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Effects of Copper Sulfate on Certain Algae and Zooplankters in Winnisquam Lake, NH

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Effects of Copper Sulfate on Certain Algae and Zooplankters In Winnisquam Lake, New Hampshire

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ABSTRACT

This report describes the effects of copper sulfate ($CuSO_4.5H_2O$) on certain algal and zooplankton populations in Winnisquam Lake, New Hampshire. The bloom alga was *Anabaena circinalis* and it was controlled by an application of four pounds of copper sulfate per surface acre. The cell numbers of 27 species of the algal community were recorded before and after copper sulfate treatment. The carbon fixation rate was found to be a more sensitive measure of bloom potential than were cell counts. Copepods and *Bosmina longirostris* were more resistant to copper sulfate than were *Daphnia*. After copper sulfate application *Bosmina* multiplied to a concentration of 154 per liter in the top meter of the water column.

INTRODUCTION

Copper sulfate has been used since 1904 to control different types of algae (Moore and Kellerman, 1905). Other substances have been tested, but copper sulfate has been the most successful under conditions of both hard and soft water. Much has been written about the toxicity of copper sulfate to different forms of aquatic life (Ellis, 1937; Doudoroff and Katz, 1953), but the effects of the chemical on many invertebrates are not well known (Tarzwell, 1963). As part of an intensive limnological investigation of Winnisquam Lake in central New Hampshire (Figure 1), the impact of copper sulfate treatment on certain lake populations was observed. The purpose of this report is to describe the effects of copper sulfate on certain algae and zooplankters in the lake.

Crews of the New Hampshire Water Supply and Pollution Control Commission routinely treat blue-green algal blooms by dragging burlap bags of copper sulfate behind outboard motorboats. Depending on the algal species involved, crews attempt to distribute three or four pounds of copper sulfate (.025 to .035 ppm Cu^{++}) in the top ten feet of the water column. However, an even distribution of the chemical does not occur for the highest concentration of copper sulfate appears in the upper few feet of the water column (Table 1). Since the highest numbers of troublesome blue-green algae commonly occur in this strata, however, desirable results do arise from the use of this technique, even though it is not a modern application procedure.

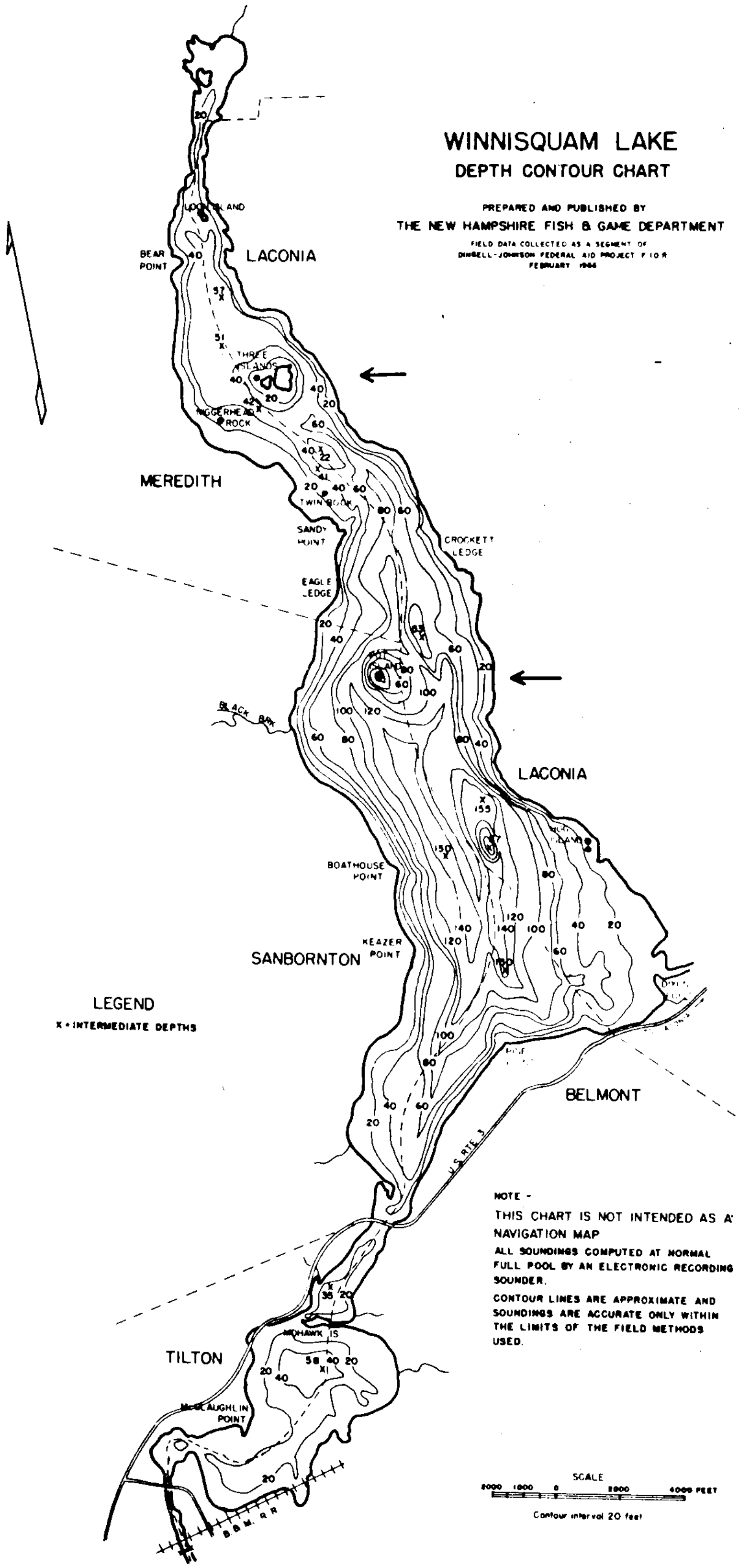

Figure 1.--Winnisquam Lake (about 4,264 acres), is located at $40^{o}30'$ N and 71^{o} $30'$ W in central New Hampshire. The first application of copper sulfate was made north of "Bear Point"; the second application was made north of the top arrow and spread south to the lower arrow. Map: Courtesy of the New Hampshire Fish and Game Department.

Table 1 -- Concentrations of copper sulfate during and after treatment in Winnisquam Lake.*

Depth	Concentrations of copper sulfate: at treatment time	Concentrations of copper sulfate: 3-hours post-treatment
feet	ppm.	ppm.
Surface	3.51	0.07
20	0.01	0.04
60	0.01	0.03

*Samples were taken 5-10 feet behind the boat at time of application, and several measurements made on different dates were averaged.

Source: New Hampshire Water Supply and Pollution Control Commission, Concord, New Hampshire

Several circumstances can affect the concentration of copper sulfate at the time of algal control. Some of these factors are water hardness, water temperature, the speed of the boat dragging the copper sulfate-laden bags and the particulate size of the copper sulfate. The most important factor or combination of factors depends upon the immediate local chemistry and physical characteristics of the lake at the time of application. With respect to water hardness, Winnisquam Lake can be classified as "soft" in character, in that phenolphthalein alkalinity was normally not detectable; the methyl orange alkalinity ranged from 5.0 to 11.0 ppm; and total dissolved solids measured from 55 to 65 ppm as calcium carbonate ($CaCO_3$) during the sampling period.

Unfortunately, actual measurement of copper sulfate concentration in the water during and after the treatment period studied was not made. However, biologists employed by the New Hampshire Water Supply and Pollution Control Commission have assayed for copper sulfate at various times during past treatments of the lake (Table 1). These data provide a measure of copper sulfate concentrations found five to ten feet behind the motorboat on Winnisquam Lake after treatments using the technique described.

Our study placed particular emphasis on phytoplankton composition and the number of algal cells present before and after treatment. Whenever algal samples were taken, measurement of primary productivity was made. Numbers of zooplankters present were recorded less systematically.

ALGAL RESPONSE

Abundance and Cell Counts

Under favorable ecological conditions, troublesome blue-green algal species may triple their numbers in one to two days (Monie, 1946). Knowing this, biologists of the New Hampshire Water Supply and Pollution Control Commission monitor Winnisquam Lake carefully during the summer, for it has a history of algal blooms. In early August, 1965, their biologists observed that the blue-green alga *Anabaena circinalis* was becoming abundant.

Our first sample of the algal population was taken on August 12, 1965 at the 1-, 3-, 5-, and 10-meter levels with an opaque water bottle. The algae were immediately preserved by the addition of acid Lugol's solution to aliquots of the sample water (Edmonson, 1959). Total algal cell counts at each sampling depth were made from one milliliter of unconcentrated water at 200x using an inverted microscope (Lund, Kipling and Le Cren, 1958). This first sample yielded a total of 17,653 *A. circinalis* cells at the four water column depths.

The New Hampshire Water Supply and Pollution Control Commission treated the lake for the first time during the study period on August 13. Copper sulfate was applied on 200 acres at the rate of three pounds per acre. On August 14 and 15, visual and microscopic examination of the lake water by biologists experienced in algal control indicated that the first application had not been successful (See Bartsch, 1954 and Mackenthun et al., 1964 for symptoms of successful algal treatment).

There were 17,562 cells of *A. circinalis* counted on August 16 at the depths sampled (Table 2). The population level was nearly identical to that before treatment. The copper sulfate applied three days earlier may have had some effect on the *A. circinalis*, but it did not destroy the bloom. Regardless of the cell number, Table 3 indicates a large increase in carbon uptake at depths sampled on August 16 over uptake assayed on August 12. This increased activity is a more significant indication of the physiological state of the algal population than cell numbers. Any effects of the initial application of copper sulfate were gone, and algal growth was rapidly proceeding again.

A second treatment of the lake using four pounds of copper sulfate per acre was begun on August 17 and completed on August 18. A total of about 1,525 acres were treated with 5,900 pounds of copper sulfate. The area treated is shown in Figure 1.

The second treatment decreased the *A. circinalis* population at sampled depths from over 17,000 cells on August 16 to 790 cells on August 24 (Table 2). This drastic reduction in numbers eliminated *A. circinalis* from the nuisance class so that the treatment of the bloom was considered successful. The species did not become dominant again that fall.

Synura uvella decreased in numbers after the first treatment (Table 2), but this decline is believed to be from causes other than copper. This is supported by the fact that after the second heavier application of copper sulfate on August 16 the species increased in numbers. Palmer (1964) reported that *Synura* and *Dinobryon* were both eliminated in the Scioto River, Ohio by 1.8 ppm copper sulfate. Concentration of copper sulfate in the bloom control effort undertaken on Winnisquam Lake probably never reached that level, particularly at the 10-meter depth where *Synura* was first found (Table 1). *Synura* responded to the treatment by increasing in numbers, and by August 28 it was present at all sampling levels.

The *Dinobryon* population dropped precipitously after the initial treatment and the species was not found again in the samples counted until August 20 (Figure 2). *Dinobryon* reappeared in Lake Winnisquam suddenly after August 24, and became dominant four days later. *Dinobryon* appeared to be the most susceptible phytoplankter present at treatment time, but its dramatic reappearance within ten days is a good example of the resiliency of a species when environmental conditions are proper for its growth.

Table 2 -- Major species enumerated and number of cells counted at the 1, 3, 5, and 10 meter levels, Winnisquam Lake, 1965.*

Species	Depth	Total cells on: Aug. 12	Aug. 16	Aug. 20	Aug. 24	Aug. 28
	meters	no./ml	no./ml	no./ml	no./ml	no./ml
Cyanophyta:						
Anabaena circinalis	1	9,800	15,430	1,088	259	309
	3	6,045	1,382	944	254	215
	5	1,764	720	395	220	558
	10	42	30	77	57	93
Oscillatoria limnetica	1	--	--	--	393	48
	3	--	--	--	540	101
	5	--	--	27	683	42
	10	--	--	17	38	119
Chrysophyta:						
Dinobryon	1	--	--	--	--	989
	3	--	--	6	--	784
	5	94	--	--	--	200
	10	--	--	9	--	--
Synura uvella	1	--	--	--	--	584
	3	--	--	--	--	260
	5	--	48	--	--	48
	10	3,012	432	1,473	1,316	928
Chlorophyta:						
Dictyosphaerium	1	105	65	--	75	60
	3	221	--	123	--	--
	5	167	110	70	--	71
	10	50	30	--	--	40

*A summary of all species and total cells in the water column is given in Appendix Table 6.
Note: Copper sulfate treatment dates were August 13, 17, and 18.

The reaction of *Oscillatoria limnetica* suggests that this species reacted to the changes in populations of other species, and responded to new ecological opportunities, rather than being directly affected by the copper sulfate (Figure 2). The species rose from obscurity in eight days, including two treatment days, to a level of 1,650 cells/ml at depths sampled. This rapid multiplication could have occurred in response to nutrients released by mineralization of cells killed by the copper sulfate, because of decreased competition, or because both conditions acted synergistically. At any rate, the high cell count was not found until after the copper sulfate treatment. Interestingly, this blue-green alga, when present in concentration, produces a translucent lime-green color in the water that does not seem to be objectionable to recreationists.

In terms of cell counts, populations of some algal species such as *Dictyosphaerium*, *Fragilaria* and *Asterionella* appeared to be unaffected by the copper sulfate treatments (Figure 2).

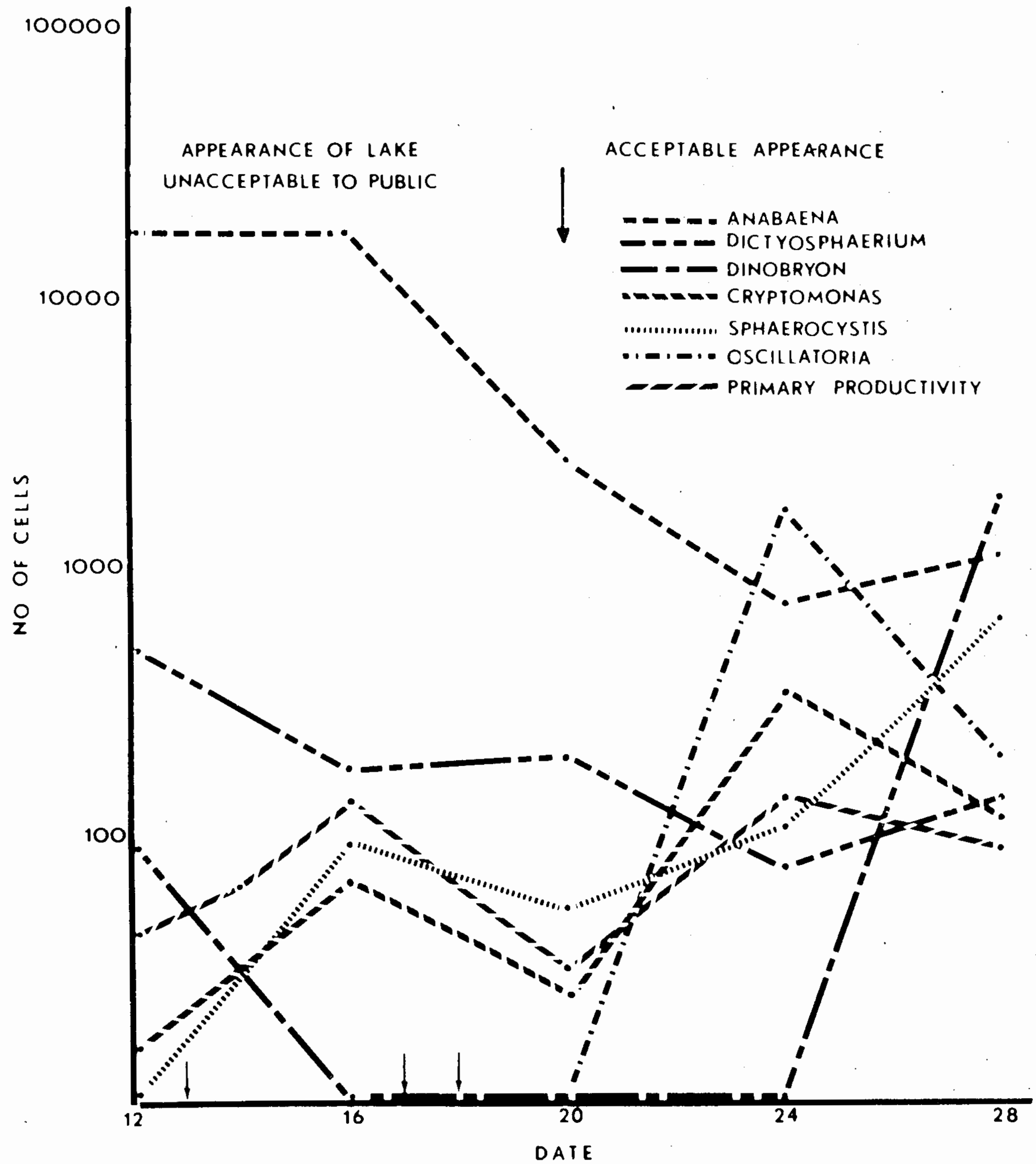

Figure 2.--The numerical relationship of the 6 most abundant algal species in Winnisquam Lake, August 1965. The lower 3 arrows indicate dates of copper sulfate applications. The upper arrow marks the division between "unacceptable" and "acceptable" lake appearance.

Primary Productivity

Primary productivity was measured concurrently with algal counts at similar depths by the carbon-14 method (Steeman-Neilson, 1952). Samples were incubated for four hours between 10:00 - 10:15 am and 2:00 - 2:15 pm at the depths from which they were collected. Primary productivity is shown in Figure 2.

Pyrheliometer data (that measures solar energy) were not available during the dates involved, so the primary productivity measurements are expressed in terms of milligrams of carbon per cubic meter (mgs. C/m^3) fixed during the four-hour incubation period used. However, weather reports that included sky conditions were available from nearby Laconia Airport. This information is included in Table 3, using the terminology of the meteorologist. Ample sunlight appears to have been available for photosynthesis on all days except August 28.

Carbon fixation continued to increase through and after the first treatment date. On August 16, three days after the first treatment, the carbon-14 technique showed that metabolic activity had increased over 100 percent at every sample depth except ten meters (Table 3). These data reinforce the decision to treat the lake a second time; a decision that the Water Supply and Pollution Control Commission biologists made based on their experience with the visual characteristics of successful algal control. Primary productivity was reduced two days after completion of the second copper sulfate treatment. However, four days later on August 24, the carbon fixation rate had increased at each level measured (Table 3). More species were present on August 24 (Table 2) than previously, although the number of cells was almost the same as on August 20.

Table 3 -- Primary productivity in mgs C/M^3 over a 4-hour incubation period at various depths, Winnisquam Lake, 1965.

Depth	Date and weather conditions					
	August 12: clear	August 14: scattered clouds	August 16: clear	August 20: clear	August 24: clear	August 28: broken clouds
meters	mgs C/M^3	mgs C/M^3	mgs C/M^3	mgs C/M^3	mgs C/M^3	mgs C/M^3
1	12.4	33.0	66.4	15.0	59.6	40.5
2	21.5	15.9	52.4	17.8	62.5	39.4
3	26.0	24.5	52.4	12.6	55.3	34.3
4	14.0	11.1	29.0	6.5	34.1	22.6
5	6.0	8.3	14.2	3.6	19.1	12.3
10	2.8	1.9	0.5	0.2	0.6	0.5

Note: Copper sulfate treatment was performed on August 13, 17, and 18.

The use of primary productivity as a measure of the copper sulfate treatment indicated that the depressing effects of the treatment on algal activity had disappeared in five or six days. The rise to dominance of species previously suppressed, and the rapid recovery of some of the copper-susceptible species, maintained the carbon fixation level of the new community (Figure 2). It appeared that the primary effects of the copper sulfate treatment (that is, death of cells) was over in this instance within four to six days. Apparently the copper sulfate had been diluted or inactivated in some way so that its concentration dropped below the toxic level. The secondary effect of the copper sulfate (that is, change in species composition) continued for a longer period after treatment.

It is difficult to decide at what point the effects of the copper sulfate were no longer responsible for the algal composition. A new ratio of cell numbers was formed by species present after treatment and species suppressed in the pre-treatment complex. New facets of competition within the new community were brought about but were not measured in this study.

The post-treatment algal community was also affected by changes in the zooplankton population (Table 4). The tremendous increase in Bosmina between the pre-treatment period and August 27 was the most spectacular numerical difference noted, but other species of zooplankton changed in numbers as well.

Table 4 -- Average numbers of zooplankters at various depths, pre- and post-treatment dates*, Winnisquam Lake, 1965.

Depth	Type of zooplankter:					
	Copepoda**		Daphnia		Bosmina	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
meters	no./liter	no./liter	no./liter	no./liter	no./liter	no./liter
1	3.5	8.1	1.5	6.5	6.5	67.6
2	5.0	13.8	11.9	0.8	3.6	28.4
3	6.2	21.1	22.8	1.1	3.5	34.3
4	5.7	16.8	16.4	1.6	2.1	30.2
5	3.3	22.2	13.3	1.0	1.7	22.1
10	4.7	6.3	1.5	0.3	1.7	10.6
Totals	28.4	88.3	67.4	11.3	19.1	193.2

*Pre-treatment dates: July 28, August 4, and August 9.
Post-treatment dates: August 20, 24, and 27.

**Adult copepod numbers are probably low, for there is a distinct possibility some adults could have avoided the water bottle lowered for collecting.

ZOOPLANKTER RESPONSE

Zooplankters were sampled at the same depths as the algae by filtration of 6.6 liters of water (three water bottles full) through a number 20 plankton net. Zooplankton was preserved in five percent formalin, and total counts were made using a dissecting microscope at 45x.

Copepods and *Bosmina longirostris* were more resistant to the copper ion than were *Daphnia* (mainly *D. galeata mendotae*) (Table 4). Anderson (1948) pointed out that immediately after moulting, the new body covering of *Daphnia* is soft and more permeable than the old, thereby permitting substances to enter. In addition, *Daphnia magna* increases in length by 26 percent at the first moult. This increase doubles the volume of the animal, and various substances in the environment enter the animal at a greater rate (Anderson, 1932). *Daphnia magna* was not present in Winnisquam Lake, but it seems reasonable that *D. g. mendotae* would react similarly to *D. magna*. At any rate, the number of *Daphnia* decreased about 600 percent after the copper sulfate treatment (Table 3). Fisher (1956) reported that in some fish ponds treated with copper sulfate, *Daphnia*, *Chironomidae* and *Cyclops* succumbed in that order. Effects on *Chironomidae* are unknown in Winnisquam Lake, but the *Daphnia* and copepods responded similarly to those in the ponds studied by Fisher.

Copepods cease to moult when mature (Anderson, 1932) and the hardened exoskeleton of the adults apparently aids them in resisting the effects of copper sulfate. In Winnisquam Lake the copepod population approximately tripled between pre- and post-treatment as shown in Table 5. Adults doubled in numbers while the immature increased over five times at the depths sampled. The copepod population shifted from one dominated by the adult form before treatment to a population after treatment with an age pyramid approaching youthful domination (Odum, 1959).

Table 5 -- Average numbers of copepods (adult and nauplii) at various depths, pre- and post-treatment dates*, Winnisquam Lake, 1965.

Depth	Age class of copepod:			
	Adults**		Nauplii	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
meters	no./liter	no./liter	no./liter	no./liter
1	2.4	3.7	1.1	3.7
2	3.4	7.9	1.6	5.9
3	5.1	9.1	1.1	11.9
4	4.6	9.1	1.2	7.8
5	2.4	8.7	0.9	13.5
10	1.9	2.3	2.2	4.0
Totals	19.8	40.8	8.1	46.8

*Pre-treatment dates: July 28, August 4, and August 9.
Post-treatment dates: August 20, 24, and 27.

**Adult copepod numbers are probably low, for there is a distinct possibility some adults could have avoided the water bottle lowered for collecting.

Bosmina longirostris rose from third position (numerically) during the treatment period to dominance of the zooplankton population during the post-treatment sampling (Table 4). Between August 24 and August 27 the numbers of *Bosmina* rose from 29 to 154/liter at one meter of depth. There are several possible reasons for this increase.

Gallup (1969) has evidence that the primary foods of *Bosmina* are bacteria and finely divided detritus. Although they were not counted, it can be assumed that the numbers of bacteria would rise rapidly in response to the destruction of millions of algal cells by the copper sulfate treatment. In addition, as the algal cells were mineralized by the bacteria, finely divided detritus would be abundant in the water. These events would provide an excellent supply of food upon which *Bosmina* could thrive.

Furthermore, Brooks and Dodson (1965) have shown that predation by fishes can selectively remove the larger zooplankters from a lake. When this occurs, the smaller zooplankter, *Bosmina longirostris*, becomes the dominant cladoceran. It is possible that in Winnisquam Lake the copper sulfate acted selectively, as did the aforementioned predation by fishes, to release the *Bosmina* from the competitive feeding activity of the larger *Daphnia* and allowed Bosmina to ascend to dominance rapidly (Table 4).

SUMMARY AND CONCLUSIONS

In a relatively unbuffered lake such as Winnisquam the control of a cyanophycean bloom can be accomplished with relatively small amounts of copper sulfate (that is, four pounds per acre). The data on algal species present before, during, and after the addition of copper sulfate indicate that a rapid shift in species relationships occurred. Susceptible species decreased in numbers; other forms responded by increasing their population; and some species appeared to be unaffected by the copper sulfate treatment. The latter group may have been protected by natural resistance or by their position in the water column.

Zooplankton reacted to the copper treatment in various ways. The effects on microcrustaceans such as copepods and daphnids seemed to follow a pattern that might have been predicted from the works of Anderson (1932, 1948) and Fisher (1956). Bosmina reacted in a manner that indicated living conditions had been greatly improved for them. No attempt was made to ascertain the impact of the copper sulfate on the benthos, fishes, or other animals such as rotifers and protozoans that may have been in the plankton.

The rise and fall of the numbers of the various species of plants and animals described, and their very rapid response to the new conditions after copper sulfate treatment, illustrate the complexities of the relationships among all these organisms. However, the crude treatment with copper sulfate of so many unknowns did produce the desired control of an obnoxious blue-green alga.

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APPENDIX:

Summary of All Species and Cell Counts

Table 6 -- Summary of all species and total number of cells counted in the water column (1-10 meters), Winnisquam Lake, 1965.

Species	Total cells on: Aug. 12 no./ml	Aug. 16 no./ml	Aug. 20 no./ml	Aug. 24 no./ml	Aug. 28 no./ml
Chlorophyta:					
Ankistrodesmus falcatus	14	-	-	6	2
Ankistrodesmus convolutus	-	-	-	1	-
Cosmarium	-	1	-	1	-
Dictyosphaerium	543	205	193	75	171
Eudorina elegans	96	48	-	36	-
Franceia	-	-	-	4	-
Kirchneriella lunaris	-	-	6	73	-
Mougeotia	53	9	-	-	-
Oocystis	-	-	-	4	-
Pediastrum duplex	-	-	-	22	-
Quadrigula	-	-	-	-	24
Scenedesmus bijuga	-	-	-	4	-
Scenedesmus incrassatalus	4	-	-	4	-
Sorastrum spinulosum	-	-	-	6	-
Sphaerocystis	-	92	52	111	646
Staurastrum	2	1	-	4	13
Chrysophyta:					
Asterionella	178	53	31	35	29
Dinobryon	94	-	15	-	1,973
Fragilaria	230	108	68	28	139
Mallomonas	5	4	-	32	-
Melosira	15	35	89	7	28
Synura uvella	3,012	480	1,473	1,316	1,820
Tabellaria	2	-	-	-	4
Cryptophyceae:					
Cryptomonas	82	189	43	329	143

Table 6 (Continued) -- Summary of all species and total number of cells counted in the water column (1-10 meters), Winnisquam Lake, 1965.

Species		Total cells on:				
		Aug. 12	Aug. 16	Aug. 20	Aug. 24	Aug. 28
		no./ml	no./ml	no./ml	no./ml	no./ml
Cyanophyta:						
Anabaena circinalis		17,651	17,562	2,504	790	1,175
Oscillatoria limnetica		-	-	44	1,654	310
Pyrrophyta:						
Ceratium hirundinella		-	-	-	-	8
Total	cells	21,981	18,787	4,518	4,542	6,485
	species present	15	13	11	22	15

Note: Copper sulfate treatment dates were August 13, 17, and 18.