Submitted for publication in
Original: Journal of Wildlife Mgt.
cc: Fish Division
Education-Game
Institute for Fisheries Res.
Jas. Scully
R. C. Ball
T. F. Waters
Pigeon R. Trout Res. Sta.

February 12, 1957

Report No. 1502

Lime application to a soft-water, unproductive lake in northern Michigan

by

Thomas F. Waters

Michigan Department of Conservation

Vanderbilt, Michigan

and

Robert C. Ball

Department of Fisheries and Wildlife,

Michigan State University

East Lansing, Michigan

Thomas F. Waters
Pigeon River Trout Research Station
Vanderbilt, Michigan

Lime application to a soft-water, unproductive lake in northern Michigan

by

Thomas F. Waters

Michigan Department of Conservation

Vanderbilt, Michigan

and

Robert C. Ball

Department of Fisheries and Wildlife,

Michigan State University

East Lansing, Michigan

In the upper peninsula of Michigan, as well as in other northern glaciated regions, there are many colored, very soft-water lakes. It has been observed by many workers that this type of lake is relatively unproductive; a rough correlation between alkalinity and productivity can be inferred from the reports of Ball (1948), Moyle (1949), and others. From these observations the hypothesis follows that increasing the alkalinity through the application of liming compounds may increase productivity. Lime application has been used extensively in European carp ponds (Neess, 1949) and has been developed by soil scientists in terrestrial agriculture to extremely good advantage.

The development of a similar technique that would increase the productivity of the soft-water lakes in Michigan would be instrumental in enlarging the sport fishery resources of this region. The Hiawatha Nationál Forest, in the Upper Peninsula of Michigan, contains a large concentration of glacial lakes, a large proportion of which is composed of the soft-water, unproductive type. Although the national forest is a popular summer resort area, fishing pressure is still relatively light; however, in the event that demand for even more fishery resources develops in the future, these unproductive lakes may be able to bear a great deal more pressure, and supply a demand for greater resources, if made productive.

One of these lakes, Stoner Lake, in Alger and Delta counties, was the object of a biological survey conducted by the Michigan Department of Conservation in 1937. In an unpublished report of the survey (Roelofs, 1941), which described Stoner Lake as having an alkalinity of 6 p.p.m., largely a barren sand bottom, little vegetation, and a scarcity of fish-food organisms, it was suggested that an experimental program of lime application be conducted on Stoner Lake. This report is an account of the research upon Stoner Lake made by the Institute for Fisheries Research of the Michigan Department of Conservation in cooperation with Michigan State University, testing the feasibility of increasing productivity in a soft-water lake through the application of lime.

Acknowledgment is extended to Dr. Peter I. Tack, Chairman, Department of Fisheries and Wildlife, Michigan State University, for administrative assistance, to Dr. Don W. Hayne, Department of Zoology, Michigan State University, for advisory assistance with statistical treatment, to Dr. Paul H. Barrett, Department of Natural Science, Michigan State University, for assistance with chemical analyses, and to Mr. Merle G. Galbraith and other personnel from the Institute for Fisheries Research, for assistance with the lime application. The drawings were prepared by Mr. William L. Cristanelli. The study was financed by the Institute for Fisheries Research, by Michigan State University, and by a fellowship received from the National Science Foundation by the senior author.

Methods

In 1943, three tons of hydrated lime (calcium hydroxide) were applied to Stoner Lake. This application was apparently too small since no change in alkalinity of any significance was effected (E. W. Roelofs, personal communication).

In 1946, 20 tons of pebble-sized limestone (calcium carbonate) were applied to Stoner Lake (Ball, 1947). The limestone was distributed near the shore in shallow water over the barren sand bottom from a small boat. The alkalinity, which was 6 p.p.m. before the application, remained at the same concentration following the application; the following year (1947) chemical analysis of the water showed the alkalinity to have remained at 6 p.p.m., there having been no increase in alkalinity effected by either application.

Barrett (1951), following laboratory experiments involving the application of calcium carbonate to beakers containing mud and water from Stoner Lake, suggested that the failure of the limestone to change the pH of the lake may have been due to the adsorption of calcium by the organic matter of the lake. He recommended that sufficient hydrated lime, which is more soluble than limestone, be applied to alkalinize the water and also to neutralize the top one centimeter of mud, and sufficient limestone be applied for slow dissolution to offset further adsorption by the mud. On the basis of these recommendations and the area and volume data from Stoner Lake, the suggested applications were calculated to total 8.5 tons of hydrated lime and 2 tons of crushed limestone.

In 1952, a more intensive study was initiated on Stoner Lake, continuing through the four summers of 1952, 1953, 1954, and 1955. This report is concerned primarily with the results of this study.

The conditions in Stoner Lake were found in 1952 to be essentially the same as determined by the biological survey of 1937; alkalinity was about 6 p.p.m., the pH was slightly acid, and the water was colored; little aquatic vegetation was found. Stoner Lake is about three-fourths of a mile long, about one-fourth mile wide and has two depressions with a shallow area between; the two depressions, with a maximum depth of about 20 feet, have pulpy peat as the bottom material, while the shallower areas are largely of barren sand bottom. The surface area, from a map constructed in 1952, was determined to be about 90 acres. Stoner Lake was not observed to stratify thermally. The fish population was composed primarily of stunted yellow perch (Perca flavescens), ranging in size to about five inches and in age to five years; a smaller population of larger yellow perch, apparently cannibalistic, was also present; other species found were common white suckers (Catostomus commersoni commersoni), bluegills (Lepomis macrochirus macrochirus), and mudminnows (Umbra limi).

The studies initiated in 1952 consisted of periodical sampling of chemical conditions relating to alkalinity, dissolved oxygen and carbon dioxide, pH, total hardness, and conductivity, and physical conditions of temperature, light penetration, and color. Net plankton samples were collected during the same periods by means of a Juday trap. These were taken at a depth of three feet from two sampling stations, one in each lake depression. The volume estimations of the samples were made by determination of the volume of the cells of the various species and cell counts.

Samples from the bottom fauna were collected periodically from two sampling stations, one in each depression, with an Ekman dredge; these samples were analyzed volumetrically by the water-displacement method. The collections of fish samples for growth rate determination were made with gill nets, a bag seine, and by angling; these collections were made at irregular times without a formal program of sampling. The collection of stunted yellow perch was made primarily by angling during 1952, but it soon became apparent that this extremely large population of stunted fish represented the group of primary interest, and in subsequent years a bag seine was used to facilitate the collection of samples from this group.

Following initial chemical analyses of the lake water in the early summer of 1952, an application of 8.5 tons of hydrated lime and 2 tons of crushed limestone was made. The materials were distributed around the shoreline of the lake in shallow water over sand bottom from a small boat.

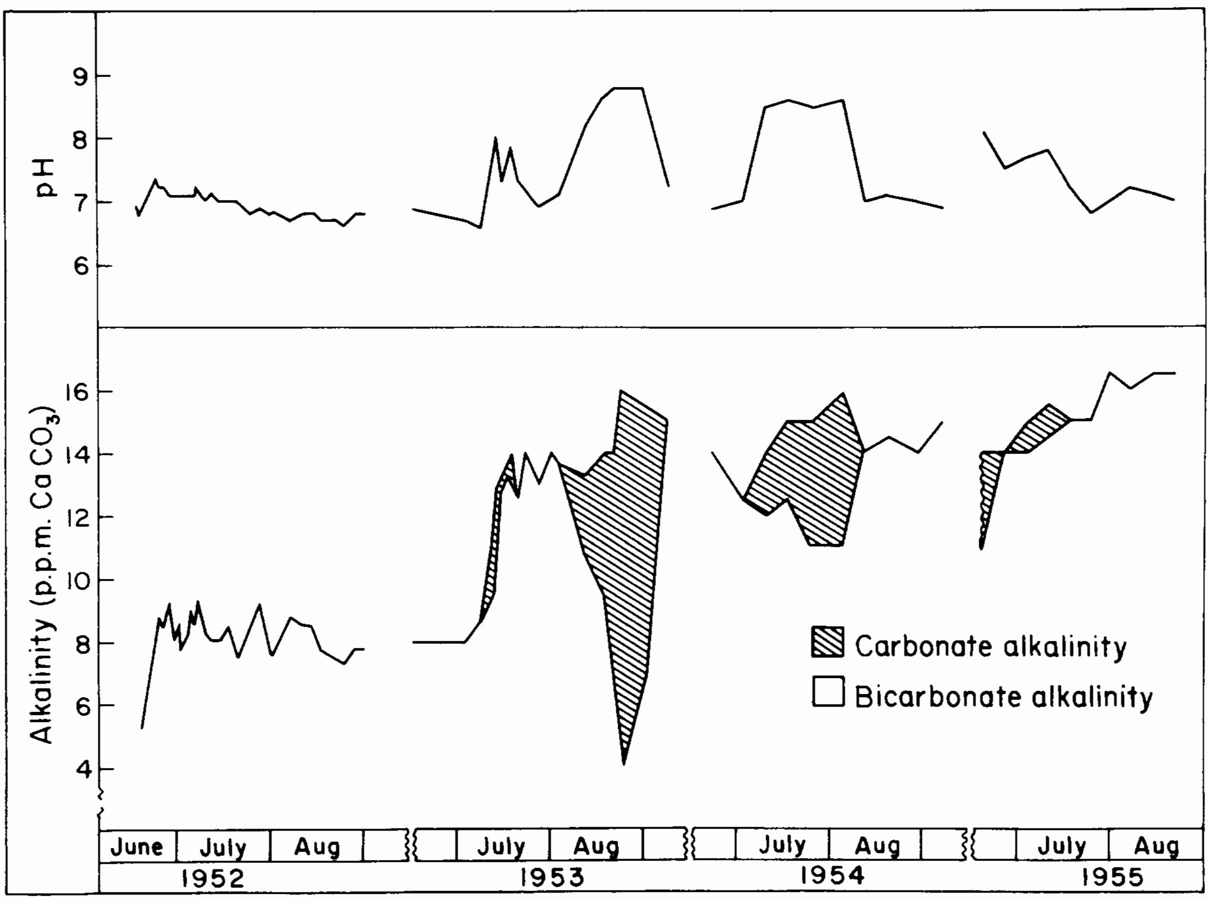
It was apparent, following this 1952 application, that the rate of application was still too small, and another application, of 20 tons of hydrated lime, was made in the early summer of 1953. This application was made in a manner similar to that employed in 1952.

Chemical effects of lime application

Figure 1 shows the changes in alkalinity and pH, at a depth of three feet, for the four years of periodical sampling. Following the 1952 lime application, the alkalinity increased from approximately 6 p.p.m. to 9 p.p.m. Since the theoretical increase, calculated from the materials applied and the volume of the lake, was about 15 p.p.m., the increase in alkalinity indicates an efficiency of about 20 percent. Immediately following the application the concentration of dissolved carbon dioxide decreased slightly, but no carbonate alkalinity appeared; the pH rose following the application, but descended again to near pre-application levels, due to the reaction of carbon dioxide with the calcium hydroxide.

Following the 1953 application, the alkalinity increased from approximately 8 p.p.m. to 14 p.p.m., again indicating an efficiency of about 20 percent; some carbonate alkalinity appeared with the corresponding loss of carbon dioxide. The pH rose following the application, but descended again to near pre-application levels.

Fig. 1. Alkalinity and pH in Stoner Lake, 1952-1955.



pH
9
8
7
6
Alkalinity (p.p.m. $CaCO_3$)
16
14
12
10
8
6
4
Carbonate alkalinity
Bicarbonate alkalinity
June
July
Aug
1952
July
Aug
1953
July
Aug
1954
July
Aug
1955

During the summers of 1953, 1954, and 1955, several plankton blooms occurred which had marked effects upon the pH and the form of alkalinity due to the extraction of carbon dioxide from the bicarbonates. These effects are shown in Figure 1 as the appearance of carbonate alkalinity and the corresponding rise of the pH at the times of plankton bloom. In each case, following the subsidence of the bloom, the alkalinity returned entirely to the bicarbonate form and the pH descended again to approximately neutral.

In addition to the data shown in Figure 1, Stoner Lake was checked in the early spring of 1956 and again in the autumn of 1956, and the alkalinity was found upon each occasion to have remained at 15 p.p.m.

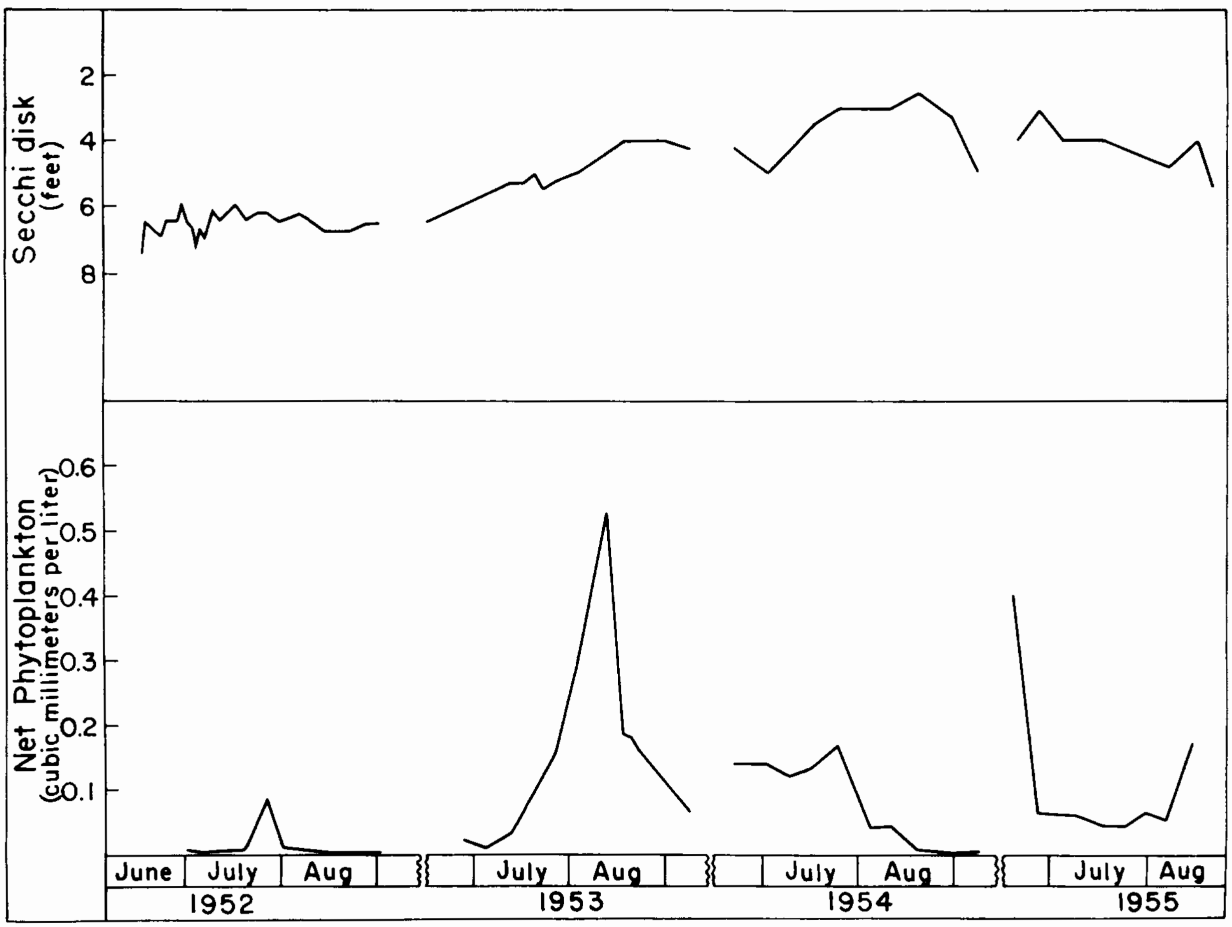
No direct effects of the lime applications upon the concentration of dissolved oxygen were observed. Total hardness and conductivity followed the same trends as total alkalinity. There were no changes in color attributable to the lime applications.

Plankton response

Figure 2 shows the average volume of net phytoplankton for the four years of intensive study; each point represents the average of four Juday plankton trap samples, two samples having been taken from each of the two sampling stations. As further indications of plankton abundance, light penetration data, as obtained with a Secchi disk, are included in Figure 2.

During 1952 the standing crop of net phytoplankton was exceptionally

Fig. 2. Secchi disk readings and average volume of net phytoplankton in Stoner Lake, 1952-1955.



Secchi disk
(feet)
2
4
6
8
Net Phytoplankton
(cubic millimeters per liter)
0.6
0.5
0.4
0.3
0.2
0.1
June
July
Aug
1952
July
Aug
1953
July
Aug
1954
July
Aug
1955

low except for that on one sampling date when a temporary increase, due principally to Dinobryon sertularia Ehrenberg, occurred. Secchi disk readings averaged about six feet, with no effects of the Dinobryon pulse observed.

During 1953, following the lime application, an intensive plankton bloom occurred, being primarily the result of increases in standing crop of Dictyosphaerium Ehrenbergianum Naegeli, the colonies of which were retained by the plankton trap net (number 20 silk bolting cloth). This bloom was responsible for the rise in pH and appearance of carbonate alkalinity due to carbon dioxide extraction discussed in relation to Figure 1, and also for the corresponding decrease in light penetration.

During 1954, another intensive plankton bloom occurred which was responsible for the chemical changes shown in Figure 1 and for the further reduction of light penetration. This bloom does not appear among the net plankton data to the proper degree because it was composed primarily of Microcystis aeruginosa Kuetzing, the cells of which were too small to be retained by the plankton trap net, and secondarily of Anabaena Viguieri Denis and Fremy which was retained by the net.

During 1955, a plankton bloom consisting of Anabaena Viguieri was in progress when sampling commenced in the spring, which is shown in Figure 2 and which was responsible for the chemical conditions shown in Figure 1 for this date. Shortly after the subsidence of this bloom, another was initiated composed primarily of _Microcystis_; the _Microcystis_ bloom again does not appear among the net plankton data because the cells were too small to be retained by the plankton trap net; however, the chemical effects of the _Microcystis_ bloom are reflected among the data of Figure 1 showing the appearance of carbonate alkalinity and a rise in pH. The small increase in standing crop shown in Figure 2 at the close of the summer sampling season was composed of _Anabaena Viguieri_, but apparently was not extensive enough to cause any chemical changes.

The volume determinations of zooplankton were made in a manner similar to the net phytoplankton, but no pertinent changes in standing crop were observed through the four years of sampling.

During the last two years of sampling (1954 and 1955) it was observed that one species of aquatic plant, _Myriophyllum tenellum_ Bigelow, had increased markedly over much of the sand bottom. During 1955, the _Myriophyllum_ invaded one of the bottom fauna sampling stations, whereupon the average standing crop of bottom organisms increased about ten-fold. Extreme variation among the Ekman dredge samples was encountered, however, apparently due to the failure of the Ekman dredge to cut consistently through the _Myriophyllum_ mat. Probably the standing crop of bottom organisms increased in those areas where the _Myriophyllum_ increased, but no quantitative data were collected relating to aquatic plants, and it was difficult to draw any valid inference from the bottom fauna data.

Growth rate of fish

Since the stunted yellow perch population was the group of primary interest, and since the abundance of the other species was so low as to preclude the collection of adequate samples, the analysis of growth rate was limited to the stunted perch.

Table 1 shows the age distribution of the fish in the stunted perch samples. As mentioned previously, the collections from this group were made by angling during 1952; a selectivity of the collecting method against the smaller fish may have caused the low numbers of age group I to appear in the 1952 samples, but bag seine samples collected the following year also showed a scarcity of age-group-I fish. Through the next three years it became apparent that age-group-I fish entered the samples in much greater proportion and the numbers of age-group-III fish decreased. This would appear to indicate that, since the bag seine was highly selective as to the size of fish collected, an increase in growth occurred, causing the age-group-I fish to enter the bag seine samples in greater numbers, a corresponding decrease in the proportion of age-group-III fish resulting; however, a conclusion of increased growth rate on this basis would probably be presumptive.

In an analysis of growth rate, an attempt was made to compare yearly growth increments for each age group represented in the samples. Difficulty was encountered, however, with both age-group-I and -III fish due to the small numbers in the samples during the early years for age-group-I and later years for age-group-III. Consequently, only the age-group-II fish were present in the samples for all years in large enough numbers

Table 1.--Numbers of yellow perch of different age groups collected in Stoner Lake, 1952-1956

Age group	Year of collection				
	1952	1953	1954	1955	1956
I	2	5	27	63	59
II	13	22	22	15	39
III	24	21	6	11	2

for growth analysis. Table 2 shows the average calculated growth for the first and second years of life for the age-group-II fish. It would appear that for the first year of life, progressive increases in growth occurred; however, the differences among the first three years are not statistically significant, and a significant increase occurs only between the samples of 1954 and 1955; the greater growth during the first year of life, observed among the 1955 collections, was made during 1953. For the second year of life the increase occurs between the samples of 1953 and 1954; the greater growth during the second year of life, observed among the 1954 collections, was made also during 1953. In other words, an increase in growth occurred during 1953 for both years of life, which was also the year during which the greatest increase in standing crop of net phytoplankton occurred.

In order to make a comparison of the growth during the first year of life of those fish that obtained their growth before 1953 (i.e., before the effects of lime application became apparent) with those that made their growth during 1953 and later (after lime application), the samples for 1952, 1953, and 1954 were averaged and compared with the average of the 1955 and 1956 samples. The former group averaged 2.77 inches, the latter 3.06 inches; the difference was highly significant when tested by the t-test. Similarly, for the growth during the second year of life, a "before-and-after" comparison was made between the average of the samples of 1952 and 1953 (growth obtained before 1953) and the average of the

Table 2.--Average calculated increments in total length (inches) for growth among two-year-old yellow perch in Stoner Lake, 1952-1956

[Standard deviations in parentheses]

Year of growth	Year of collection				
	1952	1953	1954	1955	1956
1	2.75	2.70	2.85	3.04	3.07
	(0.336)	(0.267)	(0.228)	(0.213)	(0.167)
2	0.85	0.83	0.91	0.91	0.91
	(0.279)	(0.234)	(0.203)	(0.231)	(0.155)

samples of 1954, 1955, and 1956 (growth obtained during 1953 and later); the former averaged 0.84 inches and the latter 0.91 inches; this difference was significant only at a level slightly less than 90 percent. This might indicate that the young-of-the-year perch utilized the more abundant fish-food to a greater extent than did the perch in their second year of life.

Relationship between alkalinity and productivity

Several mechanisms by which productivity may be increased in a soft-water lake through lime application have been suggested by various workers. Neess (1949), in a review of pond fertilization in Europe, suggested that lime would be advantageous to the availability of nutrients by reducing the acidity which would otherwise retard decomposition of organic matter and the mineralization of nutrients, that the calcium in lime would displace other nutrients from organic colloidal systems, and that lime increases the ability of water to store carbon dioxide. Hasler, Brynildson, and Helm (1951) added to this list the flocculation and precipitation of organic colloidal color of bog lakes, thus permitting deeper penetration of light and increasing the trophogenic zone. They were able to clear the color from bog lakes in Wisconsin, thus improving oxygen conditions for trout in deeper, cooler strata of water. Waters (in press) demonstrated the release of phosphorus from bog lake soils following the application of hydrated lime and presented data which indicate that the immediately available carbon dioxide (the sum of free carbon dioxide, carbon dioxide available in bicarbonates, and carbon dioxide produced by decomposition, atmospheric absorption, etc., over a given period of time) may limit the extent of plankton blooms; lime application increases the immediately available carbon dioxide by increasing the concentration of bicarbonates; i.e., by increasing the ability of the water to store carbon dioxide.

Thus, from improved nutrient availability to increased phytoplankton production to increased production of fish-food organisms, may be the sequence of effects following lime application. In Stoner Lake, one species of aquatic plant, Myriophyllum tenellum, enlarged its range, and, although the meager quantitative data available do not prove an increased standing crop of bottom organisms, there were some indications that the bottom fauna was increased in those areas where the Myriophyllum increased. In Stoner Lake, no increases in zooplankton were observed; however, in two bog lakes to which lime was applied (Waters, op. cit.) the standing crop of zooplankton increased following lime application. It is suggested that in Stoner Lake, the zooplankton population, under the heavy predation of an extremely large population of badly stunted fish, may have been already at the "threshold of security," and that an increase in zooplankton production was immediately absorbed by the perch through predation. A limited study of stomach samples collected during the years following lime application indicated that zooplankton was the principal item of diet among the young-of-the-year perch.

It was tentatively concluded that biological productivity was increased in Stoner Lake, apparently the result of lime application. It should be pointed out, however, that despite the increased growth rate of fish, the majority of yellow perch in Stoner Lake remain badly stunted, though slightly less so than before. The effect of the lime application upon the yield to the angler is probably negligible, since the level of stunting has only been moved up slightly. Stunting remains because of the extremely unbalanced fish population, and in a proper management program of Stoner Lake there should be included the reduction of yellow perch and the introduction of a predator species. The small change in growth that the lime application apparently effected, however, probably reflects, in view of what was obviously an extremely large population, a considerable increase in the capacity of the lake to produce fish food.

Summary

Lime application was made to Stoner Lake, in the Upper Peninsula of Michigan, to test the hypothesis that increasing the alkalinity of a soft-water, unproductive lake would increase biological productivity. A small application of hydrated lime and an application of crushed limestone failed to increase the alkalinity, while larger applications of hydrated lime increased the alkalinity from 6 p.p.m. to 15 p.p.m. During a four-year study of limnological conditions following the application of hydrated lime several extensive phytoplankton blooms were observed which caused the appearance of carbonate alkalinity and the corresponding rise in pH due to the extraction of

carbon dioxide by the phytoplankton. One species of aquatic plant, *Myriophyllum tenellum*, was observed to increase markedly over previously barren sand bottom, and the standing crop of bottom organisms increased at one sampling station which had been invaded by the *Myriophyllum*. The growth rate of stunted two-year-old yellow perch increased significantly.

Literature cited

Ball, Robert C. 1947. Report on Stoner Lake, Alger-Delta County, Michigan. Unpublished report, 2 pp.

Ball, Robert C. 1948. A summary of experiments in Michigan lakes on the elimination of fish populations with rotenone, 1934-1942. Trans. Amer. Fish. Soc., 75(1945):139-146.

Barrett, P. H. 1951. Further studies on the feasibility of artificial alkalization of Stoner Lake, Michigan. Mich. Inst. for Fish. Res., Rpt. No. 1320, unpublished, 4 pp.

Hasler, Arthur D., O. M. Brynildson, and William T. Helm. 1951. Improving conditions for fish in brown-water bog lakes by alkalization. Jour. Wildl. Mgt., 15(4):347-352.

Moyle, John B. 1949. Some indices of lake productivity. Trans. Amer. Fish. Soc., 76(1946):322-334.

Neess, John C. 1949. Development and status of pond fertilization in central Europe. Trans. Amer. Fish. Soc., 76(1946):335-358.

Roelofs, E. W. 1941. Fisheries survey of Long and Bass lakes, Alger County; and Round and Stoner lakes, Alger and Delta counties. Mich. Inst. for Fish. Res., Rpt. No. 713, unpublished, 13 pp.

Waters, Thomas F. The effects of lime application to acid bog lakes in northern Michigan. Trans. Amer. Fish. Soc. (in press).