NOTES ON THE OCCURRENCE OF OSCILLATORIA PROLIFICA (GREVILLE) GOMONT IN THE ICE OF PINE LAKE, WAUKESHA COUNTY, WISCONSIN.*

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The presence of this minute alga in Pine Lake is of particular interest since, so far as I am able to determine, it has been heretofore reported from but one locality in America, viz., from Jamaica Pond, a small lake in Jamaica Plain, a suburb of Boston. Mr. G. J. Hansen called the attention of Professor Birge to the peculiar growth in Pine Lake, furnishing some notes on its occurrence, and sent to him material which he had collected on March 25, 1905, which was floating on the surface of the lake where the ice had melted. Dr. Birge in turn gave the matter into my hands for further examination.

Isabel F. Hyams and Ellen H. Richards have had *Oscillatoria prolifica* under observation in Jamaica Pond since 1887, and their three papers on the subject so far published embrace the "Life History" (01); "Chemical Composition" (02); and "Coloring Matters" (04). It will be of advantage to review in considerable detail some of the long-continued studies of these writers in order to supplement our meager observations in connection with the occurrence in Pine Lake and thus be able to judge of the conditions which could bring about, in this instance, such an unprecedentedly vigorous growth of the plant.

Oscillatoria prolifica was first noted in Jamaica Pond by these two writers in 1887, and since that time has been so abundant as almost to exclude other forms of plant life. In some years it was much more abundant than in others, dependent upon the

*This work was done while the writer was serving as a research assistant of the Carnegie Institution of Washington.

temperature and sunlight. During the year in which the plant was most abundant, it did not entirely disappear during the winter, but was found imbedded in the ice which was cut from the water. During the period of most rapid growth—generally in June—the water of Jamaica Pond frequently became turbid and opaque. I have myself noted, some years ago, that from the hills above, the water of this pond appeared reddish or of a brownish chocolate color in bright sunlight. .The authors state that after a hot, sunny day, the gas created by the vigorous growth of the plant often caused the alga to rise to the surface and there float as a reddish brown, frothy cream; on June 11 and 12, 1901, for example, the floating masses were of such abundance that fully "one hundred barrels might easily have been obtained" (01, p. 308). When this scum was driven by the breezes on the shore, it decayed on the rocks, giving to them a rich purple coating. The odor of decay was "intensely disagreeable, fetid rather than putrefactive" (01, p. 301).

The authors assert that, whenever the plant was found below the surface, it was blue-green in color; the red pigment, which they have tentatively named "rubescin" (04, p. 274), according to their observations, appeared in the filaments only when a luxuriant growth of the plant had taken place. They suggest the theory that the red substance is probably "an important factor, if not the chief one, in the vigorous growth of plant life." (04, p. 274). The authors, in reaching this conclusion, apparently assume that this red pigment is derived from the chlorophyll of the Oscillatoria. They further bring in for comparison the association of the red coloring matter in the young shoots of oak, maple, etc., with the vigorous growth of these shoots; and, from the apparent close chemical relation of the red color in plants to the haemoglobin of animal blood, they conclude that "good red blood and a portion of red in the chlorophyll of green plants wherever found seem to indicate robust life." (04, p. 274.)

According to their further investigations, the optimum temperature for the growth of the alga lies between 64° and 66° F. After a season of such favorable conditions, a vigorous growth usually culminated in one or two days, never more, when large

quantities of the plant would come to the surface, buoyed up by the gas bubbles, a phenomenon to which they refer as the "blooming time" of the Oscillatoria. They say further in this connection that this phenomenon never happened except when an air temperature of 80° F. and over was accompanied by a bright sun and quiet water. (04, p. 270). Only on two days in thirteen years did this "blooming" result in a large amount of scum; while on about five other days of this time a slight scum was formed.

The maximum growth, which took place generally during the long days of June, was followed in July and August by a decreased development, when the plant would be colored usually a more or less brilliant blue-green. In September, the "spore-like" (04, p. 270) bodies were formed, always few in number in comparison with the amount of the plant in the water, which, in their opinion, apparently serve to carry the plant through exceptionally severe conditions. Even in late October, however, these authors have observed that a succession of warm days will frequently permit of a rejuvenescence and a fairly vigorous growth results along the edges where the water is warm. During the winter, according to these investigators, the plant lies dormant, either in the form of broken threads of various lengths and of various stages of arrested development, or in the form of spores. These fragments or spores rest either on the bottom in shallow water or they appear to be held suspended in the denser water near the bottom of the deeper portion. As the spring advances and the surface of the water becomes warmed to a temperature of about 60° F., the authors assert that the plant begins to grow; and growth continues until the water reaches a temperature of 72° F., when rapid breaking up of the filaments occurs.

The alga in Jamaica Pond was at last, in September, 1903, killed by means of an application of copper sulphate, and the authors were able to find during the following spring only the merest trace of its recurrence.

The scum which forms on the surface of many ponds and lakes, following a hot summer season, has been much studied and has been found to consist in most cases of various blue-green

algae. The phenomenon has received various names: in England it is called "breaking"; in this locality, it is sometimes called the "working" of the lakes. "Wasserblüthe," "Flos aquae," "waterbloom," are also variously applied to the scum.

In this country, Farlow (77; 83, I; 83, II) has done more work on the subject than any other investigator. According to Trelease (89), Dr. Farlow first observed the purplish color in Jamaica Pond, in Massachusetts, in the spring of 1884, and he gave to the alga the name *Oscillatoria diffusa*. This species was subsequently found, however, to correspond to the earlier described *O. prolifica* (Greville). In his earlier paper (77), Farlow discusses the odors caused by the decay of various organisms sometimes found in water supplies and speaks of Oscillatoria and Lyngbya as causing "indescribably suffocating" odors; of Beggiatoa, sulphurous odors; and of the Nostocs, Plectonema, etc., "pig-pen" odors. In this same paper, he ascribes the death of the algae forming the water-bloom as due to the broiling hot rays of the sun.

Magnus (83) investigated an instance in which the ice cut from a pond near Berlin contained a greenish growth, and, on examination, he found it to contain a species of Aphanizomenon. Trelease (89) studied the "Working" of the lakes at Madison and gives, in connection with his paper, a long list of articles relating to water-bloom. Chodat (96) has recently published observations on *Oscillatoria rubescens* D. C., which, together with *O. prolifica* (see Gomont, 93, p. 225), gives a reddish color to the surface of Lake Morat, in Switzerland. This author appears to agree with Klebahn (95), in that vacuoles of gas are regarded as present in the cortical region of the cells of the Oscillatoria; and he further believes that it is this gas which causes the alga to rise to the surface and float.

Moore (01) also agrees with Klebahn's views concerning the presence of gas-vacuoles in water-bloom, since, after his study of *Oscillatoria prolifica* from Jamaica Pond, he came to the conclusion that the buoyancy of the algal masses was due to the presence of the vacuoles, which he thought contained nitrogen. He was also lead to believe that the red color of the plant was caused by the refraction due to the presence of large numbers of these gas-vacuoles, as had been suggested by Klebahn.

A most recent discussion of Wasserblüthe and of the green, yellow or red colors given to bodies of water by various organisms has been written by Zacharias (03).

Pine Lake is similar in one respect to Jamaica Pond, viz., in that neither has any outlet to speak of. But, on the other hand, Pine Lake is considerably larger than Jamaica Pond. The former has an area of 1.2 sq. mi. and is about 2 miles long by 1 mile wide; whereas the latter has an area of only 65½ acres. The smaller lake is between 50-60 feet in its deepest part; while the greatest depth of Pine Lake is about 90 feet.

The growth of *Oscillatoria prolifica* in Pine Lake during the summer and fall of 1904 must have surpassed in luxuriance even the richest development of the plant in Jamaica Pond. For, inquiries show that the ice around the shores of the whole lake contained quantities of the alga, as evidenced by the fact that ice harvested on all sides contained the red color imparted by it. Mr. Hansen, as did the great majority of the residents about the shores of the lake, threw away all of his colored ice and replenished his supply from the neighboring Beaver Lake, which did not show any of the reddish growth. Two of the residents, however, retained some of their cut from Pine Lake, and I have examined specimens from the ice-houses on the estate of Messrs. Mayer, situated almost opposite and about one mile from the estate of Mr. Hansen. I was told that this ice was cut in January, 1905. In the most of the ice-cakes examined, the reddish color, resembling the juice of crushed cherries, appeared in small amount only, diffused about air-bubbles and cracks in the ice. One of these colored areas was melted, and, on microscopical examination, the water thus obtained was found to contain the faintly reddish filaments of *Oscillatoria prolifica*. These filaments appear rather rigid and refractive, probably partly owing to the large amount of silica which, in the investigations quoted above, was found to be present. The diameter of a filament from the Pine Lake material measures about 4μ–5μ; while the component cells are likewise about 4μ–5μ long.

I was told that some of the ice at Mr. Mayer's place was colored throughout with the "crushed cherry" color; whereas

other cakes showed ten inches or so of clear top, with the reddish substance frozen into the ice only below the ten inches.

The great abundance of the alga is further proved by the large masses which were left floating on the surface of the lake, in March last, where the ice had melted. Mr. Hansen, who collected for the purposes of identification an abundance of the alga on March 25, 1905, says that some of the floating masses were about 12 inches in diameter, while others were small—"the greater part of them being about the size of an oak leaf" (from letter of April 8th to Prof. Birge). Mr. Hansen and many others mentioned the peculiar smell readily noticable at the lake shore, which came from the decaying plant. One described the odor as resembling that from decayed flesh; but Hyams and and Richards describe it rather as fetid, not putrefactive.

An old resident claimed that at intervals during the past twenty years this red color had appeared in the ice taken from Pine Lake. Another said that the ice at North Lake, which is situated only a short distance north of Pine Lake, was colored two or three years ago in this same way. Some ventured the explanation that the fact that Pine Lake has practically no outlet except at high water, might explain the abundance of the alga here, as well as its present confinement to this lake. For, a visit to ice-houses at North and Okauchee Lakes failed to discover any signs of the growth, and careful inquiries at Mouse and Oconomowoc Lakes and Lac la Belle showed that none was present, at least, in the ice harvested from these bodies of water last winter. It is perhaps a significant fact that all of these lakes mentioned have strongly flowing outlets and inlets, excepting Pine Lake and the neighboring Beaver Lake; so that it may well be that this lack may assist in explaining the abundance of the plant in Pine Lake during the past season.

I have had opportunity to examine the plankton of Pine Lake collected on three days only—on Aug. 23, and Oct. 18, 1900, and again on July 26, 1905. The first collections were taken from waters 8—20 meters deep, but only a few blue-green forms were here found, and among them no Oscillatoria.

The more recent material was taken from the surface of both shallow and deep waters, and from various parts of the lake;

the net was also lowered in various localities to a depth of about 25 feet and then hauled straight up. Not a particle of *Oscillatoria prolifica* was found in any instance, but in all of the latter collections there was present in large quantities a species of Gleotrichia, the little colonies of which could readily be seen floating in the lake, with the naked eye, together with a small amount of other common plankton forms.

We are thus struck at once with an important difference in the midsummer conditions of Jamaica Pond and Pine Lake. In the case of Jamaica Pond, other forms of plant life appear to have been practically excluded for years by *Oscillatoria prolifica;* during the months of July and August, moreover, the growth of the alga in this Pond was but somewhat decreased from the earlier more luxuriant development. In Pine Lake, on the other hand, we have in midsummer an abundance of another species of blue-green alga, and the seeming total disappearance of *Oscillatoria prolifica.* This last fact is to me inexplicable, since one can hardly conceive of the killing off entirely of the luxuriant growth of the past year by the severity of the winter cold. I think that it is more than probable that repeated observations will surely reveal this species of Oscillatoria again during another season, if not later during this one. There is thus presented by Pine Lake a most interesting problem involving the seasonal variation and the varying predominance of different plankton forms.

When we try to obtain insight into the conditions of the past season which allowed of the production of *Oscillatoria prolifica* in such phenomenal abundance, we at once note the unusually favorable weather conditions of the latter part of last year. According to data kindly furnished by Mr. J. L. Bartlett, Weather Observer, while last October at Madison was about the average in temperature, November, on the other hand, was 6° warmer than usual. During the month of October 1904, which had a mean temperature of 51° F., several warm spells were recorded at Madison; on Oct. 1, 72°; Oct. 9, 77°; Oct. 17, 75°. On Nov. 3, the temperature reached 68°; on Nov. 19, 67°; while the mean for this month was about 40° F. But the most striking weather conditions of this time were furnished by the long

drought which then prevailed; so that possibly this also assisted the favorable conditions for algal growth. The large lakes at Madison, Monona and Mendota, froze on Dec. 13 and 14, 1904, respectively. I have no record concerning Pine Lake, but it is quite probable that it was frozen over at about the same time, notwithstanding the fact that it is considerably smaller than the Madison lakes. The likelihood of the earlier freezing of the smaller lake is somewhat counterbalanced, in this instance, by the fact that the climate of the locality of the latter is to a certain extent influenced by the proximity of Lake Michigan, since it is only 20 miles away from the large lake, and over 50 miles nearer than Madison.

Now, granting that the conditions for the growth of Oscillatoria were unusually favorable in Pine Lake particularly during last October, how can we account for the occurrence of such vast quantities of the alga, frozen up in the ice? Hyams and Richards speak of an occasional fall growth, a sort of rejuvenescence due to a new warm season, which resulted in one instance in some of the alga being found in the ice. Birge (98, p. 420) says that in the autumn there is normally "a period, beginning a little before the first of October and extending to the freezing of the lake, when the algae are present in immense quantities, and are distributed with approximate equality through the whole mass of the water." If those observers were correct, who assert that the first ten inches of the ice from Pine Lake was clear, and the alga appeared only in the lower strata, then we must assume that, after considerable freezing had been accomplished, the severe cold must somehow have killed the alga and thus caused it to rise to the surface. I have not, however, myself seen an instance in which one side only of the ice-cake was colored, but those which I examined were instead reddish in small areas, about cracks and air-bubbles. It has been suggested that possibly those who made the observation recorded above were mistaken and that it was the upper part of the ice which was thus colored and not the lower; I have not had an opportunity, however, of verifying this suggestion. But in the event of this being the case, then we must suppose that the unusually mild and long-prolonged growing season of last fall culminated in a "blooming time," or "working," of the alga. Should this prove

true, then the floating scum would have been frozen directly into the top ice. I have no means at present of determinating certainly which of these two ideas is correct, but the weight of the long-continued observations of the above quoted authors on the seasonal habits of the plant inclines me to believe that the alga did not form a scum, but was probably present, late in the season, in vast quantities in the deeper waters of the lake and that somehow the extreme cold of the month of January caused it to rise after the surface had become frozen.

Concerning the reddish color which appears in these plants, particularly on their rising to the surface, or on their undergoing decomposition, I wish to record here a suggestion at considerable variance from the theory held by Hyams and Richards, who come to the conclusion that the reddish substance is an important factor in the vigorous growth of plants.

These authors have themselves stated the fact that "whenever the plant is found below the surface it is blue-green in color" (01, p. 310), and that the reddish pigment appeared "when luxuriant, or whenever the growth is rapid" (04, p. 271). They have further said that it is the mass of filaments near the surface of the water, and the floating scum, and the decayed alga on the rocks of the shore which display the reddish or violet tints.

While it may be correct, as do the two authors above cited, to assume the probability of the great importance of these reddish pigments and perhaps even their chemical combination with the chlorophyll of these plants, it is hardly allowable, in my opinion, to bring in, to assist in establishing their point of the great importance of these substances, comparisons with the other reddish coloring matters sometimes present in the cell-sap of the young shoots and leaves of higher plants. For, I think that it is not at all established that these reddish pigments of the higher and lower plants are similar to each other, either chemically or physiologically.

The appearance, in the case of *Oscillatoria prolifica* as well as in other common species of Oscillatoria, of the reddish coloring matters in the filaments *after* they have risen to the surface and particularly on their undergoing evident decomposition, suggests that such colors arise as decomposition products, rather than that

this reddish pigment is associated with a vigorous growth. The intensification of the color, as decomposition proceeds, argues also strongly for this conclusion.

The daily determinations, from March to October, of the amount of carbon-dioxide dissolved in the water of Jamaica Pond, as made by Hyams and Richards, may be regarded as furnishing a very important clew to the revealing of one cause, at least, of the formation of a surface scum and the appearance of the reddish color. These authors found that whenever the Oscillatoria grew vigorously, the normal content of "*carbon dioxide disappeared and the water became not only neutral but alkaline. With the decay of the plant, the alkalinity disappeared and carbon-dioxide again became normal and in one or two instances appeared in excess.*" (02, p. 310).

It seems to me readily conceivable, at any rate, that we may have in the lack of this important food-substance, carbon-dioxide, a condition perhaps brought about by its being used up by the plant during the vigorous growth, the prime cause of the beginnings of decomposition and the consequent rising of the alga to the surface of the water and the appearance of the red pigment.

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