EXPERIMENTAL USE OF LIME IN TREATING A COLORED, SOFT-WATER LAKE IN MICHIGAN

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Thomas Frank Waters

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This is to certify that the

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EXPERIMENTAL USE OF LIME IN TREATING A COLORED, SOFT-WATER LAKE IN MICHIGAN

by

Thomas Frank Waters

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INTRODUCTION

Since the early times of wildlife management, which first took the course of protection of life and property against the native animal species, its evolution has progressed with an attempt to keep pace with changing attitudes and needs of the population. The utilization of fish and game for purposes of sport and recreation began early enough. Today, with more leisure time and swifter transportation available, an ever-increasing fishing and hunting population is seeking recreation in a wildlife resource that is constantly dwindling, and the attainment of satisfactory sport becomes more and more difficult. The contemporary stage of management development--habitat improvement--has found expression in many phases of fisheries management. One of the most fundamental of these is the attack upon the very base of an aquatic community: the chemical constituents of the water--the bottom of the "food pyramid."

Lake fertilization

Fertilization of lakes has been subjected to experimentation for some time but is a recent technique when compared to modern methods in terrestrial agriculture. In the south, Smith and Swingle (1940), among others, have shown fertilization to produce increases in lake and pond production. Realizing that climates different from those existing in the south may have different effects upon the results of fertilization, experimentation has been carried out in Michigan by Ball and Tanner (1951), and in other states which are subjected to severe weather conditions by others, with varying (and sometimes deleterious) results. An increasing popularity of farm fish ponds throughout the country has resulted in increased research along this line. Both organic (cottonseed meal, soy bean meal, animal manure) and commercial, inorganic fertilizer (varying ratios of nitrogen, phosphorus and potassium) have been used. The organic fertilizers supply nutrients in the form of proteins, carbohydrates, and vitamins, in addition to inorganic nutrients, while commercial types, supplying only the inorganic, must rely upon the photosynthetic levels of the food chain to produce food for higher organisms. Although most results show the inorganic fertilizer to be the more effective, both types are used with the purpose of supplying specific nutrients where the lack of those nutrients is a limiting factor upon the production and growth of the food-producing levels of the food chain.

The calcium-deficient lake

A method of fertilization which has received little attention as yet, however, is the application of lime to the calcium-deficient lake, a type which is common in the northern, forested regions of Michigan and Wisconsin, areas which are receiving more and more fishing pressure from vacationing tourists each year.

The use of lime as fertilizer has been practiced in Europe to produce increased yields in pond-culture of carp (Neess, 1949). In Wisconsin, Juday and Schloemer (1938) used lime in conjunction with other inorganic fertilizers with no apparent immediate effect upon the abundance of plankton. In a somewhat different aspect, lime and basic slag are sometimes used with other fertilizers to offset the acidity caused by the decomposition of ammonium salts when used as fertilizers (Compton, 1943, and Smith and Swingle, 1939). Lime as a direct treatment of calcium-deficient lakes has been used in this country by Hasler <u>et. al.</u> (1951) in Wisconsin, whose work was concerned with the development of acid bog lakes for trout production.

In his review of fertilization in Europe, Neess (1949) reports that lime will flocculate organic colloids and, by reducing their adsorptive capacity, release nutrients into the water. He also reports that bacterial decomposition in acid, peat soils is low, and in such a medium desired nutrients accumulate in an undesirable form; the addition of lime results in a more alkaline condition of the soil. Neess also brings out that with the addition of lime, the supply of carbon dioxide available to plants in the form of bicarbonates would be increased.

Hasler et. al. (1951) postulated that the application of calcium compounds would (1) clear the colored water, by means of the calcium flocculating and precipitating humic colloids causing the color, and increase the trophogenic zone; (2) increase bacterial decomposition of the bottom soils, by offering a more alkaline medium; and (3) increase the carbon dioxide available to plants in the form of bicarbonates. The results of their study upon two small bog lakes of about 8.5 acres each, showed an increase in the bicarbonate alkalinity, a higher pH, and a marked clearing of color.

In addition to the bog-type lakes which Hasler and his co-workers used, many lakes abound in these northern regions which characteristically are bordered by regular shorelines of hard sand bottom, are exceptionally low in bicarbonate alkalinity, and have a high color which gives the effect of "tea-colored" water. This type of lake, similar to those described as soft-water "seepage" lakes by Juday et. al. (1935) and Prescott (1951), is well known as a poor producer. A paucity of nutrients, acid conditions and a shallow trophogenic zone combine to keep production at a low level. With no inlets and a source of water which must seep through sterile glacial sands or drain from the acid podsol soils characteristic of this region, these lakes receive little in the form of carbonates from the adjoining lands.

To study the possibilities of improving these particular fishery resources the Michigan Institute for Fisheries Research, in cooperation with Michigan State College, has initiated a program of research on the alkalization of one such calcium-deficient lake in the upper peninsula of Michigan. The term "alkalization" is here used as being synonymous with "lime application," and is not meant to imply that the water is necessarily made more alkaline, even though such an effect is to be expected; the term "alkalinization" is reserved for the purpose of denoting an actual increase of alkalinity.

This report is concerned with the first year's results of the alkalization program.

Lake description

The lake used for this experiment was Stoner Lake, located in the Hiawatha National Forest in the upper peninsula of Michigan, Alger and Delta Counties. It is essentially a two-basin lake, approximately three-quarters of a mile long. While a previous survey indicated an area of 75 acres, measurements made July 21, 1952, showed the open water area to be 85 acres, and marshes with depths of water up to two feet extended the area to about 95 acres (Figure 1). A rise in lake level was felt to be the factor accounting for the increase in area. Its maximum depth was slightly over 20 feet, while its average depth was about 6.5 feet. A hard sand bottom characterized the entire shore line out to a depth of about 10 feet, while the deeper portions of each basin were found to be partially filled with an organic soil of a type classified by Roelofs (1944) as pulpy peat.

The area immediately surrounding the lake was of a forested

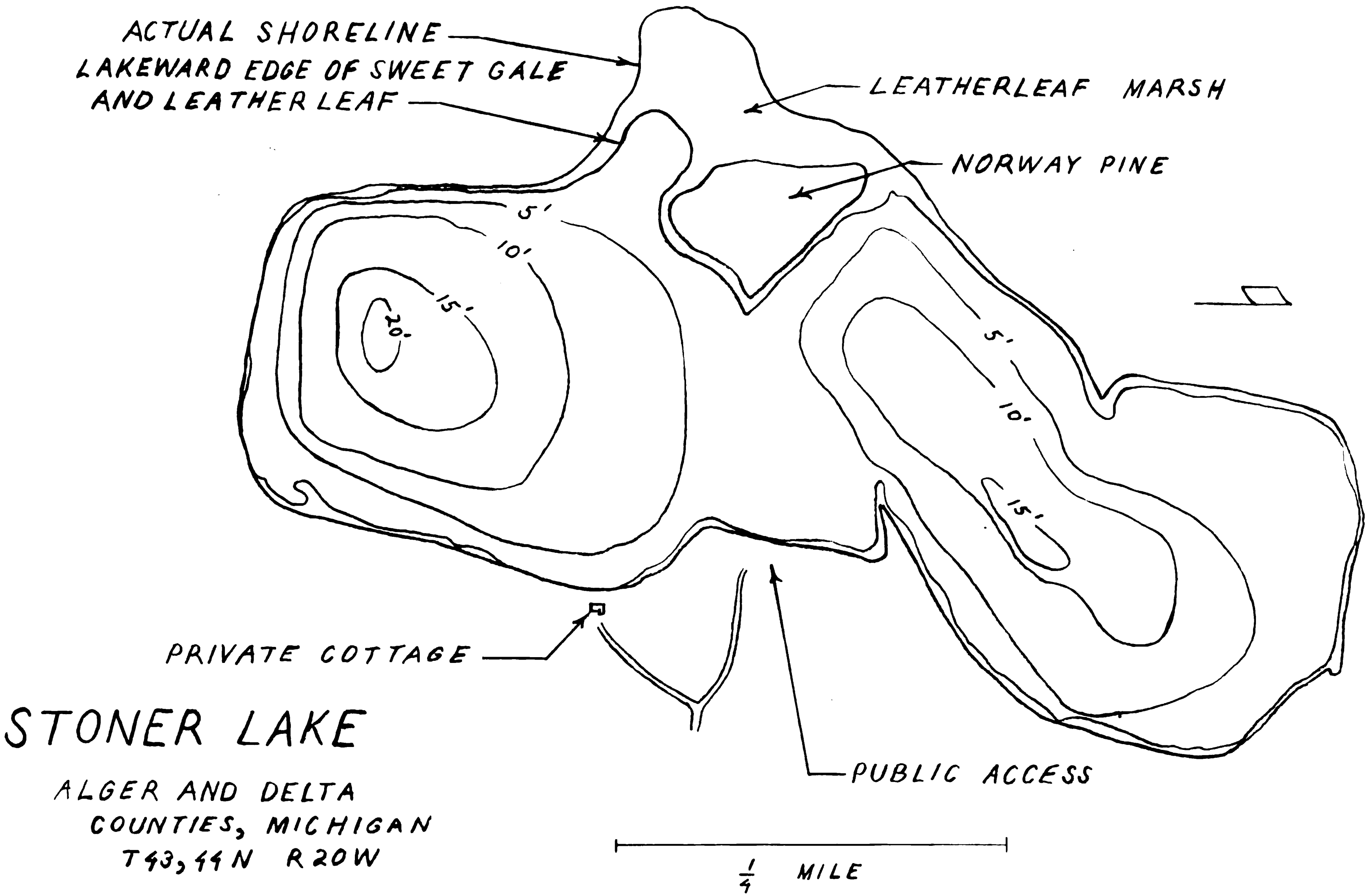


FIGURE 1. MAP OF STONER LAKE SHOWING NATURE OF SHORELINES AND BOTTOM CONTOURS.

nature, hemlock, maple and birch being predominant. In the lake itself, higher aquatic plants were scarce, the major ones being Eleocharis, Juncus and Scirpus spp. Leatherleaf (Chamaedaphne calyculata) and sweet gale (Myrica Gale) lined the entire shoreline, and also made up the shallow marshes mentioned above (Plates I, II, and III).

The fish population was made up of yellow perch (Perca flavescens), common white suckers (Catastomus commersonnii commersonnii), and bluegills (Lepomis macrochirus). Yellow perch were in great numbers and showed evidence of stunting.

Water temperature at the surface reached a maximum of 76°F., and bottom temperature a maximum of 69°F. during the summer; the formation of a thermocline was never observed. The water was highly colored, giving the characteristic "tea-colored" appearance.

Stoner Lake is a pit lake, located in the outwash plain of the Munising moraine to the north, which was described by Bergquist (1936). The lake lies in a shallow centripetal basin, and there is no inlet nor outlet. The surrounding land was privately owned except for a small public access point owned by the U. S. Forest Service from which operations were carried out and which was accessible by road. Utilization of the lake for recreational purposes was slight, only two parties of fishermen having visited the lake during the time of the experiment (June 11 to September 4).

History of research and management

Previous to the beginning of this experiment two attempts to alkalinize Stoner Lake had been made. The first, made in July, 1943, consisted of the application of three tons of hydrated lime by the Michigan Institute for Fisheries Research. The second was in August, 1946, when Ball (1947) applied 20 tons of pebble-sized crushed limestone. Chemical analysis of the water before and after the latter

Plate I. The shallow, sand-bottom bay partly encroached upon by leatherleaf.

Plate II. Showing the extent of leatherleaf encroachment upon the bay.

Plate III. Leatherleaf marshes. The bay was the only portion of the lake productive of aquatic vegetation.

application indicated a bicarbonate alkalinity of 6 p. p. m. which did not change after application, despite observations made at the time that the limestone, spread upon the sand portions of the bottom, had apparently dissolved within a few days after application. Ball also indicated that at this time aquatic vegetation had a soft and leathery consistency and that beds of vegetation were sparse. A visit to Stoner Lake in July of the following year showed the bicarbonate alkalinity to have undergone no change and the consistency of the aquatic plants similar to the previous year, but a slight increase in the vegetation beds was observed.

In 1950, Paul H. Barrett (in lett.) pointed out that organic soils exhibit the property of base-exchange, whereby cations would be adsorbed to the surface of the soil particles; in an attempt to alkalinize the water enough additional calcium must be added to neutralize the adsorptive properties of the bottom soils.

In 1951, pulpy peat samples were collected from Stoner Lake and used in laboratory experiments at Michigan State College designed to study the effects of calcium adsorption by these bottom deposits (Barrett, 1952). From the laboratory experiments, Barrett showed that more than the top centimeter is involved in the adsorptive process, and recommended that enough calcium compounds be applied to neutralize the top three centimeters. Hydrated lime, being much more soluble than limestone, would give a faster reaction and its effects more easily detected than those of limestone. (It may be that the effects of the limestone applied by Ball in 1946 were not detectable because the rate of adsorption by the organic soils equalled or exceeded the rate of dissolution.) Upon the basis of these facts and the results of the laboratory experiments on the pulpy peat, Barrett recommended the application of hydrated lime ($Ca(OH)_2$) at the rate of 20 pounds per acre-foot, calculated to increase the alkalinity 10 p. p. m.; 22.5 pounds hydrated lime per acre-centimeter to neutralize the top centimeter of pulpy peat; and 30.6 pounds crushed limestone ($CaCO_3$) per acre-centimeter for slow dissolution to offset adsorption by two additional centimeters of soil.

METHODS AND MATERIALS

Application of calcium compounds

It was decided to apply to Stoner Lake hydrated lime and limestone at the above rates recommended by Barrett. In computing the amounts to be used, an area of 75 acres and an average depth of 10 feet were used, giving a volume of 750 acre-feet. Using the above rates of application, the amounts used were 8.5 tons hydrated lime and two tons finely ground limestone. These materials were purchased from Haviland Products Company, Grand Rapids, Michigan, at a cost of $35 per ton for hydrated lime and $30 per ton for limestone, with the total cost amounting to $357. The hydrated lime was packaged in 50-pound bags, the limestone in 80-pound bags.

These materials were applied to Stoner Lake on June 20 and 21, 1952, following a limited chemical survey. The unopened bags were carried out with a rowboat, slit open in the center of the bag and released from the side of the boat (Plate IV). The material was allowed to settle where released and to dissolve and diffuse. The bags were released only over hard sand bottom along all shores and in the central portion between the two basins (Figure 2), care being taken not to release any over pulpy peat bottom, where the material would have sunk into the pulpy peat and its effects been lost to the water.

Plate IV. Method of lime application. All calcium compounds were released over sand bottom in shallow water.


CHEMICAL
CALSITE
CALCIUM
LIME
PRODUCTS CO.

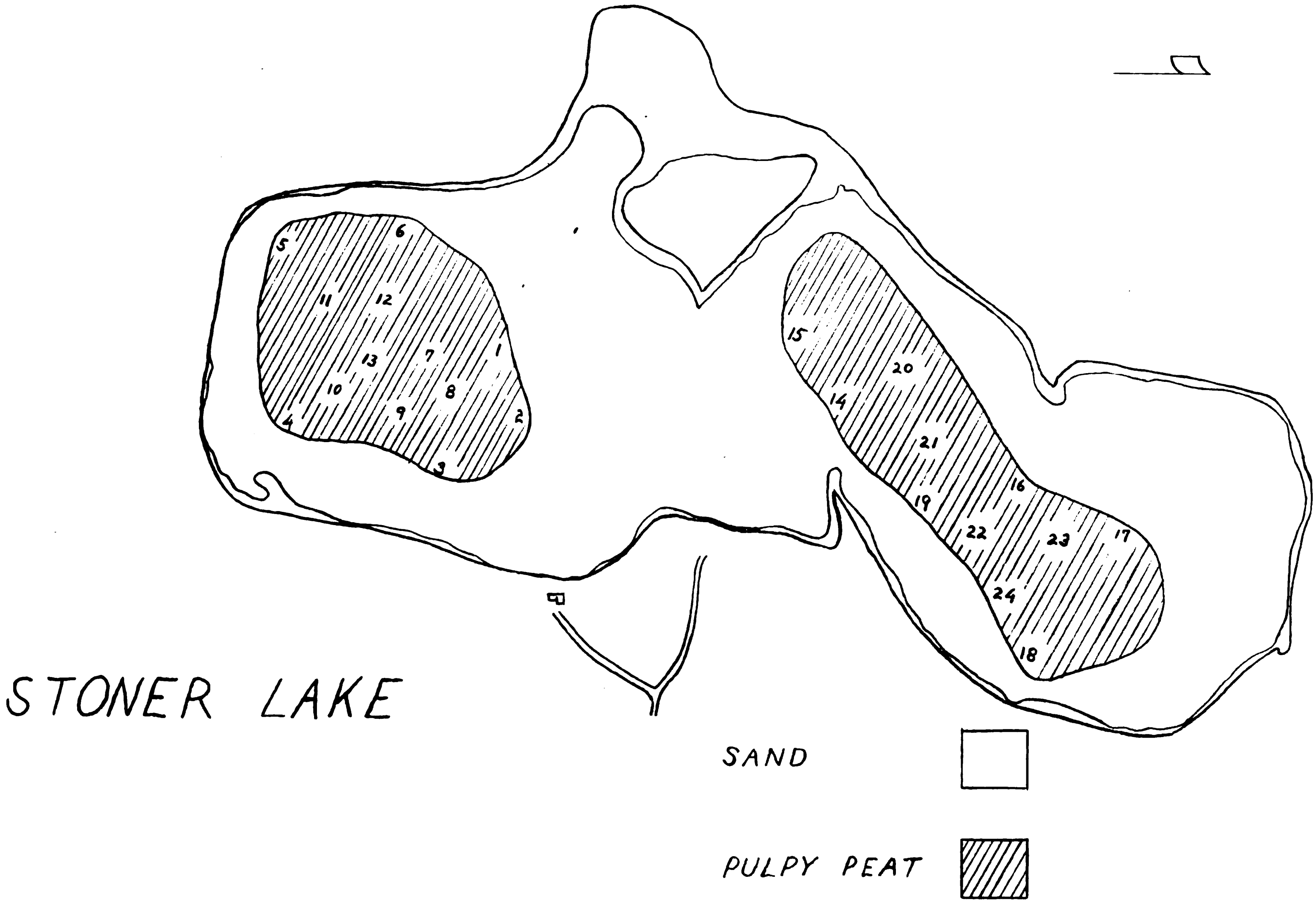


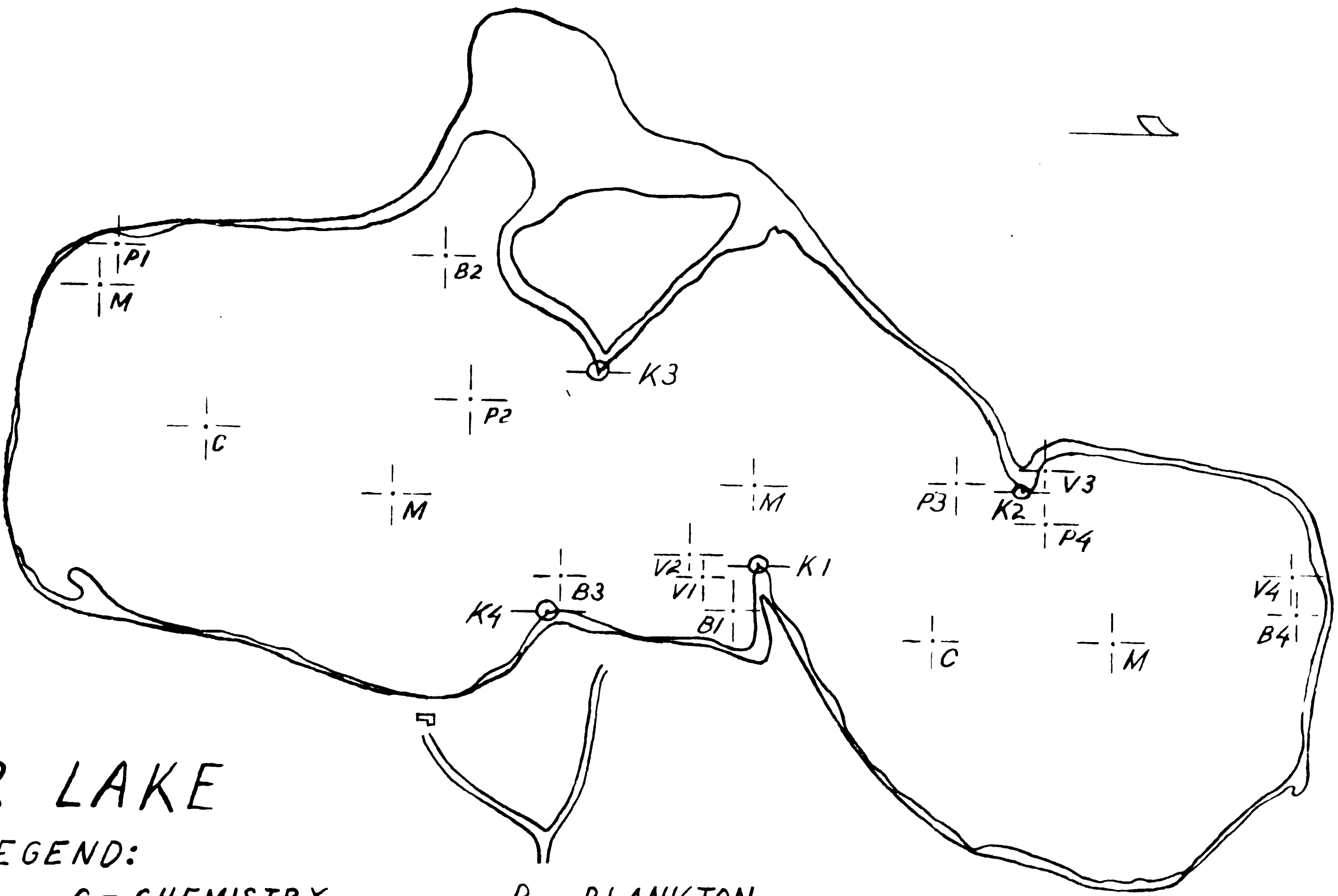
FIGURE 2. MAP OF STONER LAKE SHOWING BOTTOM TYPES AND STATIONS OF MUD SOUNDING.

Chemistry

Water

Realizing that a knowledge of chemical conditions in the environment is essential to an understanding of the status of an animal or plant population, it was desired to gain information about the more critical substances influencing the biota and its quantitative fluctuations (if any) resulting from alkalization. Also, it is possible that some substances, such as alkalinity and phosphorus, may be used directly as indices of lake productivity (Moyle, 1949).

Water samples were collected periodically through the summer with a modified Kemmerer water sampler from both basins, of which routine field analyses were made. Two stations were located and marked with an anchored buoy for this purpose, one station being set in the approximate center of each basin (Figure 3). Water from depths of three and nine feet was tested for oxygen by the rapid Winkler method (Ellis _et. al._, 1946), for carbon dioxide and alkalinity by procedures outlined in "Standard Methods" (1946), for pH with a Hellige comparator, and for color with a U. S. Geological Survey kit which uses platinum cobalt standards. Below nine feet, samples were collected at every three-foot level down to where mud was first encountered, and estimated for oxygen and carbon dioxide only. Temperature in degrees Fahrenheit was taken at all levels, at surface, and of the air, with a pocket thermometer. These data were recorded on a prepared record sheet. Secchi disk readings and a note of weather conditions were also recorded on the record form. This procedure was followed at each station, the times of analysis being 10:00 am for the north basin and 11:00 am for the south basin. The depths at which muddy water was encountered at these two stations were approximately the same, both varying between 16 and 18 feet



STONER LAKE

LEGEND:

C - CHEMISTRY
M - PULPY PEAT
B - BOTTOM FAUNA
P - PLANKTON
V - VEGETATION
K -o- - PERMANENT MARKER

FIGURE 3. SHOWING SAMPLING STATIONS, LOCATED FROM POSITIONS OF PERMANENT MARKERS.

depending on the turbulence of the water and the lake level at the time. A deliberate attempt was made to obtain a sample not more than one foot from the mud-water interface.

In addition to the above field analyses, water samples of approximately 200 ml. were collected at periodic intervals of one week throughout the summer, stored and returned to the laboratory for further analysis. Two such samples were collected at the position of each chemistry station on each sampling date, at a depth of one foot below the surface. From these samples, estimations were made of total and dissolved phosphorus by procedures outlined by Ellis et. al. (1946) using the Klett-Summerson Photoelectric Colorimeter; dissolved calcium by the Hach modification of the versenate method (Diehl et. al., 1950), with procedure and materials furnished by Hach Chemical Company; and dissolved potassium with the use of a Beckman Flame Spectophotometer (West et. al., 1950).

Soil

Because of the suspected strong effect of the organic soil upon the chemical conditions of the water, it was also desired to study further the degree to which the pulpy peat would enter into the calcium distribution after alkalization. It was necessary, therefore, to collect samples of the pulpy peat for laboratory analysis.

Collections were made from four stations, two being located in each basin (Figure 3). It was thought best to locate the stations near the edge of the pulpy peat and sand boundary, in order to obtain a sharper interface between water and soil; these points were located with a sounding line and marked with an anchored buoy. Samples were collected with an Ekman dredge, an attempt being made each time to collect the sample at such a depth that the mud-water interface was held within the dredge. When the water had been poured off, the approximate top three centimeters of mud were scooped into a jar. On shore, these samples were poured onto paper filter disks, allowed to drain, and dry in the air. The samples, after having dried, were stored for return in air-tight bottles. In the laboratory, the samples were oven dried at 60°C. to a constant weight, ground to a powder by means of a mortar and pestle and strained through a No. 40 soil seive. One gram of the resulting powder was used for each analysis.

An estimate of adsorbed calcium was made by the versenate method given by Cheng and Bray (1951). One-gram samples were used, and the results converted to a percentage figure.

An estimate of total carbonates was made of each sample according to the following method, modified from those reviewed by Alexander and Byers (1932):

1. Exactly 10.00 cc. of 0.02N sulfuric acid (H_2SO_4) was added to 1.00 gram of powdered soil in a test tube, shaken for one minute and allowed to stand for one hour.
2. The test tube was shaken for another one minute, and the contents poured into a paper filter disk folded into a funnel. The test tube was washed with boiled distilled water, and the filter paper was similarly washed until the filtrate was brought up to approximately 50 ml.
3. The filtrate was then tested with a Beckman pH meter, and titrated with 0.02N sodium hydroxide (NaOH) until a pH of 7.0 was reached.
4. The carbonate content was computed by first subtracting the number of ml. sodium hydroxide used in the titration from 10.00, and multiplying the remainder by a constant (deter-

mined by standardizing the sodium hydroxide against sulfuric acid with the pH meter) to obtain the result in grams, expressed as calcium carbonate ($CaCO_3$). Conversion was then made to a percentage figure.

It was desired to gain some further information about the quantity of pulpy peat in the two basins. For this purpose, 24 stations (11 in the north basin, 13 in the south) were either located or approximated, and an estimate of the depth of the sedimentation was made at each of these stations. This was done by taking two soundings at each station: (1) depth of water at which mud was encountered with the water sampler, and (2) depth to which a heavy weight would sink into the pulpy peat. The depth of the sedimentation was calculated as the difference between these two measurements. The weight used was a six-foot piece of angle-iron weighing about 7.5 pounds, allowed to sink vertically into the mud, point first. It must be pointed out that these measurements represented only minimums; the weight probably did not sink to the lowest level of the sedimentation. The stations of sounding are shown on the map in Figure 2; sounding measurements are given in Table 1.

The bottom areas comprised of pulpy peat were estimated from a constructed map showing bottom types (Figure 2). These were, roughly, for the south basin 14 acres; for the north basin 16 acres; and total for the lake, 30 acres.

The density of the wet pulpy peat was measured as 1.03 gm. per cc. Weight of oven-dry mud (60°C.) was measured as 0.045 gm. per cc. of wet mud.

Biology

Because the success of any inorganic fertilizer depends upon the utilization of added nutrients by a photosynthetic level of the

Table 1. Mud soundings taken on August 19 and 20, 1952.

Station	Depth of water (feet - inches)	Thickness of sedimentation (feet - inches)
1	10 - 9	6 - 6
2	10 - 3	6 - 0
3	10 - 9	4 - 0
4	12 - 6	6 - 9
5	11 - 9	4 - 9
6	10 - 9	6 - 0
7	15 - 0	10 - 6
8	15 - 0	9 - 0
9	15 - 3	8 - 3
10	15 - 6	8 - 9
11	19 - 9	9 - 3
12	14 - 6	8 - 9
13	14 - 6	9 - 3
14	9 - 6	3 - 6
15	9 - 3	5 - 6
16	10 - 6	6 - 6
17	9 - 6	4 - 9
18	7 - 0	4 - 6
19	8 - 6	6 - 6
20	11 - 0	7 - 9
21	11 - 9	7 - 3
22	15 - 9	9 - 9
23	10 - 3	4 - 0
24	7 - 9	3 - 9

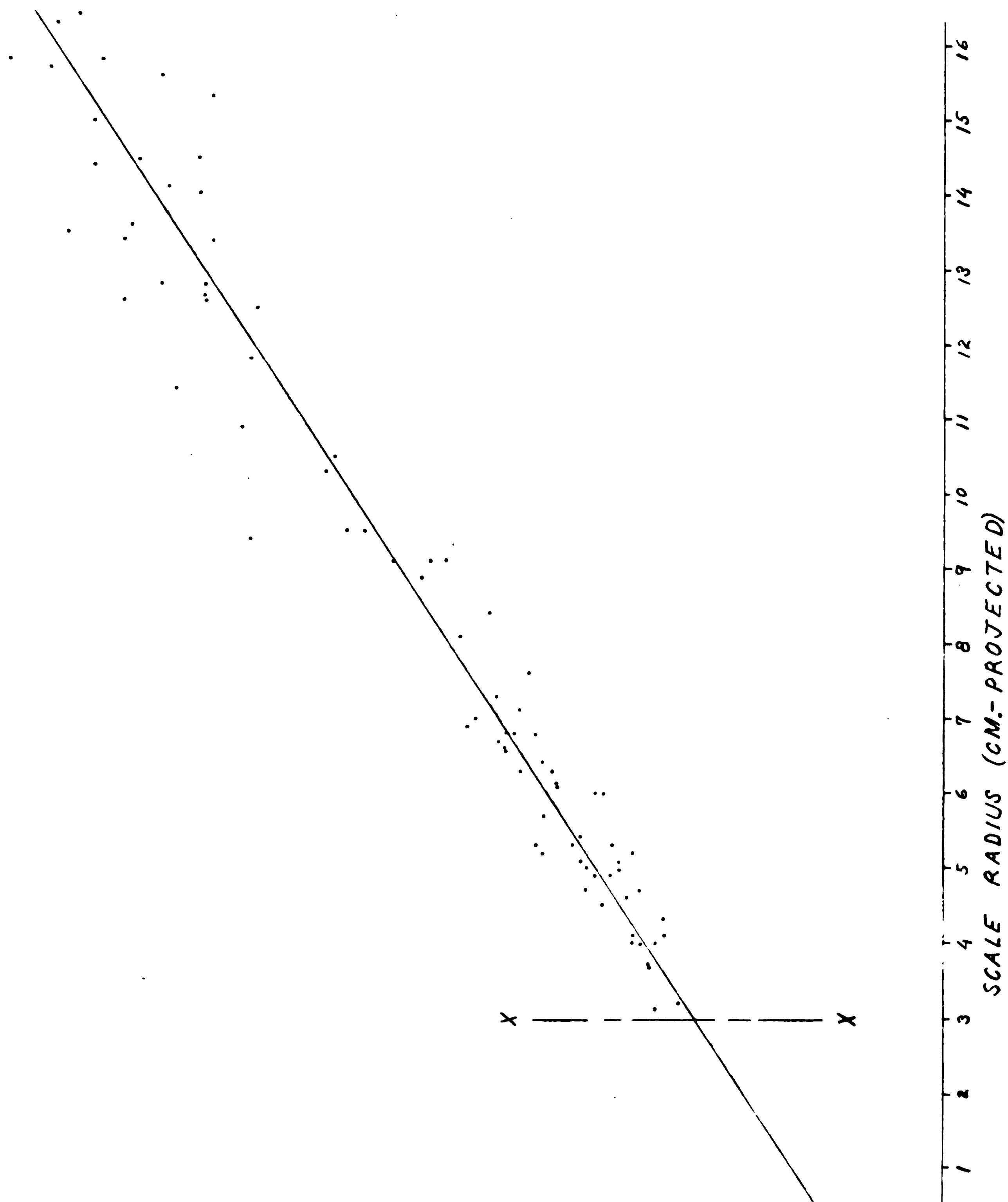
food chain, and realizing therefore, that any change in lake productivity might be reflected in all trophic levels of the chain, it was desired to sample all levels possible in the hopes of establishing the effects of the alkalization upon the various plant and animal groups.

Fish

Collections of fish were made at irregular intervals throughout the summer with the use of a gill net and by angling. Yellow perch made up the great bulk of the samples; bluegills and suckers were collected only in very small numbers. Scales were taken from the area directly behind the left pectoral fin on the yellow perch and bluegills, and on the suckers from the region dorsal to the lateral line and anterior of the dorsal fin. Total lengths, weights and sex were recorded from all fish. Because the number of suckers and bluegills taken was so low, growth studies were limited to yellow perch.

Scales from 82 yellow perch were examined with a projector having a magnification of 28.5X. Ages were determined and total lengths at previous annuli were calculated from a nomograph. The anterior radius of all scales of the yellow perch was plotted against total length at time of capture and a linear regression line fitted to the resulting scatter diagram (Figure 4). The correlation coefficient, r, (Snedecor, 1946) was calculated as .98, which was highly significant. The point at which the regression line cut the zero abscissa (zero scale radius) was taken as the calculated total length at which the scale was formed on the young fish, the figure found being 1.33 inches. Although this figure is probably higher than that existing as the actual case, more accuracy would be obtained by using it, rather than using empirical data, because the method of calculating total lengths at previous annuli (the nomo-

Figure 4. Body length-scale radius relationship of yellow perch.


TOTAL LENGTH INCHES
SCALE RADIUS (CM.-PROJECTED)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
X
X

graph) assumes a linear relationship between scale radius and total length during the period of growth following scale formation. However, data were not available for the lower section of the graph for scale radii less than three centimeters (projected), i. e., below line X-X, so any calculations made upon previous annuli with radius of less than three centimeters could not be entirely relied upon. Data that include measurements falling in this section of the graph are indicated as unreliable where presented.

Bottom fauna

Among the various biological samples taken, it was felt that the abundance of bottom organisms would be one of the most important as an index, inasmuch as this source of fish-food was the primary supply for those age groups of fish which showed the greatest degree of stunting.

For a program of sampling, four stations were located in the littoral area of the lake, with an attempt being made to include varying bottom types between the stations and a homogeneous bottom type within the area of each station. Station 1 was located near the east shore of the lake in a small, shallow bay which almost continuously received incoming wind and waves. Depth of water was 3.5 feet, the bottom being of sand overlaid with a moderate amount of partly decayed plant material and chironomid cases. Growing vegetation consisted of Nitella flexilis in very slight amounts, and Potamogeton epihydrus var. Nutalli in moderate amounts. Station 2 was located near the west shore at the entrance to a large, weedy bay and rarely received any wind or wave action. Depth of water was 4.0 feet, the bottom being of sand and slight amounts of pulpy peat. Growing vegetation consisted of Nitella flexilis, Eriocaulon septangulare and Myriophyllum tenellum in moderate amounts. Station 3 was located near the east shore directly off a point of land and was subject to continuous wind and wave action. Depth of water was 3.0 feet, the bottom being of bare sand with no growing vegetation. Station 4 was located near the extreme north end of the lake and received very little wave action. Much of the bottom area of the lake in this section was of a homogeneous nature. Depth of water was 2.0 feet, the bottom being of sand overlaid with a slight amount of dead plant material. Growing vegetation consisted of Eriocaulon septangulare in moderate amounts, with scattered plants of Glyceria borealis. (See Figure 3.)

Four Ekman dredge samples were collected from each station at one-week intervals throughout the summer, making a total of 16 samples collected per week. This program was carried out for ten weeks, all following the lime application. Each sample was washed and picked over soon after collection, and the organisms preserved in 5 percent formalin. In the laboratory, the organisms were identified and counted. Because of the great paucity of all organisms, volume measurement of the separate taxonomic groups was precluded, and organisms were separated into only two major groups for volume measurement.

Plankton

Four stations were located in the lake for plankton sampling. Station 1 was located in one corner of the lake, protected from two sides by hemlock and maple forest. This station only occasionally received any wind action, and then to receive waters blown in from other areas of the lake. Station 2 was located in the approximate center of the lake, over sand bottom between the two basins, in about five feet of water. This station was almost continuously subject to wind action, often to a very heavy turbulence. Stations 3 and 4 were located on opposite sides of a projecting point (Figure 3).

Two markers were set out and anchored 20 feet apart at each station. Sampling was done by towing a small Wisconsin plankton net of 12 cm. top diameter between each pair of markers for the distance of 20 feet at such a speed as to keep the upper rim of the tow net just below the surface. One sample was taken at each station at intervals of approximately one week, for a ten-week period following the lime application. After each tow was made, the concentrate was transferred from the collecting bucket to a one-ounce bottle. On shore the plankton concentrate was treated with a few drops of 10 percent formalin to kill the organisms, and the sample was then allowed to settle. The supernatant liquid was removed with a small pipette, the remaining concentrate then removed to a vial with the addition of enough 5 percent formalin to form a final preservative of approximately 3 percent formalin.

In the laboratory, the contents of each vial were brought up to a constant volume of 10 cc. with the addition of water. Quantitative counts were made according to methods given by Whipple (1948), with some modifications, using a Sedgewick-Rafter counting cell. The plankton sample (of 10 cc. volume) was agitated to insure uniform distribution, and 1 cc. of the concentrate was placed into the cell with a small pipette. Using a microscope with a low power 10X objective and a Whipple ocular micrometer disk, forty random fields were observed and all organisms seen recorded on a record form sheet. After counting, the average number of each organism observed per field was calculated; conversion was then made to obtain the number of organisms per sample. No attempt was made to estimate the number of organisms per unit volume of water, because the method of sampling, without an accurate knowledge of the volume of water concerned in each sample, precluded such a computation.

Rooted vegetation

Because any change in lake productivity would probably be early reflected in the abundance of the higher aquatic plants, a quantitative measure of this level was thought highly desirable. Present day methods, however, fall far short of a procedure which would quickly and accurately give a true quantitative measure of this link in the food chain. The method of Rickett (1921) was modified slightly and used in Stoner Lake.

Four sampling stations were located in the lake, each one selected as to give (1) a homogeneous floral type within the station area of sampling, (2) a type distinctly different than the others, and (3) a maximum growth of that particular type (i. e., areas of greatest abundance). Station 1 was located in a shallow bay near the east side of the lake, with a depth of 1.5 feet. Species of plants present were Juncus longistylis, Glyceria borealis, and Glyceria canadensis. Station 2 was located a short distance lakeward from Station 1, with a depth of 2.0 feet. Glyceria borealis was the only species present. Station 3 was located in the north basin in a small protected cove, with a depth of 3.0 feet. Potamogeton epihydrus var. Nutalli was the only species present. Station 4 was located near the extreme north shore, with a depth of 2.0 feet. Species present were Eriocaulon septangulare and Glyceria borealis. (See Figure 3.)

Two samples were collected at each station on each of two different dates, the first being soon after the lime application and the second at the end of the summer, for a total of 16 samples. For each sample, a square yard of the bottom was denuded of vegetation (exclusive of rhizomatous parts), and weights were obtained of the collected vegetative material under the following conditions: (1) air-dry, (2) oven-dry at 100°C., and (3) ashed. Ashing was done in a muffle furnace at a dull red heat.

A limited survey of submergent vegetation was also carried out. This was done from a rowboat by following a line from an anchored buoy in deep water (in some cases, buoys marking soil and biological stations were used) to a point on shore and sampling the bottom with an Ekman dredge approximately every 50 feet of horizontal distance covered. A total of 63 such observations were made.

Herbarium collections were made of all rooted aquatic and marginal plants found in the lake and identified in the laboratory.

Analysis of variance

In studying the effects of alkalization upon the more critical chemical characteristics of the water and soil, analyses of variance were made of the values obtained for alkalinity and pH of the water, and for total carbonates and adsorbed calcium in the pulpy peat. The analyses were made according to procedures given by Snedecor (1946).

Several accountable sources of variance were recognized among the data, the major ones being the differences among points of sampling and the differences among dates ("Among points" and "Among dates" in the analysis of variance tables). The primary purpose of the analyses, however, was to discover whether or not a significant effect resulted from the lime application; i. e., a significant difference between the values obtained before and after application. Variance due to this difference is included in the variance "Among dates," but does not account for the total variance existing among dates; the remainder is that due to differences occurring from day to day aside from the before-and-after effect, regardless of their cause. The total variance among dates was therefore divided into two recognizable portions: (1) that due to the difference between the mean values before application and the mean values after application, designated as "Before and after" in the analysis of variance tables, and (2) that due to differences among dates before application plus that due to differences among dates after application, designated as "Day to day" in the tables.

It was felt that the "Day to day" variance should be used for comparison in judging whether or not the "Before and after" variance was significant. The "Day to day" variance includes, in addition to that due to any normal, seasonal changes, some variance due to differences resulting from the lime application (for example, in the cases where the chemical values decreased from the initial high values found immediately after lime application). The "Day to day" variance, therefore, is higher than would be expected if it were wholly due to factors other than alkalization. The use of "Day to day" variance as is (i. e., including effects of alkalization), is justified in that it offers a means of determining the degree of permanence of a chemical change, at least for the duration of the experiment. In other words, a significant difference between the "Before and after" variance and "Day to day" variance, when compared in the "F" test, would support the hypothesis that a permanent change had been effected.

RESULTS OF SAMPLING

The essential feature of alkalization is immediate chemical modification, and certain biological changes may be expected later as the result. The changes, then, can be roughly classified into "fast-acting" and "slow-acting", respectively, and because this report is concerned only with the first year's results, the two distinct types of data must be recognized: (1) chemical, or fast-acting, where before-and-after conditions may be compared; and (2) biological, or slow-acting, where conditions can merely be presented and data used for comparison only after additional work has been completed. An attempt has been made, therefore, to present here all biological data is such a way that they may be used later for a statistical comparison without recourse to original records.

Chemical

Oxygen

In general, no changes in oxygen content of the water occurred which could be related to the alkalization. As no thermal stratification occurred, it should be expected that little or no oxygen depletion would be found. Such was the case. Strong winds which prevailed during most of the summer days apparently caused thorough circulation, and all water levels down to two feet above the mud-water interface contained oxygen at a concentration between 6 and 8 p. p. m.; below this level oxygen varied between 1 and 6 p. p. m., being somewhat less apparently because of organic decomposition at the bottom. These conditions were maintained throughout the time of the experiment.

Color

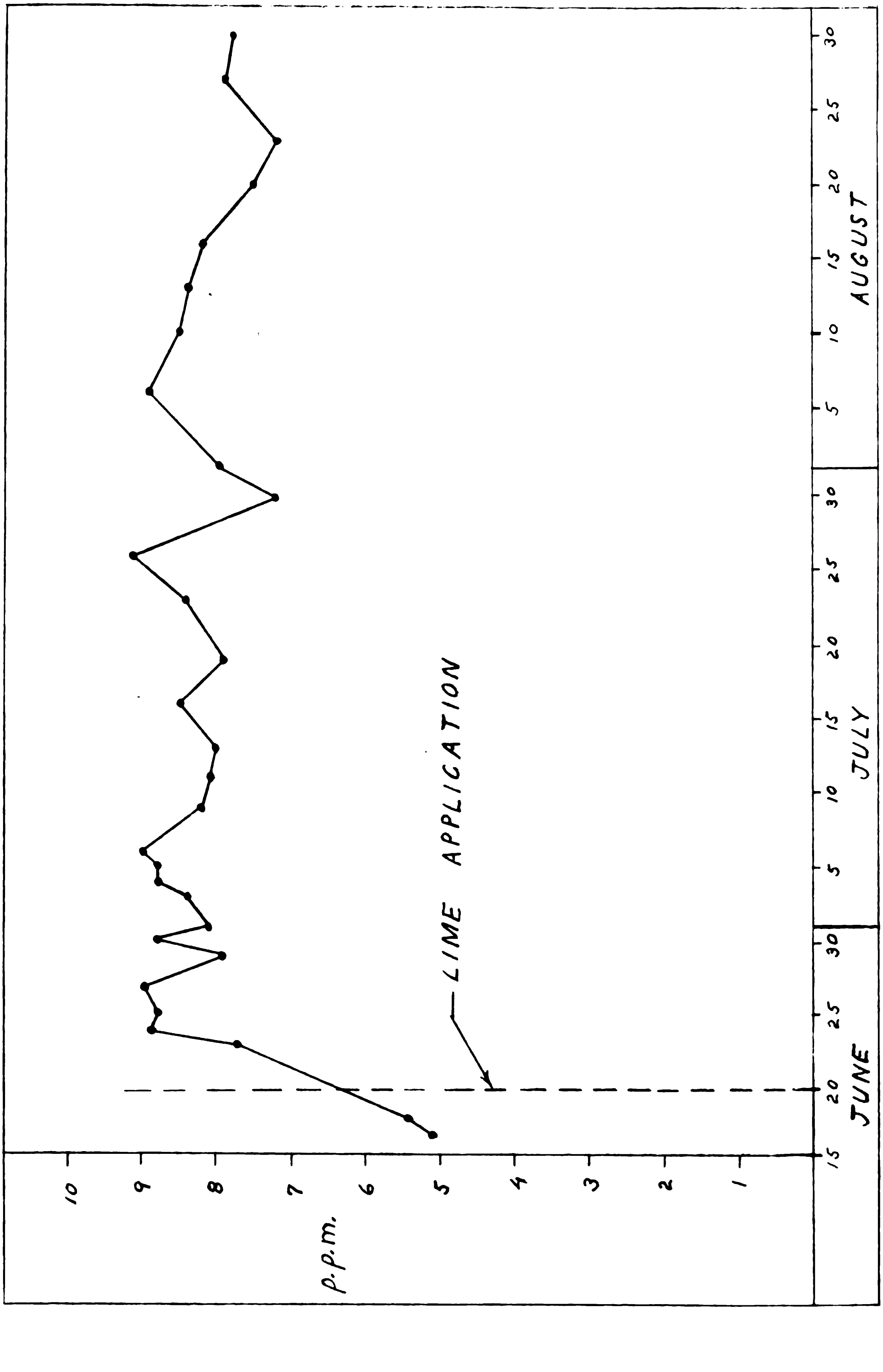
No apparent change in color of the water occurred. The high color present, measured at a value of 80 P.C.S., did not change after alkalization. Secchi disk readings of 6.5 feet were also consistent through the summer.

Alkalinity

No hydroxide or monocarbonate alkalinity was ever observed, either before or after alkalization.

Bicarbonate alkalinity, however, was found to have increased immediately after the lime application, as shown in Figure 5. An analysis of variance (Table 2) shows the variance among the different points of sampling ("Among points") to be non-significant. When the variance

Figure 5. Seasonal variation of bicarbonate alkalinity, mean of four sampling points.



p.p.m.
10
9
8
7
6
5
4
3
2
1
LIME APPLICATION
15
20
25
30
JUNE
5
10
15
20
25
30
JULY
5
10
15
20
25
30
AUGUST

Table 2. Changes in bicarbonate alkalinity (analysis of variance).

Source	d.f.	SS	MS	"F"
Total	119	132.32	1.112	
Among points	3	.57	.190	0.50 -
Among dates	29	98.95	3.412	9.05 **
Before and after	(1)	(68.40)	(68.400)	(62.69) **
Day to day	(28)	(30.55)	(1.091)	
Error	87	32.80	.377	

- Not significant
* Significant (5 percent level)
** Highly significant (1 percent level)

"Before and after" is compared to "Day to day" variance, it is found highly significant. This indicates that the increase in alkalinity was permanent for the duration of the sampling period; this permanent effect is also shown in Figure 5 as the maintenance of the increased values throughout the period.

Mean bicarbonate alkalinity before alkalization was 5.2 p. p. m., and after alkalization, 8.2 p. p. m. The difference, 3.0 p. p. m., represents an estimate of the increase due to alkalization.

pH--Temperature--Carbon dioxide

These three measurements are here treated together because of a suspected inter-relationship. Figure 6 shows the variation of the mean values of the four points of sampling (depths of 3 and 9 feet in both basins) through the sampling period. The graph indicates that, in general, pH increased at the time of lime application to a high value, and then decreased at a moderately rapid rate to the original value. Carbon dioxide content at these surface levels remained about 2 p. p. m. for most of the summer, but it appears from the graph that it, too, was affected by the alkalization as to produce a temporary decrease; this was probably due to the utilization of free carbon dioxide in the conversion of hydroxides to bicarbonates. Examination of the graph also shows an apparent correlation between pH and temperature, especially near the end of the sampling period when the effects of the alkalization had apparently dissipitated.

An analysis of variance of the pH values (Table 3) shows that highly significant differences existed between the two depths sampled, as well as between the two basins. The mean differences are given in Table 4.

The analysis of variance also shows that the "Before and after" variance is non-significant when compared to the variance "Day to day."

Figure 6. Seasonal variation of temperature, pH, and carbon dioxide, means of four sampling points.

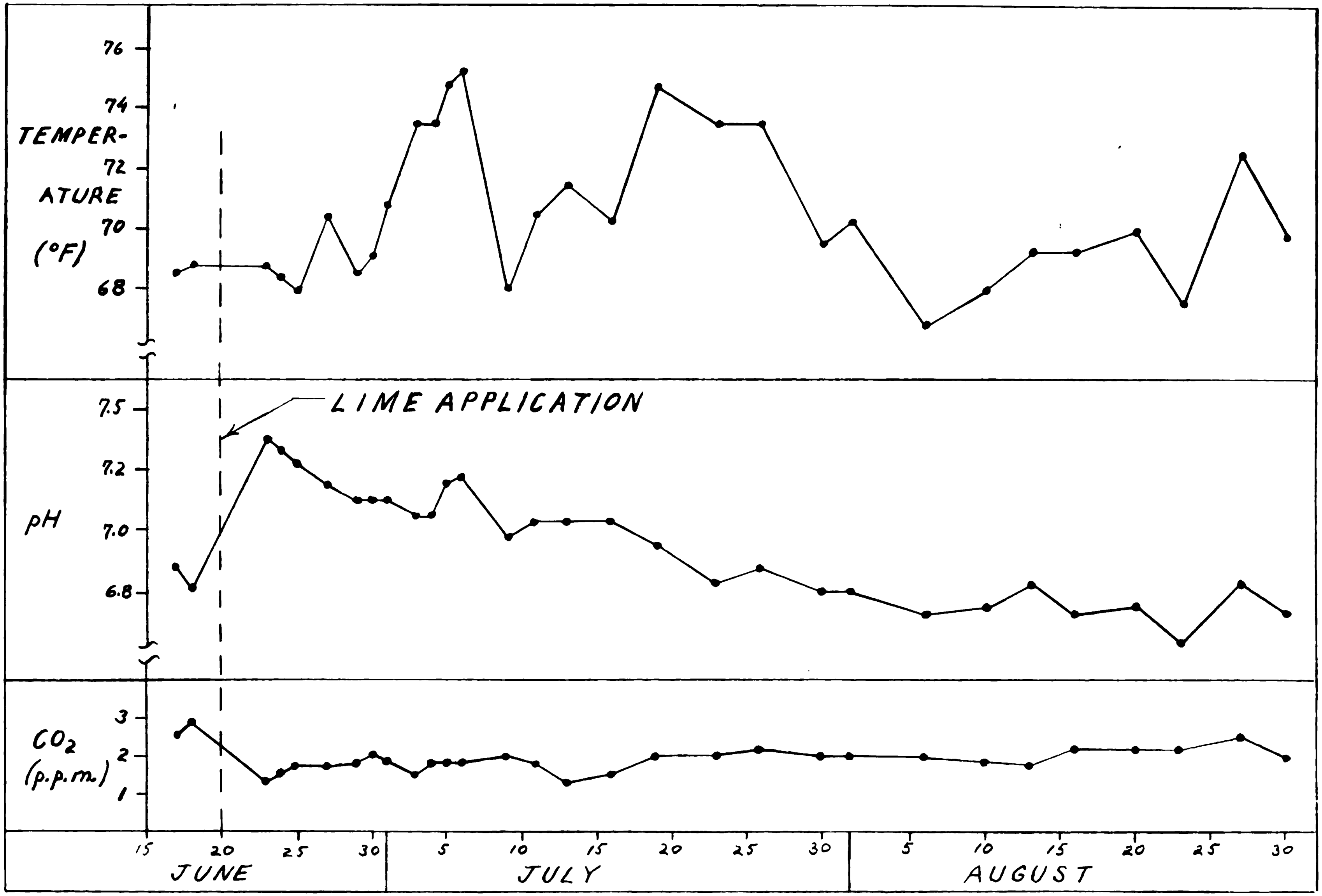

TEMPER-
ATURE
(°F)
76
74
72
70
68
LIME APPLICATION
pH
7.5
7.2
7.0
6.8
CO_2
(p.p.m.)
3
2
1
15
20
25
30
5
10
JUNE
JULY
AUGUST

Table 3. Changes in pH (analysis of variance).

Source	d.f.	SS	MS	"F"
Total	119	4.56	.0383	
Among points	3	.34	.1133	28.34 **
Between basins	(1)	(.05)	(.0500)	(12.50) **
Between depths	(1)	(.29)	(.2900)	(72.50) **
Basins X depths	(1)	(.00)	(.0000)	
Among dates	29	3.87	.1334	33.35 **
Before and after	(1)	(.12)	(.1200)	(0.90) -
Day to day	(28)	(3.75)	(.1339)	
Error	87	.35	.0040	

\- Not significant
* Significant (5 percent level)
** Highly significant (1 percent level)

Table 4. Mean values of pH found at points of sampling and the highly significant differences among points.

	South basin	North basin	Difference between basins
3 feet	7.02	6.93	.09
9 feet	6.98	6.88	.10
Difference between depths	.04	.05	

This does not indicate that a significant immediate increase was not effected, but rather that the increase was not a permanent one, even for the sampling period. From the graph in Figure 6, it appears that pH values returned to original values about five weeks after the lime application.

To study further the effect of temperature upon pH, an analysis of covariance was made of temperature and pH. No significant reduction of error variance was found; the "Among points" variance remained highly significant and the "Before and after" variance remained non-significant, as was the case in the analysis of variance. It was concluded that variations of temperature did not affect the values of pH to a measurable degree.

Phosphorus--Calcium--Potassium

The water samples collected during the first three weeks of the experiment, a period of time which included dates of sampling before and immediately after lime application, showed contamination, and no seasonal changes can be shown. Mean values of the uncontaminated samples, all taken some time after alkalization, are given in Table 5.

Adsorbed calcium in bottom soil

Adsorbed calcium in the soil increased immediately after lime application, as shown in Figure 7, and remained at a level higher than that observed before alkalization.

An analysis of variance (Table 6) shows that significant differences existed among the points of collection ("Among stations"). The "Before and after" variance is shown to be highly significant when compared to "Day to day" variance, indicating a change which was permanent for the period of sampling. It will be noted from an examination of the graph in Figure 7 that a high variation was observed in adsorbed calcium from day to day which can not be logically attributed to the

Table 5. Mean values of phosphorus, potassium and calcium.

	Mean	Standard deviation	Number samples
Phosphorus (dissolved) ppb	5.8	3.3	8
Phosphorus (total) ppb	24.2	4.3	8
Potassium ppm	.353	.095	32
Calcium ppm	10.12	.77	32

ppb - .001 miligrams per liter (parts per billion)
ppm - miligrams per liter (parts per million)

Figure 7. Seasonal variation of adsorbed calcium in pulpy peat, mean of four sampling points.

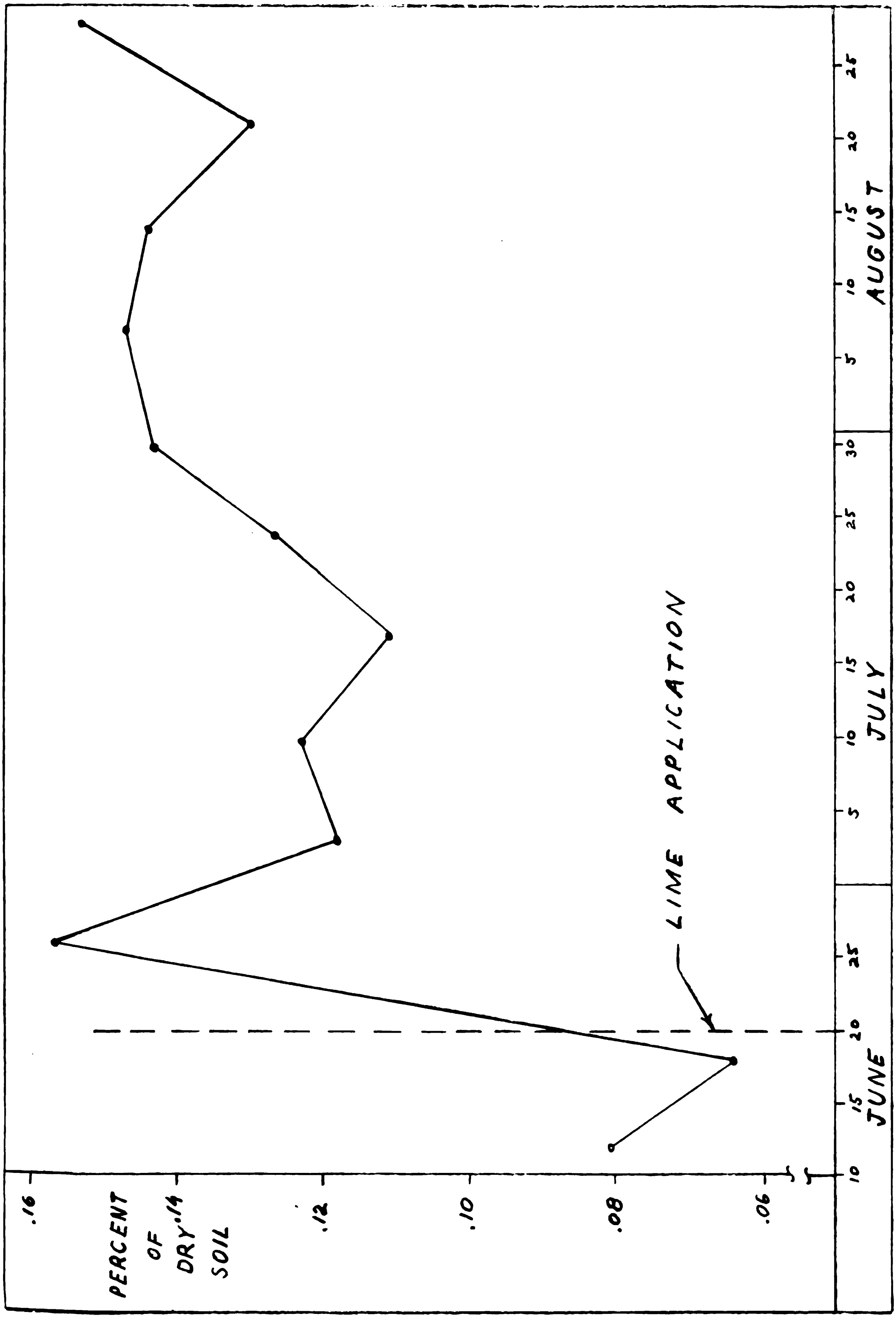

PERCENT OF DRY SOIL
.16
.14
.12
.10
.08
.06
LIME APPLICATION
JUNE
JULY
AUGUST
10
15
20
25
5
10
15
20
25
30
5
10
15
20
25

Table 6. Changes in adsorbed calcium in pulpy peat (analysis of variance).

Source	d.f.	SS	MS	"F"
Total	47	4.53	.096	
Among stations	3	.26	.087	3.35 *
Among dates	11	3.42	.311	11.96 **
Before and after	(1)	(2.38)	(2.380)	(22.88) **
Day to day	(10)	(1.04)	(.104)	(4.00) **
Error	33	.85	.026	

- Not significant
* Significant (5 percent level)
** Highly significant (1 percent level)

alkalization; this is further indicated by a highly significant "F" value for the "Day to day" variance when compared to "Error." Inasmuch as the laboratory determinations were made upon the samples in chronological order, rather than in a random order, the possibility that this highly significant variance may be due to variations in laboratory technique is suggested.

The mean value before alkalization was 0.072 percent, and after alkalization, 0.132 percent, by weight, on the basis of oven-dry soil. This represents an increase in adsorbed calcium of 86 percent.

Carbonates in bottom soil

The results of analyses of 48 soil samples for carbonates showed a mean value of 0.82 percent, by weight, on the basis of oven-dry soil, expressed as calcium carbonate ($CaCO_3$). An analysis of variance (Table 7) shows that the "Among stations" variance was highly significant; i. e., the carbonate content varied from point to point within the lake. Also, the table shows that "Among dates" variance to be highly significant; however, this high variance is accounted for almost entirely by the "Day to day" variance, compared to "Error," and because the samples were determined in a chronological order--as were those analyzed for adsorbed calcium--this variance may be due to factors within laboratory techniques. The "Before and after" variance, when compared to "Day to day", is not significant; consequently it can be concluded that alkalization had no apparent permanent effect upon the carbonate content of the pulpy peat.

Biological

Fish

The growth rate of fish is an important index to productivity

Table 7. Changes in total carbonate content of pulpy peat (analysis of variance).

Source	d.f.	SS	MS	"F"
Total	47	.2305	.0049	
Among stations	3	.0555	.0185	7.40 **
Among dates	11	.0921	.0084	3.36 **
Before and after	(1)	(.0009)	(.0009)	(0.10) -
Day to day	(10)	(.0912)	(.0091)	(3.64) **
Error	33	.0829	.0025	

- Not significant
* Significant (5 percent level)
** Highly significant (1 percent level)

because, from a fisheries management viewpoint, its increase is the desired end. Three measurements were selected to be used for comparison with data of subsequent years' sampling: (1) calculated total length at last annulus, (2) increment of growth during the last full year, and (3) instantaneous rate of growth.

Among the yellow perch collected from Stoner Lake, a bimodal size distribution was observed. From a limited number of observations made of stomach contents, it was apparent that the large fish making up the second mode had been largely feeding upon the smaller, stunted individuals; an examination of their scales showed that these large fish had had a rapid growth in their early years. This phenomenon of cannibalism, where some individuals of the community attain a large size with an exceptionally high rate of growth has been previously observed in stunted yellow perch populations by Eschmeyer (1937). Cannibalism in rearing ponds has also been observed among largemouth bass by Cooper (1937) and among smallmouth bass by Langlois (1936).

It is obvious, for reasons of size limitations, that not all individuals of a population can be cannibalistic; the reason why a certain number among the Stoner Lake perch should have had a rapid early growth, attained an early size advantage and thus apparently became destined for cannibalism is not clearly understood. But when, in a stunted population, a size large enough to become piscivorous was attained, an abundance of food in the form of small, stunted fish became available. Thereafter, for these cannibal fish, food was not a limiting factor upon growth, and in contrast to the smaller, stunted majority, their growth rate was high.

The occurrence of cannibalism among the yellow perch of Stoner Lake, with the resulting "two-level" population, makes the summarization of the above three measurements in a reliable form that may be used for statistical comparison a difficult one. Furthermore, the larger fish were collected with a gill net having a mesh-size too large to take the smaller, stunted fish, and it was felt, therefore, that these large fish were represented in the collection in a greater proportion than they were present in the lake. A definite sampling bias, then, existed in favor of these larger fish, and consequently in favor of the faster growing ones. If the calculation of mean values for the selected measurements of growth rate were to include these large individuals in the proportion collected, the mean values so calculated would overestimate the population values.

For these reasons some stratification of the data was felt necessary. The total sample was separated into three size groups for the calculation of means: (1) 3.5 to 6.0 inches, (2) 6.1 to 10.0 inches, and (3) 10.1 inches and larger. This classification was made on the basis of the abundance of food available, obviously a function of the fish's size. Fish in group (1) had available as food, primarily, bottom organisms, and those in group (3), primarily, small fish of a stunted size (i. e., group (1)). The abundance of bottom organisms was low in comparison to that of the fish in group (1); the reverse was true with the abundance of food available to group (3). Group (2) was separated out for the purpose of eliminating overlap between the other two groups, for the food of this group probably consisted of <u>both</u> bottom fauna and small fish. Therefore, the growth rates within group (1) can be expected to be lower than those of a normally growing population; in group (2) highly variable; and in group (3) higher than normal.

It was believed that the manner of collecting the fish in group (1) was unbiased, and it was thus assumed that the measurements in group (1) were normally distributed <u>within that group</u>. Furthermore, it was in group (1) that the effects of stunting were most evident.

It is felt, therefore, that an increase in productivity will be reflected earliest and most accurately in this group.

It is stressed that the mean values of the growth rate measurements for any one of the three groups are not meant to reflect the condition of the population, but only of that group, and are therefore useful only for comparison with similar data from subsequent years' sampling.

These mean values and their standard deviations, for the various age classes, are given in Tables 8, 9, and 10.

Bottom fauna

The abundance of bottom organisms varied highly among the different stations, but in general, all stations sampled showed a great paucity of this important fish food. A complete absence of any organisms was observed in some samples. A comparison with several other lakes in Michigan and Ontario is shown in Table 11, where it will be noted that the abundance of bottom fauna compares more favorably with the soft-water, dark colored lakes in Ontario, than with the more hard-water lakes in Michigan. The original data of Miller (1938) were given in terms of pounds per acre and were converted to cubic centimeters for purposes of comparison.

The seasonal variation of volume and numbers of organisms per square foot is shown in Figure 8.

These graphs exclude the Oligochaeta and Tabanidae. The large Oligochaetes and Tabanids were of relatively large volume and in few numbers; small Oligochaetes were sometimes found in large numbers but contributed little to the volume of the sample. They were so small that undoubtedly many escaped through the washing screen, which probably accounts for their inconsistent presence in the samples. It was

Table 8. Total length at last annulus of yellow perch, in inches.

		Size group (inches)		
		3.5-6.0	6.1-10.0	10.1 & larger
Age class				
II	A	3.5*	--	--
	B	.467	--	--
	C	10	--	--
III	A	4.2	6.0	--
	B	.550	.794	--
	C	22	4	--
IV	A	5.0	7.2	9.0
	B	.359	.995	.720
	C	8	10	5
V	A	5.3	7.6	10.0
	B	.265	1.118	.922
	C	4	5	9
VI	A	--	8.0	10.4
	B	--	.400	.224
	C	--	3	2

A - mean
B - standard deviation
C - number
* - mean is not reliable for this age class

Table 9. Increment of growth during last full year of growth of yellow perch, in inches.

Age class		Size group (inches) 3.5-6.0	6.1-10.0	10.1 & larger
II	A	.80*	--	--
	B	.287	--	--
	C	10	--	--
III	A	.90	1.58	--
	B	.224	.428	--
	C	22	4	--
IV	A	.79	1.21	2.00
	B	.254	.616	.752
	C	8	10	5
V	A	.50	1.14	1.86
	B	.294	.750	.548
	C	4	5	9
VI	A	--	1.13	1.90
	B	--	.381	.141
	C	--	3	2

A - mean
B - standard deviation
C - number
* - mean is not reliable for this age class

Table 10. Instantaneous rate of growth during last full year of yellow perch.

Age class		Size group (inches) 3.5-6.0	6.1-10.0	10.1 & larger
II	A	.264*	--	--
	B	.067	--	--
	C	10	--	--
III	A	.239	.305	--
	B	.055	.041	--
	C	22	4	--
IV	A	.172	.180	.253
	B	.059	.087	.104
	C	8	10	5
V	A	.101	.157	.232
	B	.060	.088	.072
	C	4	5	9
VI	A	--	.150	.199
	B	--	.048	.012
	C	--	3	2

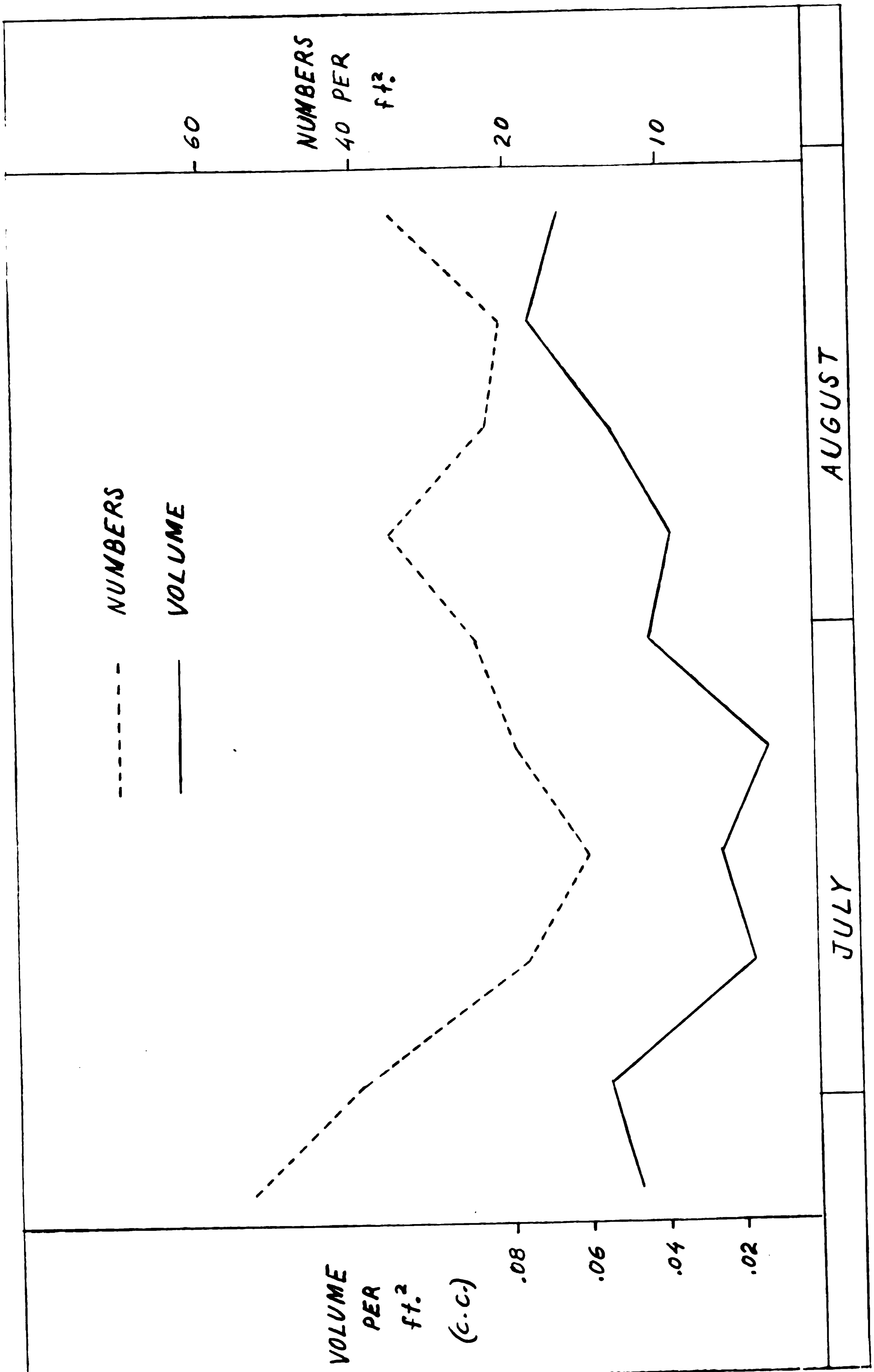
A - mean
B - standard deviation
C - number
* - mean is not reliable for this age class

Table 11. Bottom fauna of Stoner Lake compared to other lakes in Michigan and Ontario, during the months of July and August.

Investigator	Date	Region	Lake	Depth of samples	pH (surface)	Alkalinity (p.p.m.--surface)	Volume (c.c. per sq. ft.)
Ball	1948	Michigan	Third Sister	Littoral	7.2--8.4	85	0.85
Ball and Tanner	1951	Michigan	North Twin	Littoral	7.6--7.9	42--47	1.25
Miller	1938	Ontario	Red Rock	3 Meters	?	Soft, colored	0.20
Miller	1938	Ontario	Costello	1 Meter	?	Soft, colored	0.25
Waters	1953	Michigan	Stoner	Littoral	6.8*	4--6*	0.06

* Before lime application

Figure 8. Seasonal variation of bottom invertebrates, mean of four sampling stations (less Oligochaeta and Tabanidae).


NUMBERS PER ft.²
60
40
20
10
NUMBERS
VOLUME
AUGUST
JULY
VOLUME PER ft.² (c.c.)
.08
.06
.04
.02

felt that these three groups presented a source of large variation, and they were separated for volume measurement.

Unmodified data for all organisms are given in Tables 12 and 13. For the most part, these data probably represent minimum values occurring during the year. The occurrence of a mid-summer decline in abundance in the littoral zone has been observed by Ball (1948); Eggleton (1931) reported an annual minimum in the profundal area in late summer and early fall. The bulk of the sampling in Stoner Lake was done during July and August and, as with Ball's sampling, in the littoral zone. It is important, therefore, in a comparison with data from a replicate experiment, that seasonal trends be accounted for. From the graphs, a slight trend toward a summer minimum, occurring about the middle of July, can be noticed; the abundance was so low, however, and variation consequently high, that this trend is not distinct.

The possibility was considered that, with a chemical modification in alkalinity or pH, specific changes within the invertebrates might occur. To aid in evaluating alkalization as a means of producing biological modifications of this type, a study of the most abundant group, Tendipedidae, was considered the most suitable. The species of this group are listed in Table 14.

Plankton

Absence of accurate quantitative data will make comparison of these results with those of a duplicate experiment difficult. However if sampling is done by the same method and with similar equipment, any significant quantitative changes should be observed.

Total numbers of the two major groups, zooplankton and phytoplankton, are given in Table 15. In the case of colonial species, only the number of colonies were counted. Graphically, the seasonal

Table 12. Volume of bottom invertebrates per square foot of bottom (expressed in cc. X 100).

Station	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Collection dates	June 25				July 2				July 10				July 17				July 24			
Oligochaeta and Tabanidae	0	1	T	0	T	T	1	5	9	T	0	1	9	T	T	1	0	T	T	11
All others	2	8	2	7	6	7	T	9	1	2	T	4	T	5	1	4	1	1	1	2
Total	2	9	2	7	6	7	1	14	10	2	T	5	9	5	1	5	1	1	1	13
Collection dates	July 31				August 7				August 14				August 21				August 28			
Oligochaeta and Tabanidae	T	1	T	2	0	0	T	1	T	T	T	1	0	T	3	3	7	1	0	2
All others	5	4	3	5	4	2	1	8	5	6	1	9	11	4	4	10	8	4	T	14
Total	5	5	3	7	4	2	1	9	5	6	1	10	11	4	7	13	15	5	T	16

T - Trace

Table 13. Numbers of bottom invertebrates per square foot of bottom.

Station	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Collection dates	June 25				July 2				July 10				July 17				July 24			
Tendipedidae	7	31	35	51	14	22	4	62	4	7	7	22	2	4	5	26	9	1	23	21
Ceratapogonidae	2	3		1	4	2	2		11	12		2	7	7		3	13	3	1	1
Chaoborus									2					1						
Tabanidae									1											
Odonata							1							2				1		
Caenis		8		6	2			1	1	1		1		1						5
Trichoptera		1	1			1		2	1			1		1						
Coleoptera					1															
Lepidoptera															1					
Oligochaeta (large)		1	1		1	3		4	1	1		7	2	2	1	6		3	2	6
Oligochaeta (small)			1	3	3	4	3	12		5	2	29		11	3	23	2	7	6	80
Hydracarina		2			1			1	2			2								
Collection dates	July 31				August 7				August 14				August 21				August 28			
Tendipedidae	7	4	15	18	12	13	15	20	12	11	4	22	6	4	2	15	8	7	1	26
Ceratapogonidae	20	2	1	3	7	3		1	12	3	1	1	13	6		1	8	5		
Chaoborus																				
Tabanidae																	1			
Odonata		2		1	1	1					1	1			1	3		2		1
Caenis	2	2		9	6	1	1	21	2	3		6	10	1		10	5	14		17
Trichoptera		1	1		3	2			2	1		2	2			2	1	2	2	6
Coleoptera																	1			
Lepidoptera																2				
Oligochaeta (large)	3	3	1				2	1	2	1	1	2		1	3	4	1	9		4
Oligochaeta (small)	11	4	1	57	7	4		36	1	9	1	2	5	1		1		1		1
Hydracarina	1				1			2	2				1			1	2			1

Table 14. Species of Tendipedidae (= Chironomidae) found in Stoner Lake.*

Subfamily Hydrobaeninae
Subfamily Pelopiinae
Harnischia tenuicaudata (Malloch)
Metrocnemius lundbeckii Johannsen
Metrocnemius sp.
Pentaneura monilis (Linne)
Pentaneura sp. (monilis group)
Procladius spp.
Other Pelopiinae
Subfamily Tendipedinae
Tribe Calopsectrini
Calopsectra (Micropsectra) sp.
Calopsectra (Zavrelia)? sp.
Tribe Tendipedini
Cryptochironomus blarina Townes?
Cryptochironomus psittacinus (Meigen)
Microtendipes pedellus (DeGeer)
Paratendipes albimanus (Meigen)
Polypedilum (Pentapedilum) sp.
Polypedilum (Tripodura) halterale (Coq.)
Tanytarsus (Stictochironomus) devinctus (Say)?
Tendipes fumidus (Johannsen)?
Tendipes (Limnochironomus) modestus (Say)
Tendipes staegeri (Lundbeck)?
Other Tendipedini

*Identified by Dr. La Verne L. Curry

Table 15. Plankton counts in thousands per sample.

Date	Phytoplankton						Zooplankton					
	Station				Total	Average per date	Station				Total	Average per date
	1	2	3	4			1	2	3	4		
July 1	7.2	2.0	10.2	10.8	30.2	7.6	10.2	16.0	15.2	24.2	65.6	16.4
July 5	4.8	3.8	9.2	3.0	20.8	5.2	22.5	15.2	21.0	10.8	69.5	17.4
July 12	3.8	5.8	7.0	9.2	25.8	6.4	58.0	23.0	32.0	43.5	156.5	39.1
July 19	11.8	18.8	23.5	19.0	73.1	18.3	39.2	49.5	66.2	38.5	193.4	48.4
July 26	52.2	144.2	86.8	149.0	432.2	108.0	46.8	11.0	15.5	20.8	94.1	23.5
August 1	16.2	38.8	24.5	33.8	113.3	28.3	9.2	26.5	16.8	20.2	72.7	18.2
August 9	17.2	14.5	15.0	11.8	58.5	14.6	18.2	13.5	13.2	26.8	71.7	17.9
August 16	6.8	8.0	8.2	9.0	32.0	8.0	15.2	14.8	20.2	15.0	65.2	16.3
August 23	7.0	15.2	14.0	17.0	53.2	13.3	13.2	17.0	9.5	7.0	46.7	11.7
August 30	9.5	11.8	9.2	9.2	39.7	9.9	12.2	14.2	13.5	9.8	49.7	12.4

trend is shown in Figure 9. Pre-alkalization data were not available and any direct effects attributable to the lime application cannot be demonstrated for this season. Peaks in the abundance of both zooplankton and phytoplankton, the latter occurring after the former, were noted; the maximum of phytoplankton, occurring on July 25, was almost entirely the result of a sudden and temporary increase in abundance of one organism, Dinobryon sertularia.

Perhaps of more importance than the quantity of plankton is the quality, especially of the phytoplankton. It is well known that these organisms have distinct preferences for certain environments. Prescott (1951) points out that in soft-water seepage lakes the algal flora is predominantly of green algae (Chlorophyta), while that of more alkaline lakes is predominantly of blue-green algae (Cyanophyta). A total list of the zooplankton species is given in Table 16; the phytoplankton species are listed in Table 17, where the predominance of chlorophycean species will be noted among the phytoplankton. Only two species of the Cyanophyta were present, and these were very scarce.

In addition to the planktonic species listed in Table 17, several filamentous algae were observed in the lake. These filamentous forms were all members of the Chlorophyta and consisted of Oedogonium sp., Mougeotia sp., Spirogyra sp., Desmidium Baileyi (Ralfs) Nordst., Desmidium Grevillii (Kutz.) DBy., and Gymnozyga moniliformis Ehrenb. One of these, Mougeotia sp., was very abundant, being thickly wrapped around almost every individual of the rooted aquatic plants.

Rooted vegetation

The results of the quantitative sampling of the rooted aquatic plants are given in Table 18.

Rickett (1921) indicated that significant errors will result in this method unless a large number of samples are taken, a prac-

Figure 9. Seasonal variation of plankton, mean of four stations.

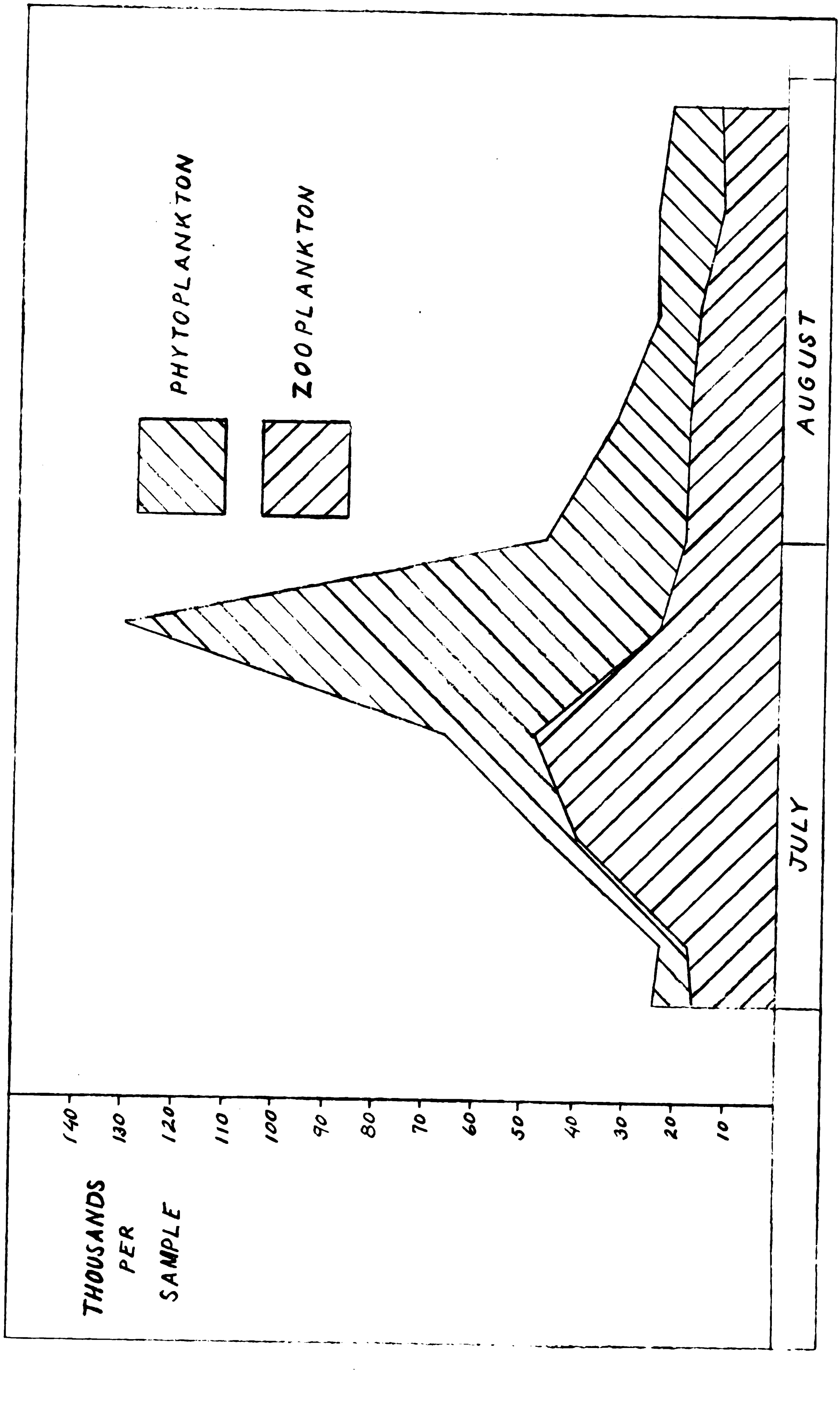

PHYTOPLANKTON
ZOOPLANKTON
AUGUST
JULY
THOUSANDS PER SAMPLE
140
130
120
110
100
90
80
70
60
50
40
30
20
10

Table 16. Zooplankton found in Stoner Lake.

Species	Abundance
Cladocera	
Acroperus angustatus Sars	R
Bosmina longirostris (O. F. Muller) ?	A
Ciriodaphnia lacustris Birge ?	A
Daphnia arcuata Forbes ?	C
Sida crystallina (O. F. Muller)*	
Copepoda	
Cyclops fimbriatus Fischer ?	A
Nauplius	A
Rotatoria	
Anuraea cochlearis Gosse	A
Notholca longispina Kellicott	R
Rattulus longiseta Schrank	R
Other rotifers not identified	

A - abundant
C - common
R - rare
* - observed in lake; not found in plankton

Table 17. Phytoplankton found in Stoner Lake.

Species	Abundance
Cyanophyta	
Coelosphaerium sp.	R
Merismopedia glauca (Ehrenb.) Naegeli	R
Chlorophyta	
Dictyosphaerium Ehrenbergianum Naegeli	C
Dictyosphaerium pulchellum Wood	C
Dinobryon sertularia Ehrenb.	A
Nephrocytium Agardhianum Naegeli	C
Pediastrum araneosum (Racib.) G. M. Smith	R
Scenedesmus armatus (Chod.) G. M. Smith	R
Volvox tertius A. Meyer	C
Desmidaceae (Desmids)	
Closterium Kutzingii Breb.	R
Micrasterias radiata Hass.	C
Micrasterias radiosa Ralfs	C
Staurastrum Johnsonii West and West	C
Staurastrum Ophiura Lund.	A
Staurastrum O'Mearii Arch.	A
Chrysophyta	
Chrysosphaerella longispina Lauterborn	A
Bacillariophyceae (Diatoms)	
Tabellaria fenestrata (Lyngb.) Kutz.	A
Tabellaria flocculosa (Roth) Kutz.	A
Pyrrhophyta	
Peridinium limbatum (Stokes) Lemmermann	R
Other phytoplankters not identified	

A - abundant
C - common
R - rare

Table 18. Weight of rooted aquatic plants per square yard of bottom, means of two samples.

Date	Station		Air-dry (grams)	Oven-dry--100°C. (grams)	Ash (percent of oven-dry)
June 30	1	A	242	212	4.30
		B	36.8	31.1	.022
	2	A	30	21	11.38
		B	2.1	1.4	.701
	3	A	135	115	18.26
		B	8.5	7.1	.262
	4	A	22	20	26.61
		B	2.1	2.1	.028
August 14	1	A	314	270	2.86
		B	8.5	7.1	.010
	2	A	14	10	6.84
		B	.7	.7	.134
	3	A	76	66	18.74
		B	13.4	12.0	.177
	4	A	48	40	24.44
		B	.7	.7	1.350

A - mean
B - standard deviation

tice that would entail much time and effort. Some error was felt to be eliminated in Stoner Lake by sampling areas of maximum abundance for comparative purposes rather than randomly selected points, but because maxima were selected extreme care should be exercised to select the same areas in any replicate experiment. It will be noted that the standard deviations are high; this will make statistical comparison difficult unless changes in abundance are great. Probably the abundance of rooted aquatic vegetation, sampled by this method, cannot be considered an efficient index.

The results of bottom sampling for vegetation indicated that very few plants were present beyond depths of three feet. Large areas of sandy bottom were present in the lake at depths of three feet but were almost completely devoid of any rooted aquatic vegetation. Possibly this absence of vegetation was due to the reduction of light by the high color present in the water.

In Table 19 are listed the total species found in Stoner Lake.

DISCUSSION

In evaluating alkalization as a means of increasing the productivity of a natural lake, the ultimate test of the value of this method as a tool of fisheries management is whether or not fish production is increased. To use fish production as the sole index of productivity, however, might require many years before a significant difference may be observed, if at all. It is important, then, that the experimenter follow through the chain of events which he would expect to take place if fish production were eventually to be increased.

In attempting to estimate the amount of lime to be used in a lake to produce desired chemical results, such factors as volume of the lake, extent of the organic soils, and the chemical properties

Table 19. Rooted aquatic plants found in Stoner Lake.

Brasenia Schreberi Gmel.
Carex rostrata Stokes
Chamaedaphne calyculata (L.) Moench
Dulichium arundinaceum (L.) Britt.
Eleocharis Smallii Britt.
Eriocaulon septangulare With.
Glyceria borealis (Nash) Batchelder
Glyceria canadensis (Michx.)
Isoetes muricata Dur.
Juncus articulatus var. *obtusatus* Engelm.
Juncus longistylis Torr.
Myrica Gale L.
Myriophyllum tenellum Bigel.
Nitella flexilis (L.) C. A. Agardh
Nuphar variegatum Engelm.
Potamogeton epihydrus var. *Nutalli* Fern.
Potamogeton Oakesianus Robbins
Scirpus subterminalis Torr.
Scirpus validus Vahl
Sparganium angustifolium Michx.
Sparganium sp.
Sphagnum sp.

of both the water and soil must be considered as primary. In estimating the amount of lime to be used in Stoner Lake, only approximate values for the area and volume were used. Also, it was learned that the lake level had fluctuated since earlier physical measurements were made, so it was necessary that corrections in volume and area be made. An area of 75 acres and a volume of 750 acre-feet were used in the lime calculations, and the area of organic soil was assumed to be 75 acres also; at the time of the experiment, the measurements made of area and volume were 95 acres and 630 acre-feet, respectively, and the area of organic soil 30 acres.

The first event following lime application is chemical modification, but even this initial phase is complicated by the activity of the bottom soil.

Theoretically, if all the calcium compounds applied (8.5 tons hydrated lime ($Ca(OH)_2$) and two tons limestone ($CaCO_3$), equivalent to 19,950 pounds hydrated lime) were to have been converted to the bicarbonate form, the application would have resulted in an increase of 16 p. p. m. bicarbonate alkalinity. Actually, the alkalinity was increased by only 3 p. p. m. This, in terms of hydrated lime, is equivalent to 3,800 pounds, or 1.9 tons. If it is assumed that the remainder, 16,150 pounds (in terms of hydrated lime), was accounted for by the pulpy peat, the rate of utilization was 540 pounds hydrated lime per acre of pulpy peat. If the data on adsorbed calcium in the soil are converted to the proper units, they show an accounting of only 13.2 pounds hydrated lime per acre of pulpy peat, for the top three centimeters, or about 4.4 pounds per acre-centimeter. Obviously, the results of the determinations of adsorbed calcium in the pulpy peat do not tell the full story. The figure of 540 pounds per acre is undoubtedly high, because a part of the lime unaccounted for was probably distributed in portions of the lake other than the pulpy peat; for example, acid organic material along the shores and in the marshes might also have a high lime requirement. And probably more than the top three centimeters of the soil was active in the adsorption process. At any rate, it is safe to say that about 16,150 pounds of hydrated lime were distributed to elements of the lake other than the water.

The question arises whether the lime requirement of the pulpy peat in Stoner Lake is an exact amount, such as 540 or 13.2 pounds hydrated lime per acre, or whether the requirement is a function of the concentration of calcium in the water.

In a general discussion of base-exchange, Millar and Turk (1948) state that the efficiency of ion exchange depends upon, among other factors, the relative concentrations of the ions involved. Neess (1949) reports that laboratory experiments in Europe showed that the concentration of potassium, added to water with a soil suspension, decreased for some time until it reached an equilibrium at a point where the concentration was only a fraction of the original; and "As the potassium was removed from the water by agents other than the soil, more was released from the latter, which appeared to be acting as a reservoir." Neess also makes reference to a somewhat similar situation with phosphorus in ponds.

It would be reasonable, then, to postulate that a relationship exists between the rate of lime application and the rate of calcium adsorption; in other words, if higher rates of application are used in Stoner Lake, and presumingly in other similar lakes, a corresponding increase of calcium adsorption by the soil can be expected.

Another chemical effect of alkalization, the change of pH, appears to have a somewhat different relationship. The fact that the increase was only of a temporary nature, while the increase in alkalinity was more permanent, would seem to indicate that some factors other than calcium adsorption of the soil were effective in reducing the pH of the water to the original values within a short time after alkalization. This reversal to original values can probably be attributed to the buffering effect of weak electrolytes in the water.

No data were taken in regard to the pH of the bottom soil, nor of the water at the levels near the mud-water interface, so it would be difficult to estimate the effects of alkalization in terms of increased bacterial activity and decomposition due to a change of pH at these levels. If a buffering effect were present at these lower levels, as at levels nearer the surface, it is doubtful whether any permanent change of pH was effected.

That no observable clearing of the color in the water occurred was well established. Theoretically, if the color is caused by suspended colloidal organic material, as is thought to be the case, these particles, carrying a negative charge, would adsorb positively charged calcium ions, flocculate, and precipitate out. Experiments carried out in the laboratory on water from Stoner Lake indicated that such a clearing would result when lime had been added at the rate of approximately 400 pounds per acre-foot. The failure of the water to clear at the rates applied to Stoner Lake may also be due to the lack of a more efficient coagulating substance. In water and sewage treatment plants, the coagulants most commonly used to remove color are aluminum sulfate, ferrous sulfate, ferric sulfate, iron chloride and sodium aluminate; use is also made of magnesium naturally present in the water (Theroux, et. al., 1943). Failure of the water to clear may be attributed to two possibilities: (1) an insufficient amount of lime applied, and (2) a lack of a more efficient coagulant, such as magnesium, in the water.

By far the most important, from a management viewpoint, is the increase of biological production which may result from an alkalization program.

In view of the large degree of stunting among the yellow perch of Stoner Lake, however, significant changes in certain levels of the food chain may be difficult to detect. For example, if the capacity of the lake to produce bottom organisms is increased, the resultant increase in production of these organisms may not be reflected in the results of a bottom sampling program because of a greater utilization by the large population of stunted fish. Similar situations may possibly be found at other levels of the food chain. It is important, therefore, that an attempt to measure all levels be made.

It is possible that a higher growth rate of the fish could be effected more rapidly by some other management program directed toward an adjustment of the fish population; for example, the introduction of a species predatory upon yellow perch might reduce the number of stunted fish and increase the average size. However, a program of this type would not change the fundamental capacity of the lake to produce, and the effects, although desirable, may not have the degree of permanency that the effects of higher productivity are presumed to have.

Because certain chemical modifications may be produced is no real assurance that an increase of productivity will necessarily follow. An increase of 3 p. p. m. alkalinity does not remove Stoner Lake from the class of soft-water lakes, and it is difficult to believe that such a small change will greatly alter biological conditions. No doubt it is possible to increase the concentration of bicarbonates by 10, 50, or even 100 p. p. m. if enough calcium compounds are applied, but even then it would still be necessary to justify such a program as a management method by increased biological production. The values obtained for the various biological indices are presented here for comparison in later years. The real test of whether or not this method of habitat modification can be developed into an efficient tool of management, for the purpose of improving the sport fisheries of the soft-water, tea-colored lakes in these northern regions, lies in the degree to which fish production is increased. This degree has yet to be determined.

SUMMARY

1. Calcium compounds were applied at the rate of 26.5 pounds hydrated lime ($Ca(OH)_2$) and 6.2 pounds ground limestone ($CaCO_3$) per acre-foot of water, the total being equivalent to 31.2 pounds hydrated lime or 42.2 pounds limestone per acre-foot.

2. Concentrations of oxygen and carbon dioxide were not significantly affected.

3. The high amount of color present in the water (80 P.C.S.) was not affected.

4. Bicarbonate alkalinity increased from 5.2 p. p. m. to 8.2 p. p. m.; this increased was highly significant statistically.

5. pH values increased from 6.8 to 7.3 immediately after the lime application, but returned to original values after about five weeks.

6. The carbonate content of the bottom soil was not affected.

7. Adsorbed calcium in the pulpy peat increased from 0.072 percent to 0.132 percent; this increase was highly significant statistically.

8. Quantitative and qualitative biological data of fish, bottom invertebrates, net plankton and rooted aquatic vegetation were collected and are presented for the purpose of making an evaluation of biological effects after further sampling in subsequent years.

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