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THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Sister Remberta (Westkaemper) for the degree of Master of Science.
They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

Josephine E. Tilden
Chairman

Royal N. Chapman

L. I. Knight

Date ____________________

10-20 5M

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Sister Remberta (Westkaemper) final oral examination for the degree of

Master of Science

We recommend that the degree of

Master of Science

be conferred upon the candidate.

Josephine E. Tilden
Chairman

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Royal N. Chapman

L. I. Knight

C. O. Rosendahl

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Date_______________

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10-20 5M

On the

Occurrence, Distribution and Periodicity

of some Minnesota Algae

A thesis presented to the Faculty of the

Graduate School of the University of

Minnesota in partial fulfilment

of the requirements for the

Degree of Master of

Science

by

Sister Remberta Westkaemper

June 1922

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Introduction

It has long been known by students of the algae that the composition of both marine and freshwater algal vegetation changes very considerably from season to season. Some species occur all the year round, some appear only during the warmer months and some are found only for a short time at some particular season.

Again, the life of any one species of algae is divided into stages: the young plant develops from the germinating gonidium or spore, passes through a period of growth, enters upon a period of asexual or sexual reproduction and ends, usually, with a period of rest or dormancy.

For many years interest has been growing in the problems which are based on the facts just stated and a considerable amount of material had accumulated before the term "periodicity" appeared in algal literature and before any precise observations were made. As the term "periodicity" is now used it refers to the cycle of stages in the life of any one species -- germination, maximum growth, reproduction and dormancy.

Review of literature

Vaucher, a Genoese botanist, as early as 1803 attempted to work out the life history of *Spirogyra*. He found that *Spirogyra jugalis* would fruit and disappear as early as February 15th and as late as March 20th. The zygotes he collected all seemed to germinate on the same day, July 15th.

Hassall (1857, p.132) makes but one statement in reference to the conjugation of *Spirogyra*: "The species of this group of *Confervae* may be found occasionally in a state of conjugation during the entire of the spring, summer, and autumnal months; they are chiefly met with, however, in this state in the spring."

Wood (1872, p.159) mentions Zygnemaceae as being one of the commonest and most widely distributed of all families of freshwater algae. "The spores appear to be formed only in the spring and early summer, at least these are the only times in which I have found fertile filaments. In this neighborhood I have collected them in excellent condition, as early as the beginning of April and as late as the latter part of June."

Paul Petit (1880, p.30,31) found that all Spirogyra species but two, in the neighborhood of Paris, had matured by July. Spirogyra orthospira and S. bellis were found fruiting in October.

West, W. and G.S. (1898) melted out of ice from Micham Common, Surrey, filaments of Spirogyra catenaeformis in conjugation with vitality nowise impaired.

Fanning (1901) found that cold weather caused the disappearance of Chlorophyceae but not of Myxophyceae.

Pfeffer (1903) emphasizes the importance of currents of water in providing aquatic plants with a continual supply of dissolved CO_2. He considers maxima and minima of growth and division to be due to the accumulation of the effects of regularly repeated stimuli, especially light and temperature. Intense illumination results in loss of turgor and cessation of growth. Cooler temperature retards rate of growth. Minimum growth occurs at night in Spirogyra.

Williams (1905) enumerated temperature, pressure and aeration as factors influencing periodicity, but considered increased illumination as the most important one.

Hoyt (1907) states that light is not the sole factor determining the time of fruiting.

In regard to daily periodicity Jost (1907) made the statement that it cannot be due to external factors and their after effects only. The resting period is often not to be considered as an inevitable consequence of growth. Internal factors play an important part in bringing about the state of activity which enables an alga to react to the outer world in different ways. Environment acts merely as a releasing stimulus. He found Ulothrix in vegetative condition only under favorable natural conditions. Cessation of flow of water and decrease of oxygen supply acted as inducements to zoospore formation.

Brown (1908) found that in Spirogyra growth was indefinite as long as conditions of environment did not become adverse. A sudden change in external conditions caused it either to enter upon a resting stage or to fruit sexually. Benecke (1908) concluded that for Spirogyra communis conditions governing conjugation are very simple in nature. He attributed fruiting to the lack of available nitrogen.

Copeland (1909) found that of thirteen species of Spirogyra, ten passed their period of maximum abundance in May, one in August and one in October. The only reliable example of a second fruiting period found was S. dubia, which fruited in May and again during the latter part of July. The period of maximum abundance occurred in every case with the period of maximum conjugation. The decline of one was always accompanied by the decline of the other. The fruiting filaments disappeared more or less gradually after conjugation. The vegetative filaments also disappeared. Spirogyra was found fruiting at the surface of the water, with few exceptions, in nature, but in the laboratory it fruited near the substratum. He concluded that Spirogyra has definite periods of growth and reproductive activity.

Nieuland (1909) states that in nature algae are never found in pure culture. Disappearance of one species is often but the reason for the appearance of another that waited for its predecessor to go in order to come upon the scene itself. When the same algal forms reappear after a period of absence it is but a sign the resting stages of reproductive organs had been slowly adapting themselves to an environment in which they finally found it possible to germinate and thrive. Though most algae appear annually in a locality, the periodic appearances in abundance may be years apart. Some water insects and shrimps consume the resting spores of algae. Beds of clean sand promote the growth of Spirogyra, Mongeotia, Zygnema and Oedogonium. Metallic salts are very destructive to algal life especially to Conjugales and the unicellular forms. Algae thrive better in soft than in hard water.

Klebs (1910) concludes that under appropriate external conditions growth and division only take place. He also stated that reproductive organs are formed only under definite external conditions. The nature of these organs is not determined by internal causes only. Fruiting of algae may be accelerated by increasing the concentration of the water. In Oedogonium darkness and the presence of canesugar in the nutrient solution inducedfruiting. In another species of the same genus fruiting was induced by transferring the plants from flowing to still H_2O, or from low to high temperature, or from inorganic nutrient solution to pure H_2O. High light intensity effects photosynthesis, increases the amount of carbohydrate produced and thus brings about reproduction. Results when working with nutrient solution depend on conditions never realized in nature, though many may be paralleled. Klebs worked especially with nutrient solutions under varying conditions of temperature. Both may act together to produce a dormant period. The amount of light which produces optimum growth or reproduction varies with the species. Limited light may produce rest even if salts are present. Intense photosynthesis may produce rest if nutrient salts are present in insufficient quantities. One growth period exhausts the salt supply and a period of rest follows to be followed by another period of activity when the salt supply again rises. Klebs does not class salts with anaesthetics but considers their nutritive qualities only.

Danforth (1910) questions Benecke's conclusion that fruiting in all Spirogyra occurs because of lack of available nitrogen, though it produced that result in S. communis. He considers Spirogyra inherently periodic in functions although periodicity may be influenced by environment.

Birge and Juday (1911) did considerable work on the gases dissolved in Wisconsin lakes. They found that the cycle of seasons induces a cycle of physico-chemical changes in the water, conditioned chiefly by temperature. Aeration is confined to the epilimnion or upper stratum in summer. In fall the circulation is more general. In winter free circulation of H_2O and exchange of gases with the air is restricted or cut off completely. In spring winds may restore circulation. Plankton consumes some substances and manufactures others. The plant and animal activities are grouped as those consuming oxygen and those liberating it. A lake is divided into two vertical zones -- the zone of photosynthesis and the zone of decomposition. In the zone of photosynthesis the water may be saturated with oxygen, or in calm weather may even be supersaturated. If photosynthesis proceeds slowly this zone is not saturated with oxygen. The zone of decomposition is rich in CO_2. This CO_2 may be locked in the lower part of the lake till in fall when the season of growth is past. In shallow lakes the two zones may overlap. Lakes with shallow margins produce more plankton, other things being equal, than those with steep slopes and deep water. If bicarbonates are present in a lake more plankton is found than in its absence. When bicarbonates reduce to monocarbonates more CO_2 is absorbed from the air than would otherwise be the case.

Only small additions to the food supply are made from without. A lake is dependent on its own stock of green plants for available organic matter. The inhabitants of a lake form a closed community which has lived together since glacial times. The members have acquired certain habitual actions and reactions upon each other and on the environment. The critical factor in their growth is the vertical circulation of the water. Factors that may be involved in the productivity of a lake are area and depth, form of lake basin, organic and inorganic substances dissolved in the water and the effect of several crops of algae on their successors by withdrawing certain substances from the zone of photosynthesis. In shallow lakes exposed to the wind gas conditions are the same from bottom to surface. Diatoms are found in definite strata in lake water, corresponding to the strata of maximum oxygen content.

West W. and G.S. (1911 - 1912) concluded that the amount of dissolved salts present in the water is the most important factor in determining the distribution of plankton both quantitatively and qualitatively. Slightly contaminated lakes contain a greater number of diatoms than uncontaminated ones. Nitrites may cause maximum growth. The salt contents of a lake depends on the nature of the lakebed. The average green alga is very sensitive to external influences. It is not improbable that external factors really determine successive phases of an alga's life history. In a few algae certain successive phases are obligatory and over these external factors have no control. Post-sexual phenomena of an obligatory character occur in Ulothricaceae, Conjugales, Oedongoniales, Coleochaetaceae etc. In British lakes West found an annual cycle of different phases, that is, a number of dominant forms succeeded each other in the course of twelve months. Desmids are usually perennial. He found no zoning of algal growth of a lake, but blue-greens usually were more abundant in the warmer months of the year or in autumn.

Chambers (1912) expressed the view that cold water gently agitated by wind or currents is richer in algal growth than warm stagnant water. Filamentous forms with large cells and thin cell-walls are best adapted to stagnant waters. Stagnant water rich in CO_2 and poor in O_2 favors the formation of colonies and filaments rather than of free cells. Narrow much-branched filaments are produced in poorly aerated waters. Algae are bright green when well aerated. Periodicity of spore-formation is hereditary.

Fritsch and Rich (1913) accounted for all phenomena of germination, vegetative development and reproduction on basis of changes in environment, especially changes in temperature, light and concentration of medium. They do not give concentrations with which they dealt. Oedogonium fruits in the first month with plenty of bright sunshine. In Spirogyra stimulus to conjugation is probably an external one, consisting of complex factors, presumably different for different species. In some algae reproduction and maximum abundance are definite periodic phenomena influenced by periodically recurring factors, in others periodicity is less regular. They found that Spirogyra and Oedogonium pass through the period of maximum growth and through the period of maximum reproduction at about the same time. It would seem as though they responded to the same external conditions in the same way.

If aeration is poor, filaments are narrower. Dominant forms succeed each other in the course of the year, then disappear either suddenly or gradually. They may remain in small numbers all year or vanish completely. Very few filaments are perennial; unicellular forms are more commonly perennial.

Besides seasonal periodicity Fritsch and Rich consider irregular periodicity caused by abnormal changes in environmental conditions and by the influence of man. They also consider the influence of one plant on another, by shading etc. When Diatoms are epiphytic on Cladophora they may increase to such an extent as to impair growth of Cladophora by shading it. After reaching their maximum the diatoms decrease and then Cladophora increases again. Cladophora species are often found near Myriophyllum; Conjugates occur with Ranunculus. Some algae bear characteristic epiphytes; other epiphytes attach themselves to any alga. These interrelations depend on structure of cell-wall, position in water and metabolic activities.

Delf (1915) stated that the season of greatest diversity and abundance (February to May) corresponds to the period of variable rainfall, gradually increasing temperature, increasing light intensity and comparatively slight development of animal life. As the temperature rises from May to July, algae diminish or disappear entirely till October.

Griffith (1916) concluded that probably an investigation of small pools over a large area would reveal the widespread existence of many algae now considered rare.

Crocker (1916) affirmed that reduction in available nitrogen causes hydration and induces fruiting in tropical trees. Reproduction as well as any other character is due to both heredity and environment.

Transeau (1916) who worked in lakes of Illinois showed that germination of algae occurs at ordinary temperature and that the importance of temperature as a factor influencing periodicity has been overestimated. The same factors that influence germination of seed are active here. As the oxygen supply in water increases, the mineral content also increases and these changes in mineral content change the permeability of the spore coats. Temperature controls the speed of germination. The length of the vegetative cycle differs for the various genera and species. Vaucheria may fruit soon after germination. In Zygnema and Desmids growth and accumulation of reserve food must proceed to a certain stage before reproduction is possible. Metabolic processes must reach a certain minimum before reproduction closes the cycle. Temperature, degree of illumination, available CO_2 and O_2 are limiting factors to metabolic processes and in so far influence length of the vegetative period. The length of this vegetative period is regular under given conditions.

Transeau differs from most other workers in this that he contends that periods of high water are also periods of high concentration in pools, ponds and streams fed by surface run-off. Therefore algae fruit more abundantly during periods of high water. The concentration of water is so low (even when highest) in comparison to concentration of the cell contents it may be of no significance in initiating reproduction. In some algae reproduction may be induced at any time by change in environment. _Zygnema_ and _Oedogonium_ are exceptions to this. Other things being equal the greater the specific surface of an alga the sooner it reaches maturity.

Hodgetts (1921-22) did some excellent work on the periodicity of algae giving special attention to the concentration of water as an influencing factor. He finds that a moderately low concentration is the most favorable to algae. He found _Spirogyra inflata_ most tolerant. A high temperature is unfavorable. Bright sunshine however favors the growth of algae. It induces conjugation in Desmids. In _Oedogonium_ the maximum growth and reproduction coincides with highest temperature, with little or no relation to bright sunshine. Competition with _Zygnema_ may prevent _Oedogonium_ from attaining its maximum earlier than it does. He finds no relation between concentration and maximum growth in this genus. Wide species may have dispensed with fruiting and become perennials. _Vaucheria_ requires no sunshine to bring it into fruiting. It fruits at low temperatures but requires aeration of water. Low concentration of water is most favorable to _Vaucheria_.

Object of problem

During the summer session of 1918, at the University of Minnesota, a group of graduate students in algology became interested in the subject of periodicity in freshwater algae. They decided to undertake, as a special problem, a definite study of the algae of some body of water near their home, for a period of two or more years. The writer selected a stream, Watab Creek, in Stearns County, Minnesota, in which it had been noted during previous years that the algal vegetation had fluctuated in a marked degree. To account for this fluctuation, as far as possible, this study of the algal flora was undertaken. For the sake of comparison a lake, Lake Sagatagan, and a river, Sauk River, both within a radius of four miles, were included in the study. The results of these investigations are embodied in this paper.

Explanation of methods

Watab Creek was visited, at intervals of two weeks, from August 8th, 1918, till November 1st. The last collection was taken on October 16th. By the time the next trip was taken, all algal vegetation had disappeared and therefore collections were discontinued after November 1st.

Definite places about two rods apart in the stream were selected as "stations" and from these collections were made regularly. Small vials, partly filled with a 2% solution of formaldehyde, were prepared and numbered consecutively beforehand. The usual method followed was to take two specimens of the free-floating or attached filamentous algae, which formed large green masses, from each place selected, one near the edge of the stream, the other somewhat farthér from the edge. A third vial was filled with material that coated the stones on the bed of the stream. If a patch seemed to have a different appearance, a fourth vial was filled with some of this material. Data concerning each vial were carefully recorded, such as date, place, depth of water, temperature of air, temperature of water, whether attached or free floating, quantity present and anything else noted.

The vials were well corked and kept in a dark place. They were examined as soon as possible for the purpose of naming the genera. The greater part of the taxonomic work, including the naming and describing of the species, was done later, during the winter months, when all the vials containing material of the same genus could be examined at the same time. Two copies of all notes were kept, one in a note-book, the other on cards, a card representing each vial and having the same number and date.

In the spring of 1919 trips to Watab Creek were resumed April first. Only attached forms coating sticks and stones were found. The last trip of that season was taken June 16th. Cladophora was the only filamentous green form that had appeared.

Work was again taken up during the summer of 1920. Collecting trips were made at fortnightly or monthly intervals from April to October. No algal vegetation appeared. Records of these trips were kept.

Again, in 1921, beginning in April, visits were made to the creek at regular intervals, but no algae were in evidence until July 15th. After that samples were taken, as before, at intervals of two weeks till November 11th, when ice was being formed along the edge of the stream. This was the last trip.

Sauk River was visited but three times: once in September, 1918, again in April, 1919, and the last time in June, 1919. Specimens were taken in three places about ten rods apart. The same methods were followed as given for Watab Creek.

Lake Sagatagan was visited the first time on August 28th, 1918. Four places were marked as stations to be visited regularly and collections were taken, three samples from each place, using the same methods as described above. No trips were made after October 5th when the last collection was taken. Collections were taken in the spring, beginning April 5th and continued at fortnightly intervals till June 19th, 1919.

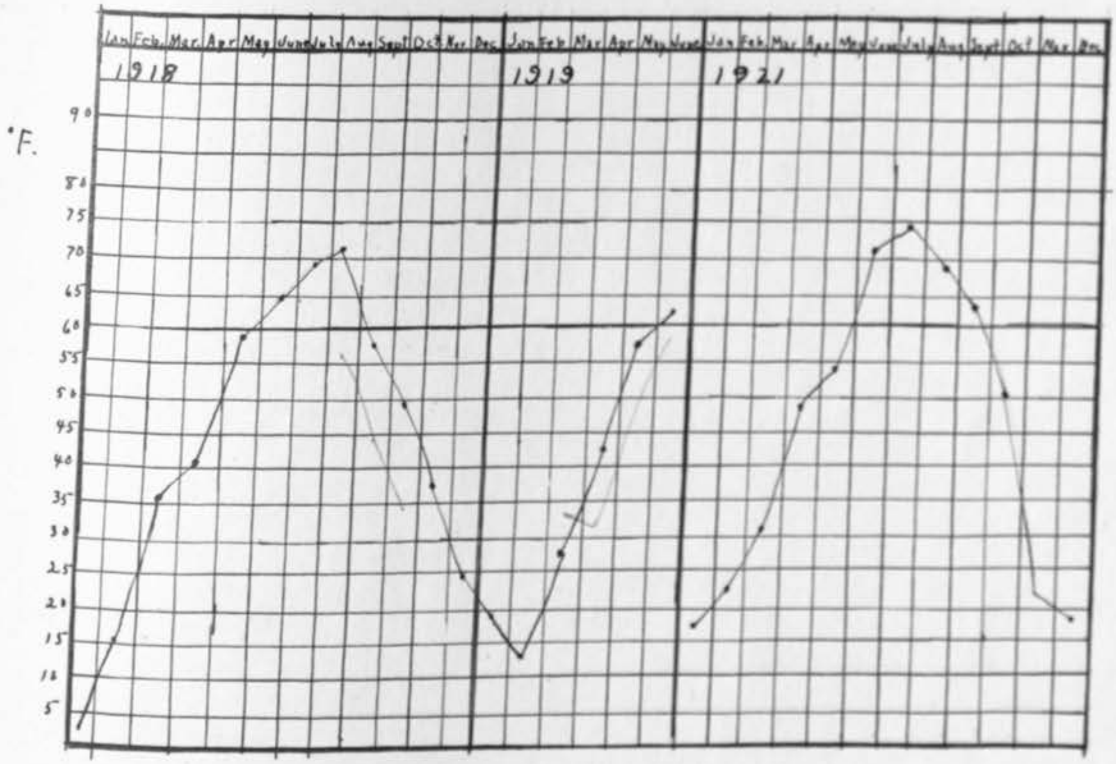
General consideration of the physical features and of the meteorological data of Watab Creek, Sauk River and Lake Sagatan

Watab Creek, popularly called the "Mill Stream", is located in the northeastern part of Stearns County, Minnesota. It rises in a small lake and flows northeast into Watab River which in turn empties into the Mississippi River. The part with which this paper is concerned follows a meandering course through a pasture, undercutting its banks here and there and also building up sandbars in places. The banks are steep and high for short stretches and here the stream is rather narrower than in other parts. It is at no place wider than eight feet. The bed is of clean sand and the water is always clear. The water level varies with the rainfall, but normally the stream is from 12 to 15 inches deep, with two deeper places. There is no shallow margin.

Geological data. This stream flows through a flat undulating region with a morainic system of red drift. There is also outwash gravel containing limestone in this region. It is at an elevation of 1050 feet above sea level.

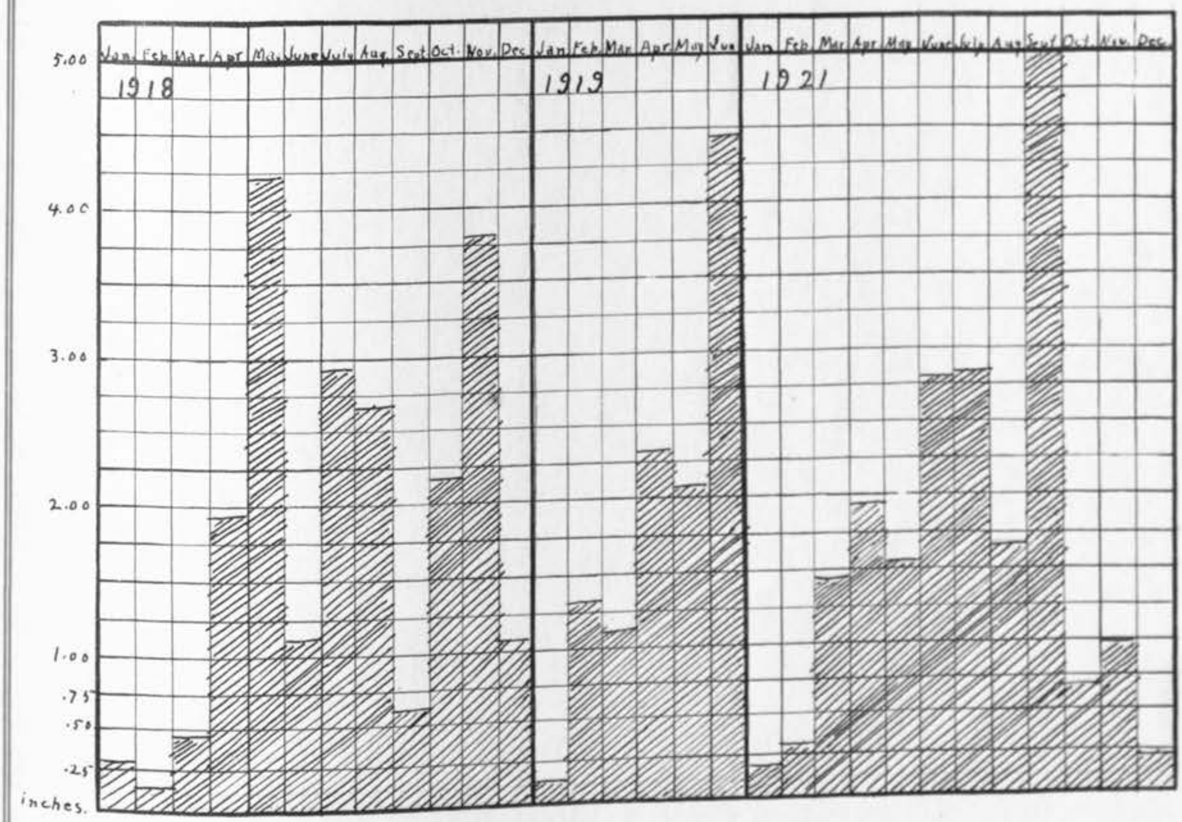
Meteorological data. Temperature, rainfall, and sunlight are to be considered. The monthly averages were obtained for Collegeville station from the U.S.Department of Agriculture, Weather Bureau office in Minneapolis. These hold for the three bodies of water. (See graphs).

Phanerogamic flora. Higher plants were conspicuously absent. grass and low flowering plants grew along the bank but there were none that shaded the stream.



—— Temperature of the air at Collegeville, Minnesota (in degrees Fahrenheit).

—— Temperature of the water in Watab Creek, Stearns County, Minnesota



Rainfall at Collegeville, Minnesota (in inches).

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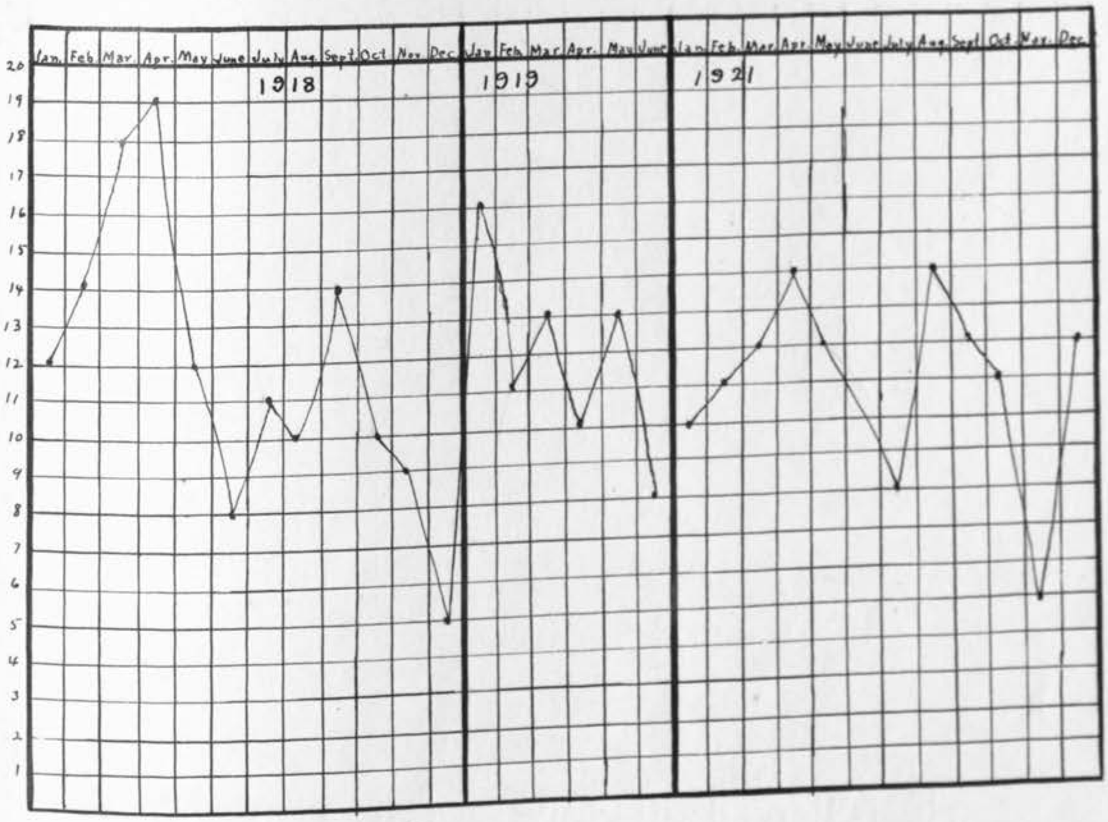

Number of clear days at Collegeville, Minnesota.

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Physical Features of Sauk River.

Sauk River is three miles southeast of Watab Creek, in eastern Stearns County. It drains the greater portion of Stearns County. It empties into the Mississippi above St. Cloud. It is about thirty feet wide and is sluggish and treacherous. During seasons of normal rainfall it is 12 - 15 inches deep along the margin and two feet or more in deeper parts. The water is rather muddy. The nature of the riverbed varies, - firm sandy bottom, black loam and quicksand occurring in irregular patches. The river is swollen in early spring but is quite low in late summer. Specimens were collected just below a bridge, for a stretch of about eighty rods.

Geological Data.

The part of Sauk River from which collections were made, lies within the same geological area as Watab Creek. It is an undulating region of red drift, 1100 feet above sea-level.

Phanerogamic Flora

A species of Lemna occurred abundantly along the shore, an Elodea was less abundant. Both served as substrata to attached forms and also shaded each other and the algae. Along the banks there was no vegetation tall enough to shade the water.

Physical Features of Lake Sagatagan.

This beautiful lake, approximately half a mile wide and long, is within four miles northwest from Watab Creek. Its outlet is the Watab River which later receives the water from Watab Creek. It is rather deep,- forty feet or more, - for its size. Collections were made along the northern shore where the bed descends rather steeply. The water is quite clear. It is rather soft according to recent tests.

Collections were taken only near the edge of the lake along the northern bank where the water was not two feet deep. This part is all included in the epilimnion and lies above the thermocline. The oxygen supply is ample for both plant and animal life.

Geological Data.

This region contains rolling to gently undulating deposits laid down at the border of the ice-sheet. The composition varies from stony, sandy material to heavy clay. It is 1150 feet above sea-level.

Phanerogamic Flora

At the very margin in the shallow water *Eleocharis acicularis* is found. Farther in occur several species of *Potamogeton*, *Najas flexilis* in abundance, *Myriophyllum spicatum* and *Ceratophyllum demersum*. The shore is a sandy beach, so there are no landplants to shade the area worked on.

Occurrence and Distribution of Algae in Watab Creek.

No algal flora had been noticeable in Watab Creek for a number of years previous to 1918. In the spring of that year, however, quite a growth of algae appeared rather suddenly and in considerable quantity.

The following is a list of the dominant genera: *Spirogyra*, *Oscillatoria*, *Vaucheria*, *Cladophora*, *Tribonema*, *Microspora*. Of these *Spirogyra*, *Vaucheria* and *Cladophora* were the most common.

Five species of Spirogyra were found: S. longata (Vauch.) Kützing, S. communis (Hass.) Kützing, S. Grevilliana (Hass.) Kützing, S. decimina (Müller) Kützing, S. quadrata (Hass.) Petit (?). S. communis was found in fruit in October. Four species of Spirogyra could not be named as they were not found in fruit.

Oscillatoria occurred as follows: O. formosa Bory, 8 times; O. amphibia Ag., 4 times; O. limosa Agardh and O. prolifera (Grev.) Gomont each once. These plants never appeared in great quantities though fairly constant.

Vaucheria material was gathered along the edge of the stream after the water-level had fallen. Vaucheria geminata (Vauch.) D.C. was found in fruit in August and again in October. Several collections of Vaucheria, not in fruit, were found and could not be identified.

Cladophora was very abundant during all the fall months. C. Kützingiana predominated. C. fracta subsimplex was rather rare. One common species was so densely covered with Diatoms that it could not be identified.

Tribonema bombycinum (Ag.) Derb. and Sol. and Microspora floccosa generally occurred together. The latter was more abundant than the former. T. utriculosum Hazen was also found.

Subdominant forms were Oedogonium vaucherii (Le.Cl.) A.Braun, Tetraspora gelatinosa (Vauch.) Desvaux, Aphanothece conferta Richter, Stigeoclonium lubricum varians (Hazen) Collins, Mougeotia sp., Zygnema sp., Cocconeis pediculus Ehrenb., Fragillaria virescens Ralfs., Cosmarium Beckii Wille, Gomphonema sp., Syndedra sp., and Anabaena flos-Aquae. (Lyngbye) Bréb.

Summary:

During the fall of 1918 and the spring of 1919 the algal flora of Watab Creek was dominated by filamentous green forms, notably Spirogyra, Cladophora and Vaucheria. Diatoms were present in almost every mount. Vaucheria geminata (Vauch.) D.C. and Spirogyra communis (Hass.) Kützing, both were found in fruit in October. S. quadrata (Hass.) Petit was in conjugation October 16 but no zygotes were found.

No material was gathered in 1919 after June. During the summer of 1920 algae failed to appear in Watab Creek nor did they appear in 1921 until the second week in July. Collecting was then again resumed and continued till the stream froze.

Spirogyra, Cladophora, Vaucheria and Oedogonium were the dominant genera. Tribonema and Microspora, common in 1917, did not appear at all in 1920 and Oscillatoria was found only once, O. brevis Kützing, a species not seen in 1918. Oedogonium vaucherii (Le.Cl.) A.Braun fruited in September; Vaucheria hamata (Vauch.) D.C. in September, while Stigeoclonium varians (Hazen) Collins fruited in July. These last two were not found in 1918.

Algal Flora of Sauk River.

The algal flora of Sauk River shows less variation than that of either Watab Creek or Lake Sagatagan. Algae formed large dense rather brownish masses along the shore for many rods, the quantity far exceeding that for the other two bodies, although but few genera were represented. Hydrodictyon reticulatum (L.) Lagerheim predominated. This alga can be distinguished with the naked eye. Cladophora fracta (Dillw.) Kütz. also was very common. Spirogyra sp. was less common. Diatoms occurred in great numbers. Oscillatoria formosa Bory was rare.

On the whole Sauk River algal flora was found to be quite different from that of the two other bodies: the quantity was much greater, the periodicity seemed to be less marked, and Hydrodictyon, absent elsewhere, predominated strongly here.

Occurrence and distribution of algal flora in Lake Sagatagan.

The algal flora of Lake Sagatagan is more constant than that of Watab Creek. It is never entirely absent. Algae also appear earlier in spring than they do in Watab Creek. Oedogonium, Spirogyra, Cladophora and Zygnema are the predominating filamentous forms. Nostoc is very common. Oedogonium was represented by three species, O. crenulato-costatum Wittrock which fruited in August, O. pachydermum W. & G. West and O. capilliforme Kütz. Nostoc caeruleum Lyngbye was usually associated with Myriophyllum spicatum. No other species of Nostoc occurred. There were two species of Cladophora, C. Kützingiana Grunow and C. fracta subsimplex, which were both very common in Watab Creek. Zygnema was difficult to name as only one species, Z. pectinatum var. decussatum (Vauch.) Kirchner, was found in fruit (June 19). Two other species, probably Z. stellinum (Müll.) Ag. and Z. pachydermum W. & G.S. West, were also present.

Subdominant forms were Tetraspora gelatinosa (Vauch.) Desvaux, Dichotrix hosfordii (Wolle) Bornet, Calothrix braunii Bornet and Flahault, Oscillatoria curviceps Agardh., O. limosa Agardh., Tribonema bombycinum Agardh., Microspora floccosa (Vauch.) Thuret. Chaetophora incrassata (Huds.) Hazen, C. elegans (Roth.) Agardh., Bulbochaete sp., Aphanothece prasina A. Braun, Eudorina elegans Ehrenb., Microcystis sp., Mougeotia sp., Lyngbye birgei

Smith, Rivularia compacta Collins, Phormidium ambigium Gomont and Cosmarium margariteferum Mengh.

Spirogyra, Cladophora and Oedogonium are common in both Watab Creek and Lake Sagatagan Vaucheria Oscillatoria, Tribonema and Microspora though common in Watab Creek are rare or absent in Lake Sagatagan. Nostoc, characteristic in Lake Sagatagan, does not occur in Watab Creek. In both bodies the filamentous green forms predominate.

List of algae

CHLOROPHYCEAE

— Isokontae

Order Protococcales

Eudorina elegans Ehrenberg

Tetraspora gelatinosa (Vauch.) Desvaux

Hydrodictyon reticulatum (L.) Lagerheim

Order Siphonales

Vaucheria geminata (Vauch.)D C.

Vaucheria hamata (Vauch.) D C.

Cladophora Kützingiana Grunow

Cladophora fracta v. subsimplex Kützing

Cladophora fracta (Dillw.) Kützing

Order Ulotrichales

Microspora floccosa (Vauch.) Thur.

Chaetophora incrassata (Huds.) Hazen

Chaetophora elegans (Roth) Agardh.

Stigeoclonium lubricum varians (Hazen) Collins

Akontae

Order Conjugatae

Spirogyra insignis (Hass.) Kützing

Spirogyra longata (Vauch.) Kützing (?)

Spirogyra communis (Hass.) Kützing

Spirogyra decimina (Müller) Kützing

Spirogyra quadrata (Hass.) Petit

Spirogyra grevilliana (Hass.) Kützing (?)

Mougeotia scalaris Hassall(?)

Zygnema pachydermum W. & G.S.West (?)

Zygnema stellinum (Müll) Agardh.

Zygnema pectinatum var. decussatum (Vauch.) Kirchner

Cosmarium Boeckii Wille

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Cosmarium margaritiferum (Turp.) Menegh

Stephanokontae

Order Oedogoniales

Oedogonium crenulato-costatum Wittrock

Oedogonium vaucherii (Le Cl.) A.Braun

Oedogonium capilliforme Kützing

Bulbochaete species

Heterokontae

Order Heterotrichales

Tribonema bombycenum (Ag.) Derb. & Sol.

Tribonema utriculosum Hazen

BACILLARIEAE

Cocconeis pediculus Ehrenb (?)

Melosira species

Gomphonema species

Fragilaria virescens Ralfs

Synedra species

MYXOPHYCEAE

Order Coccogoneae

Aphanothece conferta Richter

Aphanothece prasina A. Braun

Microcystis species

Order Hormogoneae

Oscillatoria amphibia Agardh

Oscillatoria formosa Bory

Oscillatoria limosa Agardh

Oscillatoria prolifica (Greville) Gomont

Oscillatoria curviceps Agardh

Oscillatoria brevis Kütz

Phormidium ambiguum Gomont

Lyngbya bergei Smith

Nostoc caeruleum Lyngbye

Anabaena flos-aquae (Lyngb.) Brib

Calothrix species

Dichotrix hosfordii (Wolle) Bornet

Rivularia compacta Collins

Sexual Reproduction - Watab Creek

Species	Date
Vaucheria geminata (Vauch.) D.C.	August 26, 1918
Vaucheria hamata (Vauch.) D.C.	September 10, 1921
Oedogonium vaucherii (Le Cl.) A.Braun	September 16, 1918
Spirogyra communis (Hass.) Kütz.	October 2, 1918
Vaucheria geminata (Vauch.) D.C.	October 2, 1918
Spirogyra quadrata	October 16, 1918

Sexual Reproduction - Lake Sagatagan

Zygnema pachydermum W.& G.S. West	June 19, 1919
Vaucheria geminata (Vauch.) D.C.	August 8, 1918
Oedogonium crenulato-costatum Wittrock	August 28, 1918
Spirogyra insignis (Hass.) Küt.	August 28, 1918
Oedogonium capilleforme Kütz.	Sept. 25, 1918

Sexual reproduction was less common in 1921 than in 1918, only Vaucheria hamata being found in fruit in 1921. August 1918 was warm and wet but not sunny. September was cool and dry with abundant sunshine. In 1921 however August was warmer and drier than usual with plenty of bright sunshine. September 1921 was warm with very heavy rainfall and little sunshine. Whether the lack of sunshine or the heavy precipitation interfered with reproduction or to what extent could not be decided. Oedogonium fruited during September 1918, the first month with plenty of bright sunshine. Fritsch and Rich (1913) also found that Oedogonium fruits in the first month with plenty of bright sunshine. Hodgetts (1922) however says he found that fruiting in Oedogonium bears little or no relation to sunshine.

Vaucheria hamata (Vauch.) D.C. was the only alga found in fruit in September 1921, a month with little sunshine. This corroborates Hodgett's statement (1922) that Vaucheria does not require much sunlight to arrive at the fruiting stage.

No algae were found in fruit in Sauk River.

Periodicity - Watab Creek

The year or annual cycle is divided into a number of periods, each of which is marked more or less definitely by its own algal flora. Such a period is spoken of as a phase. The filamentous green algae marked the later summer and autumn phase 1918 - Spirogyra, Vaucheria and Cladophora predominating. Oscillatoris, a blue-green filamentous alga was also common. All algal vegetation had disappeared from the stream by October 16.

Diatoms were dominant during the spring and early summer phase. 1919 The only filamentous forms present during this time were Cladophora, a green alga and Oscillatoria, a blue-green. They were found at the time of the first collection April 5, 1919. As no material was collected after June 16, it is impossible to state when this phase gave place to the next one.

Annual Cycle 1920

April, 1920 was the coldest on record with the exception of that of 1907. The precipitation was less than the average. The season was still backward in May and precipitation was again below normal.

The first and third weeks of June were unusually cool, frost occurring in the third. Unusual heat prevailed the rest of the month. The precipitation was much greater than the average. July was very wet and cool the first half, and very dry the second half. This drought continued till August 11. September was warm and fine. The first killing frost occurred September 29. No algae appeared in Watab Creek at any time during 1920 though trips were taken at fort-nightly or longer intervals from April to October. Fanning (1901) found that cool weather retards the growth of algae.

Annual cycle 1921

No algal vegetation appeared during the spring and early summer phase. The filamentous green algae, Spirogyra, Oedogonium, Cladophora and Vaucheria marked the late summer and early fall phase.

Periodicity of Certain Genera

The first trip was made April 10 and after that others at intervals of two or three weeks but no algae were found till July 15. April and May were unusually warm and dry though unseasonable cold prevailed for short intervals. June had a notably wide range of temperature with rainfall equalling one half the usual amount. July had a very high average temperature and rainfall was above normal. When the stream was visited July 15, masses of green algae were present, (the first of the season), - Spirogyra and Cladophora predominating.

Oedogonium and Vaucheria appeared a little later, but all four genera reached their maximum growth and maximum reproduction at about the same time in August and September. Soon after this Spirogyra disappeared. This bears out Copeland's (1909) statements regarding Spirogyra that maximum growth and maximum reproduction occur at the same time and that all filaments of Spirogyra both fertile and vegetative disappear gradually soon after conjugation.

Cladophora began to wane the second half of September. Filaments of this alga were found densely covered with Cocconeis pediculus. As these increased the Cladophora decreased. Fritsch and Rich (1913) emphasized the influence of one plant on another by shading etc., and gave Cladophora and diatoms as an example, the one decreasing as the other increases.

September 1918 was cooler and dryer than the average. The first killing frost occurred the 10th. October was warmer and wetter than usual. In 1921 September was warmer than usual with the rainfall above normal. October was mild, dry and sunny. The first frost did not occur till October 3. In 1918 no algae were found after October 16. In 1921, however, algae were found as late as November 11.

Periodicity - Sauk River

Annual cycle - Hydrodictyon, Cladophora and Spirogyra were characteristic of the late summer and fall phase. They also marked the spring and early summer phase. None were found in fruit.

The periodicity of this stream is least marked of the three bodies studied. Quantitatively there was little variation and in spring the same genera appeared that had been found in fall. Hydrodictyon predominated. Masses two or more feet long were raised by means of a stick.

Periodicity - Lake Sagatagan

Annual cycle - Oedogonium, Spirogyra and Cladophora dominated during the late summer and autumn phase, except at one "station" where Nostoc was the dominant genus.

The spring and early summer phase was characterized by the same three genera Oedogonium, Cladophora and Spirogyra. Nostoc again prevailed at the same "station". There is no marked difference between the two phases except that Spirogyra and Cladophora exchanged places in order of preminence.

Periodicity of certain species.

Maximum growth and maximum reproduction occurred at the same time here as in Watab Creek, again bearing out the statement of Copeland (1909). Spirogyra disappeared soon after fruiting. This coincides with what was found to occur in Watab Creek and also with Copeland's conclusion.

Oedogonium and Spirogyra were found in fruit at the same time, after having also reached their maximum growth at the same time. In Watab Creek, however, Oedogonium fruited a month earlier than Spirogyra. The first case agrees with the statement made by Fritsch and Rich, that Oedogonium reaches maximum growth and maximum reproduction at the same time that Spirogyra does. The second case, however, does not bear out Fritsch's statement.

Zygnema pachyderma W. and G.S.West was found in fruit June 19th. It was the only instance in which sexual reproduction was found to occur so early in the season, all others occurring in August and September.

The subdominant forms varied more from phase to phase, some being found only in the fall and others in the spring. (See table).

One notable feature holding for all three bodies of water studied is that all algae reach their maximum period of growth much later than is shown in the literature cited. However, the principal work has been carried out by European workers and the difference in climate very likely accounts for the deviation. Likewise, the work of Transeau in this country has been done in localities to the south of Minnesota.

Summary

1. Phases. Watab Creek. *Spirogyra*, *Cladophora*, *Vaucheria* and *Oscillatoria* were the dominant genera in Watab Creek during the late summer and autumn of 1918. There was no marked spring phase in 1919 and no spring phase whatever in 1921. *Spirogyra*, *Oedogonium*, *Cladophora* and *Vaucheria* predominated in the summer and autumn phase in 1921.

Sauk River. The annual cycle in Sauk River was not divided into phases, the same genera, viz., *Hydrodictyon*, *Cladophora* and *Spirogyra*, appearing in late summer and fall and again in late spring.

Lake Sagatagan. In Lake Sagatagan the two phases were not distinguished from each other in a marked way, *Nostoc*, *Oedogonium*, *Cladophora* and *Spirogyra* being dominant in both the spring phase and late summer and autumn phase.

2. Variation in algal vegetation. Watab Creek. *Oscillatoria*, so common in 1918 was rare in 1921. No algal vegetation appeared in 1920. The cause for this may have been due to meteorological conditions.

3. The filamentous green algae predominated in all three bodies of water.

4. Each of these three bodies of water had one dominant form not present in the other two: *Vaucheria* in Watab Creek; *Nostoc* in Lake Sagatagan; and *Hydrodictyon* in Sauk River.

5. In all 51 species of algae were studied and determined, including 30 Green Algae, 16 Blue green algae, and 5 diatoms. In Watab Creek were found 37 species; in Lake Sagatagan 31 species; while only six species occurred in the Sauk River.

6. Sauk River ranks first in quantity of algal vegetation, Watab Creek second, and Lake Sagatagan third.

7. Diatoms and unicellular forms were found early in spring and late in the fall.

Conclusions

1. Spirogyra, Oedogonium and Vaucheria in Minnesota pass through the period of maximum growth and of maximum reproduction one month later than they do in Illinois, according to Transeau, and two months later than they do in England, according to Fritsch and Rich.

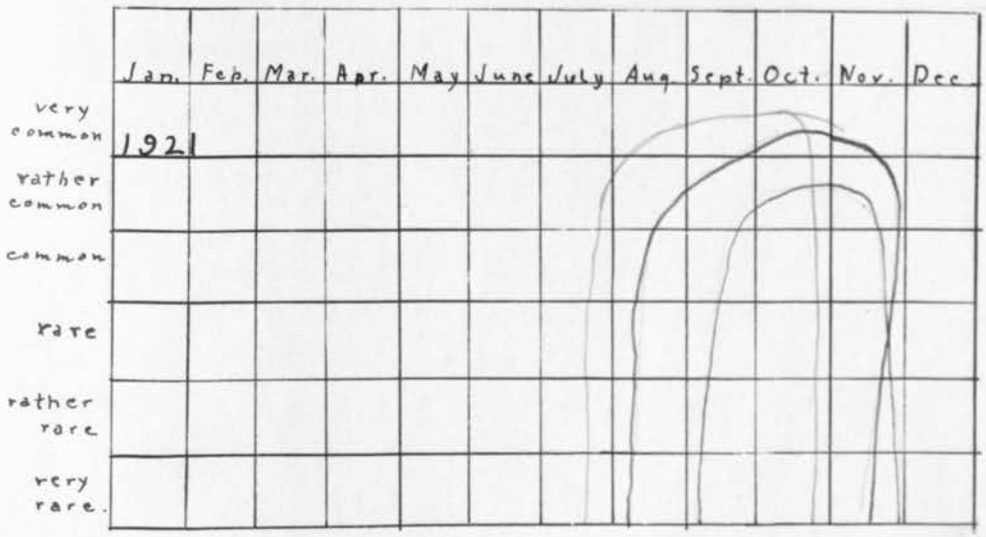
2. Oedogonium, Spirogyra and Vaucheria reproduce during the period of maximum growth. This is in agreement with the conclusion of Copeland.

3. Oedogonium and Spirogyra usually pass through the period of maximum growth and of maximum reproduction at the same time, as was found to be the case in the work of Fritsch and Rich.

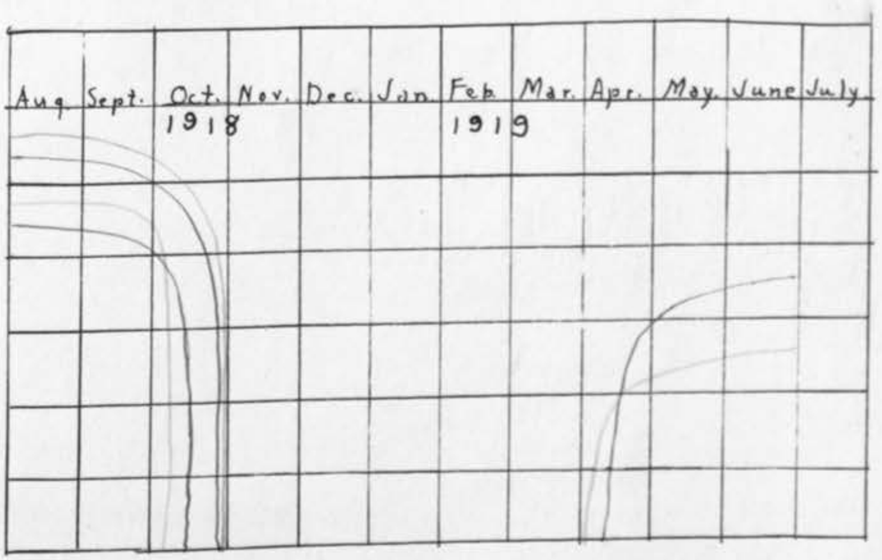
4. Oedogonium reproduces during the first month in which there is an abundance of bright sunshine. This corroborates the belief of Fritsch and Rich.

5. Vaucheria was the only alga found in fruit during a period of little sunshine. Hodgetts affirms that Vaucheria does not require sunlight in order to enter upon the period of reproduction.

Periodicity of four dominant genera in Watab Creek.

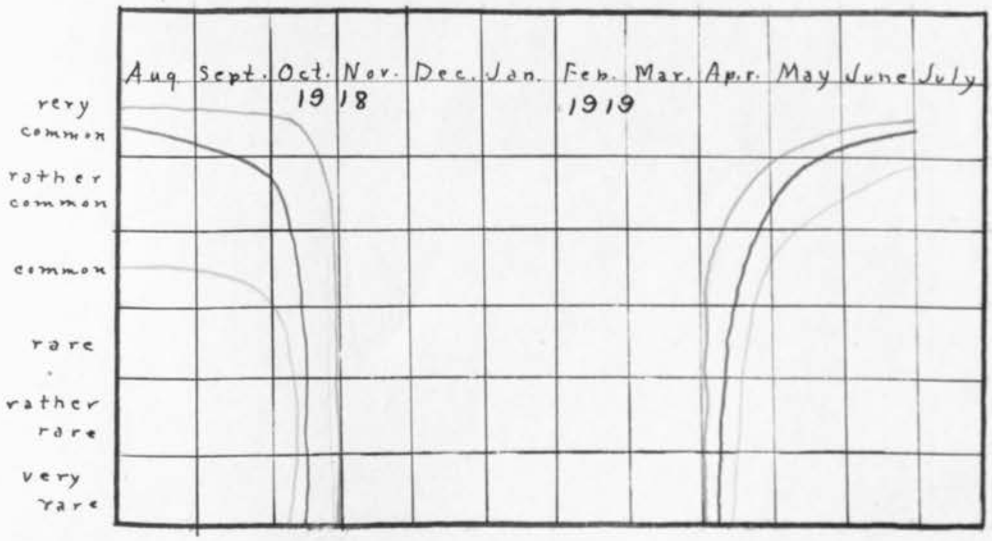


Spirogyra —
Cladophora —
Oedogonium —
Vaucheria —



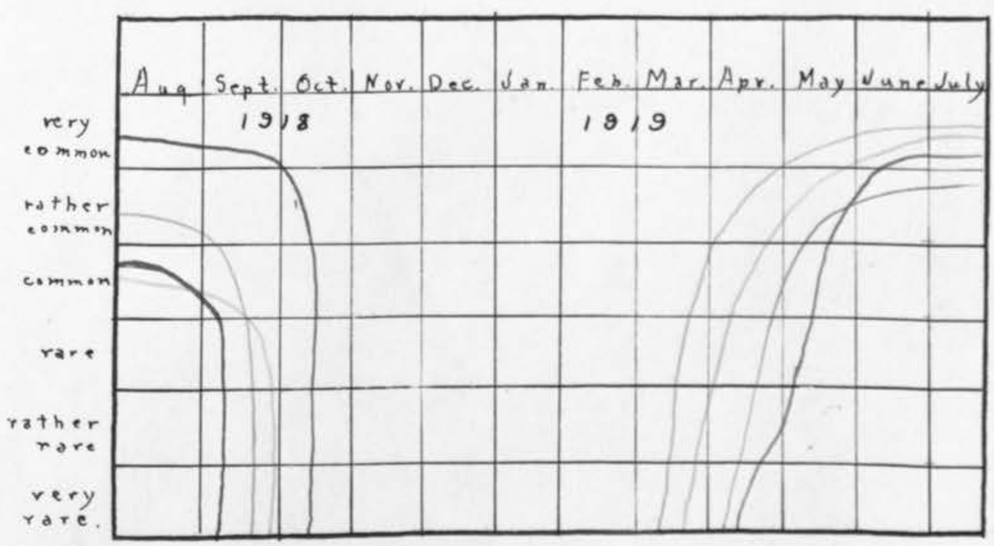
Spirogyra —
Oscillatoria —
Vaucheria —
Cladophora —

Periodicity of three dominant genera in Sauk River.



Hydrodicton — Cladophora — Spirogyra —

Periodicity of four dominant genera in Lake Sagatagan.



Spirogyra — Nostoc —

Oedogonium — Cladophora —

Table to show periodicity of algae in Watab Creek from August 1918 to July 1919

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
Nostoc	ccc	ccc									ccc	
Oedogonium	cc	cc							cc		ccc	
Spirogyra	c	c						r	c	ccc	ccc	
Cladophora	c	c							r	c	cc	
Zygnema	c										c	
Oscillatoria											r	
Tribonema								r				
Microspora								r				
Chaetophora											rr	
Lyngbya											r	
Tetraspora								r			r	
Aphanothece		c										
Rivularia											c	
Phormidium			r									
Bulbochaete											r	
Cosmarium	r	r								r	r	
Microcystis		r										
Calothrix	c											
Dicothrix	c	c										
Eudorina		r										

Table to show periodicity of algae in Watab Creek during 1921

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug	Sept.	Oct	Nov.	Dec
Spirogyra							cc	ccc	ccc	c		
Cladophora							cc	cc	ccc	c		
Oedogonium									cc	cc	c	
Vaucheria								cc	cc	cc	c	
Stigeoclonium							c				r	
Fragellaria									cc	cc		
Zygnema									r			
Synedra											c	
Cocconeis								c	ccc	cc		
Melosira										c		
Oscillatoria							r		r			
Gomphonema							c					
Tetraspora									cc			

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Table to show periodicity of algae in Lake Sagatagan from August 1918 to July 1919

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
Spirogyra	ccc	ccc	cc									
Oscillatoria	ccc	ccc	cc						rr	r	c	
Vaucheria												
Cladophora	ccc	ccc	cc						rr	r	r	
Tribonema	c	c	c									
Microspora	c	c	c									
Fragellaria	ccc	ccc	ccc									
Oedogonium		c										
Tetraspora		c										
Cocconeis	cc								r	c	c	
Anabaena	r											
Stigeoclonium	r											
Aphanothece	r											
Cosmarium	c											
Gomphonema									c	c	c	
Mougeotia		r										
Synedra	r	r							r	r	c	

Table to show periodicity of algae in Sauk River from September 1918 to June 1919

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June	July
Hydrodictyon	ccc	ccc	c						r	cc	ccc	
Cladophora	ccc	cc	c					rr	r	c	ccc	
Spirogyra	c	c	r						r	c	cc	
Oedogonium	cc											
Oscillatoria	r											
Microspora								r				

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BIBLIOGRAPHY

1. Anderson, H.A. The algae of the Ithaca marshes. Science II. 30:654. N 1909

2. Barton, E.S. Recent Literature on freshwater algae. Jour. Bot. 36: 195-199. 1898.

3. Benecke, W. Über die Ursachen der Periodicitat im Auftreten der Algen, auf Grund von Versuchen über die Bedingungen der Zygotenbildung bei _Spirogyra communis_. _Internat. Rev. d. Gesmt. Hydrobiologie u. Hydrographie._ 1: 533-552. 1908.

4. Birge, E.A. and Juday, Chaney. The inland lakes of Wisconsin. Dissolved gases of the water and biological significance. Wis. Sur. Bul. 22: 1911.

5. Brown, H.E. Algal periodicity in ponds and streams. Bul. Tor. Bot. Club 35: 223-248. 1908.

6. Chambers, C.O. Relation of algae to dissolved CO_2 and O_2 with special reference to carbonates. Mo. Bot. Gar. 23: 171. 1912.

7. Copeland, W.F. Periodicity in Spirogyra. Bot. Gaz. 47: 9-25. 1909.

8. Cotton, A. D. Distribution of British algae. Jour. of Bot. 52: 35-40. 1914.

9. Crocker, Wm. Periodicity in tropical trees. Bot. Gaz. 62: 244-246. 1916.

10. Danforth, C.H. Periodicity in Spirogyra with speciеal reference to work of Benecke. Mo. Bot. Gar. 21: 49-59. 1911.

11. Delf, E. Marion. The algal vegetation of some ponds on Hampstead Heath. New Phytologist, 14: 63-80. 1915

12. Fanning, M.G. Observations on the algae of the St. Paul city water. Minn. Bot. Stud. 2: 609-618. 1901.

13. Fritsch, F.E. Problems in aquatic biology. New Phyt. 5: 149-169. 1906.

14. Fritsch, F.E. and Rich F. Studies in the occurrence of British freshwater algae in nature. Annales de Biologie lacustre. Vol. 6. 1913.

15. Fritsch, F.E. Moisture relations of terrestrial algae. Ann. Bot. 36: 1-19. 1922.

16. Griffiths, B.M. The August Heleoplankton of some North Worcestershire Pools. Jour. Lin. Soc. 43: 423. 1916.

17. Hassall, A.H. A History of the British freshwater algae. 1:132. 1845.

18. Hodgetts, Wm.J. A study of the factors controlling the periodicity of the freshwater algae in nature. New Phyt. 20: 150-164, 195-227. 1921. 21: 15-33. 1922.

19. Hoyt, W.D. Periodicity in the production of the sexual cells of Dictyota dichomata. Bot. Gaz. 43: 383-392. 1907.

20. Huff, N.L. Response of Micro-organisms to Copper Sulphate. Minn. Bot. Stud. Part IV. Vol. IV. p.407. Sept. 20, 1916.

21. Jost, Ludwig. Plant Physiology (Trans. Gibson) 1907. p. 340-366.

22. Klebs, Geo. Alterations in the Deveopment and forms of plants as a result of environment. Proc. Roy. Soc. London 82: 547-558. 1910.

23. Lewis, I.F. Periodicity in Dictyota at Naples. Bot. Gaz. 59-64. 1910.

24. Petit, Paul. Spirogyra des environs de Paris. 30-31. 1880.

25. Pfeffer, W. Plant Physiology (Trans. Ewart) 2:197. 1903.

26. Smith, G.M. Phyto-plankton of the inland lakes of Wisconsin. Wis. Geol. & Nat. Hist. Survey. Bul. 57, 1920.

27. Transeau, E.N. The Periodicity of the freshwater algae. Amer. Jour. Bot. 3: 121-133. 1916.

28. Weatherwax, P. Ecological notes on certain White River Algae. Proc. Ind. Acad. Sc. 107-108. 1914.

29. West, W. and G.S. Notes on freshwater algae. I. Jour. Bot. 36: 330-338. 1898.

Notes on freshwater algae. II. Jour. Bot. 38: 289-299. 1900.

Notes on freshwater algae. III. Jour. Bot. 33-41, 74-82. 1903.

30. West, W. and G.S. The algae of the Yan Yean Reservoir, Victoria. Jour. Linn. Soc. Bot. 39: 1-88. 1909.

31. West, W. & G. S. On the Periodicity of the phyto-planton of some British lakes. Jour. Lin. Soc. Bot. 40: 395. 1911-1912.

32. Williams, J.L. Studies in the Dictyotaceae. III. The Periodicity of the sexual cells in Dictyota dichotoma. Ann. Bot. 19: 531-560. 1905.

33. Wood, H.C. A contribution to the history of the freshwater algae of North America. 159. 1872.

34. Vaucher, J.P. Histoire des Conferves d'eau douce. 1803