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LAKE TROPHIC STATE AND ALGAL GROWTH AS INFLUENCED BY CATION CONCENTRATIONS
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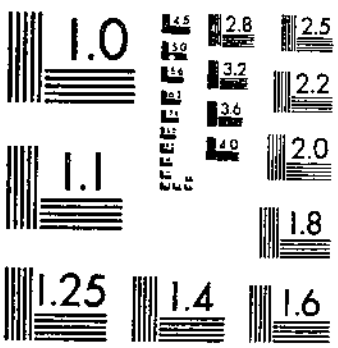

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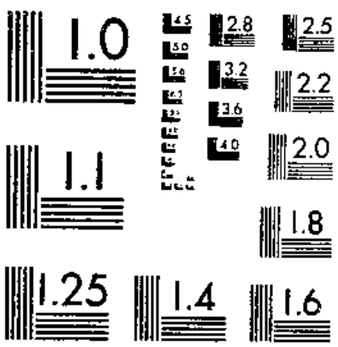

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Lake Trophic State and Algal Growth as Influenced by Cation Concentrations

Abstract

Batchelder, A. R. 1981. Lake Trophic State and Algal Growth as Influenced by Cation Concentrations. U.S. Department of Agriculture, Technical Bulletin No. 1649, 8 p.

Laboratory experiments were conducted to evaluate the effects of variations in the Ca, Mg, and Na concentrations in eutrophic waters on the standing crop and growth rates of three algal species. Each species was grown in a standard nutrient medium enriched with Ca, Mg, and Na in varying combinations and at concentrations of 2 and 8 milliequivalents per liter (meq/L) each. The dry weights of *Anabaena subcylindrica* and *Selenastrum capricornutum* were reduced by the 8 meq/L Mg treatment, but the toxic effects were overcome by adding Ca to the *A. subcylindrica* and Ca and Na to the *S. capricornutum*. None of the cation concentration variations affected the standing crop of *Chlorella ellipsoidea*. The addition of Na alone to the cultures produced little or no effect, but in combination with added Ca and Mg, it enhanced the growth rates of *A. subcylindrica* and *S. capricornutum*. Neither pH, monovalent to divalent cation ratio, or ionic strength of the media affected the algal growth in these studies.

Based on data for 85 U.S. lakes that were compiled from literature, a concentration of 0.5 meq/L of either Ca, Mg, or Na appears to be as a threshold above which the lakes were usually eutrophic. Results demonstrated that Ca, Mg, and Na concentrations need to be considered as factors in saline and hard water eutrophication.

Keywords: Cations, calcium, magnesium, sodium, trophic state, *Anabaena*, *Selenastrum*, *Chlorella*, algae.

Contents

Glossary

The classification of bodies of water is based on their chemical, physical, and biological characteristics, and the definitions of class names may vary with the user. The following definitions are applicable to this discussion.

Dystrophic .... Having imperfect nutrition and usually brown because of dissolved humic material. As used by the author in the literature cited (*19*), probably similar to *oligotrophic*.

Eutrophic ..... Usually rich in dissolved nutrients, especially N and P, and frequently shallow and oxygen-deficient in the lower waters. Often associated with excessive weed and phytoplankton growth.

Eutrophication. The process of becoming more eutrophic, either naturally, as the body of water matures, or artificially.

Mesotrophic... Having characteristics between those of eutrophic and oligotrophic.

Oligotrophic... Usually deficient in nutrients, especially N and P, having ample dissolved oxygen and few aquatic plants.

Phytoplankton.. The passively floating plant life of a body of water.

Sonification ... Cell disruption by ultrahigh frequency sound.

Trophic state .. The nutritional state of a body of water; oligotrophic, mesotrophic, or eutrophic.

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Lake Trophic State and Algal Growth as Influenced by Cation Concentrations

By A. R. Batchelder[1]

Introduction

The effects of Ca, Mg, and Na[2] on algae growth have been investigated for several years, but they have not been as widely publicized as those for other nutrients. Trelease and Selsam (*18*),[3] using an enriched standard plant nutrient medium, showed that Ca concentrations between 0 and 80 milliequivalents per liter (meq/L) did not affect *Chlorella vulgaris* Beyerinck growth. As they increased Mg concentrations above 40 meq/L, however, cell counts decreased. At 440 meq/L, the counts had decreased by about 97 percent. Adding Ca did not lessen the toxic effects. Dvorakova-Hladaka (*4*) showed that Ca is essential to algae and that it is involved in N utilization. MacCarthy and Patterson (*10*) showed that *Chlorella sorokiniana* Shihira and Krauss growth rates were not affected by Ca concentrations between 0.001 and 10.0 meq/L, but 100 meq/L Ca was toxic. They also found that growth rates were not affected by Mg concentrations between 0.05 and 100 meq/L, but at higher or lower concentrations the growth rates were slower.

Finkle and Appleman (*6*) concluded that 49 parts per million Mg (4.03 meq/L) were adequate for *Chlorella*—cell division was rapid and cell counts increased from about 10^3 cells/mm at 0.02 meq/L to about 10^5 cells/mm at 4.03 meq/L. At lower concentrations, cell size increased but cell division rates did not.

Sodium is an essential element for the growth of many blue-green algae (*9, 14*). Allen and Arnon (*1*) showed that *Anabaena cylindrica* Lemm has a specific Na requirement, but they found no evidence that amounts between 0.22 and 4.00 meq/L were detrimental to growth.

In a survey of 18 irrigation reservoirs in northeastern Colorado, Batchelder and Braden (*2*) observed relationships between algal growth and the aqueous Ca, Mg, and Na concentrations. Usually, the Na/Ca, Na/Mg, and Na/(Ca + Mg) ratios in the least algal productive waters were about 50 percent lower than those from the most algal productive waters. During that survey, several irrigation reservoir users indicated that extensive algal growth had not been a severe problem until western slope Colorado waters, which often have high cation concentrations, were introduced into the eastern slope reservoirs. Also in Colorado, Pennak (*15*) found that plains lakes that had the greatest Ca concentrations usually had the most phytoplankton. In Poland, Zdanowski (*19*) showed that the addition of Ca to dystrophic lakes was the primary factor that caused productivity changes.

Ca concentration was once used as a measure of lake trophic state (*7*), but in modern terminology eutrophic relates to waters that have high nutrient concentrations, especially P or N, or both. Several forms of N and P are present in most waters, and field analyses to evaluate the algal production potential might be needlessly difficult. Cation concentrations might be used more effectively to indicate the lake trophic state.

The objectives of my studies were to determine how varying the concentrations of Ca, Mg, and Na affects the growth and yield of different algal species and to determine possible relationships of those cations to lake trophic state.

Materials and Methods

The objectives were accomplished by several laboratory experiments and by analyses of water quality data compiled from the literature.

Laboratory Experiments

Three algal cultures (culture 246, *Chlorella ellipsoidea* Gerneck; culture 1648, *Selenastrum capricornutum* Printz; and culture B1617, *Anabaena subcylindrica* Borge) were purchased from the Culture Collection of Algae, Department of Botany, University of Texas. Each culture was immediately transferred aseptically to a synthetic algal nutrient medium (5). Subcultures were aseptically transferred to fresh media weekly.

Each of the algal cultures was subjected to 15 treatments of synthetic algal nutrient medium enriched with Ca, Mg, and Na as chloride salts. The final cation concentrations, cation ratios, and ionic strengths are shown in table 1.

Table 1.—*Treatment descriptions: Ca, Mg, and Na concentrations, cation ratios, and ionic strengths*

Treatment No.	Ca	Mg	Na	Ratio: (Na + K[1]) / (Ca + Mg)	Ionic strength
	—Milliequivalents per liter—				*Molar*
1	0.06	0.24	0.48	1.64	1.03×10^{-3}
2	2	.24	.48	.22	4.03×10^{-3}
3	8	.24	.48	.06	1.30×10^{-2}
4	.06	2	.48	.24	3.73×10^{-3}
5	.06	8	.48	.06	1.27×10^{-2}
6	.06	.24	2	6.70	2.53×10^{-3}
7	.06	.24	8	26.71	8.53×10^{-3}
8	2	2	2	.50	8.23×10^{-3}
9	2	8	2	.20	1.72×10^{-2}
10	8	2	2	.20	1.72×10^{-2}
11	8	8	2	.13	2.62×10^{-2}
12	2	2	8	2.00	1.42×10^{-2}
13	2	8	8	.80	1.72×10^{-2}
14	8	2	8	.80	2.32×10^{-2}
15	8	8	8	.50	3.22×10^{-2}

[1]K = 0.012 meq/L in all treatments.

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[2]Chemical symbols are shown without positive or negative charges, but they indicate ionic species.

[3]Italic numbers in parentheses refer to Literature Cited, p.7.

I selected the 2- and 8-meq/L concentrations because they were within the concentration range frequently found in the most algal productive water bodies in a northeastern Colorado survey (2). Cultures were also grown in the algal nutrient medium alone, treatment 1, for comparison. The pH of each solution was adjusted to 7.2 by adding small amounts of dilute HCl or KOH.

All glassware used was washed with detergent, then rinsed three times with tapwater, once with 0.1 *N* HCl, five times with tapwater, and five times with distilled water. Then, 40-ml aliquots of each treatment solution were dispensed into 125-ml Erlenmeyer flasks, and 15-ml aliquots were dispensed into 16- by 150-mm culture tubes. All the containers were stoppered with cotton and gauze and autoclaved for 15 to 20 min at 120°C and 1.4×10^4 kg/m^2. When the solutions were cool, they were inoculated aseptically, and the flasks were placed on a reciprocating shaker in a three-replication randomized block design. The shaker was operated at about 100 oscillations/min. The culture tubes were similarly randomized in culture tube holders. Each day, the cultures in the tubes were mixed using a vortex mixer. Lighting was controlled at about 200 footcandles (2150 lux) for a 12-hour photoperiod, using cool-white fluorescent lights. Temperatures were maintained at between 24° and 26°C.

Inocula were prepared by centrifuging stock cultures of the selected algal species at 10,000 revolutions per minute (12,100 *g*)[4] for 10 min in sterile tubes, resuspending the cells in a sterile solution of 15 mg/L $NaHCO_3$, and recentrifuging. After two such washings, the cells were resuspended in the $NaHCO_3$ solution and used as the inoculum. Based on hemocytometer counts, enough inoculum was added to each flask so that the initial algae concentrations were 10^3 cells/ml for the *Chlorella* and *Selenastrum* cultures and 10^4 cells/ml for the *Anabaena* cultures. The possibility of nutrient carry-over during culture transfer was minimal because the unspiked nutrient medium was relatively dilute and the stock cultures were diluted about 1:10 to obtain the desired inoculum cell concentrations.

Each experiment was run for 14 days. During this period, culture tubes from each treatment and each replication were randomly selected for cell counts and pH measurements with different tubes used for each measurement. The flask-grown cultures were only sampled at the end of each experiment. Because of the filamentous growth, before the cell counts were made, the *Anabaena* cultures were sonicated at a frequency of 20,000 Hz with nine pulses within 10 seconds to break the filaments without destroying the cells. On day 14, cell counts were also made on the flask-grown cultures for comparison with the tube-grown cultures. The cell counts were made on two to four subsamples from each tube and flask using a hemocytometer. Because the 15 treatments produced a variety of effects among the three algal species, rather than presenting 45 growth curves, I calculated specific growth rate, μ, using the following equation, adapted from the Environmental Protection Agency (5):

$$\mu = \frac{\ln\,(\text{cell count, day}_l/\text{cell count, day}_i)}{\text{day}_l - \text{day}_i} = \text{days}^{-1}$$

where day_i is the first day of the growth period and day_l is the last day. The maximum specific growth, which occurs during the logarithmic growth phase, is a measure of the treatment effect on algal growth.

Total biomass dry weights of the flask cultures after 14 days were determined from the dry weights retained on 0.45 μm tared filters.

Water Quality Data

To compare lake trophic state and the Ca, Mg, and Na concentrations, data were compiled for 85 U.S. lakes. Only those lakes for which the trophic state was designated and for which concentrations of at least one of the three cations were reported were selected for analysis. Thirty-nine of the lakes are in north central Florida (*16*) and 23 are in Connecticut (*13*). The other 23 lakes (*11*) are distributed as follows: Minnesota, 6; California, Oregon, and Wisconson, 4 each; South Dakota, 2; and Michigan, Indiana, and North Carolina, 1 each. Thus, the lakes represent a wide range of climatic, physical, and chemical environments.

The Florida lakes were classified into five groups by the authors: Hyper-eutrophic, eutrophic, meso-eutrophic, oligo-mesotrophic, and oligotrophic. To conform with the classifications used in the other reports, only three classifications are used in this report: eutrophic, mesotrophic, and oligotrophic. Hyper-eutrophic is considered as eutrophic, and meso-eutrophic and oligo-mesotrophic are considered as mesotrophic.

Results

Laboratory Experiments

Anabaena subcylindrica. Holding the solution Ca concentrations constant and varying the Mg and Na concentrations did not significantly affect the final cell counts (table 2). The cell counts differed, however, when either the Mg or Na concentrations were kept constant and the other two cation concentrations were varied.

Although cell counts did not differ after 14 days when all three cation concentrations were increased to 2 or 8 meq/L, or both (treatments 8 through 15), the cell counts for treatments 9 and 11 were significantly greater than those in the control nutrient medium (treatment 1). At 8 meq/L Mg, without additional Ca or Na (treatment 5), the cell counts were significantly less than in any treatment where all three cations were added to the nutrient solution, although counts did not differ significantly from the control treatment. While a high Mg concentration tended to decrease cell counts after 14 days, adding Ca and Na negated this effect. Similarly, the cell counts were lower for treatment 7 (8 meq/L Na without added Ca or Mg) than at 8 meq/L Na when both Ca and Mg were added to the nutrient solution (treatments 12 through 15).

[4]Centrifugal gravity.

Table 2.—*Cell counts of 3 algal species after 14 days, average of 3 replications*

Treatment No.	Cation concentrations Ca	Mg	Na	Algal species *Anabaena subcylindrica*	*Chlorella ellipsoidea*	*Selenastrum capricornutum*
	....Milliequivalents per liter....			*..................10[6] cells per milliliter..................*		
1	0.06	0.24	0.48	1.90 bcdef[1]	14.63 ab	7.26 a
2	2	.24	.48	2.57 abcdef	12.87 b	6.33 ab
3	8	.24	.48	2.68 abcde	12.98 b	3.73 c
4	.06	2	.48	1.57 cdef	20.14 ab	7.10 a
5	.06	8	.48	.28 f	15.57 ab	5.25 abc
6	.06	.24	2	1.19 def	14.88 ab	6.86 ab
7	.06	.24	8	1 ef	16.45 ab	5.63 abc
8	2	2	2	3.26 abcde	14.92 ab	5.17 abc
9	2	8	2	4.93 a	15.38 ab	4.35 bc
10	8	2	2	4.16 ab	15.70 ab	5.15 abc
11	8	8	2	4.43 a	16.67 ab	3.54 c
12	2	2	8	3.68 abc	19.30 ab	6.77 ab
13	2	8	8	4.22 ab	16.18 ab	4.73 abc
14	8	2	8	3.50 abcd	16.10 ab	4.71 abc
15	8	8	8	4.23 ab	22.39 a	6.41 ab
Significance level			.01	.05	.01	

[1]Column means followed by the same letter do not differ significantly at the indicated significance level, according to Duncan's multiple range test.

Algal dry weights (table 3) were also affected by cation concentrations. Dry weights were always greater when Ca was added to the nutrient solution, either alone or in combination with Mg and Na, than when Ca was not added. When Mg was added alone, dry weights decreased as the Mg concentrations increased, but not when Ca concentrations were also increased. Na concentrations did not affect algal dry weights.

The interactive effects of the three cations are shown in figure 1. When the Ca concentration was 2 meq/L and the Na concentration was either 2 or 8 meq/L, the dry weights increased as the Mg concentration was increased from 2 to 8 meq/L. At a Na concentration of 8 meq/L, however, the respective dry weights were less than they were at 2 meq Na/L. The 8 meq Ca/L treatments negated effects of the high Na or high Mg treatments.

Within 2 or 3 days after the cultures were inoculated, some cell counts decreased to less than the 10^{-4} cells/ml inoculation rate; however, because sonification was used to shorten the algal chains while not separating filaments into single cells, cells were arranged in diffuse short chains so the counts were probably not as accurate as they were subsequently. Specific growth rate (table 4) varied among the treatments. At 8 meq/L Ca, with Na and Mg also added (treatments 10, 11, 14, and 15), the specific growth was maximum (μ_{max}) between days 3 and 5. In all but two other treatments (treatments 5 and 6), μ_{max} occurred between days 5 and 7. Thus, the high Ca level with added Mg and Na increased logarithmic growth rate whereas high Mg without added Ca or Na reduced it. The greatest μ_{max} was when Ca was added alone to 8 meq/L.

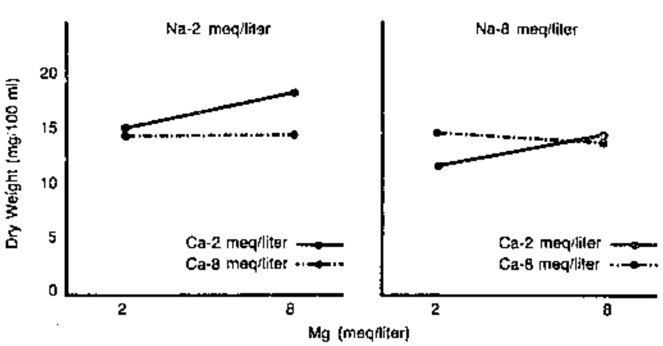

Figure 1.—Interactive effects of Ca, Mg, and Na on *Anabaena subcylindrica* dry weights.

Chlorella ellipsoidea. The cation concentrations and variations had little effect on either the final cell counts or the dry weights of this species (tables 2 and 3). There were no significant differences among the dry weights, and cell counts differed significantly only when Ca was added alone (treatments 2 and 3). Counts were significantly less than when the concentration of each cation was 8 meq/L (treatment 15).

Specific growth rates did differ, but the differences were not apparent until day 3 (table 4). Then, the cell counts ranged from 1×10^4 cells/ml for treatment 13 (2 meq/L Ca, 8 meq/L Mg, and 8 meq/L Na) to 6.5×10^4 cells/ml for the control (treatment 1). For all individual cation additions, μ_{max} occurred later than it did for the control treatment. When the cations were added in various combinations, the effects on μ_{max} were not definitive except for treatment 8, in which all three cation concentrations were 2 meq/L, when μ_{max} did not occur until between days 7 and 9.

Selenastrum capricornutum. Adding 8 meq/L Ca (treatment 3) and adding 8 meq/L Mg, 2 meq/L Na, and either 2 or 8 meq/L Ca (treatments 9 and 11), significantly reduced cell growth as compared with the control

Table 3.—*Dry weights of 3 algal species after 14 days, averages of 3 replications*

Treatment No.	Cation concentrations Ca	Mg	Na	Algal species *Anabaena subcylindrica*	*Chlorella ellipsoidea*	*Selenastrum capricornutum*
	Milliequivalents per liter			*Milligrams per 100 milliliters*		
1	0.06	0.24	0.48	6.75 d[1]	10.79	11.58 abc
2	2	.24	.48	12.50 b	13.92	13.25 ab
3	8	.24	.48	13.08 b	14.83	10.83 bcd
4	.06	2	.48	7.50 cd	15.75	14.83 a
5	.06	8	.48	1.75 e	17.58	10.33 bcd
6	.06	.24	2	4.83 de	14.85	10.08 bcd
7	.06	.24	8	6.33 de	14.33	8.92 cd
8	2	2	2	14.50 ab	15.44	12.08 abc
9	2	8	2	18.58 a	14.25	9.50 cd
10	8	2	2	15.42 ab	15.08	12.22 abc
11	8	8	2	14.67 ab	13.17	7.58 d
12	2	2	8	11.67 bc	15.17	10.06 bcd
13	2	8	8	13.92 ab	14.42	9.42 cd
14	8	2	8	14.67 ab	14.02	13.17 ab
15	8	8	8	13.58 b	15.50	13.25 ab
Significance level				.01	NS	.01

[1]Column means followed by the same letter do not differ significantly at the indicated significance level, according to Duncan's multiple range test.

Table 4.—*A comparison of specific growth rates of the 3 algal species, averages of 3 replications*

Treatment No.	Growth period	Algal species *Anabaena subcylindrica*	*Chlorella ellipsoidea*	*Selenastrum capricornutum*
	Days	*Days*$^{-1}$		
1	3-5	-0.14	1.14	0.93
	5-7	1.59	.83	.52
	7-9	.22	.34	.42
	9-12	.34	.17	.26
2	3-5	.68	.02	.69
	5-7	.90	1.29	.51
	7-9	.16	.56	.59
	9-12	.29	.06	.27
3	3-5	-.01	.57	.61
	5-7	2.43	1.18	.82
	7-9	.09	.37	.40
	9-12	.26	.14	.21
4	3-5	-.03	.39	.83
	5-7	1.13	1.36	.71
	7-9	.51	.36	.49
	9-12	.24	.25	.26
5	3-5	.27	.08	.26
	5-7	.28	1.43	.70
	7-9	.43	.50	.50
	9-12	.35	.27	.29
6	3-5	.51	.52	.61
	5-7	.53	1.30	.87
	7-9	.32	.68	.17
	9-12	.51	.12	.45
7	3-5	.27	.35	1.10
	5-7	1	1.07	.47
	7-9	.55	1.02	.49
	9-12	.01	.09	.24
8	3-5	.42	.26	.81
	5-7	.97	.17	.63
8 Con.	7-9	.35	1.32	.42
	9-12	.34	.14	.31
9	3-5	.65	.14	.55
	5-7	.55	1.38	.72
	7-9	.19	.60	.42
	9-12	.19	.15	.33
10	3-5	1.06	.98	.69
	5-7	.15	.71	.74
	7-9	.18	.16	.36
	9-12	.20	.26	.28
11	3-5	.81	.42	.48
	5-7	.40	1.26	.82
	7-9	.19	.52	.36
	9-12	.22	.16	.29
12	3-5	.77	1.13	1
	5-7	1	.85	.41
	7-9	.46	.18	.52
	9-12	.14	.25	.25
13	3-5	.83	1.42	.72
	5-7	1	.65	.52
	7-9	.44	.22	.52
	9-12	.21	.30	.27
14	3-5	1	.55	1.02
	5-7	.08	1.24	.54
	7-9	.30	.52	.45
	9-12	.25	.15	.23
15	3-5	.54	.46	.75
	5-7	.25	1.28	.64
	7-9	.22	.56	.45
	9-12	.21	.15	.24

treatment (table 2). Increasing either Mg or Na alone did not significantly effect cell counts, but increasing Na to 8 meq/L at any concentration of Ca and Mg eliminated cell count reductions.

Neither increasing Ca alone nor Na alone affected the dry weights (table 3). At 8 meq/L Mg (treatment 5), the dry weights were significantly lower than those at 2 meq/L Mg (treatment 4); however, neither differed significantly in dry weights from that for the control treatment. Only treatment 11 had significantly less dry weight than the control. Dry weights tended to decrease for all treatments with 8 meq/L Mg, and only the addition of both Ca and Na at 8 meq/L negated this trend.

As evidenced by the lack of crossing lines in figure 2, there were no Ca × Mg × Na interactions.

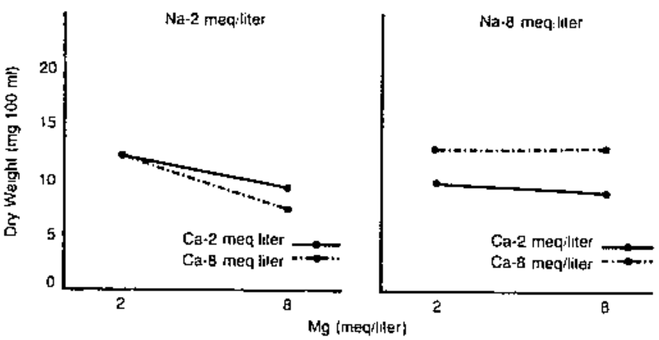

Figure 2—Interactive effects of Ca, Mg, and Na on *Selenastrum capricornutum* dry weights.

During the first 3 days of the study, growth rates among the 15 treatments were more similar for this species than they were for the other two (table 4). When either Ca or Mg concentrations alone were increased from 2 to 8 meq/L (treatments 2 through 5), the μ_{max} was delayed (at days 5 to 7 for the latter concentration and 3 to 5 for the former). The reverse was true for Na. When all three cations were added to 8 meq/L Ca or Mg; or both, and 2 meq/L Na (treatment 9, 10, and 11), μ_{max} was delayed until the 5 to 7 day period, but when Na was increased to 8 meq/L (treatments 12 through 15), μ_{max} occurred within 3 to 5 days.

Water Quality Data

Tables 5, 6, and 7 show the cation concentrations and electrical conductivities for the 85 lakes. Ca concentrations were available for all lakes. The available data for Mg (52 lakes) and Na (62 lakes) were fewer but still sufficient to evaluate the cation relationships to trophic state.

The Ca, Mg, and Na concentrations were usually indicative of the lake trophic state. Reid and Wood (*17*) presented a biological productivity scheme that was proposed in 1934 by W. Ohle, a German limnologist. In that scheme, lakes having Ca concentrations less than 10 mg/L were classified as "poor." I have considered that concentration as a Ca threshold value that, on an equivalent weight basis, is 0.5 meq/L. For comparison, Mg and Na were also evaluated using a threshold of 0.5 meq/L.

Fifty-two lakes had Ca concentrations less than 0.5 meq/L. Of those, 42 (81 percent) were classified as not eutrophic. The other 33 lakes had Ca concentrations of 0.5 meq/L or more, and 24 (72 percent) were eutrophic. Similar relationships were found for the Mg and Na threshold values. Of the 31 lakes that had Mg concentrations below the treshold, 23 (74 percent) were not eutrophic, and 17 of the 21 (81 percent) lakes having Mg

Table 5.—*Electrical conductivity (EC) and cation concentrations of 39 Florida lakes, December 1968. Compiled from Putnam et al.* (16)

Lake	EC	Ca	Mg	Na
	µmhos per centimeter	........*Milliequivalents per liter*........		
Eutrophic Group				
Lake Alice	533	3.54	—	0.70
Biven's Arm Lake	263	2.50	—	.65
Unnamed No. 20 (Still No. 21).	275	2.40	—	.65
Lake Hawthorne	185	1.65	—	.48
Lake Dora	335	1.52	1.17	.79
Lake Griffin	290	1.44	.79	.61
Lake Eustis	275	1.31	.88	.63
Lake Apopka	330	1.25	1.21	.51
Lake Kanapaha	166	.95	—	.47
Burnt Pond	67	.50	—	.28
Clear Lake	106	.50	—	.30
Lake Wauberg	59	.30	—	.41
Newnan's Lake	60	.20	—	.43
Mesotrophic Group				
Lake Harris	230	1.15	.50	.42
Unnamed No. 25	106	1.	—	.13
Lake Meta	86	.50	—	.30
Lake Lochloosa	90	.50	—	.42
Orange Lake	67	.30	—	.35
Lake Tuscawilla	55	.20	—	.26
Cooter Pond	63	.11	—	.25
Little Orange Lake	54	.11	—	.29
Unnamed No. 27	43	.10	—	.24
Lake Altho	49	.10	—	.31
Lake Elizabeth	38	.09	—	.23
Lake Moss Lee	43	.09	—	.21
Unnamed No. 10	44	.08	—	.29
Calf Pond (Trout Pond).	41	.08	—	.26
Lake Weir	135	.07	.26	.67
Lake Santa Fe	48	.06	—	.33
Lake Little Santa Fe.	50	.06	—	.30
Belville's Pond	38	.04	—	.27
Hickory Pond	39	.04	—	.26
Lake Mize	45	.04	—	.23
Lake Clearwater	33	.03	—	.23
Long Pond	16	.03	—	.11
Lake Jeggord	53	.02	—	.33
Watermelon Pond	32	.02	—	.20
Palatka Pond	22	.02	—	.13
Oligotrophic Group				
Still Pond	40	.05	—	.24

Note: Dashes indicate no data.

Table 6.—*Electrical conductivity (EC) and cation concentrations of 23 Connecticut lakes, Spring 1974. Compiled from Norvell and Frink* (13)[1]

Lake	EC	Ca	Mg	Na
	µmhos per centimeter	*Milliequivalents per liter*		
Eutrophic Group				
Lake Lillinonah	184	1.21	0.71	0.39
Lake Zoar	217	1.14	.68	.38
Wononscopomuc Lake	217	1.12	1.23	.25
Linsley Pond	241	.90	.51	.95
Cedar Pond	237	.80	.48	1.27
Beseck Lake	103	.51	.29	.32
Roseland Lake	73	.47	.14	.22
Bantam Lake	96	.45	.32	.27
Waramaug Lake	66	.31	.19	.25
Mesotrophic Group				
East Twin Lake	219	1.43	.88	.12
Mudge Pond	262	1.43	1.38	.18
Candlewood Lake	130	.72	.41	.28
Taunton Pond	106	.44	.23	.37
Terramuggus Lake	86	.29	.16	.48
Lake Pocotopaug	57	.19	.09	.27
Long Pond	51	.19	.10	.22
Gardner Lake	50	.18	.07	.27
Quassapaug Lake	46	.17	.11	.18
Shenipsit Lake	52	.16	.10	.23
Lake Hayward	39	.12	.08	.19
Pataganset Lake	63	.11	.09	.24
Oligotrophic Group				
Alexander Lake	27	.16	.05	.13
West Hill Pond	24	.15	.07	.12

[1]Cation data are fall 1973–summer 1974 averages; EC are for spring and summer only for most lakes.

concentrations of at least 0.5 meq/L were eutrophic. Fifty-two lakes had a Na concentration less than 0.5 meq/L, and 39 (75 percent) were not eutrophic. Only 10 lakes exceeded that threshold value, and 9 of them were eutrophic.

Electrical conductivity, a measure of cation concentration, was also related to lake trophic state. A threshold based on the concentrations of the three cations was not obvious; however, 27 of the 34 lakes with EC of at least 90 µmhos/cm were eutrophic and 40 of the 51 lakes with EC less than 90 µmhos/cm were either mesotrophic or oligotrophic.

Discussion

Lake systems are complex and classifying them by trophic state based on the concentrations of individual nutrients is difficult. Hooper (*8*), however, stated that because the concentrations of ions such as SO_4, Cl, K, and Ca have fewer seasonal fluctuations than do the different forms of nitrogen and phosphorus, they are more stable eutrophication indicators. The laboratory studies and the data gleaned from the literature showed the relationships of aqueous cation concentrations to lake trophic state and algal growth. Usually, the lake trophic state was related to concentration of one or more of the three cations, Ca, Mg, and Na. A concentration of 0.5 meq/L was a threshold above which the lakes were eutrophic. Because more lakes were classified not eutrophic than eutrophic, the lakes with cation concentrations below the threshold value are a better indication of the importance of that value. When each cation is considered independently, 81 percent of those with a Ca concentration less than 0.5 meq/L were not eutrophic. For Mg, the percentage was 74 and for Na it was 75. Of the 36 lakes in which the concentration of at least one of the cations exceeded 0.5 meq/L, 72 percent were eutrophic. Conversely, of the 49 lakes in which none of the three cation concentrations exceeded that threshold value, 84 percent were not eutrophic.

Based on those threshold values, all of the laboratory treatments except treatment 1 were eutrophic. With those eutrophic conditions, algal growth effects varied as the cation concentrations were varied. The specific effects of each cation on algal standing crop and growth rates cannot be readily determined from the laboratory studies because there were interactive effects among the three cations; however, differences among the three algal cultures and among the treatments within each culture were pronounced.

Table 7.—*Electrical conductivity (EC) and cation concentrations of 23 U.S. lakes, July 1971. Compiled from Miller et al.* (11)[1]

Lake	State	EC	Ca	Mg	Na
		µmhos per centimeter	*Milliequivalents per liter*		
Eutrophic Group					
Santee Reservoir No. 5	Calif.	1160	4.14	2.55	—
Herman	S.D.	616	3.69	3.29	—
Bigstone	—do—	555	2.89	2.88	—
Stone	Ind.	352	1.40	.91	—
Minnetonka	Minn.	273	1.35	1.23	—
Lansing	Mich.	284	1.30	1.35	—
Clear	Calif.	214	.75	1.02	—
Sallie	Minn.	319	.49	2.30	—
Mendota	Wis.	266	.46	2.14	—
Upper Klamath	Oreg.	107	.34	.26	—
Shagawa	Minn.	68	.34	.13	—
University	N.C.	87	.30	.19	—
Mesotrophic Group					
Tahoe	Calif.	92	.39	.18	—
Fall	Minn.	52	.21	.17	—
Burntside	—do—	34	.14	.07	—
Nebish	Wis.	66	.13	.14	—
Odell	Oreg.	37	.12	.07	—
Triangle	—do—	42	.11	.07	—
Castle	Calif.	28	.08	.16	—
Oligotrophic Group					
Michigan	Wis.	248	1.40	.87	—
Superior	Minn.	100	.61	.24	—
Crystal	Wis.	18	.06	.03	—
Waldo	Oreg.	6	.01	.01	—

[1]All samples were autoclaved and filtered except Bigstone, S.D., and Castle, Calif.
Note: Dashes indicate no data.

Cation additions greatly affected dry weights of the *A. subcylindrica* cultures, slightly affected those for *S. capricornutum*, and did not affect those for *C. ellipsoidea*. Differences in cell counts among the three cultures were not as pronounced as were differences in dry weights. The decreases in dry weight of *A. subcylindrica* when the Mg concentration was increased to 8 meq/L and the negligible increase from the Na additions both changed when Ca was added. At that point, dry weights increased over those for the control treatment. Trends in decreased dry weight values observed with the *S. capricornutum* did not occur when the Ca and Na concentrations were both 8 meq/L. In higher plant forms, Mg often partially substitutes for Ca in some physiological functions, but in these three algal species there was no evidence of this.

Na, which had little or no effect on algal growth when it was added individually, did affect the standing crop and the growth rates when Ca and Mg were also added. The cell count decreases observed in some *S. capricornutum* cultures were not observed when 8 meq/L Na was included. Conversely, for the *A. subcylindrica* cultures, the increase in cell counts when the Mg concentration was high and Ca was also added was mitigated somewhat when the Na concentration was also high.

In the *A. subcylindrica* cultures, none of the cell counts was significantly less than those of the control treatment. Conversely, none of the *S. capricornutum* cell counts was significantly greater than those of the control treatment. In treatments 9 and 11, where the cation concentrations were 2 meq/L Mg, 2 meq/L Na, and either 2 or 8 meq/L Ca, the *A. subcylindrica* cell counts were significantly greater than those of the control treatment; whereas, the *S. capricornutum* cell counts were less than those for the control.

At 8 meq/L Ca with Mg and Na added, μ_{max} occurred earlier for *A. subcylindrica* than it did for all except one other treatment. The delay in μ_{max} for *S. capricornutum* when Ca, Mg, or both were 8 meq/L was eliminated when the Na concentration was increased to 8 meq/L. Dickman (*3*), in a study of the effects of bicarbonate additions to a stream on algal growth, added $NaHCO_3$, which increased the Na concentration from 0.02 to 0.47 meq/L. That final concentration was about equal to the initial Na level in the laboratory studies. He observed large increases in the algal standing crop, which he attributed to the bicarbonate. In this study, however, the Na concentration probably was a salient factor, which affected the algal standing crop.

In a study of many algal genera, Moss (*12*) found that the monovalent to divalent cation ratio did not affect algal growth. Similarly, in the three genera used in the laboratory, these ratios had no effect on cell counts, dry weights, or specific growth rates. The observed effects were the results of changes in specific cation concentrations relative to the other cations. Also, there was no evidence that cation ratios were related to lake trophic state.

Neither the pH nor the ionic strength of the laboratory media affected algal growth. After 14 days, the pH values of the spiked treatments for the *A. subcylindrica* and *S. capricornutum* were within 0.3 to 0.5 pH units of the control treatment. For the *C. ellipsoidea* where little or no cation effects were observed, the pH varied from that of the control by up to 1.0. The ionic strength of the solutions ranged from 1×10^{-3} to 3×10^{-2} M, but no algal growth differences could be related to these variations.

Although the laboratory experiments did not show the cation effects in mixed algal cultures where algal excretion products might inhibit or stimulate other algae growth, they did show that the interactive effects of Ca, Mg, and Na can markedly affect algal growth even in eutrophic conditions. However, these effects were noticeably different among the three species. The highest Ca concentration tended to decrease *S. capricornutum* growth, but the highest Na concentration reversed this trend. Conversely, lower *A. subcylindrica* cell counts were not found when either Mg or Na was added to the cultures and 2 meq/L Ca was added.

When the concentrations of either Ca, Mg, or Na exceed 0.5 meq/L, lakes are usually eutrophic. In eutrophic waters, there are marked effects on algal growth as the concentration of one or more of those cations is varied. Because variations in Ca, Mg, and Na concentrations can affect algal growth, those cations should be evaluated in eutrophication problems of saline and hard water locations.

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