; oogonia 64-68 u broad, 77-80 u long. Pl. 6, Figs. 6-7.

Order ZYGNEMATALES

Family Zygnemataceae

Mougeotia Agardh 1824

1. Mougeotia scalaris Hassall

Prescott, 1931, p. 106; Borge and Pascher, 1913, p. 41, Fig. 66.

Filament 31 u broad; zygospore $3\frac{1}{4}$ u broad, 45 u long. Pl. 11, Fig. 1. Filamentous growth along shore. June.

Spirogyra Link 1820

1. Spirogyra crassa Kuetzing

Prescott, 1931, p. 107; Borge and Pascher, 1913, p. 30, Fig. 42.

Filament 127 u wide; zygospore 114 u in diameter.

Pl. 11, Fig. 2. Filamentous growth in shallow water near boat dock. June.

2. Spirogyra decimina (Mueller) Kuetzing

Prescott, 1931, p. 107, Pl. 30, Fig. 7.

Filament 32-38 u broad; zygospore 30-35 u broad, 53-60 u long. Pl. 11, Fig. 3. Filamentous growth along shore in inlet. May.

3. Spirogyra lutetiana Petit

Collins, F. C., 1909, p. 34; Borge, O. and Pascher, 1913, p. 25, Fig. 30.

Filament 39-45 u broad; zygospore 32-43 u broad, 55-75 u long. Pl. 11, Fig. 4. Beach pool. May.

4. Spirogyra mirabilis (Hassall) Kuetzing

Prescott, 1931, p. 109; Borge and Pascher, 1913, p. 21, Fig. 17.

Filament 27 u broad; zygospore 30 u broad, 53-55 u long. Pl. 11, Fig. 6. Beach pool. July.

5. Spirogyra porticalis (Mueller) Cleve

Prescott, 1931, p. 109; Smith, G. M., 1920, p. 185, Pl. 51, Fig. 3.

Filament 41 u broad; zygospor e 40 u broad, 73-86 u long. Pl. 11, Fig. 7. Plankton tow. June. Smith lists this species as planktonic.

6. Spirogyra Spreeliana Rabenhorst

Prescott, 1931, p. 110; Borge and Pascher, 1913, p. 17, Fig. 5.

Filament 17-18 u broad; zygospor e 25-32 u broad, 86-116 u long. Pl. 11, Fig. 5. Beach pool. June.

7. Spirogyra sp.

Filament 28-32 u broad; zygospor e 40-49 u broad, 75-117 u long. Pl. 12, Figs. 1-4. Beach pool. May. This specimen appears to be a new species. Proper publication will ensue if thorough investigation shows it to be thus.

Family Desmidiaceae

Closterium Nitzsch 1817

1. Closterium acerosum (Shrank) Ehrenberg

Smith, 1925, p. 10, Pl. 53, Fig. 1.

Cells 320-336 u long, 21. 5 u broad at girdle. Pl. 9, Fig. 10. Plankton. July.

2. Closterium acerosum var. elongatum Brébisson

Irene-Marie, 1938, p. 72, Pl. 6, Fig. 6.

Cells 563 u long, 28 u broad at girdle. Pl. 9, Fig.

11. Mixed in filamentous algae among reeds at inlet. May.

3. Closterium gracile var. elongatum W. & G. S. West

Smith, 1924, p. 11, Pl. 53, Fig. 2.

Cells 608 u long; 20 u broad at girdle; 4.3 u broad at

poles. Pl. 9, Fig. 9. Mixed with filamentous algae along shore. May.

4. Closterium lunula (Mueller) Ralfs

Irene-Marie, 1938, p. 73, Pl. 6, Fig. 2-5.

Cells 400-409 u long; 56-64 u broad at girdle; 6.45 at poles. Pl. 9, Fig. 12. Plankton tow. May.

5. Closterium moniliferum (Bory) Ehrenberg

Smith, 1924, p. 9, Pl. 52, Fig. 10.

Cells 225 u long; 35 u broad at girdle; 4.3 u broad at poles. Pl. 9, Fig. 13, Plankton. May.

6. Closterium parvulum Naegeli

Irene-Marie 1938, p. 68, Pl. 4, Figs. 4-6.

Cells 96 u long; 11.5 u at girdle; 3 u broad at poles. Pl. 9, Fig. 14. Mixed with filamentous material at storm sewer entrance. October. This form is close to Closterium venus. The curvative appears more pronounced than Closterium parvulum, but the measurements place it here.

Pleurotaenium Naegeli 1849

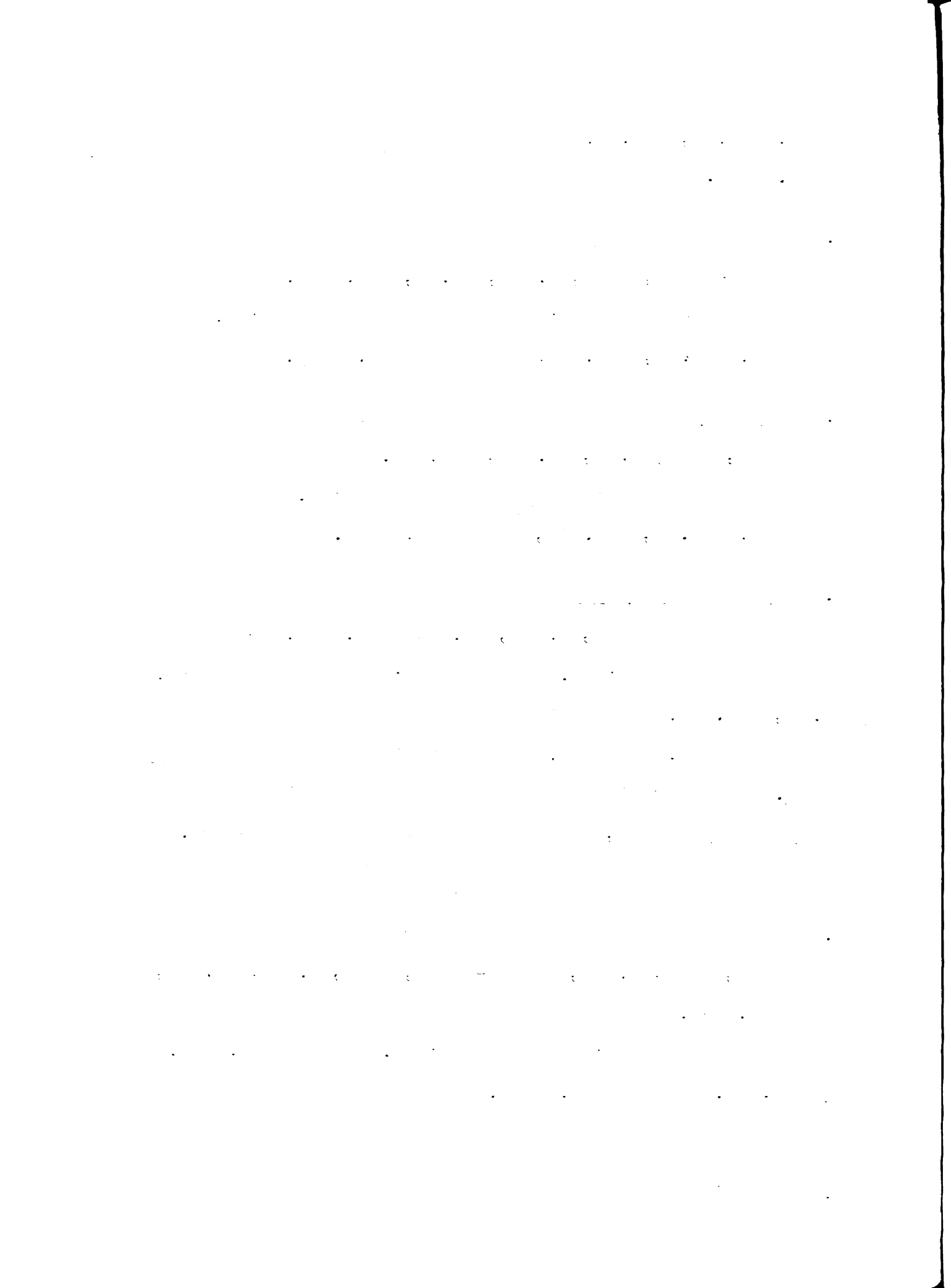
1. Pleurotaenium trabecula (Ehrenberg) Naegeli

Smith, 1924, p. 14, Irene-Marie, 1938, p. 94, Pl. 10, Figs. 5-6.

Cells 564 u long; 37 u at base; 23.6 u at poles. Pl. 9, Fig. 15. Beach pool. May.

Cosmarium Corda 1834

1. Cosmarium angulosum Brebisson



Irene-Marie, 1938, p. 177, Pl. 24, Fig. 5.

Cells 14 u wide; 17.2 u long. Pl. 9, Fig. 17. Beach pool. May.

2. Cosmarium angulosum var. concinnum (Rabenhorst) W. & G. S. West.

Gronblad, 1924, p. 7, Pl. 2, Figs. 31-35.

Cells 12.9 u wide; 18 u long. 4 u wide at isthmus.

Pl. 9, Fig. 16. Attached to aquatic plant stem. August.

3. Cosmarium Botrytis (Bory) Meneghini

Smith, 1924, p. 33, Pl. 57, Fig. 22

Cells 56 u wide; 69 u long; 15 u at isthmus. Pl. 9, Fig. 18. Beach pool. June.

4. Cosmarium connatum Brébisson

Irene-Marie, 1938, p. 173, Pl. 22, Figs. 8-9.

Cells 43 u broad; 70 u long; 39 u at isthmus. Pl. 9,

Fig. 19. Mixed with filamentous algae along shore. Oct.

5. Cosmarium reniforme (Ralfs) Archer

Smith, 1924, p. 33, Pl. 57, Fig. 23.

Cells 47 u broad; 47 u long; 16 u broad at isthmus.

Pl. 9, Fig. 21. Scrapings from aquatic plant stem. Aug.

6. Cosmarium sub-reniforme Nordstedt

Irene-Marie, 1938, p. 194, Pl. 31, Fig. 17.

Cells 35 u broad; 37 u long; 10 u broad at isthmus.

Pl. 9, Fig. 21. Mixed with Zygnema filaments floating among lily pads (Nymphaea). August.

7. Cosmarium Turpini Brébisson

Irene-Marie, 1938, p. 199, Pl. 6, Fig. 1.

Cells 58 u broad; 71 u long, 17 u broad at isthmus.

Pl. 9, Fig. 22. Beach pool. May.

Staurastrum Meyen 1892

1. Staurastrum alternans Brébisson

Smith, 1924, p. 70, Pl. 68, Fig. 4.

Cells 30 u broad; 34 u long; 10.75 u broad at isthmus.

Pl. 10, Fig. 5. Among filamentous algae in reeds in inlet.
May.

2. Staurastrum chaetoceras (Schroeder) G. M. Smith

Smith, 1924, p. 99, Pl. 76, Figs. 21-24; Pl. 77,
Fig. 1.

Breadth with processes 65 u, without processes 21 u;
length with processes 65 u, 25 u without processes; breadth
at isthmus 7 u. Pl. 10, Fig. 1. Plankton, November.

3. Staurastrum gracile Ralfs

Irene-Marie, 1938, p. 313, Pl. 48, Fig. 4.

Cells 60 u long with processes, 28 u long without
processes; breadth with processes 65 u, breadth without
processes 13 u; breadth 8.6 u at isthmus. Pl. 10, Fig.

3. Plankton. July.

4. Staurastrum longiradiatum W. & G. S. West

Smith, 1925, p. 90, Pl. 74, Figs. 5-11.

Cells 46-96 u long with processes, 43 u long without
processes; 86 u broad with processes, 20-28 u broad without

processes; 10.75 u broad at isthmus. Pl. 10, Fig. 2.
Plankton. July.

5. Staurostrum paradoxum Meyen

Smith, 1924, p. 85, Pl. 72, Figs. 15-22; Pl. 73,
Figs. 1-2.

Cells 37-65 u long with processes, 25-35 u long without
processes; breadth with processes 57-88 (83) u, without
processes 18-25 (22) u; breadth at isthmus 7.5-11 u. Pl.
10, Fig. 4. Plankton. July.

Phylum PYRRHOPHYTA

Class DINOPHYCEAE

Order PERIDINIALES

Family Peridiniaceae

Peridinium Ehrenberg 1832

1. Peridinium cinctum (Mueller) Ehrenberg

Prescott, (manuscript), Pl. 91, Figs. 1-4. Plankton.
March.

Family Ceratiaceae

Ceratium Schrank 1793

1. Ceratium hirundinella (O. F. Mueller) Du Jardin

Smith, G. M., 1933, p. 605, Fig. 428.
Pl. 10., Fig. 6. Common in summer and early fall
plankton.

Phylum EUGLENOPHYTA

Family Euglenaceae

Englena Ehrenberg 18381. *Englena acus* Ehrenberg

Prescott, 1931, p. 142; Walton, 1915, p. 371, Pl. 14,
Fig. 8.

Cells 193 u long, 18 u broad. Pl. 10, Fig. 7. Storm
Sewer. June.

2. *Englena proxima* Dangeard

Prescott, 1931, p. 143; Walton, 1915, p. 367, Pl. 13,
Fig. 4.

Cells 97 u long, 21.5 u broad. Pl. 10, Fig. 8. Plank-
ton. May.

Plate I.

- Fig. 1. Chroococcus dispersus (v. Keissler) Lemmermann (x 430).
2. C. limneticus var. carneus (Chodat) Lemmermann (x 430).
3. C. minutus (Kuetzing) Naegeli (x 430).
4. Merismopedia tenuissima Lemmermann (x 430).
- 5-6. Microcystis aeruginosa Kuetzing (x 215, x 100).
7. M. aeruginosa var. major G. M. Smith (x 430).
8. Aphanothece stagnalis (Sprengel) A. Braun (x 430).
9. Coelosphaerium Naegelianum Unger (x 430).
10. Spirulina major Kuetzing (x 430).
11. Arthrospira Jenneri (Kuetzing) Stizenberger (x 430).
12. Oscillatoria Agardhii Gomont (x 430).
13. O. amphibia Agardh (x 430).
14. O. chlorina Kuetzing (x 430).
15. O. formosa Bory (x 430).
16. O. limnetica Lemmermann (x 430).
17. O. limosa Agardh (x 430).
18. O. rubescens De Candolle (x 430).
19. O. sancta Kuetzing (x 430).
20. O. princeps Vaucher (x 430).
21. O. tenuis Agardh (x 430).
22. Phormidium Retzii (Agardh) Gomont (x 430).
23. Lyngbya aerugineo-caerula (Kuetzing) Gomont (x 430).
24. L. Aestuarii Gomont (x 430).
25. L. Birgei G. M. Smith (x 430).

Plate I. cont.

- Fig. 26. L. Hieronymusii Lemmermann (x 430).
27. L. penicillata Kuetzing (x 860).
28. L. epiphytica Hieronymus (attached to Toly-
pothrix) (x 950).
29. Microcoleus paludosus (Kuetzing) Gomont (x 375).
30. Anabaena Circinalis var. macrospora (Wittrock)
De Toni (x 430).
31. A. cylindrica Lemmermann (x 430).
32. A. limnetica G. M. Smith (x 430).
33. A. oscillarioides Bory (x 430).
34. A. spiroides var. crassa Lemmermann (x 215).

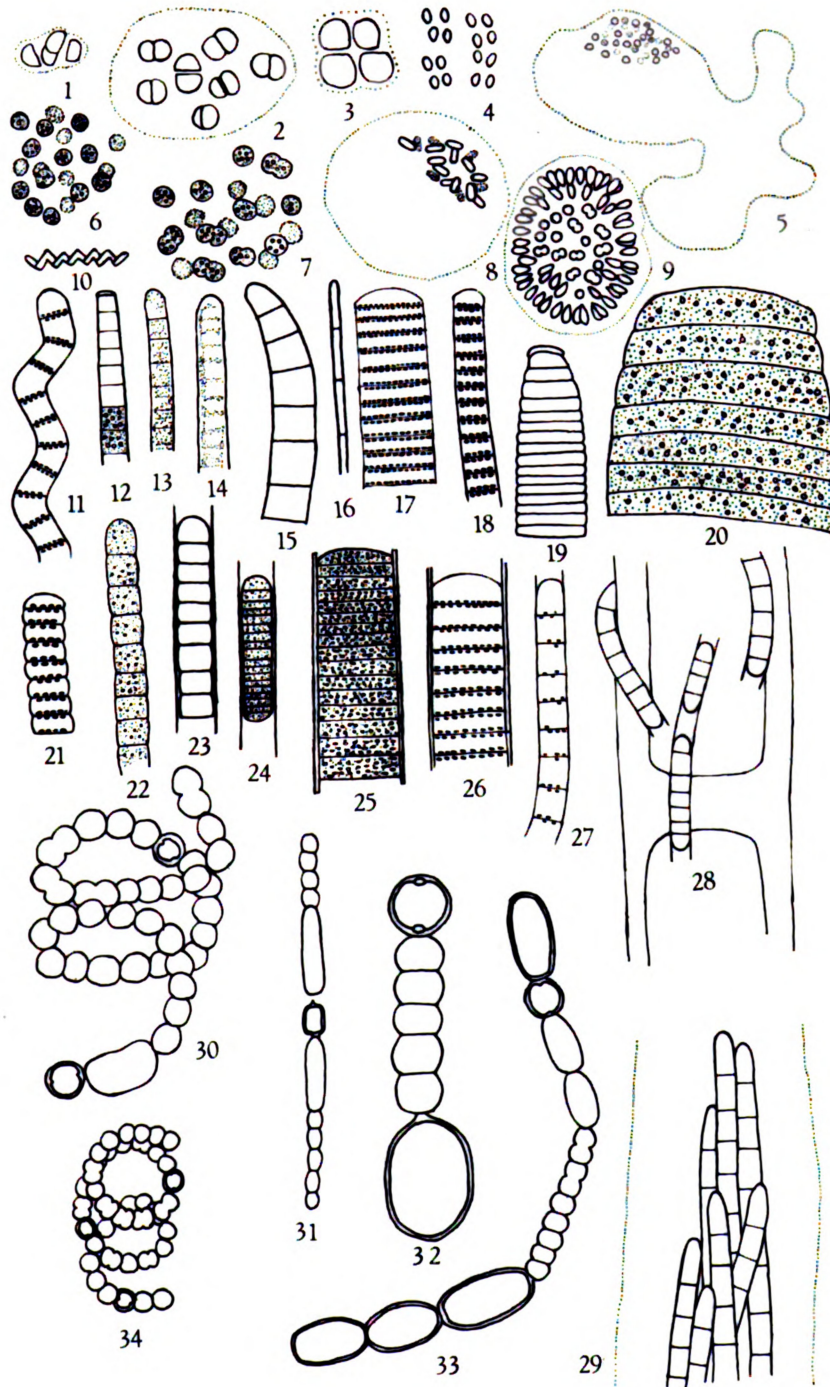


Plate II.

- Fig. 1. Anabaena Lemmermannii P. Richter (x 215).
2. Nostoc microscopicum Carmichael (x 430).
3. Aphanizomenon flos-aquae (Linnaeus) Ralfs
(x 187.5).
4. Nostoc paludosum Kuetzing (x 430).
5. Aphanizomenon flos-aquae (Linnaeus) Ralfs (x 430).
6. Cylindrospermum stagnale (Kuetzing) Bornet and
Flahault (x 430).
7. Tolypothrix lanata (Desvaux) Wartmann (x 215).
8. Microchaete tenera Thuret (x 215).
9. Plectonema Wollei Farlow (x 215).
10. Microchaete tenuissima W. & G. S. West (x 430).
11. Stigonema ocellatum (Dillwyn) Thuret (x 215).
12. Calothrix fusca (Kuetzing) Bornet and Flahault
(x 430).
13. C. Juliana (Meneghini) Bornet and Flahault
(x 430).
14. Gloeotrichia visum (Agardh) Thuret (x 215).
15-16. Calothrix stagnalis Gomont (x 430, x 50).

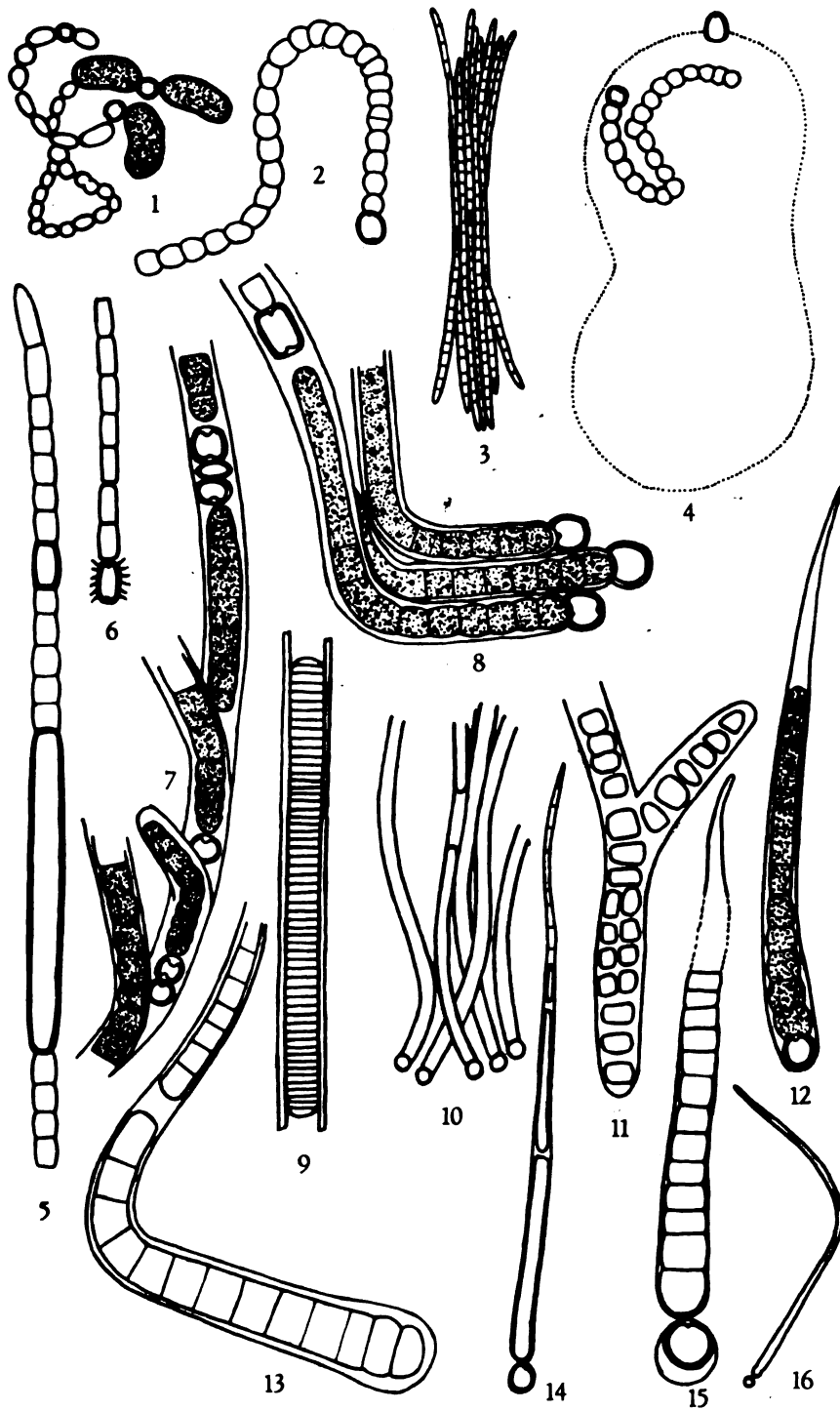


Plate III.

- Fig. 1. Botryococcus Braunii Kuetzing (x 430).
- 2-3. Ophiocytium cochleare (Eichwald) A. Braun
(x 430).
4. O. parvulum (Perty) A. Braun (x 430).
5. Tribonema bombycinum (Agardh) Derbes and Solier
(x 430).
6. T. minus (Wolle) Hazen (x 430).
7. Synura uvella Ehrenberg (x 430).
8. Mallomonas caudata Iwanoff (Redrawn from
G. M. Smith 1920) (x 250).
9. Pandorina morum Bory (x 430).
10. Eudorina elegans Ehrenberg (x 430).
11. E. unicocca G. M. Smith (x 430).
12. Pleodorina californica Shaw (x 215).
13. Volvox aureus Ehrenberg (x 100) (Modified
after G. M. Smith 1920).

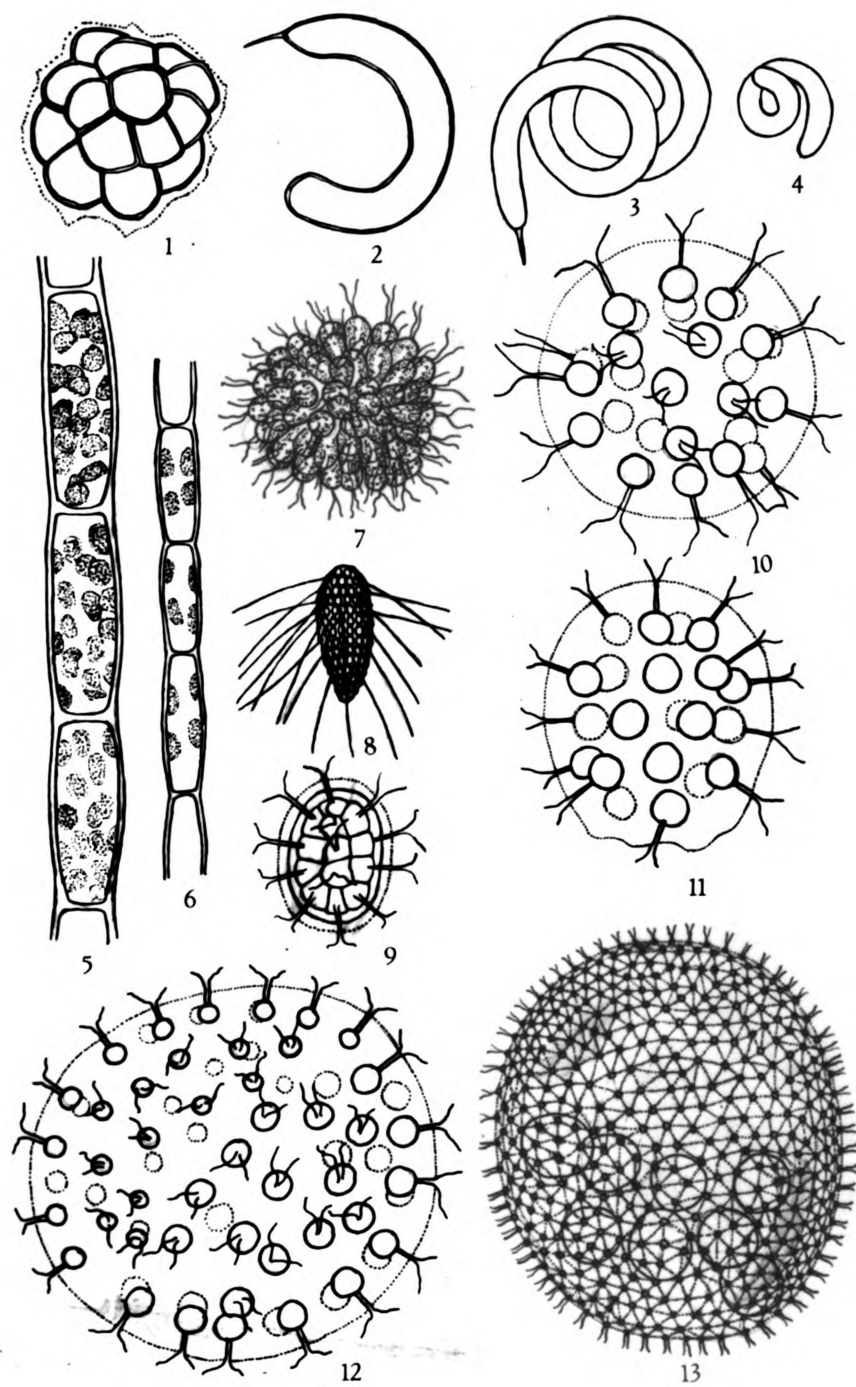


Plate IV.

- Fig. 1. Sphaerocystis Schroeteri Chodat (x 430).
2. Gloeocystis gigas (Kuetzing) Lagerheim
(x 430).
3. G. amola Kuetzing (x 430).
4-5. Tetraspora gelatinosa (Vaucher) Desvaux
(portion of colony x 215) (Habit of colony x 10).
6. Ulothrix tenuissima Kuetzing (x 430).
7. U. variabilis Kuetzing (x 430).
8. U. zonata (Weber and Mohr) Kuetzing (x 430).
9. Uronema elongatum Hodgetts (x 430).
10. Microspora stagnorum (Kuetzing) Lagerheim
(x 430).
11. M. tumidula Hazen (x 430).
12. Stigeoclonium lubricum (Dillwyn) Kuetzing
(x 215).
13. S. tenue (Agardh) Kuetzing (x 215).

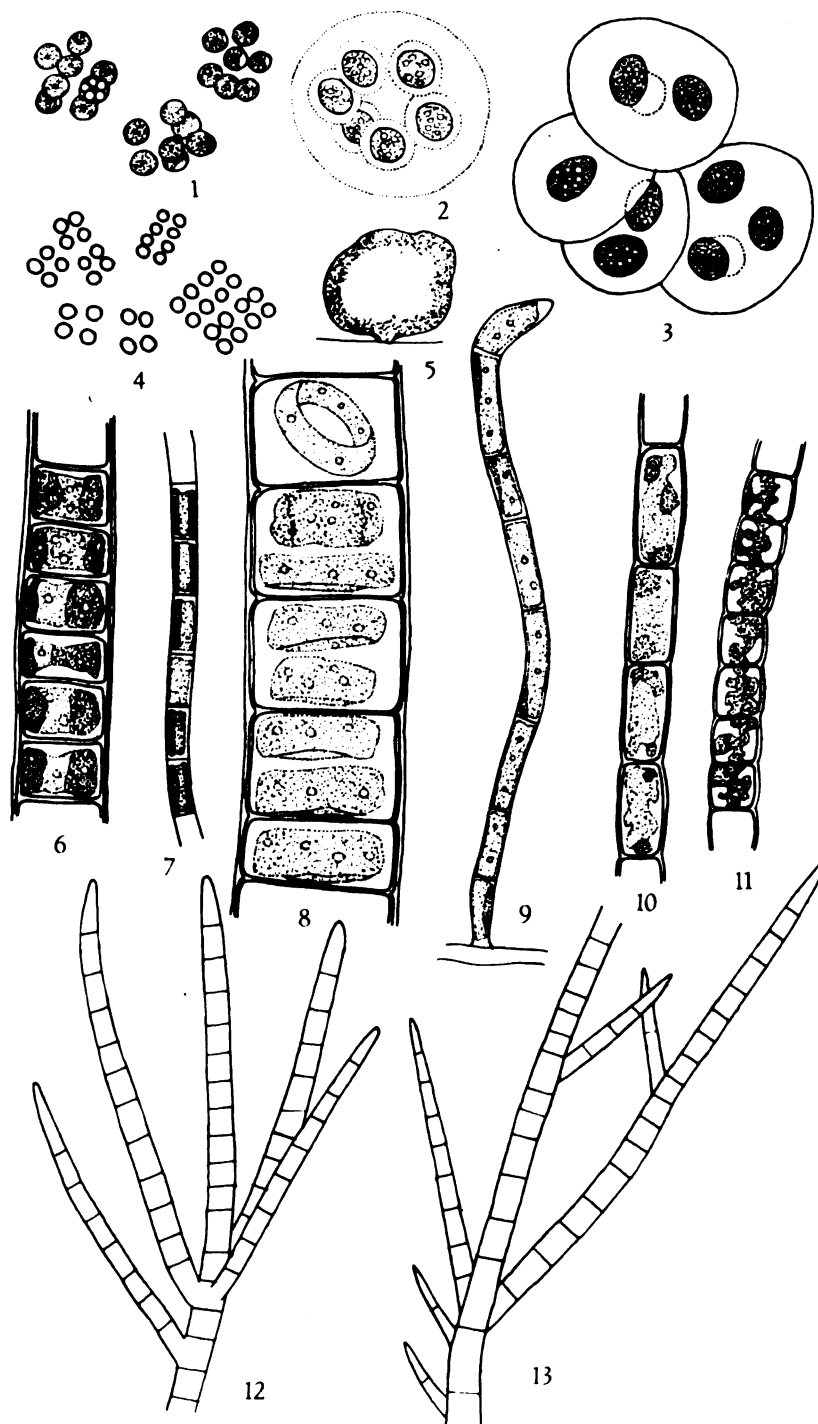


Plate V.

- Fig. 1. Chaetophora elegans (Roth) Agardh (x 430).
2. Draparnaldia glomerata (Vaucher) Agardh
(x 215).
3. Coleochaete orbicularis Pringsheim (x 215).
4. C. Scutata Brebisson (x 215).
5. Gomontia Holdenii (x 215).
6. Cladophora callicoma Kuetzing (x 215).
7-8. C. fracta (Dillwyn) Kuetzing (x 50, x 100).

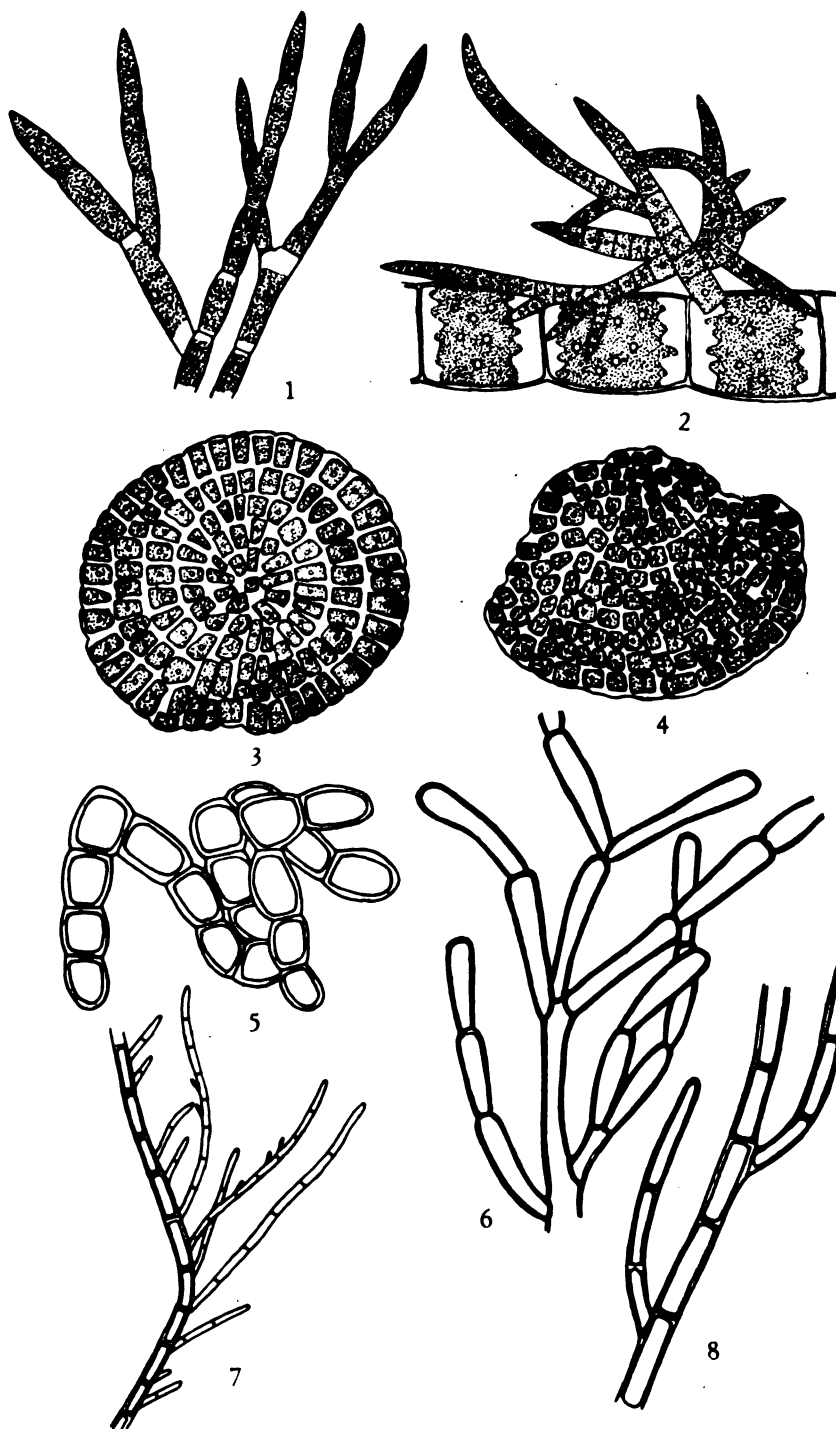


Plate VI

- Fig. 1. Pithophora varia Wille (x 50).
2. Rhizoclonium hieroglyphicum (Agardh) Kuetzing
(x 100).
3-4. Schizomeris Leibleinii Kuetzing (x 430, x 215).
5. Vaucheria geminata var. racemosa (Vaucher)
Walz (x 215).
6-7. V. sessilis (Vaucher) De Candolle (x 215.)

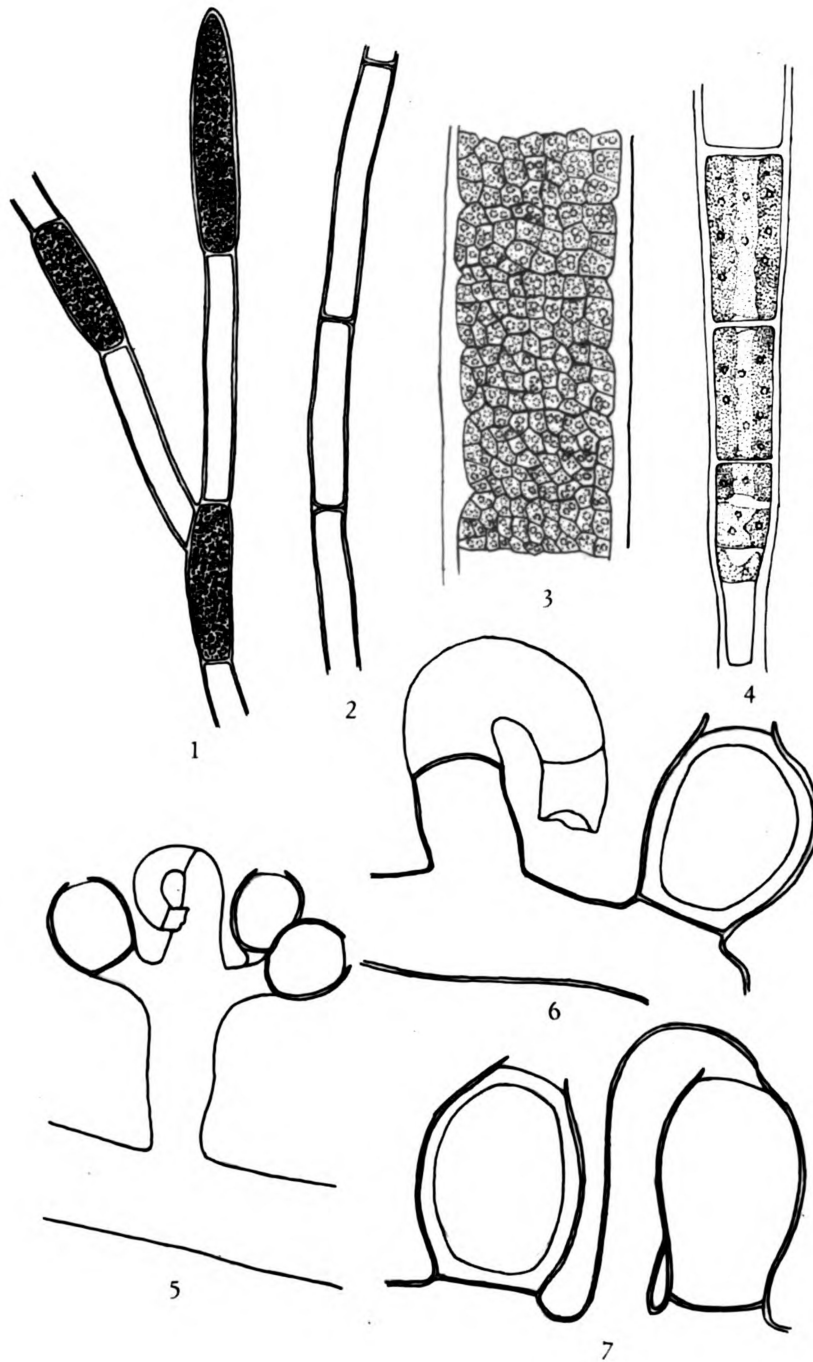


Plate VII.

- Fig. 1. Oedogonium crispum (Hassall) Wittrock (x 430).
2. O. hystericinum Transeau and Tiffany (x 430).
3. O. globosum Nordstedt (x 430).
4. O. grande Kuetzing (x 215).
5-6. O. princeps (Hassall) Wittrock (oogonial
filament x 430) (antheridial filament x 430).
7. O. upsaliense Wittrock (x 215).

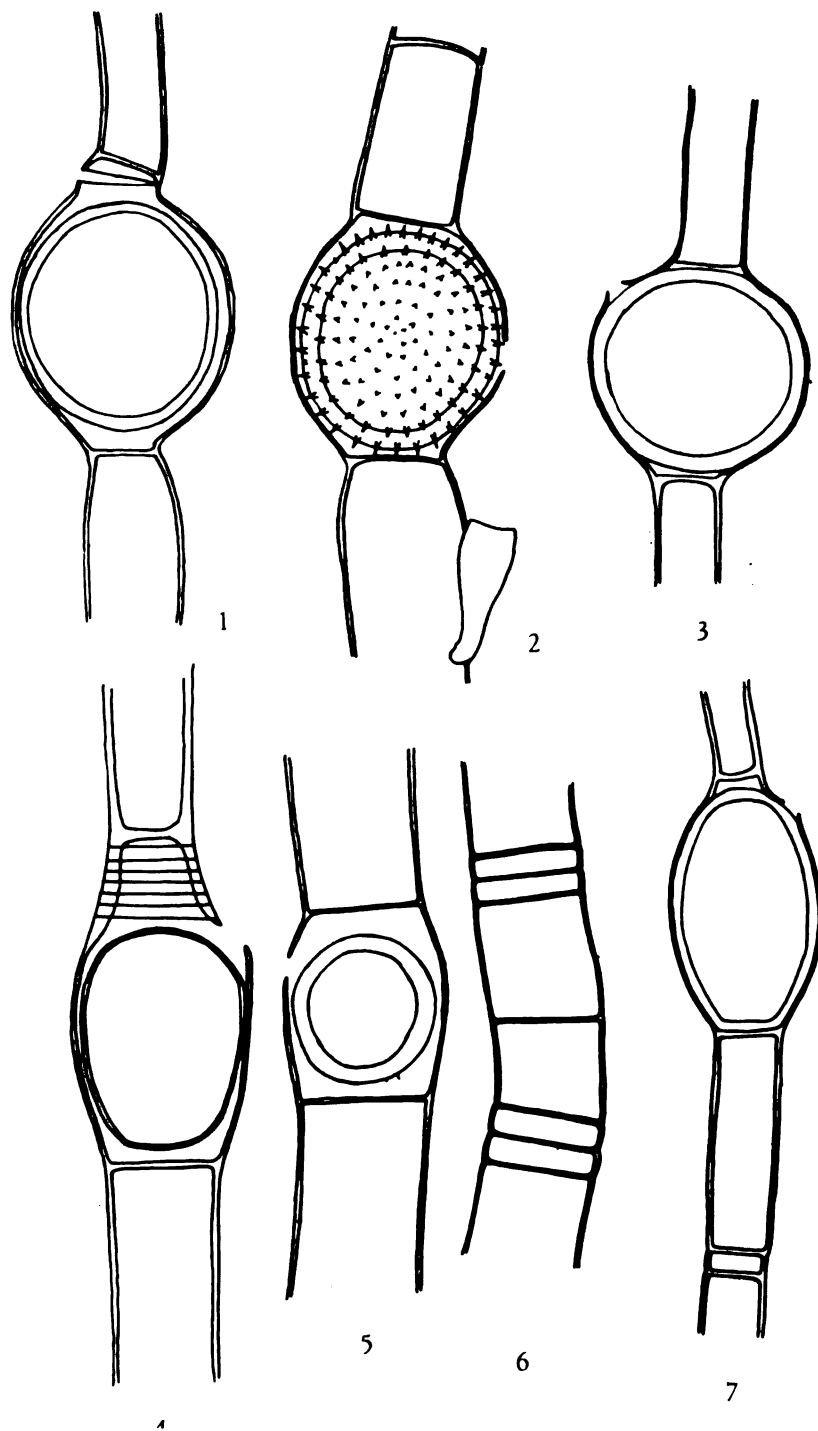




Plate VIII.

- Fig. 1. Pediastrum Boryanum (Turpin) Meneghini (x 430).
 2. P. duplex Mayen (x 430).
 3. P. duplex var. clathratum (A. Braun) Lagerheim (x 430).
 4. P. tetras var. tetraodon (Corda) Hansgrig (x 430).
 5. Sorastrum americanum var. undulatum G. M. Smith (x 430).
 6. Coelastrum microporum Naegeli (x 430).
 7. Oocystis Borgei Snow (x 430).
 8. O. parva W. & G. S. West (x 430).
 9. Dictyosphaerium pulchellum Wood (x 430).
 10. Oocystis lacustris Chodat (x 430).
 11. Gloeotaenium Loitlesbergerianum Hansgrig (x 430).
 12. Oocystis elliptica W. West (x 430).
 13. Kirchneriella obesa var. major (Bernard) G. M. Smith (x 430).
 14. Hydrodictyon reticulatum (Linnaeus) Lagerheim (x 100).

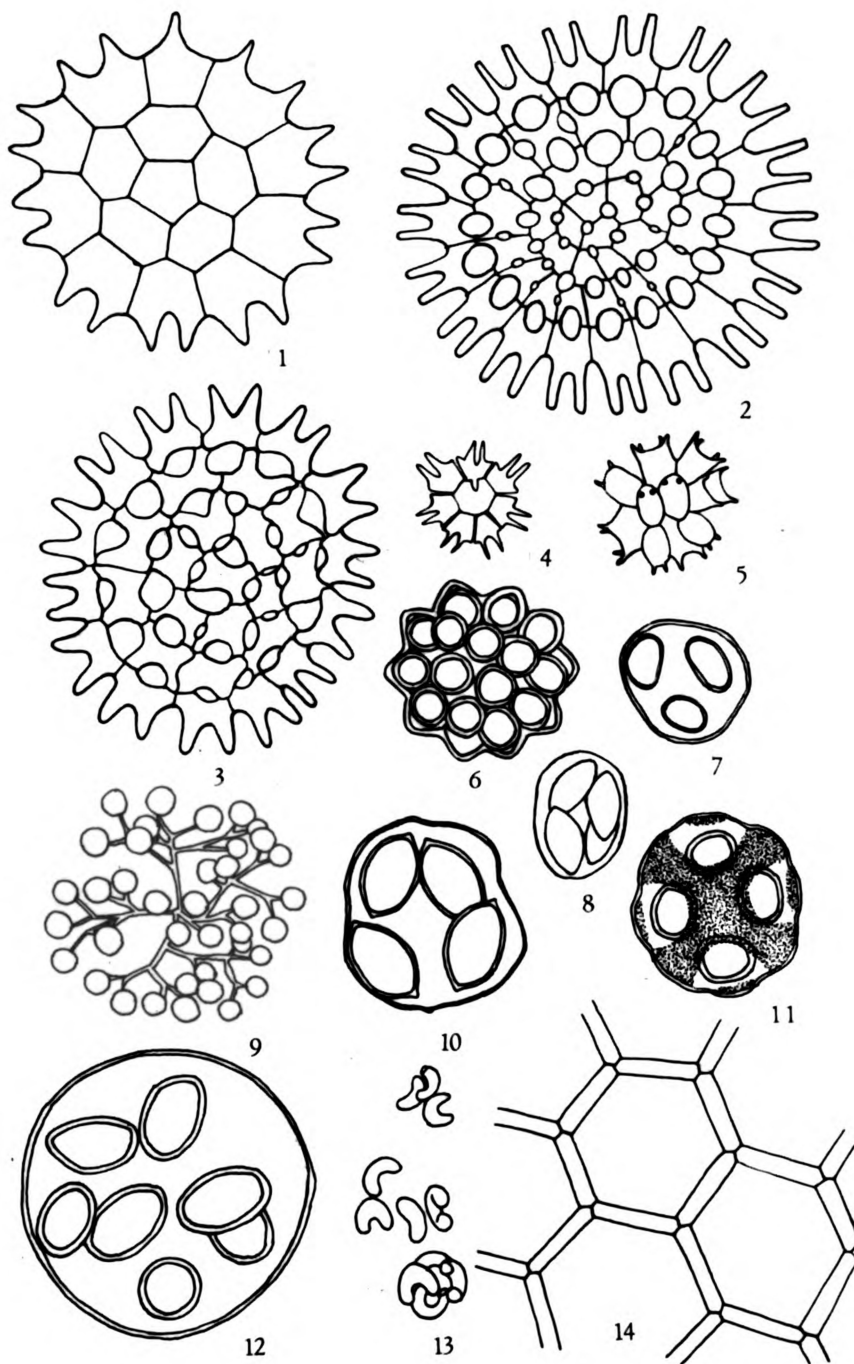


Plate IX.

- Fig. 1. Scenedesmus armatus (Chodat) G. M. Smith
(x 430).
2. S. bijuga (Turpin) Lagerheim (x 430).
3. S. dimorphus (Turpin) Kuetzing (x 430).
4. S. obliquus (Turpin) Kuetzing (x 430).
5. S. quadricauda (Turpin) Brebisson (x 430).
6. S. quadricauda var. quadrispina (Chodat)
G. M. Smith (x 430).
- 7-8. Crucigenia irregularis Wille (x 430).
9. Closterium gracile var. elongatum W. & G. S.
West (x 100).
10. C. acerosum (Schränk) Ehrenberg (x 154).
11. C. acerosum var. elongatum Brebisson (x 100).
12. C. lunula (Mueller) Ralfs (x 100).
13. C. moniliferum (Bory) Ehrenberg (x 215).
14. C. parvulum Naegeli (x 430).
15. Pleurotaenium trabecula (Ehrenberg) Naegeli
(semi-cell) (x 215).
16. Cosmarium angulosum var. concinnum (Rabenhorst)
(x 430).
17. C. angulosum Brebisson (x 430).
18. C. Botrytis (Bory) Meneghini (x 215).
19. C. connatum Brebisson (x 215).
20. C. subreniforme Nordstedt (x 430).
21. C. reniforme (Ralfs) Archer (x 430).
22. C. Turoni Brebisson (x 215).

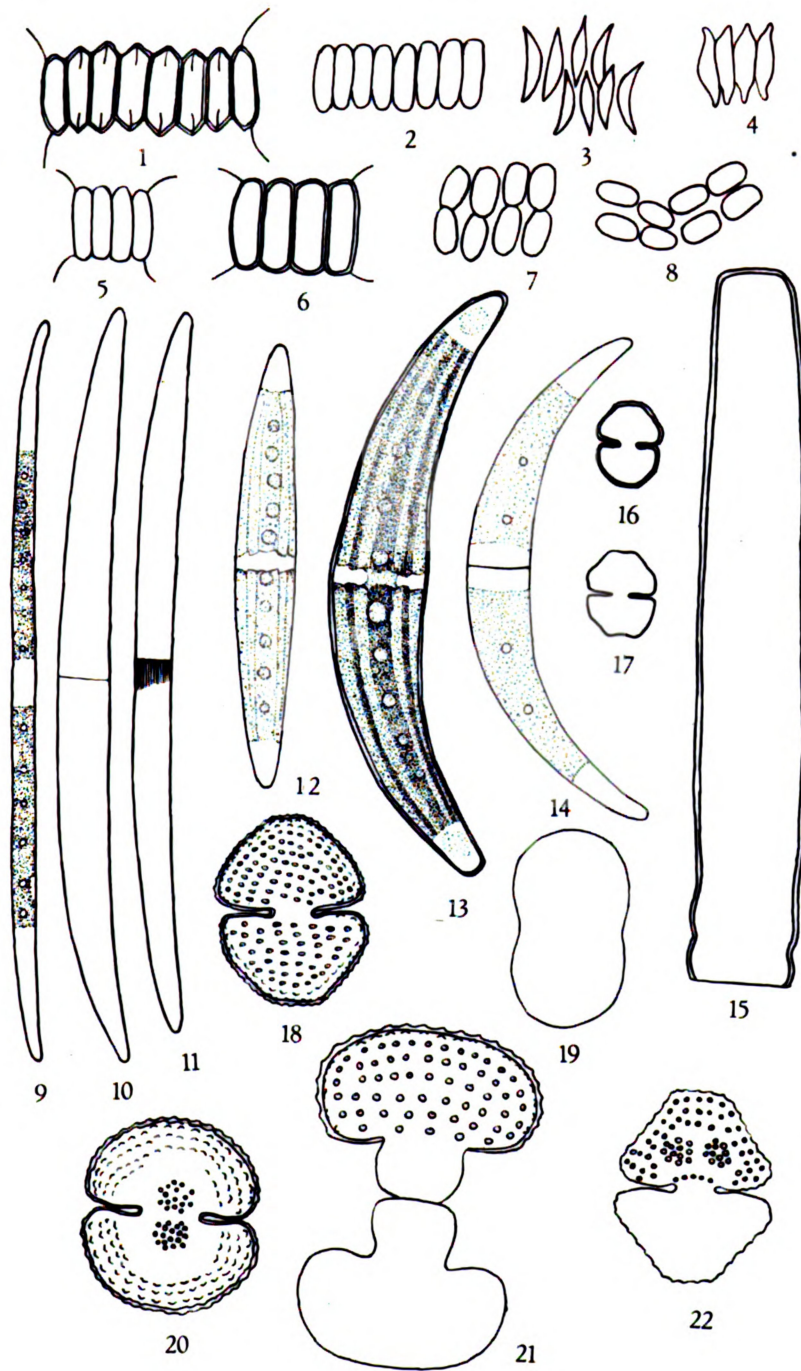


Plate X.

- Fig. 1. Staurostrum chaetoceras (Schroeder) Smith
(x 430).
2. S. longiradiatum W. & G. S. West (x 430).
3. S. gracile Ralfs (x 430).
4. S. paradoxum Meyen (x 430).
5. S. alternans Brebisson (x 430).
6. Ceratium hirundinella (O. F. Mueller) Schrank
(x 430).
7. Englena acus Ehrenberg (x 430).
8. E. proxima Dangeard (x 430).

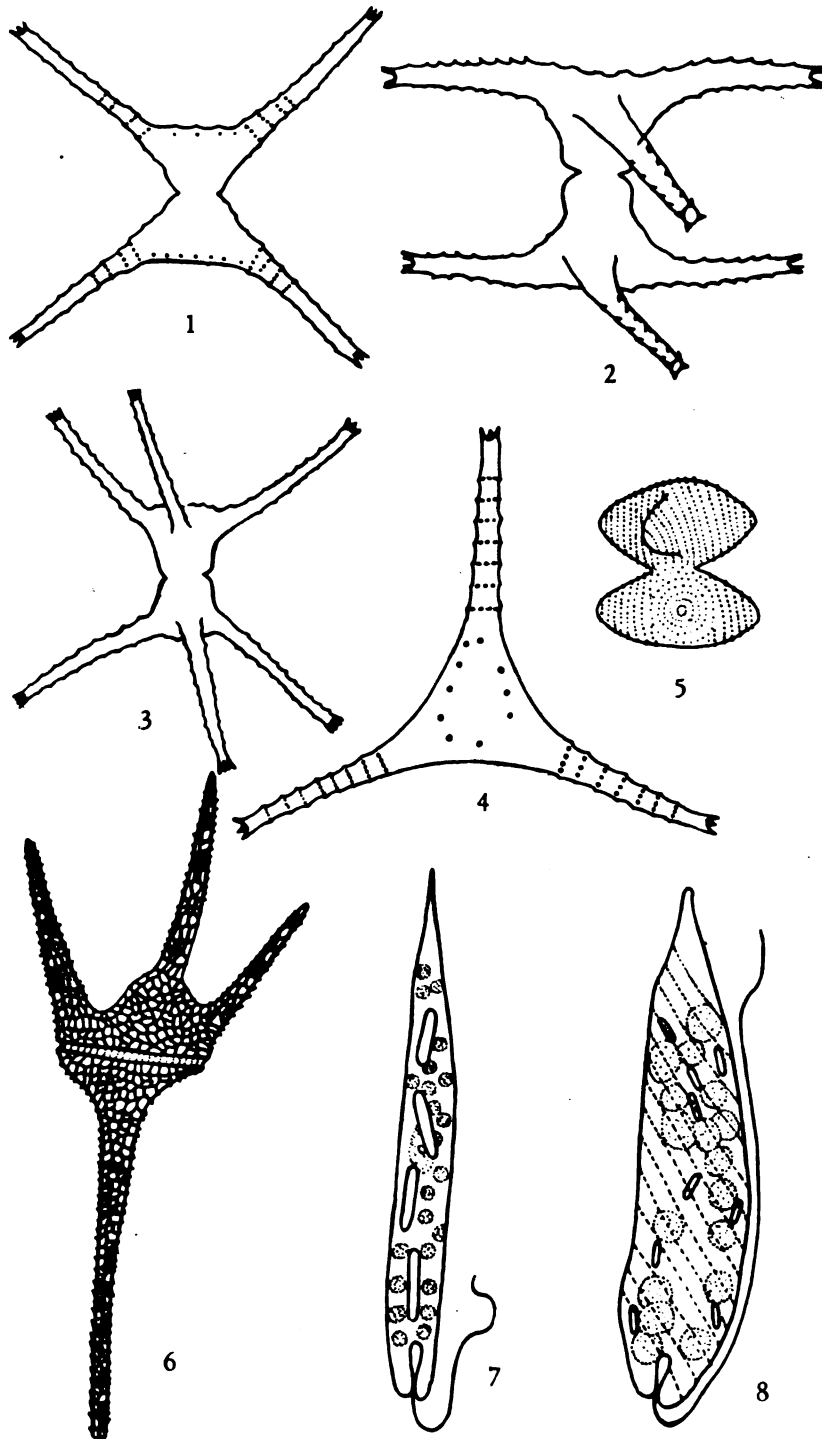


Plate XI.

- Fig. 1. Morugeotia scalaris Hassall (x 215).
2. Spirogyra crassa Kuetzing (x 100).
3. S. decimina (Mueller) Kuetzing (x 215).
4. S. lutetiana Petit (x 215).
5. S. Spreeiana Rabenhorst (x 100).
6. S. mirabilis (Hassall) Kuetzing (x 215).
7. S. porticalis (Mueller) Cleve (x 430).

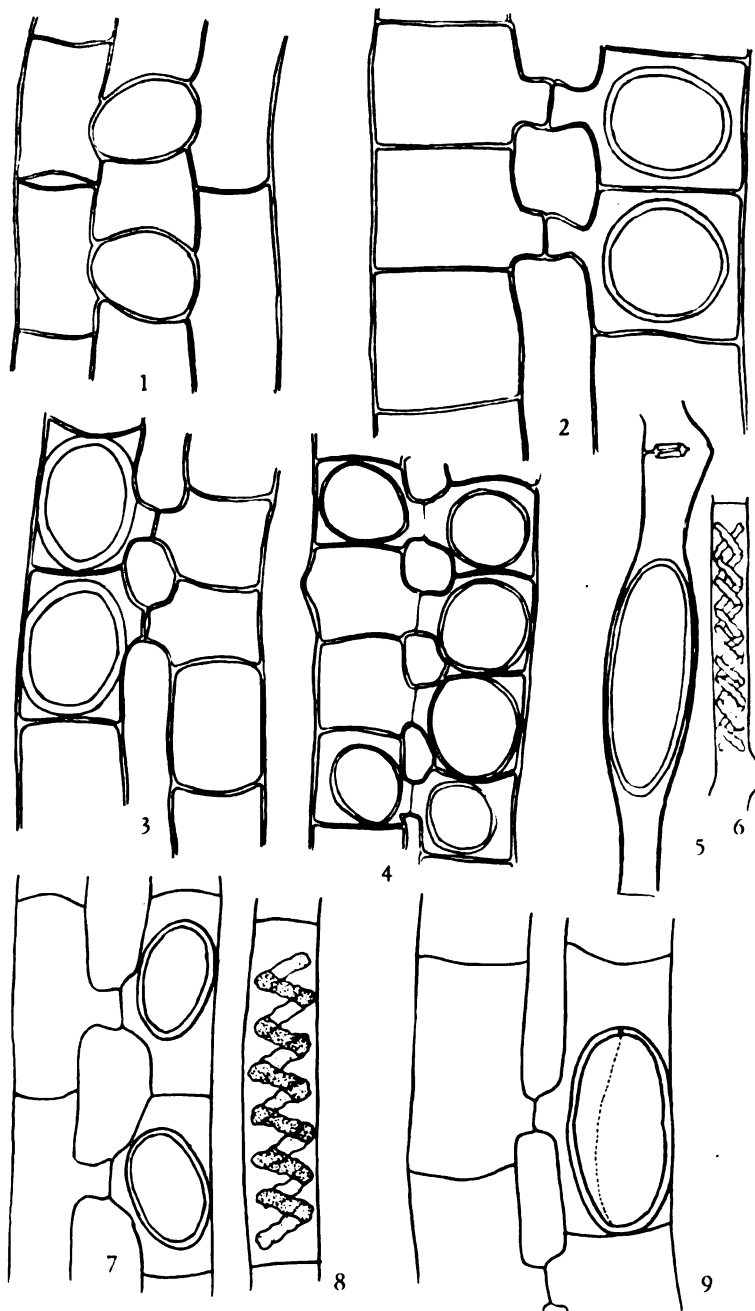
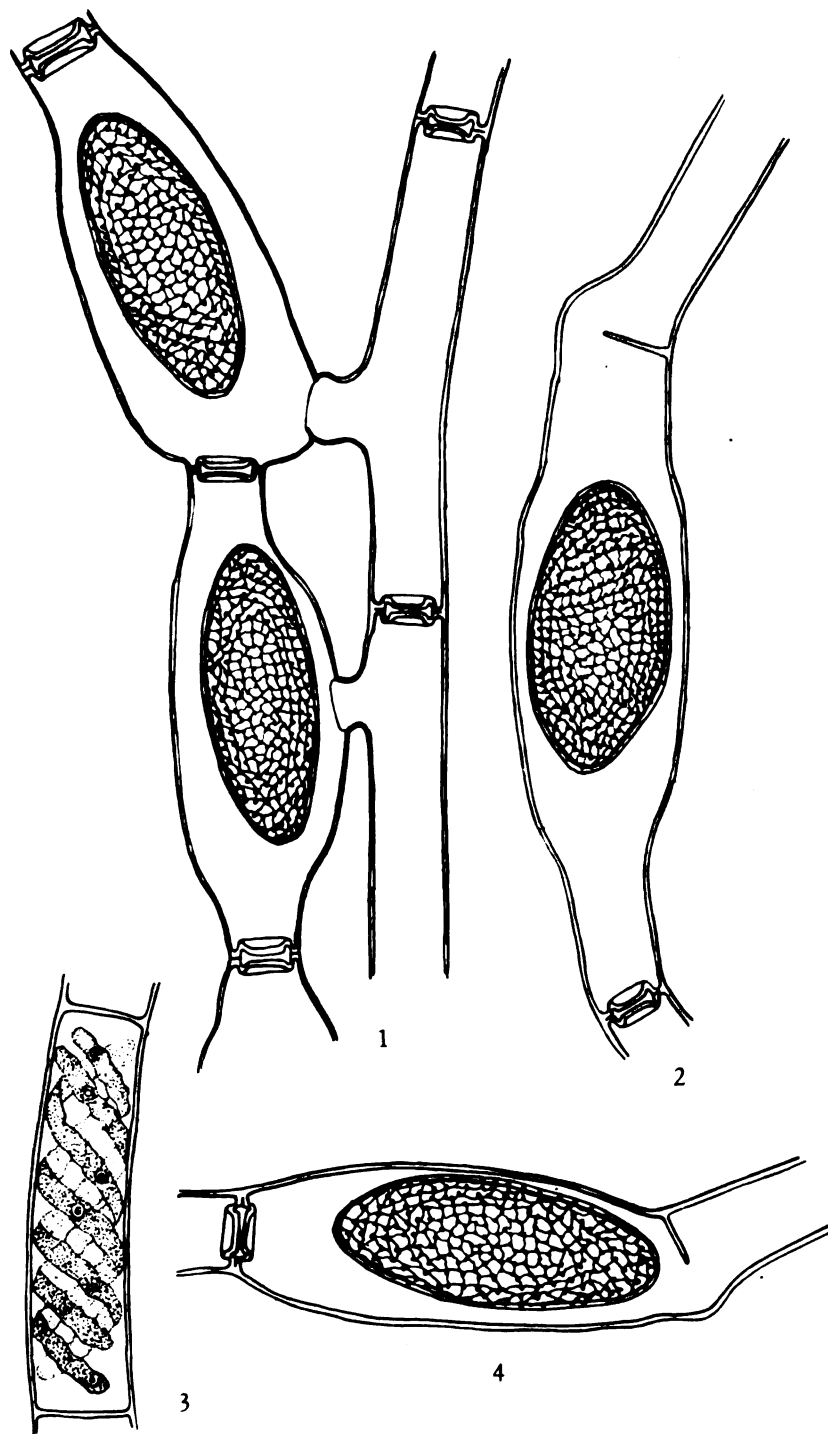


Plate XII.

Fig. 1-4 Spirogyra sp. (x 215).



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