WATER QUALITY AND PRODUCTIVITY CHANGES
ASSOCIATED WITH THE LIMING
OF A SOFT WATER LAKE

by

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INTRODUCTION

Need and Scope of Study

Projected population increases and the resultant sportsman pressure on fishing waters, particularly in highly urbanized areas of the United States, have brought into focus the need for additional fishing waters and the development of methods which are economically feasible to increase the productivity of existing waters.

Problems common to many streams result from natural infertility of the water and acid mine drainage resulting from the mining of coal, iron ore, and other minerals. Latest figures available on the extent of waters deleteriously affected by acid mine drainage pollution in the United States reveal that a total of 5,890 miles of streams and 14,967 acres of impoundments are affected. This represents a loss of an estimated 2,000,000 days of recreational fishing annually with a total value of more than $11,500,000 (Kinney, 1964:2). In the Appalachian Area (includes the Appalachian Mountain region of the States of Alabama, Georgia, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia) 832,605 acres of land have been disturbed by surface mining alone which represents .36 percent of the total land area (Boccardy and Spaulding, 1968:2). Much of the drainage from these disturbed areas is of an acid nature.

The addition of lime, which neutralizes acid water conditions, acts as a buffer against rapid pH changes, and acts as an indirect fertilizer, would seem to hold promise as a desirable management practice for these naturally infertile and/or acid streams and lakes.

The objective of this research was to determine what chemical changes took place in Sherwood Lake as a result of treatment with lime. Supporting biological data were also collected.

The limestone drum treatment station was put into operation in the winter of 1964 and continued through 1968 (Zurbuch, 1963:174). Four years of data, during which treatment was continuous, are presented and compared with pre-treatment data.

Biological data collected included volumetric determinations of plankton abundance. Fish population samples were taken annually and age and growth analyses for largemouth bass, *Micropterus salmoides*, and bluegill sunfish, *Lepomis macrochirus*, are presented and compared with previous years.

Description and Management History of Sherwood Lake

Sherwood Lake Public Fishing Area is located approximately 25 miles northeast of White Sulphur Springs, West Virginia, in the Monongahela National Forest in Greenbrier County at an altitude of 2950 feet (Fig. 1). Meadow Creek was impounded by the West Virginia Department of Natural Resources in 1958 under the terms of a cooperative agreement with the United States Forest Service and was first opened to fishing in 1959. The lake is 165 acres in size with a maximum depth of 22 feet, a drainage area of 4020 acres of forest land, and 3.33 miles of shoreline (Fig. 2).

Prior to impoundment in 1958, the watershed above the lake was treated with rotenone to rid the stream of all resident fish. Following reclamation, an initial stocking of 330 largemouth bass, six to

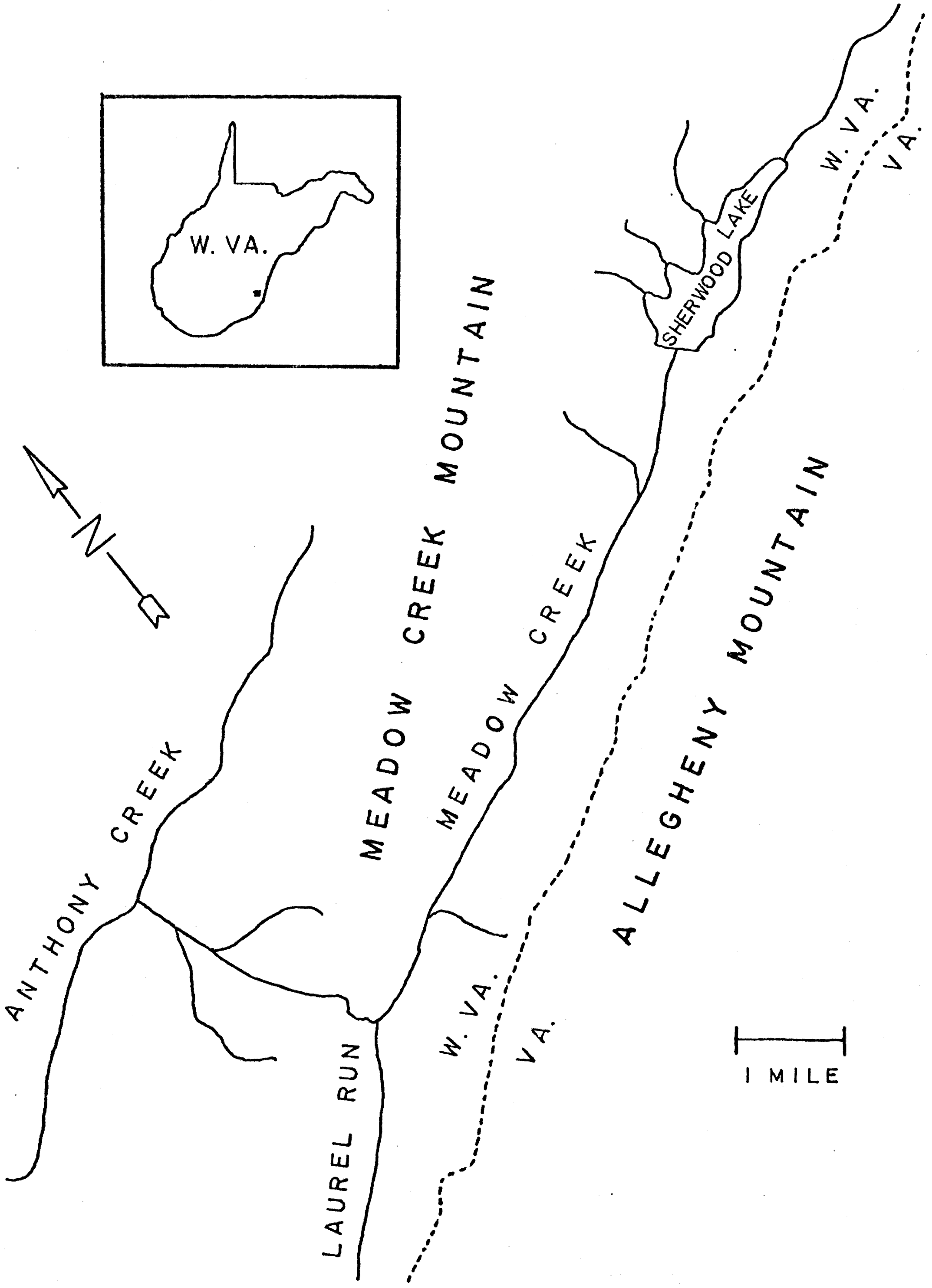

Fig. 1. Geographic location of Sherwood Lake

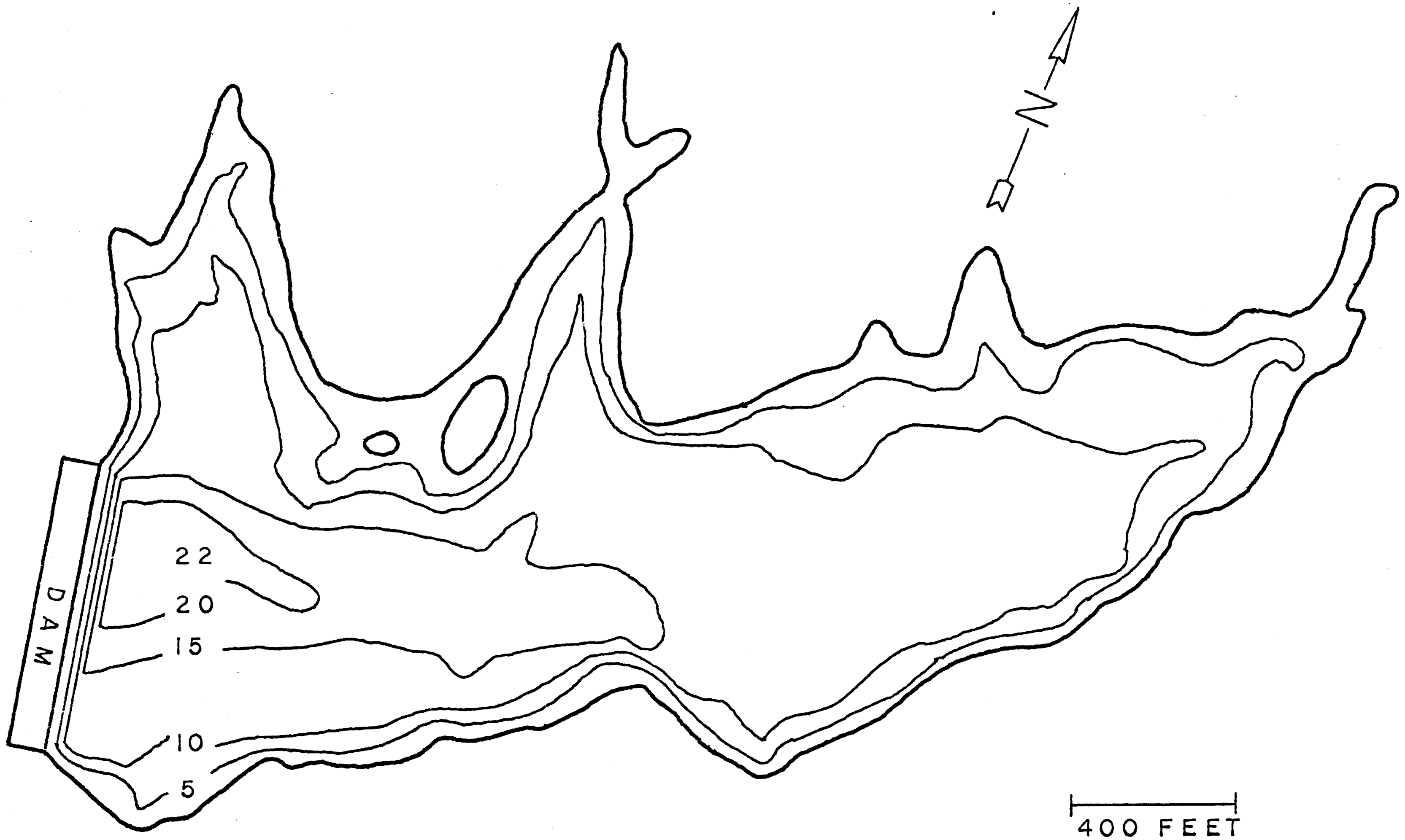

Fig. 2. Depth contours at Sherwood Lake in feet

sixteen inches long, was made. Bluegill sunfish were apparently stocked by fishermen in 1961 and by 1964 a sizable population of harvestable size bluegill were found to be present. These two species are the only gamefish present in the lake. Two additional species, black bullheads, *Ictalurus melas*, and white suckers, *Catostomus commersoni*, are known to exist in the lake but were not stocked by the West Virginia Department of Natural Resources.

Geology, Soils, and Climatology of Study Area

Sherwood Lake is in the Meadow Creek Syncline, the axis of which nearly coincides with Meadow Creek and Laurel Run. The syncline parallels the West Virginia-Virginia state line and its total length is probably not much greater than the 15 miles, all being in Greenbrier County. The surface rocks along the axis belong to the Pocono Series, a lenticular sandstone, which produce a soil that is better fitted for timber production than for cultivation (Price and Heck, 1939:148).

The soils of the drainage are primarily Dekalb stony loam with smaller areas of Clymer loam and Atkins silt loam in the flood plain of Meadow Creek.

Dekalb stony loam surface soil is a grayish-yellow friable loam five to six inches deep. The subsoil is a yellow friable heavy loam to a depth of 12 to 15 inches, where it gives way to brownish-yellow loam or silt loam. In most places the sandstone bedrock occurs at a depth ranging from 26 to 30 inches, but in steep areas it is very near the surface (Vessel, Swann, and Fridley, 1941:51).

Climatological data from the nearest station located at White

Sulphur Springs, West Virginia show that the average annual temperature is 52.8°F (11.6°C) and the average annual precipitation is 38.53 inches (United States Department of Commerce, 1968:147).

In natural waters, the chemistry of soils in the lake basin and its watershed are related to the productivity of the lake (Bennett, 1962:38). The drainage basin and the climate of the Sherwood Lake watershed have characteristics which result in a relatively infertile soft water lake.

LITERATURE REVIEW

The application of fertilizers to aquatic environments has been a standard practice in pond culture in many parts of the world. European pond fertilization began about 1600 and is one of the oldest agricultural practices in use today. Although only recently seen in the United States, the background of pond culture dates back to China about five centuries before Christ. More recently, pond culture and fertilization have been developed by a complex and sophisticated methodology (Neess, 1949:335).

Artificial aquatic enrichment has been limited mainly to standing water due to the complexities involved with running water or brackish water. The fertilizers used are of two basic types, inorganic and organic. Among the various inorganic fertilizers that have been used are: ammonium sulfate, basic slag, caustic lime, colloidal phosphate, limate, manganous sulfate, N: P: K combinations, noncaustic lime, potash and potassium salts, rhenania phosphate, rhodium nitrate and superphosphate. Organic fertilizers that have been used include aquatic plants, bone meal, hay manure, peanut meal, poultry laying mash, sea mussels, shrimp bran, and soybean meal.

The addition of an inorganic fertilizer (lime) to an infertile and slightly acidic lentic habitat has been shown to be beneficial by increasing the supply of available nutrients in solution and by providing a pH buffer (Neess, 1949:340).

The theoretical approach of nutrient liberation by the addition of inorganic fertilizers such as noncaustic lime has been considered by Hasler and Einsele (1948:541) for the activation of phosphorus and iron and their mutual sedimentation as $FePO_4$ at the fall overturn. Two schemes were presented for the removal of ferrous iron. One is the precipitation of ferrous ions with sulfate. Implication of other nutrient liberations are given by Welch (1935:204) who noted that magnesium may free calcium and that sodium may release potassium. Compounds of calcium and magnesium for the most part function similarly in the nutrient cycles of aquatic habitats. As an individual element, calcium is generally the more abundant and important of the two and often occurs naturally in large quantities. Calcium was considered in the following roles: (1) Related to the translocation of carbohydrates; (2) an intergral component of plant tissue; (3) acts to increase the availability of other ions; (4) reduces toxic effects of single salt solutions of other elements. Its presence is obvious in some animal tissue, especially the exoskeletons of arthropods and mollusks. Magnesium, Welch stated, is a component of chlorophyll and in some instances, acts as a carrier of phosphorous. Schaeperclaus (1933:57) claimed that he had never encountered a pond too rich in calcium; however, Surber (1945:378) stated that he believed waters that acquired hardness by contact with limestone formations may foster growths of Chara that reach great density and curtail fish production. The affinity of calcium and magnesium for free carbon dioxide results in the formation of soluble bicarbonates and carbonates.

Numerous factors inherent in the nutrient cycles of freshwater ecosystems concern the process and outcome of artificial fertilization.

They may be broadly grouped as chemical, biological and physical. The variability and interaction of these factors present basic problems in the understanding and success of aquatic fertilization. Aspects of the chemical and biological factors will be reviewed here.

The chemical aspect of the aquatic environment is the most important consideration involved in the fertilization process. Neess (1949: 340) pointed out the function of the bottom colloidal fraction (humic substances, ferric gels, clay) which absorbs and regulates the distribution of certain soluble nutrients, and also facilitates chemical decomposition and transformation by microorganic life occurring within.

The hydrogen ion concentration (pH) is one of the most significant chemical factors affecting fish in the aquatic environment. Schaeperclaus (1933:52) termed pH 9.0 the alkaline danger point and further recommended raising the pH of waters rated 6.5 or lower. It is well known that acid waters are poor producers, therefore, an optimal pH range of 7.0 to 8.5 can be established. To maintain a constant pH, water and soil must show a buffering action caused by the presence of calcium and magnesium carbonates.

Alkalinity is the result of a combined effect of several substances and conditions and is caused by the presence of carbonates, bicarbonates, hydroxides and to a lesser extent borates, silicates, phosphates and organic substances (American Public Health Association, 1960:46)

A positive correlation between the biological productivity and alkalinity of lake waters has been reported frequently. Ball (1945:

143) reclaimed 32 Michigan lakes with rotenone and found that, in general, the more productive lakes were the ones with the highest alkalinity. Barrett (1953:86), while studying four Michigan trout lakes which ranged in methyl orange alkalinity from 138 to 192 ppm, found that the increases in the epilimnial phosphorus content which occurred as a result of fertilization were only temporary. He found that the theoretical lower limit of the "alkalitrophic" (excess total alkalinity) condition seemed to be between 120 and 160 ppm methyl orange alkalinity. His findings supported the postulate that the ratio of marl to organic matter is important in the control of adsorption and regneration of phosphorus.

Bowling and Busbee (1964:285) found that lime applied to Georgia farm ponds did increase the productivity of the ponds; however, an inverse relationship existed between the calcium oxide content of the bottom soil and the total hardness of the water. They suggested that the relatively high concentration of calcium in the water one year after liming might have begun to precipitate out and be deposited in the bottom soils the second year after liming.

A significant increase in the standing crop per acre with increased alkalinity was demonstrated by Carlander (1955:551) on trout lakes, warm-water lakes, and Midwestern reservoirs. Eddy (1938:10) designated trout lakes as "soft" and relatively infertile if they had a carbonate concentration of 10 to 50 ppm. Bass and crappie lakes having a carbonate concentration of 40 to 200 ppm were considered by Hasler et al. (1951:351), to be fertile, producing abundant vegetation, bottom fauna, and plankton.

in their attempts to increase productivity in bog lakes found that alkalization of the water tends to mobilize nutrients bound up in acid undecomposed lake soils. Moreover, the lime treatment raised the bicarbonate content and hence makes available an abundant source of CO_2 an essential nutrient.

In attempting to relate the productive capacity of North American lake to trophic level of fish, the lake dimensions, and the water chemistry, Hayes and Anthony (1964:57) used the log of the methyl orange alkalinity (X_3) as the chemical parameter. The formula to predict Productivity Index for any lake using acres and feet is: $\log P1 = 0.031 + 7.31 \cdot 10^{-5}X_1 - 0.517X_2 + 0.287X_3$ where X_1 is the area, X_2 the mean depth, and X_3 the alkalinity. Kemmerer et al. (1968:83) failed to show a strong correlation between plankton photosynthesis and alkalinity. They suggested that the range within which added increments of alkalinity result in approximately linear photosynthetic response is 0-100 mg/l of $CaCO_3$.

Moyle (1946:326) classified Minnesota waters on the basis of carbonate content. Total alkalinity values (ppm) from 0.0-20.0 were classified as very soft, 21.0-40.0 as soft, 41.0-90.0 as medium hard and 91.0 or more as hard. Lakes with total alkalinities of 100.0 ppm or more were considered alkali (having total alkalinity values in excess of that needed for optimum biological productivity). Northcote and Larkin (1956:520) examined the relationship between physical and chemical indices of production and standing crops of plankton, bottom fauna and fish in 100 British Columbia lakes. In general, larger gill net catches of fish were taken in lakes with moderate to high total dissolved solids (over 100 ppm), than in lakes where total dissolved solids were low. Lakes with TDS less than 50 ppm appear to be particularly unproductive in respect to fish, however, low catches were also made in a few lakes of relatively high dissolved solid content. In attempting to estimate fish production for 34 north temperate lakes, Ryder (1965:214) relied on regression of yield on mean depth and total dissolved solids. Of the 34 lakes used for regression the 23 that have moderate to intensive fishing pressure fell into two groups, oligotrophic or unproductive and eutrophic or productive. Walker (1949:78) found that limed ponds produced a very good bloom after the second application of lime (in March) at one ton per acre, while the unlimed ponds went from no bloom to a very light bloom. Waters (1956:335) tested the observed correlation between alkalinity and productivity by liming two acid, soft water, bog lakes in Michigan. Lime was applied at 100 pounds per acre-foot. While the liming did not decrease the organic colloidal color, it did significantly increase the standing crops of net phytoplankton the following summer. Increases in standing crop of zooplankton also occurred the year following lime application. Waters and Ball (1959:388) observed an intensive plankton bloom in Stoner Lake the year following liming. Summer blooms continued to occur for three years after lime treatment at a higher level than pre-treatment.

Waters (1956:334) conducted laboratory experiments to obtain some information upon the possibility of a release of phosphorus from the lake soils following lime application. Hydrated lime was added to bottles at different concentrations. Three mud-water combinations from each of the two bog lakes were treated with lime: (1) surface water with mud, (2) bottom water with mud, (3) surface water without mud (control). Six rates of lime application were used: 0 (control), 25, 50, 100, 150, and 200 pounds per acre-foot. Results of this experiment showed that dissolved phosphorus concentrations were higher at the higher rates of lime application. This was true in all series containing mud except one where the dissolved phosphorus concentration was originally high. Under optimum conditions of alkalinity the availability of nutrients such as phosphorus is improved, and the availability of such nutrients probably limits the level of standing crop.

Several methods for treating infertile and/or acid waters with lime have been used. The most successful method is one which employs a mechanical device which provides continuous treatment.

Schaeperclaus (1933:166) described a water wheel powered lime distributor which was used to treat acid ponds to prevent winter kills of fish. A 30 foot long, revolving limestone drum has been successfully used by the Rochester and Pittsburg Coal Company (1969:112). The drum was used to treat acid coal mine water that had a pH of 3.1, 56 mg/l iron, 350 mg/l acidity and 1600 mg/l dissolved solids. After treatment and sedimentation the effluent from the retention ponds had a pH of 6.9, 1.4 mg/l iron and 18 mg/l alkalinity.

METHODS AND MATERIALS

Water Quality Sampling Station Locations

Water quality at two stations on Meadow Creek and five stations on Sherwood Lake was monitored (Figs. 3 and 4). Sampling stations on Meadow Creek were immediately above the limestone drum treatment site (station A) and immediately below the treatment site (station B). Surface and bottom samples were taken at each of the lake sampling sites. Water depth at station number 1 was five feet, stations 2, 3, and 5 was 14 feet deep and station 4 was 22 feet deep.

Chemical and Physical Measurements

Pre-treatment water quality data on Sherwood Lake were collected periodically from 1958 to 1964 by former District Fisheries Biologist H. Ronald Preston (Preston, 1964:4 Zurbuch, 1965:4). Post-treatment water quality data were collected by the writer from December 1964 to November 1968.

Monthly measurements taken at all lake stations included: air and water temperature, pH, conductivity, total alkalinity, dissolved calcium, total phosphates, total nitrates, oxygen, and Secchi disk transparency. Bottom water samples were collected with a 1200 ml Kemmerer Water Sampler.

Stream stations A and B were sampled weekly in conjunction with regular maintenance work. Weekly stream measurements included: air and water temperature, pH, conductivity and total alkalinity. Monthly water quality checks were also made at stream stations A and B and included all the measurements made on the lake, with the exception of

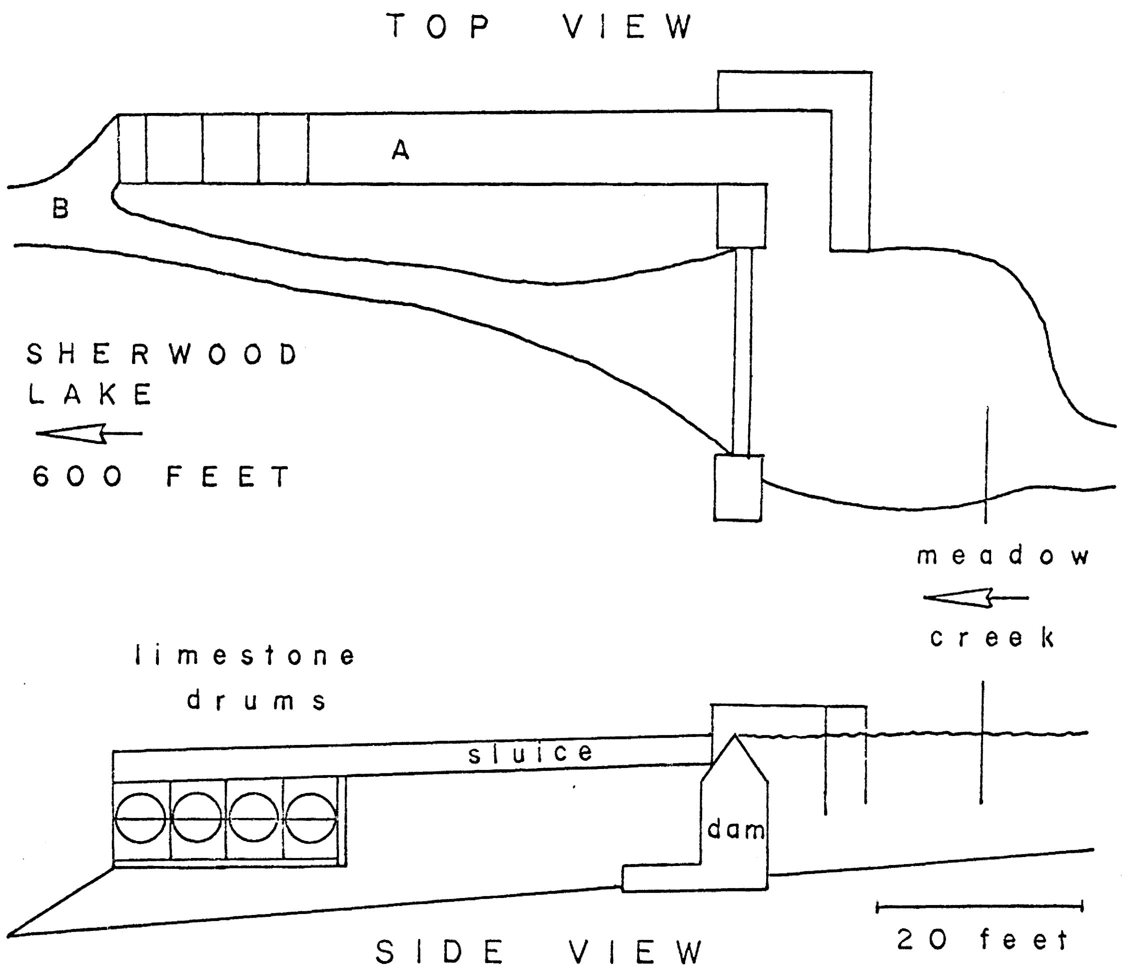

Fig. 3. Diagrammatic sketch of the lime treatment facility above Sherwood Lake showing the location of sampling stations A and B

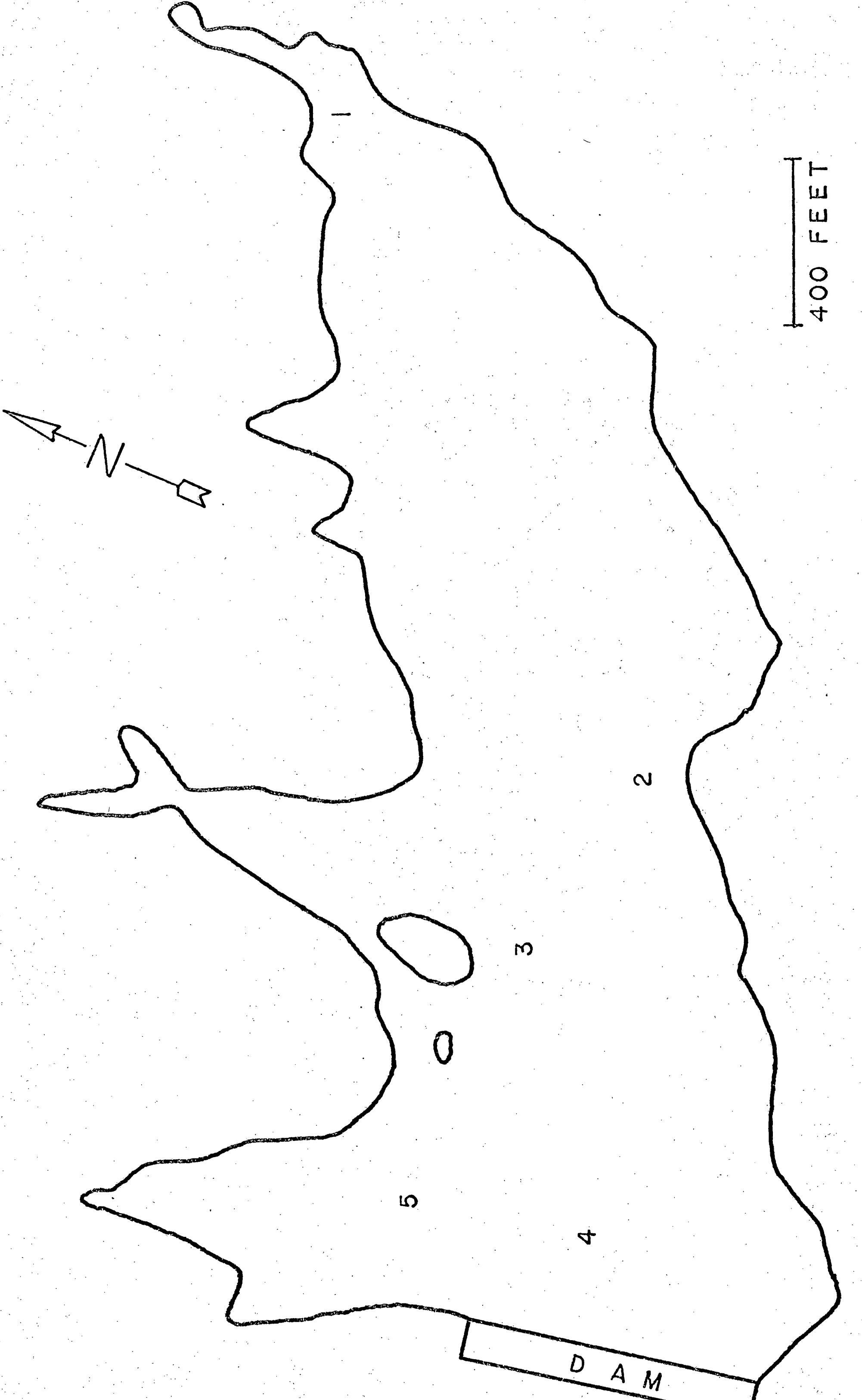

Fig. 4. Sherwood Lake sampling station locations

oxygen and Secchi disk transparency measurements.

Air temperature (°C) was taken with a pocket thermometer. Water temperature (°C) was taken with a Model FT3 electronic, direct reading hydrographic thermometer made by Applied Research Inc. The pH was measured with a Hellige pH comparator and interpolated to the nearest 0.1 units. Conductivity (micromhos/cm) was determined with a Beckman Model RA-2A solubridge conductivity meter.

Total alkalinity, dissolved calcium, total phosphate, total nitrate and oxygen determinations were made with a Hach Model DR-EL portable water engineer's laboratory.

Transparency determinations were made using a standard (20 cm diameter) Secchi disk with alternate quarter panels of black and white.

Plankton Samples

Plankton samples were collected in conjunction with monthly physical and chemical determinations at each lake station. Each sample was taken with a Wisconsin style plankton net and bucket 12 cm in diameter across the top and constructed of Number 20 mesh silk bolting cloth. Five vertical hauls (bottom to surface) at each station constituted one sample. Plankters were preserved in 2 percent formalin and later measured volumetrically using a calibrated centrifuge tube.

Fish Collections

Annual rotenone cove samples of the fish population were taken in 1965, 1966, 1967, and 1968. In 1964, the fish population sample was collected by means of a boat shocker. This was done because the lake had been drawn down to approximately one-half its normal size to facilitate repairs to the trickle tube and there were no areas that could be effectively sampled with rotenone.

Rotenone cove samples were taken in the same area each year. A 3/4 inch mesh nylon blocking net was used to block off the cove. A 2 1/2 percent synergized liquid rotenone was then applied from a boat by means of a portable water pump and weighted hose at a concentration of approximately 2 ppm. Fish were picked up for two days following treatment. All fish were sorted by species and individually weighed to the nearest 0.01 pound and measured to the nearest one tenth inch. These measurements were later converted to grams and millimeters respectively.

The 1964 sample was collected with a 230 volt, 3 amp, alternating current boat shocker similar to the one described by Loeb (1957:111).

Common and scientific names of fishes conform to the list of Common and Scientific Names of Fishes from the United States and Canada (1960).

Age and Growth

Scale samples were used for an age and growth investigation on largemouth bass and bluegill sunfish. The scale samples were collected during each annual population survey with additional scales collected during creel surveys conducted on Sherwood Lake during 1965 through 1968. After scraping the mucus off the skin, ten to 15 scales were taken from the left side of each fish at a point directly below the anterior insertion of the dorsal fin and above the lateral line. The scales were then placed in a scale envelope and the appropriate data recorded thereon. The scales were later mounted between glass microscope slides. Scales were projected by a Bausch and Lomb, Tri-Simplex Micro-Projector with a 5X eyepiece on a piece of white poster paper. The length of the scale from the focus to the anterior edge of the scale was then marked on a strip of paper and each annulus was then found and similarly marked. Back calculations of lengths at previous annuli were made using a nomograph similar to the one described by Carlander and Smith (1944:157). An intercept of 0.5 inches was assumed in all back calculations.

The length-weight relationship for largemouth bass and bluegill sunfish was calculated by using a standard statistical computer program for an unweighted linear regression. Slopes of the regression lines thus obtained were then tested by a Student's t test at the .95 level for a significant difference for each species for each year.

RESULTS AND DISCUSSION

Limnological Conditions of Sherwood Lake Prior to Lime Treatment

Sherwood Lake was first impounded and stocked with fish in 1958 and then opened for fishing in 1959. The limestone treatment facility was installed in 1964 and put into full operation in January 1965.

Physicochemical Conditions

Prior to the start of limestone treatment operations on Sherwood Lake, periodic checks on the water quality were made. These data were collected by former District Fisheries Biologist H. Ronald Preston (1964:4; Zurbuch, 1965:4) from 1958 when the lake was first impounded to 1964 when the limestone drums were installed (Appendix I).

To facilitate ease of comparison with post treatment data, mean values for water quality parameters from lake sampling station number 4 (surface) 1958 to 1964 are presented here. The mean pH was 6.6, total alkalinity 11 ppm, conductivity 18 micromhos/cm, and Secchi disk transparency 241 cm. According to Moyle's classification of water which is based on the carbonate content (1946:326) Sherwood Lake would be a very soft lake with low fish and plant productivity.

Plankton

Pre-treatment plankton samples were collected during 1963 (Preston, 1964:6). The volume of plankters in these collections ranged from 5.69 to 28.25 cc/m^3 with a mean of 12.92 cc/m^3 (Appendix I) and could be due to sampling during periodic plankton "blooms" when concentrations are much larger than normal. It is commonly recognized that newly created lakes exhibit an initial period of high productivity due to the availability of nutrients released from the inundated soil and then gradually over a period of several years experience a decline in productivity until a relatively stable condition is reached. The plankton production of Sherwood Lake seems to follow this general pattern, however, the establishment of higher aquatic plants and animals complicates the overall picture.

The most abundant plankters in the 1963 samples were cladocerans copepods, protozoans and phytoplankton.

Fish Population

After impoundment in 1958, Sherwood Lake was stocked with largemouth bass and bluegill and then opened to fishing in 1959. During the winter of 1963-64, shifting ice broke off the drop inlet trickle tube which resulted in an almost complete draining of the lake. The lake was temporarily fixed and refilled during 1964 and additional adult largemouth bass were stocked.

During the summer of 1964, before the lake had reached normal pool level, a population sample was taken by means of a boat shocker. While these data are not directly comparable to later population sampling data, valuable information on the effect of the drastic drawdown of the previous winter on the fish population was gained.

Three species of fish, largemouth bass, bluegill, and white suckers, weighing a total of 7.44 kg were collected (Table I). All size groups of largemouth bass were collected. The smallest bluegill collected was 76 mm long with larger bluegills being the most abundant group of all fish collected. Two adult white suckers were also collected.

Table I. Number and weight for three size categories of three fish species taken from Sherwood Lake, 1964

Species	Fingerlings			Intermediates			Harvestables		
	Size Range (mm)	Number	Weight (kg)	Size Range (mm)	Number	Weight (kg)	Size Range (mm)	Number	Weight (kg)
Largemouth bass	58-102	17	0.17	114-198	3	0.15	208-311	10	2.32
Bluegill	-	-	-	76-152	18	0.75	155-185	20	1.82
White sucker	-	-	-	-	-	-	457-483	2	2.26

Total weight (kg) - 7.44
Total number - - - 70

It was evident from the sample that the smaller fish were the most vulnerable group. Predation during the spring and summer was undoubtedly responsible for the almost complete loss of an entire year class of game fish. No young of the year bluegill and relatively few young of the year bass were collected in the population sample.

Back calculations from scales collected from largemouth bass and bluegill during 1964 are presented in Table II. Largemouth bass attained a length of 3.6 and 5.9 inches at annuli I and II respectively and bluegill were 1.9, 4.1, and 5.4 inches long at annuli I, II, and III respectively.

Water Quality Changes in Meadow Creek Due to Liming

Water quality changes in Meadow Creek, the main tributary of Sherwood Lake, were checked monthly in conjunction with the monthly sampling of Sherwood Lake. Measurements taken at Station A reflect the natural water quality before limestone treatment and measurements taken st Station B show the changes in water quality after limestone treatment.

Significant changes in the pH, total alkalinity, dissolved calcium, and conductivity due to the limestone treatment were noted and will be discussed here. Complete water quality data are given in Appendix II.

When the limestone drums were operating normally, a rise in pH of two full units, i.e. 6.6 to 8.6, from Station A to Station B was common. During periods of low flow this change in pH was less pronounced but readings at Station B were always higher than Station A (Fig. 5). Mean values for four years of treatment (1965-1968) at Stations A and B revealed that the total alkalinity increased from 6.8 ppm to 15.0 ppm,

Table II. Age and growth data for largemouth bass and bluegill from Sherwood Lake, 1964

Largemouth bass	No.	Age Group	Length at capture	Calculated length at each annulus			
				0	I	II	III
1964	10	1	3.4	3.4	-	-	-
1963	42	2	6.8	-	3.6	-	-
1962	9	3	9.2	-	3.6	5.9	-
Grand Ave. Y.C.	-	-	-	-	3.6	5.9	-
Number of Fish	51	-	-	-	51	9	-
Ave. Ann. Inc.	-	-	-	-	3.6	2.3	-

Bluegill	No.	Age Group	Length at capture	Calculated length at each annulus			
				0	I	II	III
1964	0	1	-	-	-	-	-
1963	13	2	4.7	-	1.9	-	-
1962	74	3	6.2	-	2.1	4.1	-
1961	10	4	6.9	-	1.9	3.8	5.4
Grand Ave. Y.C.	-	-	-	-	2.1	4.1	5.4
Number of Fish	97	-	-	-	97	84	10
Ave. Ann. Inc.	-	-	-	-	2.1	2.0	1.3

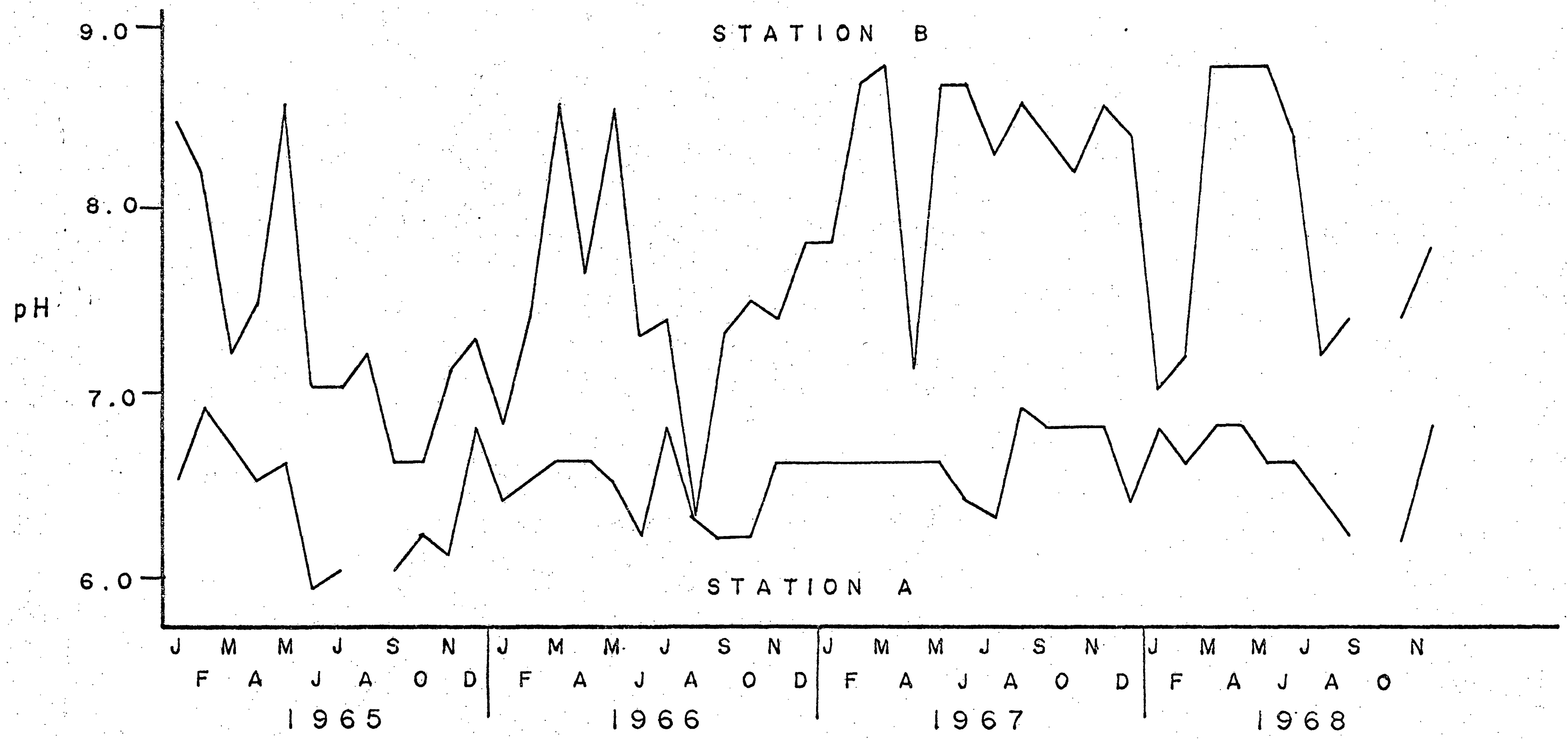

Fig. 5. pH measurements taken at Meadow Creek sampling stations A and B, 1965 - 1968

dissolved calcium from 0.94 ppm to 1.92 ppm and the conductivity from 10.8 to 22.6 micromhos/cm. There was no significant change in the concentrations of phosphates or nitrates from Station A to Station B.

Limnological Conditions of Sherwood Lake During Liming

Monthly water quality measurements were made at five stations on Sherwood Lake from January 1965, when the limestone drums were first put into full operation, until November of 1968 when this study was terminated. Annual fish population samples were also taken. Limnological measurements were made as outlined in the Materials and Methods section (pages 14-19). The majority of data were collected between the months of May and September. Supplementary winter water quality data were also taken as time and weather conditions permitted.

Biological activity is generally suppressed by cold water temperatures and generally accelerated by warm water temperatures (Thomas, 1967:30). While sampling during the summer months does not give a true picture of annual lake conditions as pointed out by Welch (1948:273), it does show annual peaks of physicochemical and biological activity. Over a period of years the relative heights of these annual peaks serve as indicators of productivity. Studying limnological conditions of lakes during the summer months is a widely used procedure (Langford, 1948:135; Ball and Tanner, 1951:10; Zeller, 1953:285; Schelske, Hooper and Haertl, 1962:649; Rawson, 1953:233; Nelson and Edmondson, 1955:423; Northcote and Larkin, 1956:522).

Physicochemical Conditions

Physicochemical measurements were made monthly at each of the five lake sampling stations. During the summer months, Sherwood Lake thermally stratified and dissolved oxygen was depleted at depth greater than 13 feet. This oxygen depletion below the thermocline was the main factor limiting biological activity. There was adequate dissolved oxygen (5.0-8.0 ppm) in the epilimnion at all times throughout the year.

Physicochemical conditions in the surface water of sampling station number 4 most accurately represents the average lake conditions during limestone treatment and will therefore be used in the following discussion to show changes that occurred in the lake. Complete water quality data are presented in Appendix II.

pH. The pH values ranged from 6.6 in 1965 to 7.4 in 1967. From 1965, at the start of limestone treatment, to 1968 there was a gradual increase in the pH (Fig. 6). The mean pre-treatment (prior to 1965) pH value was 6.6 and the mean pH value for 1968 was 7.1. While the increase in pH is relatively small, this shift from a slightly acidic environment to a slightly alkaline one had a great biological significance.

Fish themselves are euryionic and can easily live in waters with pH values between 6.0 and 10.0 (Bennett, 1962:45). Schaeperclaus (1933:52) recommended raising the pH of water rated 6.5 or below by adding lime. This buffering action by high concentrations of calcium prevents wide pH fluctuations. Moyle (1946:325) pointed out that soft water lakes usually have a lower pH and a corresponding lower productive potential than do hard water lakes. Many factors influence

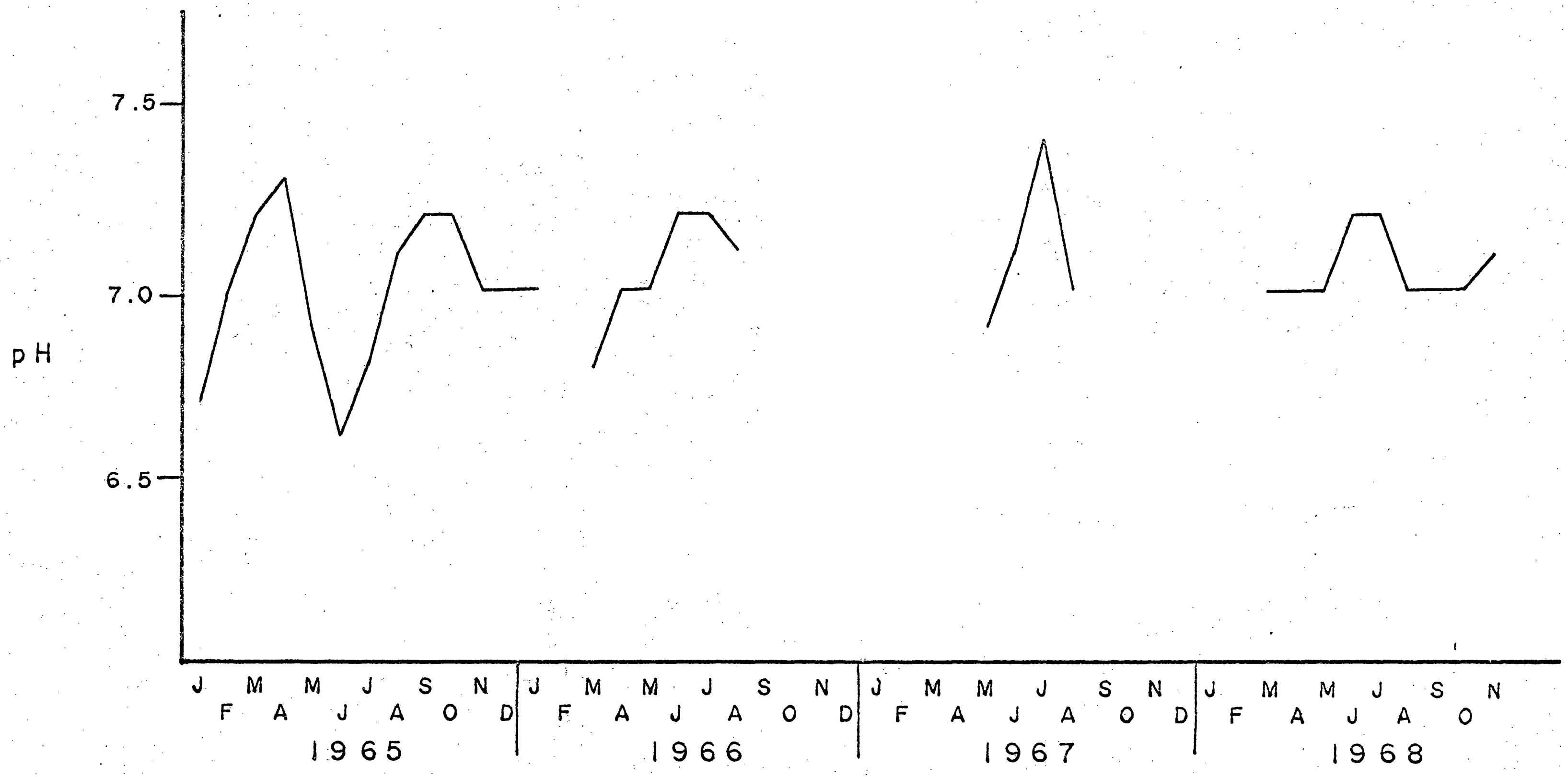

Fig. 6. pH measurements taken at Sherwood Lake (station 4, surface), 1965 - 1968

pH levels and can therefore lead to erroneous conclusions, however, the pH increases in Sherwood Lake which are due to limestone treatments would seem to be a valid criterion in assessing relative productivity changes.

Total Alkalinity. The total alkalinity values measured from 1965 to 1968 ranged between 6 and 27 ppm. The mean pre-treatment (prior to 1965) total alkalinity of Sherwood Lake was 11 ppm and the corresponding value for the last year of this study (1968) was 21 ppm. Thus total alkalinity values nearly doubled in four years (Fig. 7).

Alkalinity can be caused by carbonates, bicarbonates, hydroxides and to a lesser extent by borates, silicates, phosphates and organic substances (American Public Health Association, 1960:46). The alkalinity in Sherwood Lake was caused almost entirely by bicarbonates with some free carbon dioxide.

A positive correlation between the biological productivity and alkalinity of lake water has been reported frequently. For example, Ball (1945:143) reclaimed 32 Michigan lakes with rotenone and found that in general the more productive lakes were the ones with the highest alkalinity. Carlander (1955:551) showed a significant increase in the standing crop of fish per acre in lakes with increased alkalinity. Hayes and Anthony (1964:57) used the methyl orange alkalinity as one of three parameters to estimate productivity for any lake. They further suggested that the range within which added increments of alkalinity result in approximately linear photosynthetic response is 0-100 mg/l of $CaCO_3$.

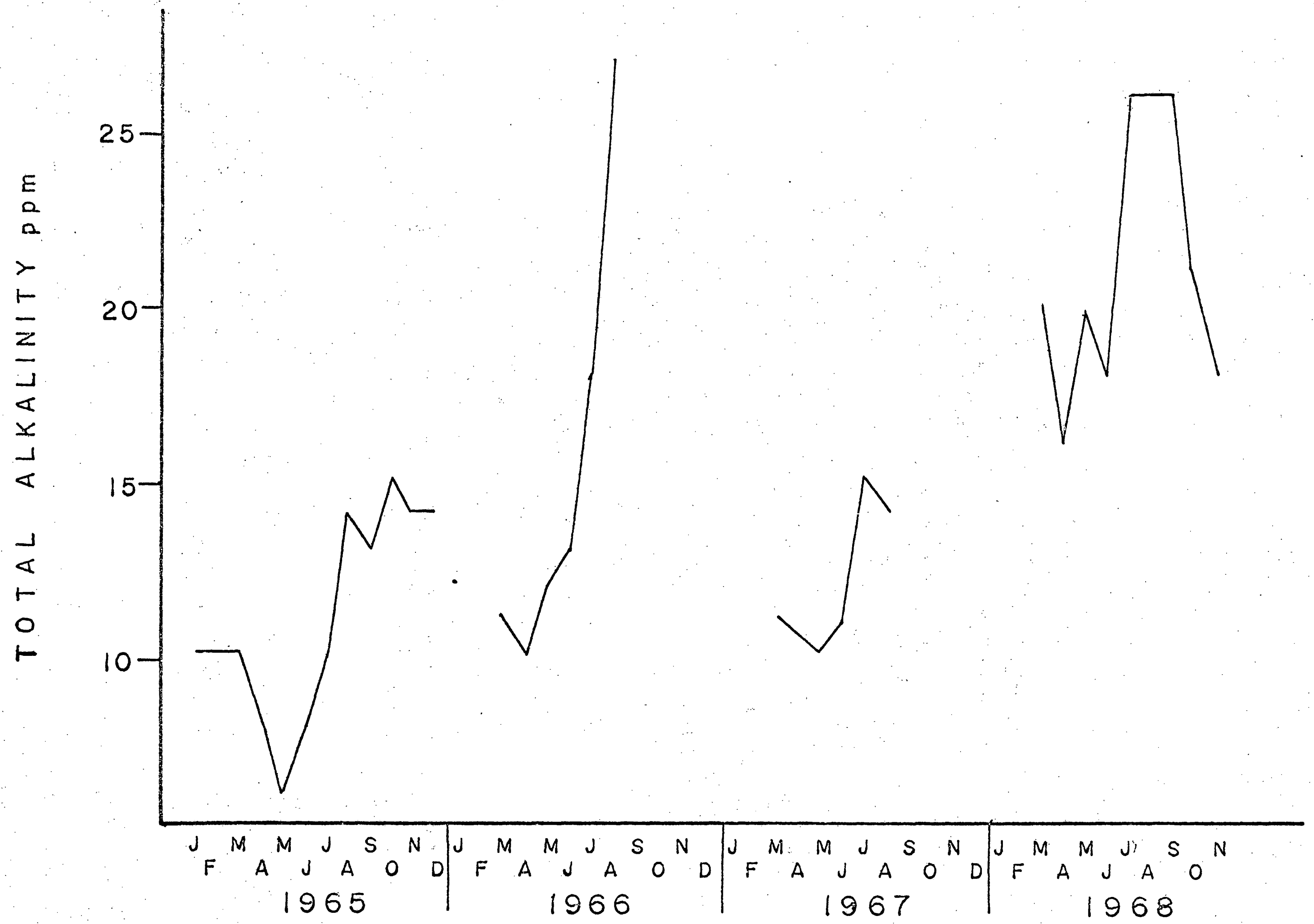

Fig. 7. Total alkalinity measurements (ppm) taken at Sherwood Lake (station 4, surface), 1965 - 1968

On the basis of Moyle's (1946:326) classifications, based on the carbonate content, of Minnesota waters, the productivity of Sherwood Lake has increased from that of a very soft lake to that of a soft lake.

Dissolved Calcium. The amount of total dissolved calcium remained low for the first two years of limestone treatment, never exceeding 1.6 ppm. A slight increase was noted in 1967 when the concentration of calcium reached 2.8 ppm. In 1968, dissolved calcium levels showed a dramatic increase with concentrations ranging from 3.6 to 6.8 ppm throughout the year (Fig. 8).

This increase in dissolved calcium could be due in part to the fact that calcium bicarbonate is almost completely disassociated in a very dilute solution and this disassociation is increased by a rise in pH (Ruttner, 1963:64). Barrett (1953:80) made a laboratory investigation of mud and water from Stoner Lake and 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 on the bottom of the lake. He recommended that sufficient lime be applied to neutralize the top one centimeter of mud and that lime treatment be continued to offset further adsorption by the mud. While no data are available from Sherwood Lake in this regard, it seems probable that the limestone, which was added relatively slow by the limestone drums, was readily adsorbed by the mud on the lake bottom. If this is true, continued limestone treatment should result in even more significant rises in dissolved calcium and pH levels.

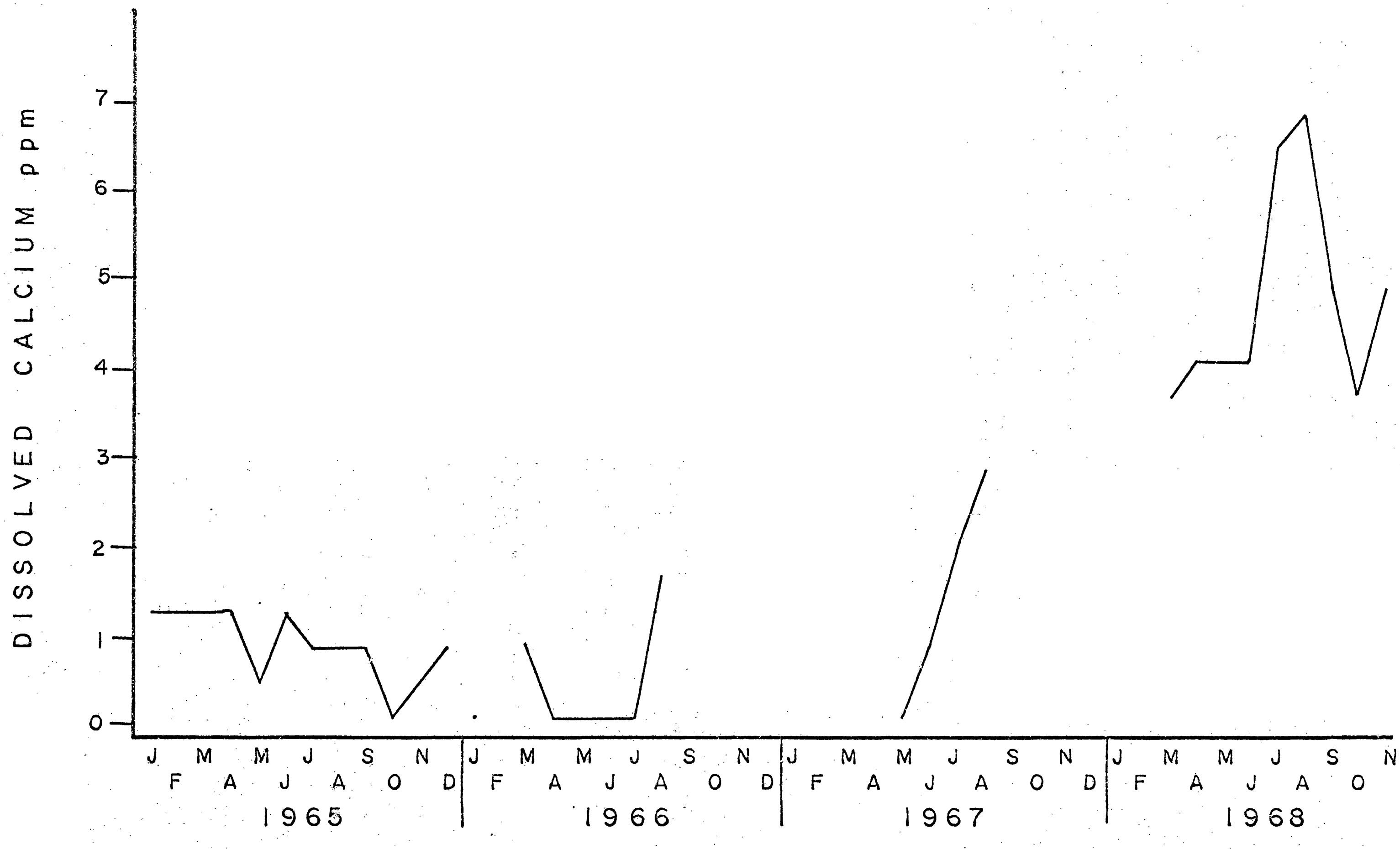

Fig. 8. Dissolved calcium measurements (ppm) taken at Sherwood Lake (station 4, surface), 1965 - 1968

Calcium is described by Lagler, Bardach and Miller (1962:435) as being one of the key chemical factors influencing nutrients in the first link of the food chain of fishes. Even at its highest concentration of dissolved calcium, Sherwood Lake would still be considered a soft water lake.

Specific Conductance. The specific electrical conductance of water is a measure of the dissolved salts present and is therefore an indirect measure of productivity.

The mean pre-treatment (before 1965) conductivity of Sherwood Lake was 18 micromhos/cm. After four years of limestone treatment, the mean conductivity in 1968 was 28 micromhos/cm. The highest measurements were obtained in 1966 when a conductivity of 50 was reached in August (Fig. 9). While there has not been a great overall increase in the concentration of dissolved salts, the base level has been raised from 13 ppm in 1965 to 20 ppm in 1968. Smith (1969:3112) noted a similar lack of effect on conductance by fertilization in Crecy Lake.

Total Phosphorus. Total phosphorus in Sherwood Lake remained at a low level throughout the first three years of limestone treatment, from 1965 to 1967, and rose somewhat during 1968 (Fig. 10).

Zeller (1953:281), in his work on Missouri farm ponds concluded that the major chemical factor limiting productivity was soluble phosphate. Yearly mean concentrations in the unfertilized ponds he studied ranged from 0.010 to 0.016 ppm and in the fertilized ponds from 0.016 to 0.028 ppm. A complete fertilizer was used by Zeller and, as pointed out by Waters (1956:340), a clear difference exists between fertilization

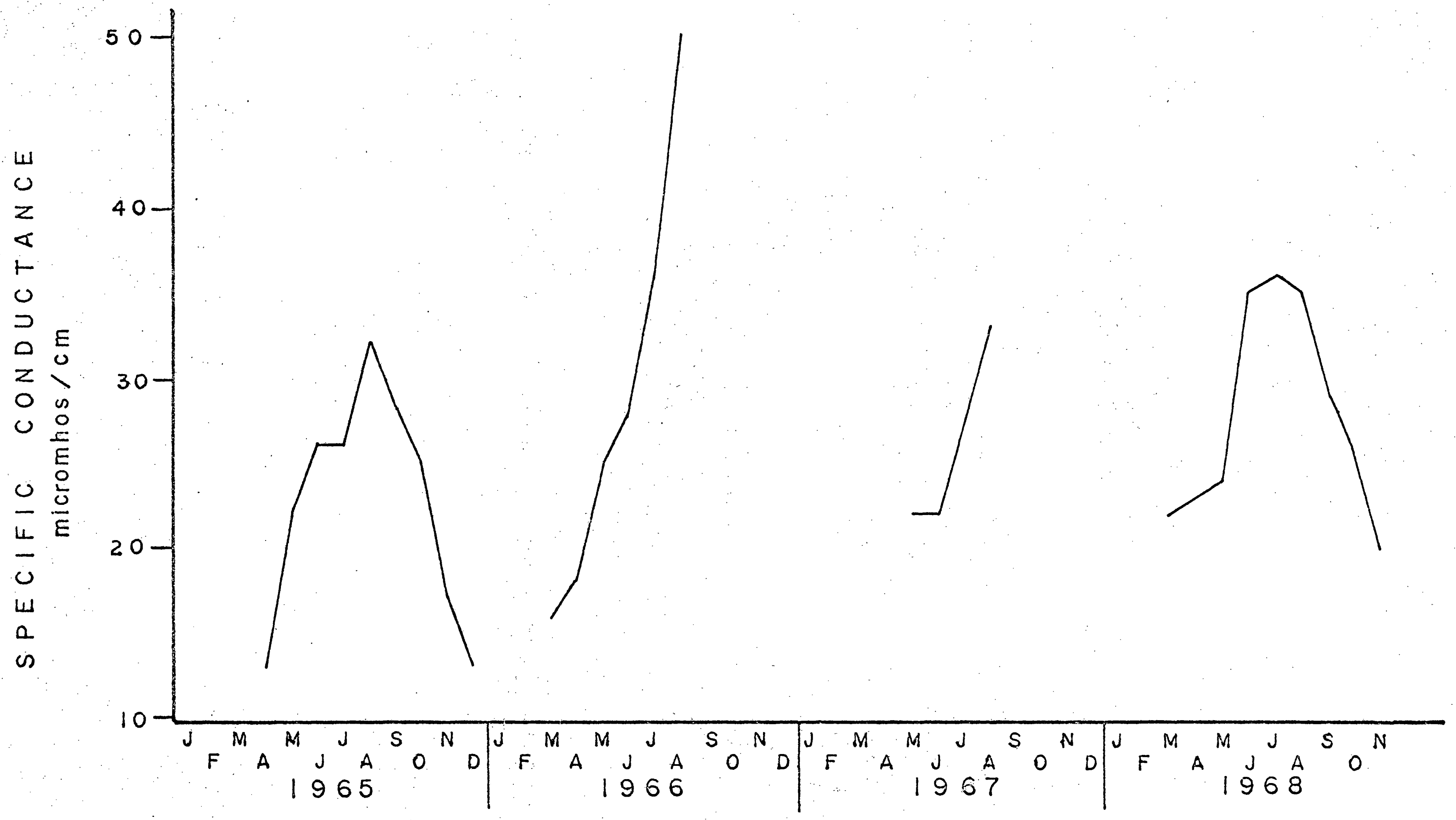

Fig. 9. Conductivity measurements (micromhos/cm) taken at Sherwood Lake (station 4, surface), 1965 - 1968

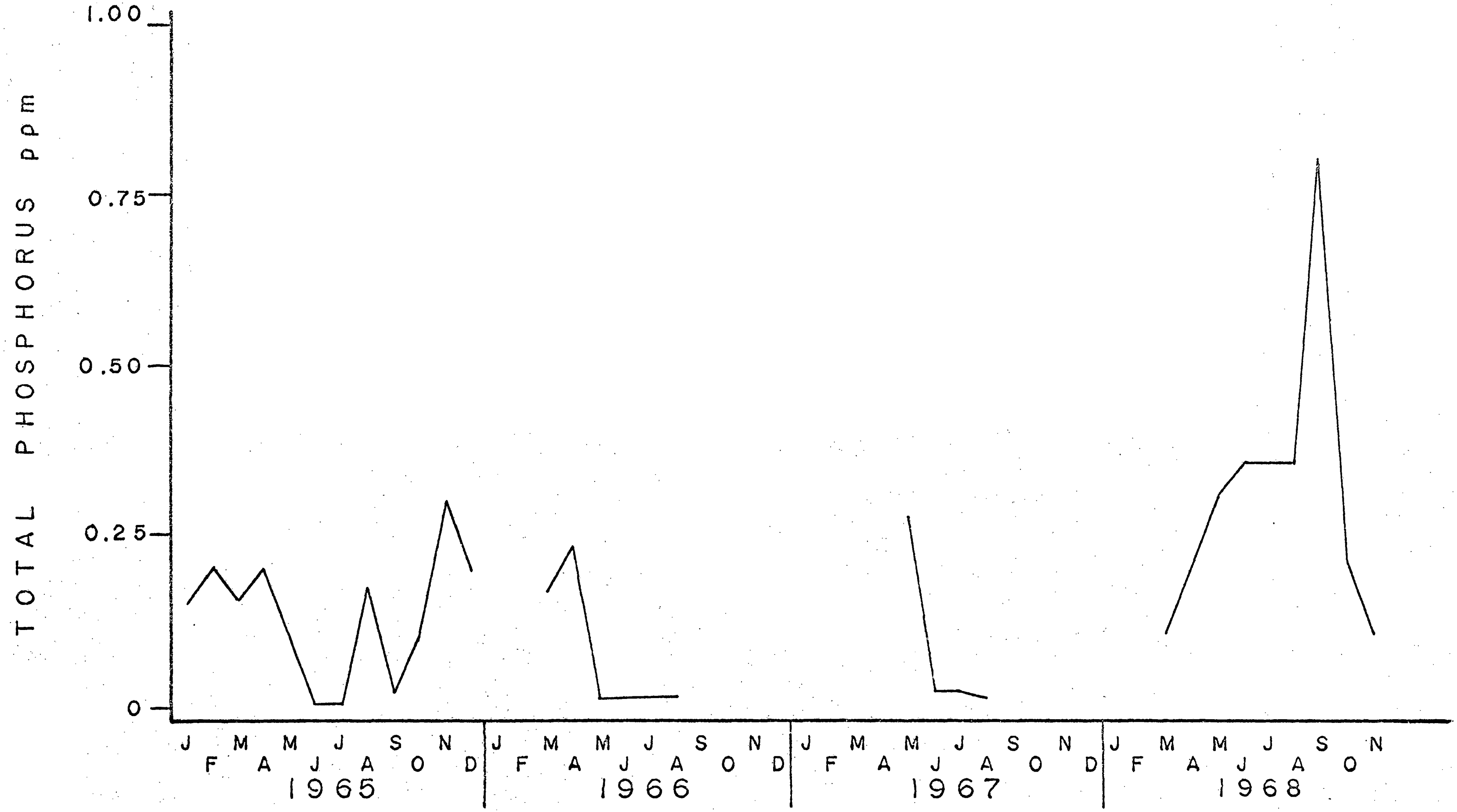

Fig. 10. Total phosphorus measurements (ppm) taken at Sherwood Lake (station 4, surface), 1965 - 1968

and lime applications. Direct fertilization with a complete fertilizer (N:P:K) adds nutrients to the aquatic environment while lime applications act indirectly in that nutrient availability (phosphorus) is improved due to more optimum reactions (pH) and ion concentrations. A greater concentration of immediately available carbon dioxide is also present after liming. Pennak (1946:45) considered phosphorus to be the limiting factor much more frequently than nitrogen.

A paucity of soluble phosphate would seem to be a major limiting factor in Sherwood Lake. Phosphate concentrations recorded have generally been substantially less than 0.25 ppm. This would suggest the possibility of increasing the basic fertility of Sherwood Lake by the addition of phosphorus, however, extensive growths of aquatic weeds would preclude treatment until these weeds are controlled. The uptake of phosphate and nitrate added to Bare Lake, Alaska by aquatic plants was noted by Nelson and Edmondson (1955:422). From visual observations made at Sherwood Lake, it appears that much of the available nutrients are being utilized and tied up by growths of aquatic weeds, primarily <u>Elodea</u>, before those nutrients can be incorporated at higher trophic levels. The extent and density of these weeds appear to increase each year. These observations tend to be substantiated by decreased plankton production and corresponding higher Secchi disk readings.

<u>Nitrate Nitrogen</u>. The concentration of nitrate nitrogen in Sherwood Lake remained at relatively low levels except for a brief period early in 1965 and again in 1968 (Fig. 11). Concentrations were less

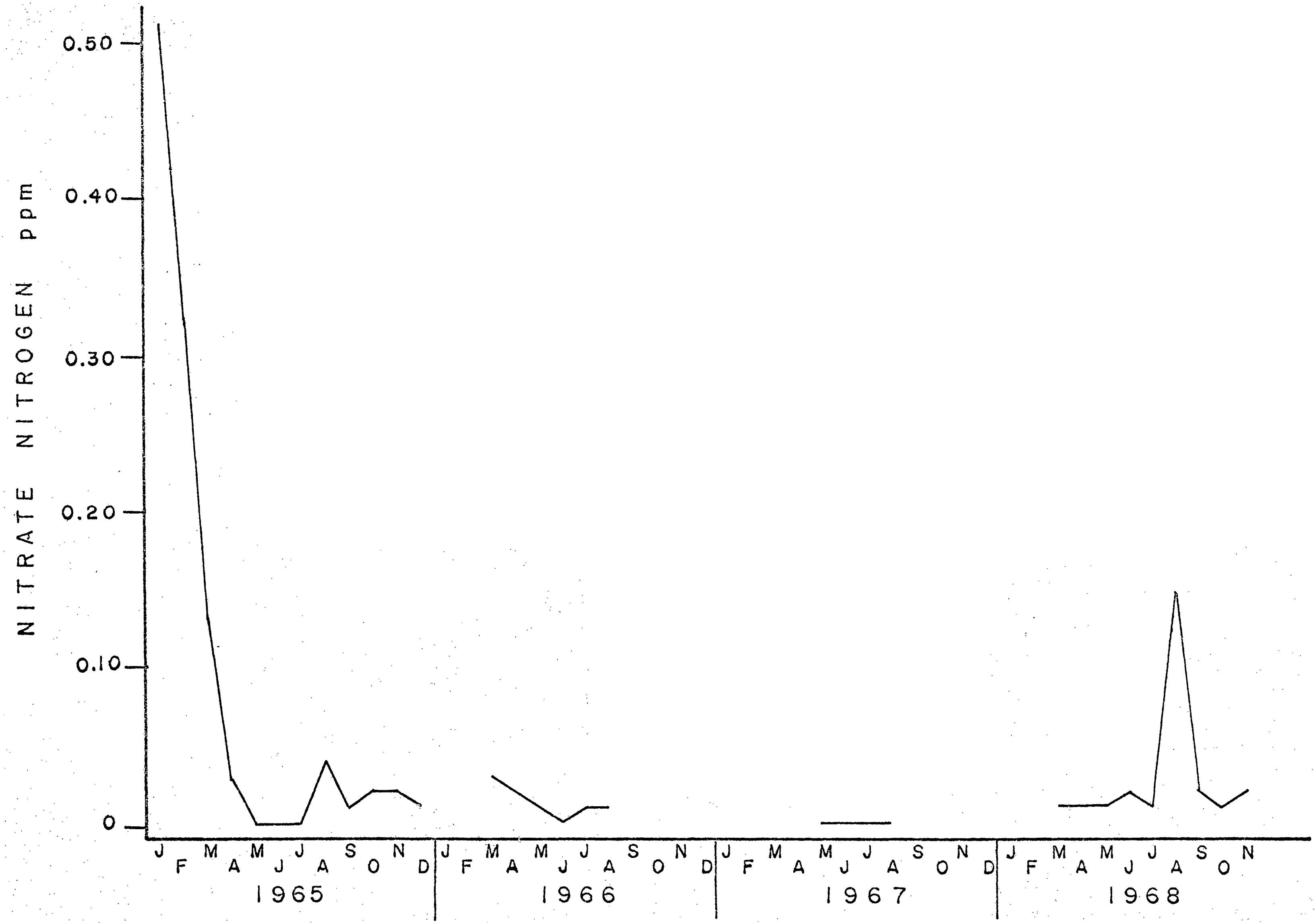

Fig. 11. Nitrate nitrogen measurements (ppm) taken at Sherwood Lake (station 4, surface), 1965 - 1968

than 0.05 ppm from April 1965 to June 1968 and on several occasions there was no detectable nitrogen present.

Nitrogen is generally not considered to be a limiting factor in aquatic environments. Zeller (1953:282), in his study of the fertilization of Missouri farm ponds, stated that nitrogen apparently did not limit fish production. Pennak (1946:45) supported this basic conclusion. In the unfertilized ponds where growth of fish was poor, nitrogen was found in greater concentrations than in the fertilized ponds, however, he attributed this increased nitrogen supply to the planting of legumes in the watershed of the unfertilized ponds.

These findings indicate that while nitrogen levels in Sherwood Lake are relatively low they are not major limiting factors of biological production.

Air and Water Temperatures. Water temperature is one of the most important and influential water quality characteristics to life in water (Thomas, 1967:30). In the north temperate zones of the United States, the temperature strickly regulates the length of the growing season and therefore the net annual biological productivity. The growing season for fish in Sherwood Lake extends from about mid-April to mid-September, or about five months, which is adequate for good biological production.

The maximum water temperature recorded at Sherwood Lake from 1965 to 1968 was 27.8°C in August of 1965.

Water temperatures closely paralleled air temperatures with generally a week, or less, lag period (Fig. 12).

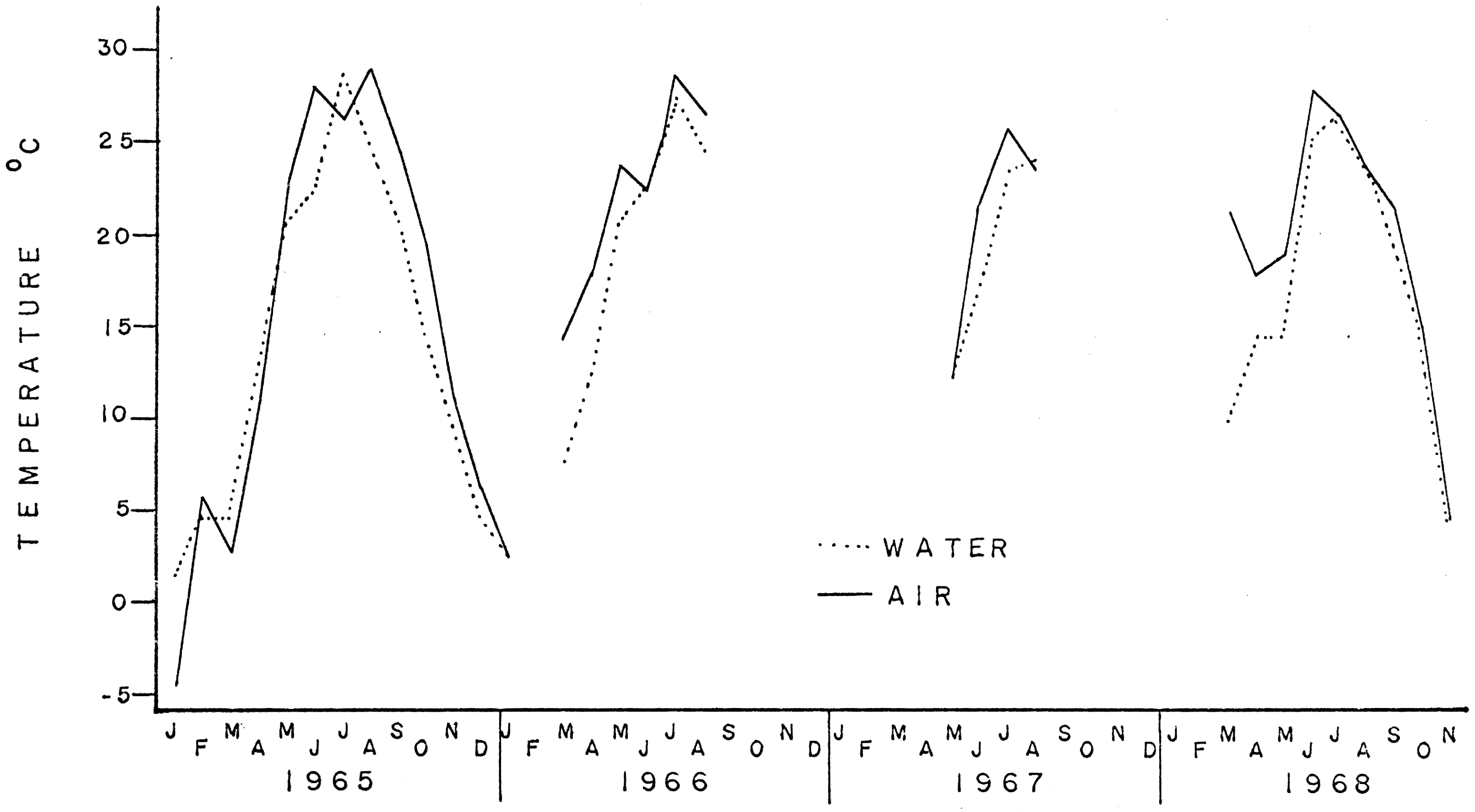

Fig. 12. Air and water temperature measurements (°C) taken at Sherwood Lake (station 4, surface), 1965 - 1968

Transparency. Secchi disk transparencies were taken monthly from 1965 to 1968. The mean value for pre-limestone treatment (prior to 1965) Secchi disk readings was 241 cm. From 1965 to 1967 there was a gradual decrease in lake transparencies. Values went from a peak of 366 cm in July 1965 to a peak of 290 cm in June 1967 (Fig. 13). During 1968 there was a marked increase in lake transparency and a peak depth of 427 cm was recorded in June. These measurements are consistent with other chemical indices of fertility which increased slightly during the same period.

Biological Conditions

Plankton. Plankton samples were collected monthly at each lake sampling station from 1965 to 1968 in conjunction with other physico-chemical determinations. Yearly means of the volume of plankton samples showed a gradual decrease from 1965 to 1968 (Fig. 14). Volumetric measurements went from 3.37 cc/m^3 in 1965 to 1.63 cc/m^3 in 1968 (Appendix II). Pennak (1946:353) used the mean annual standing crop of plankton as a general index which he used to reflect the sum total of ecological conditions in a lake.

A significant plankton "bloom", such as that observed by Waters (1956:338) in a Michigan bog lake following lime application, has not occurred in Sherwood Lake to date. This could be due to insufficient lime in the bottom mud to neutralize the colloidal fraction and thereby release the bound phosphorus which would then be available to the plankton community.

An interesting correlation seems to exist between the mean annual

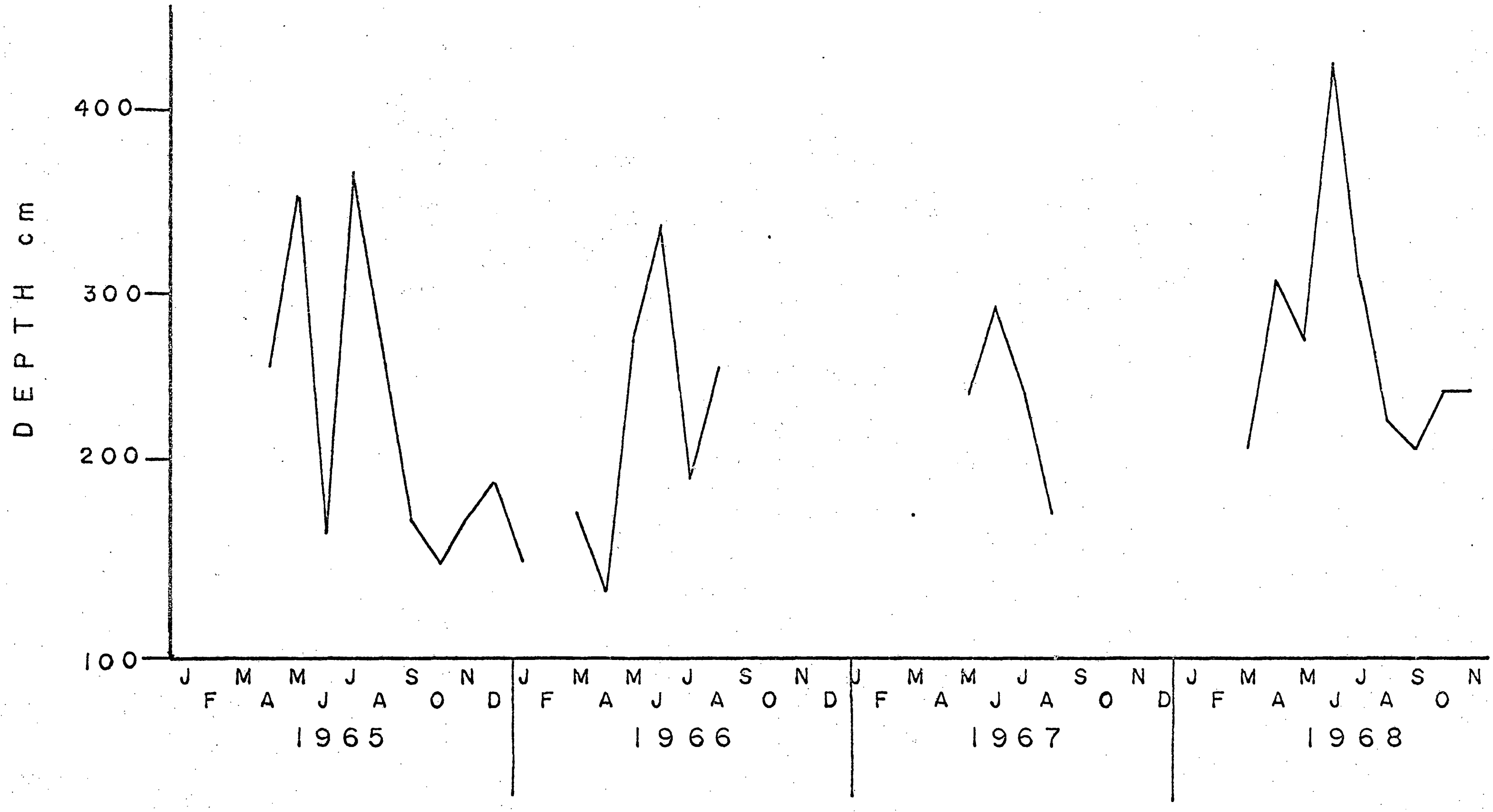

Fig. 13. Secchi disk transparency measurements (cm) taken at Sherwood Lake (station 4), 1965 - 1968

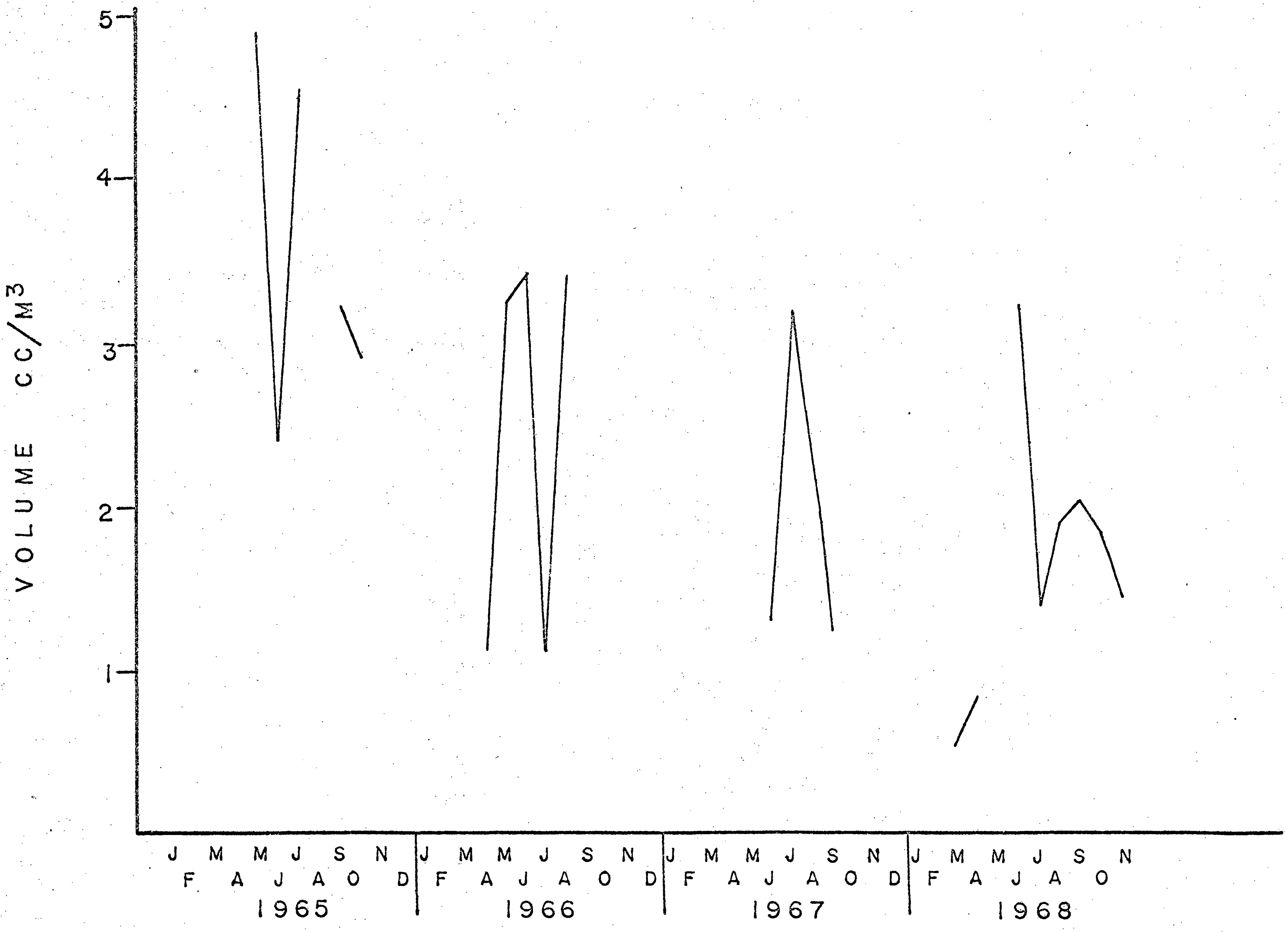

Fig. 14. Volumetric measurements (cc/m) of plankton samples from Sherwood Lake (average of five stations), 1965 - 1968

standing crop of plankton and the higher aquatic plants. While the mean volume of plankton has steadily decreased over the period 1965-1968, it would appear, from visual observations, that there has been a corresponding increase in the higher aquatic plants. These higher aquatic plants, primarily _Elodea_, have expanded their coverage of Sherwood Lake from less than 10 percent of the surface acreage and a five foot maximum depth in 1965 to approximately 60 percent of the surface acreage and a maximum depth of 15 feet.

Surber (1945:378) noted that in the hard water ponds at Leetown Fish Hatchery dense growths of _Chara_ curtailed fish production. _Elodea_ has been classified by Moyle (1945:412) as belonging to the hard water flora. Fassett (1966:99) also states that _Elodea_ is usually found in calcareous waters.

These findings would support the visual observations made on Sherwood Lake that the growth and density of _Elodea_ was enhanced by the addition of limestone. This would further suggest the possibility of increasing the fertility and thus fish production of Sherwood Lake by controlling the dense growths of higher aquatic plants.

Fish. Annual fish population samples were collected in Sherwood Lake, by means of a rotenone application, from 1965 to 1968. Three species of fish, largemouth bass, bluegill and black bullheads were the only fish collected.

From 1965 to 1968, the number of fish per acre increased approximately ten fold (Table III). The most significant increase in numbers was by bluegills during 1968 when 1931 per acre were

Table III. Comparison of the numbers and weight of three fish species taken from Sherwood Lake, 1965 - 1968

	1965	1966	1967	1968
Number per acre	395	1260	1083	3135
Fingerlings	331	1032	836	2829
Intermediates	55	205	229	289
Harvestables	9	23	18	17
Percent of the total number				
Largemouth bass	56.2	20.4	12.9	31.7
Bluegill	25.1	73.6	85.4	61.6
Black bullhead	18.4	6.0	1.7	6.7
Weight per acre (kg)	5.64	13.30	8.86	23.07
Fingerlings	1.57	5.82	3.07	13.94
Intermediates	2.87	4.85	2.52	5.94
Harvestables	1.20	2.63	3.27	3.19
Percent of the total weight				
Largemouth bass	57.6	37.1	41.6	38.4
Bluegill	12.8	48.8	51.5	56.2
Black bullhead	29.6	14.1	6.9	5.4

recorded. The previous high was 925 per acre recorded in 1967 (Appendix II0.

Largemouth bass numbers, expressed as a percent of the total, declined from 56.5 in 1965 to 12.9 in 1967. In 1968 there was an increase to 31.7 percent of the total number. Percent of the total population by weight made up of largemouth bass remained relatively stable. The weight percentages of bluegill and bullheads seemed to be inversely proportional in that bluegill weight increased during the period 1965-1968 while the weight of black bullheads decreased during the same period.

The large number of fingerling bluegill present in 1968 was undoubtedly correlated with the amount of cover available in the dense growths of aquatic weeds which reached a peak during the same year.

Age and growth data for largemouth bass and bluegill revealed that the growth rate of age I fish of both species declined during the period 1965-1968 (Table IV). The only other discernable growth trend was that of age III bass whose growth rate increased from 1965 to 1968. No significant growth increments for any species of fish at any age that could be attributed directly to the limestone treatment of Sherwood Lake was evident. Roland (1970:69) noted increased condition factors for bluegill and bullheads following the introduction of hard water into Carvin Cove Reservoir, Virginia and the growth increments for white suckers at annuli I-VI nearly doubled.

Linear regression equations for length-weight data were calculated

Table IV. Age and growth data for largemouth bass and bluegill sunfish from Sherwood Lake, 1965 - 1968

Largemouth bass

	Annuli	1965	1966	1967	1968
Length at annulus	I	3.6	3.4	3.0	2.9
	II	6.3	7.1	7.0	7.1
	III	7.7	9.0	9.1	9.8
	IV	9.7	14.2	-	-
	V	-	-	15.3	-
	VI	-	-	16.0	-

Bluegill

	Annuli	1965	1966	1967	1968
Length at annulus	I	2.7	1.8	1.8	1.4
	II	5.3	6.4	4.3	3.7
	III	6.1	7.3	6.9	6.1
	IV	7.0	8.8	8.1	7.1
	V	-	-	8.5	7.7

for largemouth bass and bluegill using a standard linear regression computer program. These regression equations and other pertinent statistical data are presented in Table V. The graphical representation of these regression lines for largemouth bass are presented in Figure 15 and for bluegill in Figure 16.

An analysis of covariance was made to determine the statistical significance of the regression lines obtained for the largemouth bass and bluegill. There was a significant difference at the .95 level between at least two years data for each species on the rate of growth when the initial X value (length) was taken into consideration. Succeeding years for each species were then compared at the .95 level of significance using a Student's t test. A graphical representation of these tests is presented in Figure 17.

The coefficient of condition for the bluegill population decreased between 1964 and 1966 and then increased between 1966 and 1968. Similar data for largemouth bass showed no significant increase in the coefficient of condition between 1964 and 1965, a positive relation between 1965 and 1966, a negative relation between 1966 and 1967 and no significant change between 1967 and 1968.

These statistical tests support other population data previously mentioned. There was a large population of adult bluegills present in 1966. Prior to and during 1966 there was a reduction of the growth rate of these fish as they approached their maximum size. Following this bluegill population peak in 1966 the growth rate was positive as smaller fish became more numerous.

Table V. Length-weight relationships for largemouth bass and bluegill sunfish from Sherwood Lake, 1964 - 1968

Year		Sample size	S.D. about the line	Correlation coefficient
	Largemouth bass			
1964	Log W = - 2.92048 + 2.58459 Log L	30	.09830	.98909
1965	Log W = - 2.95613 + 2.49712 Log L	52	.08717	.97728
1966	Log W = - 3.17789 + 2.77671 Log L	52	.12403	.98272
1967	Log W = - 2.79733 + 2.39201 Log L	77	.15076	.97429
1968	Log W = - 2.84134 + 2.51085 Log L	50	.13175	.98728
	Bluegill			
1964	Log W = - 3.50551 + 3.36883 Log L	37	.07670	.95201
1965	Log W = - 2.70871 + 2.51189 Log L	42	.13982	.98049
1966	Log W = - 2.13755 + .93053 Log L	50	.10343	.83830
1967	Log W = - 2.30778 + 1.87299 Log L	102	.17691	.94759
1968	Log W = - 2.92569 + 2.66871 Log L	50	.12423	.96669

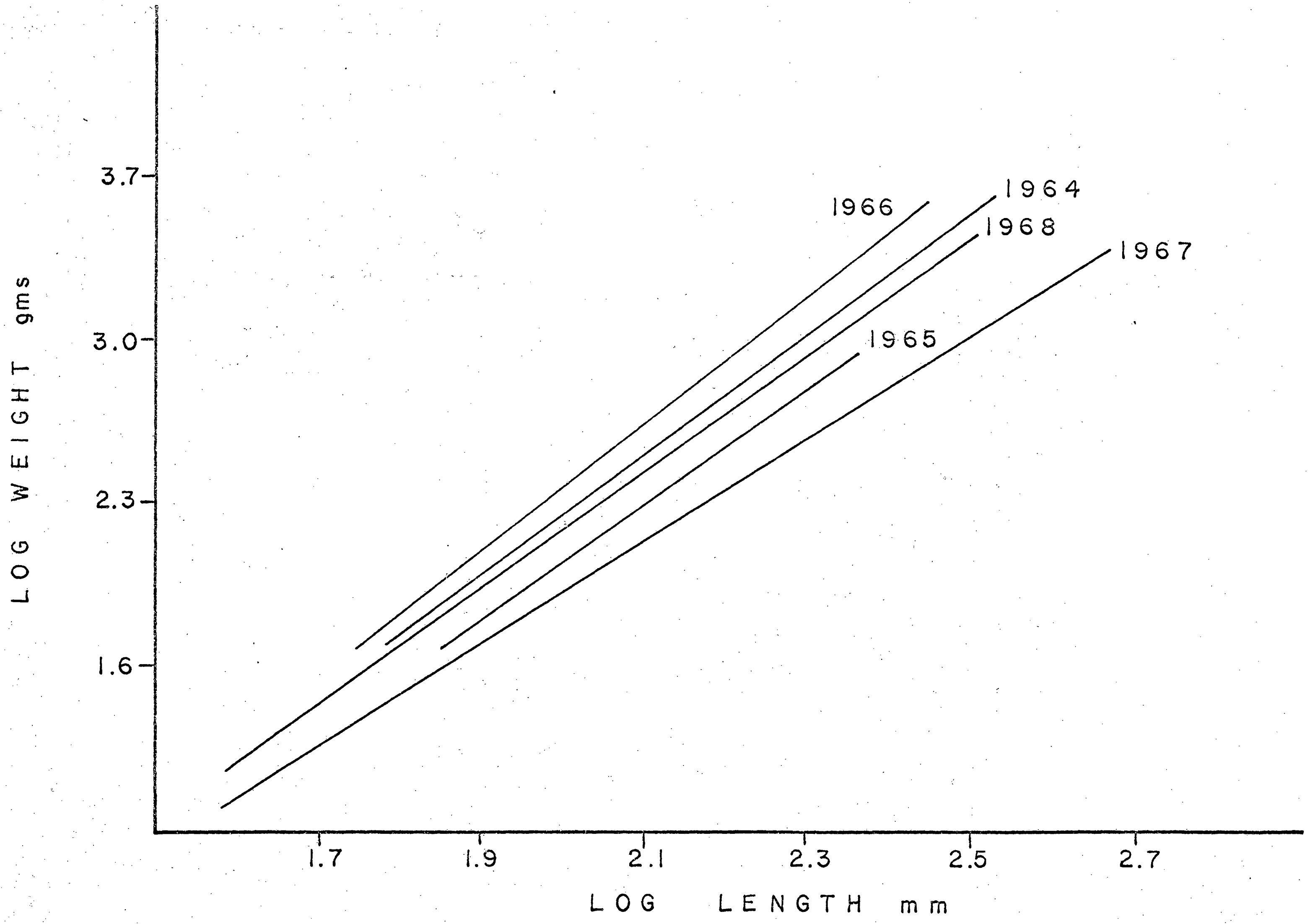

Fig. 15. Linear regression lines for length-weight data from Sherwood Lake largemouth bass, 1964 - 1968

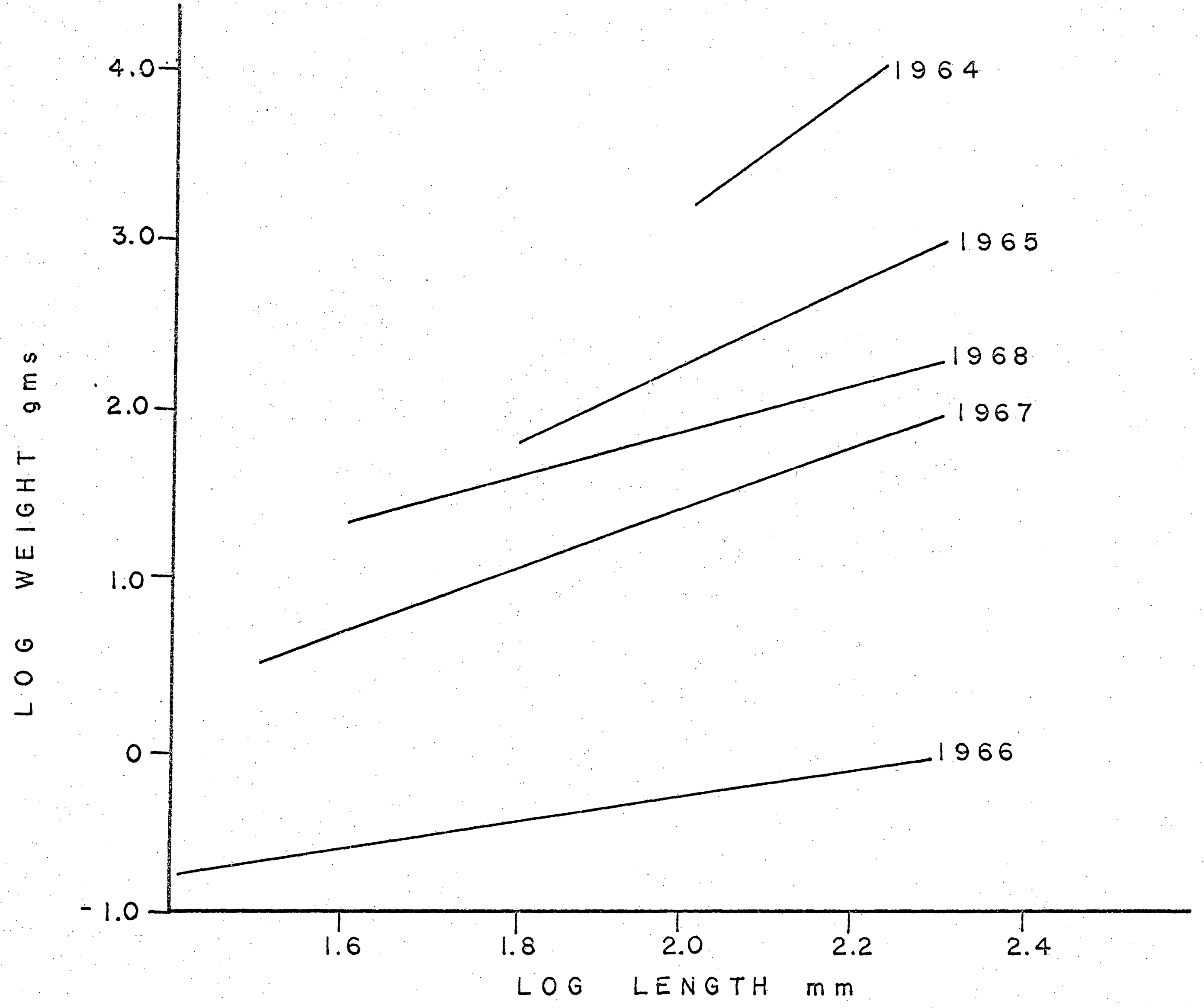

Fig. 16. Linear regression lines for length-weight data from Sherwood Lake bluegill, 1964 - 1968

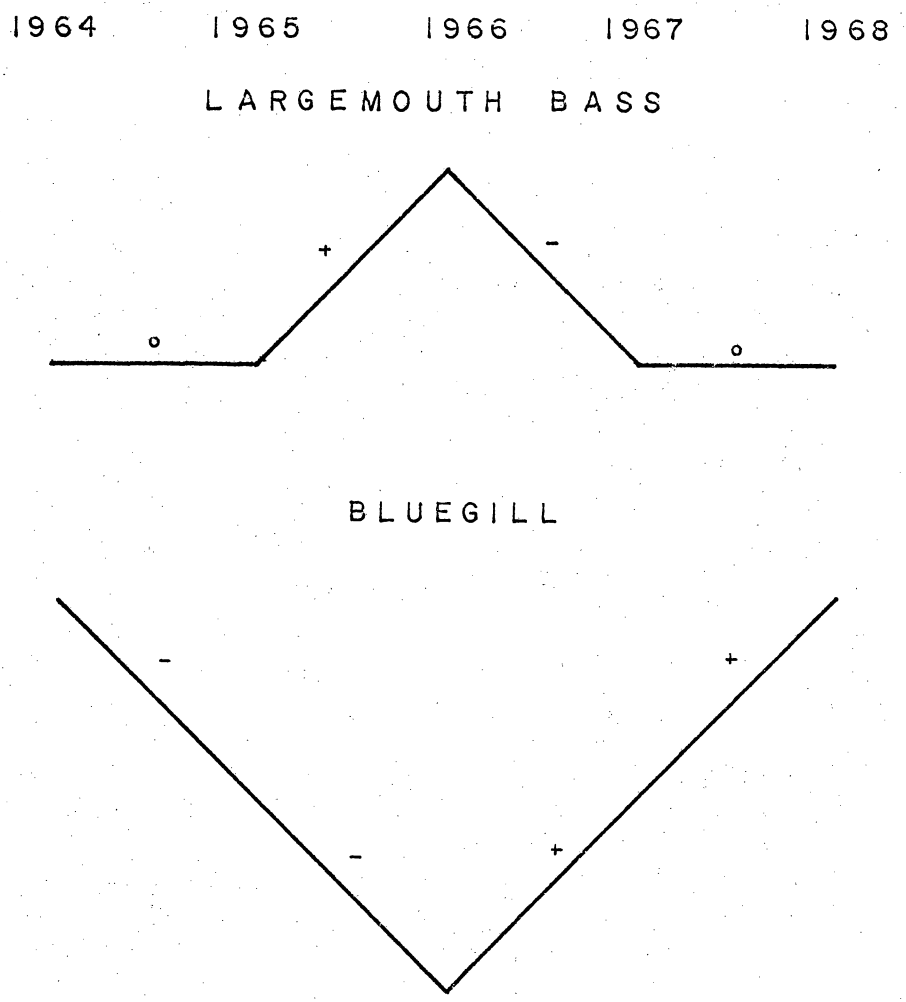

Fig. 17. Significance (t .95) of linear regression lines for length-weight data of largemouth bass and bluegill from Sherwood Lake, 1964 - 1968

smaller fish became more numerous.

The largemouth bass population has exhibited some fluctuation, however, when compared to the bluegill population, it has been relatively stable.

A lake drawdown in the fall of 1965 is thought to have contributed to the increased growth rate of largemouth bass. The lake was drawn down to one half its normal size or to approximately 75 acres in September of 1965. The availability of the smaller bluegill to the large bass was evident during this time. Observation made by walking around the drawn down lake revealed abundant activity of larger fish chasing the forage size fish. The net effect of the drawdown was to create excellent sport fishing the following year.

There was an increase in the standing crop of fish in Sherwood Lake in 1968, however, due to other complicating factors it would be difficult to attribute this increase solely to the addition of limestone.

SUMMARY AND CONCLUSIONS

1. The limestone treatment of Sherwood Lake, which was begun in 1965, changed the water quality from that of a very soft water lake (0-20 ppm alkalinity) to that of a soft water lake (21-40 ppm alkalinity) by 1968.
2. Water quality changes in Meadow Creek, effected by limestone treatment, were much greater than the changes in water quality that occurred in Sherwood Lake. Significantly higher pH, alkalinity, dissolved calcium and conductivity measurements were recorded in Meadow Creek.
3. A low concentration of available phosphorus is the major limiting factor of biological production in Sherwood Lake.
4. The mean annual volume of plankton decreased throughout the limestone treatment period.
5. The growth of *Elodea* was encouraged by the addition of calcium carbonate. A decrease in productivity at higher trophic levels was related to significant increases in the density of *Elodea*.
6. No significant growth increments was evident for any species of fish of any age that could be attributed directly to the limestone treatment of Sherwood Lake.
7. The increase in the standing crop of fish could not be attributed entirely to the addition of limestone.

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APPENDIX I

Table I. Pre-treatment water quality data from Sherwood Lake (station #4, surface), 1958 - 1964 (Preston, 1964; Zurbuch, 1965)

Date	Water temperature (°C)	pH	Total alkalinity (ppm)	Conductivity (micromhos/cm)	O_2 (ppm)	Secchi disk (cm)
8/29/58	23.9	6.4	16	-	-	-
3/22/59	-	6.3	10	-	-	-
8/13/59	27.2	6.4	16	-	8.4	-
7/9/60	26.7	7.1	12	-	5.0	-
6/7/62	23.4	6.7	10	-	-	-
6/4/63	19.5	6.7	5	12	-	336
8/28/63	20.0	6.7	10	16	5.5	-
10/1/63	15.6	6.6	10	14	-	275
10/10/63	16.1	6.3	10	18	-	275
8/19/64	18.9	-	15	28	8.0	76

Table II. Analysis of plankton samples from Sherwood Lake, 1963 (Preston, 1964:6)

Most abundant plankters	Station #1 7/26/63	Station #4 7/26/63	Station #2 10/10/63	Station #4 10/10/63
Cladocera				
Daphnia	X	X	X	X
Bosmina			X	X
Copepoda				
Cyclona	X	X	X	X
Diaptomus			X	X
Protozoa				
Actinocomidae	X	X	X	X
Difflugiidae	X	X	X	X
Phytoplankton				
Filamentous algae			X	X
Volume (cc/m^3)	28.25	6.77	5.69	10.98
Average 12.92				

APPENDIX II

Table I. pH measurements (surface) taken at Sherwood Lake, 1965 - 1968

1965

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	6.5	6.9	6.7	6.5	6.6	5.9	6.0	-	6.0	6.2	6.1	6.8
B	8.4	8.2	7.2	7.5	8.6	7.0	7.0	7.2	6.6	6.6	7.1	7.3
1	7.0	7.1	7.1	7.1	6.8	7.1	6.8	7.0	7.1	7.2	7.1	7.0
2	-	6.7	7.1	7.2	7.1	6.9	6.8	7.2	7.1	7.2	7.0	7.0
3	-	7.0	7.2	7.2	7.0	6.7	6.8	7.0	7.1	7.2	6.9	7.0
4	6.7	7.0	7.2	7.3	6.9	6.6	6.8	7.1	7.2	7.2	7.0	7.0
5	-	7.0	7.1	6.9	6.8	6.9	6.7	7.1	7.1	7.2	6.9	7.0

1966

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	6.4	6.5	6.6	6.6	6.5	6.2	6.8	6.3	6.2	6.2	6.6	6.6
B	6.8	7.4	8.6	7.6	8.6	7.3	7.4	6.3	7.3	7.5	7.4	7.8
1	6.7	-	7.0	7.0	7.0	7.0	7.0	7.0	-	-	-	-
2	7.1	-	7.0	7.0	7.0	7.1	7.2	7.0	-	-	-	-
3	7.0	-	6.9	7.0	7.2	7.2	7.2	7.0	-	-	-	-
4	7.0	-	6.8	7.0	7.0	7.2	7.2	7.1	-	-	-	-
5	7.0	-	6.8	6.8	7.0	7.1	7.2	7.0	-	-	-	-

1967

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	6.6	6.6	6.6	6.6	6.6	6.4	6.3	6.9	6.8	6.8	6.8	6.4
B	7.8	8.7	8.8	7.1	8.7	8.7	8.3	8.6	8.4	8.2	8.6	8.4
1	-	-	7.0	-	7.0	7.0	7.2	7.0	-	-	-	-
2	-	-	7.0	-	7.0	7.0	7.2	7.0	-	-	-	-
3	-	-	7.0	-	7.0	7.2	7.2	7.0	-	-	-	-
4	-	-	7.0	-	6.9	7.1	7.4	7.0	-	-	-	-
5	-	-	7.0	-	7.0	7.0	7.2	7.0	-	-	-	-

1968

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	6.8	6.6	6.8	6.8	6.6	6.6	6.4	6.2	-	6.2	6.8	-
B	7.0	7.2	8.8	8.8	8.8	8.4	7.2	7.4	-	7.4	7.8	-
1	-	-	7.2	7.2	7.2	7.2	7.0	7.2	7.2	7.1	7.2	-
2	-	-	7.2	7.0	7.2	7.2	7.2	7.0	7.0	7.0	7.1	-
3	-	-	7.0	7.0	7.0	7.2	7.2	7.0	7.0	7.0	7.1	-
4	-	-	7.0	7.0	7.0	7.2	7.2	7.0	7.0	7.0	7.1	-
5	-	-	7.0	7.0	7.0	7.2	7.2	-	7.0	7.0	7.1	-

Table II. Total alkalinity measurements (ppm, surface) taken at Sherwood Lake, 1965 - 1968

1965

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	5	5	3	3	3	3	7	-	8	4	4	5
B	20	15	12	8	9	10	16	14	12	7	11	10
1	10	10	10	8	7	9	7	8	11	12	9	13
2	-	10	10	7	8	9	12	17	11	15	10	13
3	-	10	10	7	7	7	10	9	15	14	12	15
4	10	10	10	8	6	8	10	14	13	15	14	14
5	-	7	5	8	8	6	10	10	14	15	13	13

1966

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	5	5	3	3	6	8	17	8	8	8	6	6
B	7	10	11	11	12	14	19	8	16	15	12	12
1	8	-	7	6	11	12	16	19	-	-	-	-
2	14	-	9	9	11	12	18	21	-	-	-	-
3	13	-	11	12	12	12	17	27	-	-	-	-
4	12	-	11	10	12	13	18	27	-	-	-	-
5	12	-	11	7	15	12	18	20	-	-	-	-

1967

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	4	7	4	4	4	5	7	4	8	9	6	9
B	11	15	11	9	11	9	12	12	13	18	15	18
1	-	-	10	-	10	11	21	12	-	-	-	-
2	-	-	10	-	10	9	16	16	-	-	-	-
3	-	-	10	-	11	10	18	15	-	-	-	-
4	-	-	11	-	10	11	15	14	-	-	-	-
5	-	-	10	-	10	10	15	16	-	-	-	-

1968

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	6	9	10	10	10	12	18	10	-	-	-	-
B	18	15	26	22	29	23	23	28	-	21	20	-
1	-	-	23	16	20	11	25	24	25	20	19	-
2	-	-	22	15	20	17	25	30	25	22	19	-
3	-	-	19	16	20	17	25	25	25	21	18	-
4	-	-	20	16	20	18	26	26	26	21	18	-
5	-	-	21	17	19	18	22	24	26	20	17	-

Table III. Calcium measurements (ppm, surface) taken at Sherwood Lake, 1965 - 1968

1965

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	0.4	0.4	0.8	0.8	0.8	2.0	-	0.8	0	0.4	0
B	-	2.8	1.2	2.0	0.8	0.8	1.6	2.0	1.2	0.4	0.8	0.4
1	1.6	2.4	1.6	1.2	0.4	1.6	1.2	1.6	1.2	0.4	0.4	0.4
2	-	2.0	1.6	1.2	0.4	1.6	1.2	1.2	0.8	1.2	0.8	0.4
3	-	1.6	1.2	1.2	0.4	1.6	1.2	0.8	1.2	0	0.4	0.4
4	1.2	1.2	1.2	1.2	0.4	1.2	0.8	0.8	0.8	0	0.4	0.8
5	-	1.2	1.2	1.2	0.4	1.2	0.8	1.2	1.2	0.4	0.4	0.4

1966

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	0	-	0	0	0	0	2.0	2.4	-	-	-	-
B	0	-	0.4	0	0	0	-	2.0	-	-	-	-
1	0	-	0.4	0	0	0	1.6	0.8	-	-	-	-
2	0	-	0.4	0	0	0	2.0	1.2	-	-	-	-
3	0	-	0.4	0	0	0	1.2	1.6	-	-	-	-
4	0	-	0.8	0	0	0	0	1.6	-	-	-	-
5	0	-	0.4	0	0	0	0	1.2	-	-	-	-

1967

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	-	0	-	0	1.2	2.4	1.6	-	-	-	-
B	-	-	1.2	-	0.8	0.8	3.6	2.4	-	-	-	-
1	-	-	0.8	-	0.4	0.4	2.4	2.4	-	-	-	-
2	-	-	0.8	-	0.4	0.8	2.0	2.8	-	-	-	-
3	-	-	0.8	-	0.4	0.8	2.0	2.4	-	-	-	-
4	-	-	0.8	-	0	0.8	2.0	2.8	-	-	-	-
5	-	-	0.4	-	0.4	0.4	2.0	3.2	-	-	-	-

1968

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	-	0.8	2.0	2.0	0.4	2.4	-	-	1.2	1.6	-
B	-	-	5.2	4.4	4.0	3.6	4.8	-	-	3.2	5.2	-
1	-	-	4.4	4.0	4.4	3.2	6.4	6.0	4.4	3.6	4.8	-
2	-	-	4.8	4.4	4.4	2.8	4.4	6.8	4.8	3.6	4.8	-
3	-	-	3.6	3.6	4.4	4.4	6.0	6.0	4.4	3.6	4.8	-
4	-	-	3.6	4.0	4.0	4.0	6.4	6.8	4.8	3.6	4.8	-
5	-	-	4.8	4.0	4.0	4.4	6.0	6.0	4.8	3.6	4.8	-

Table IV. Total phosphate measurements (ppm, surface) taken at Sherwood Lake, 1965 - 1968

1965

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	0.15	0.10	0.10	0.10	0	0	-	0.18	0.20	0.30	0
B	-	0.18	0.28	0.13	0.10	0	0	-	0.05	0.21	0.35	0.20
1	0.13	0.30	0.30	0.25	0.10	0	0	0.18	0.05	0.10	0.19	0.38
2	-	0.30	0.08	0.25	0.09	0	0	0.10	0.15	0.19	0.17	0.30
3	-	0.20	0.10	0.25	0.10	0	0	0.10	0.10	0.09	0.30	0.32
4	0.15	0.20	0.15	0.20	0.10	0	0	0.17	0.02	0.10	0.30	0.20
5	-	0.20	0.20	0.11	0.10	0	0	0.19	0.20	0.12	0.15	0.18

1966

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	0.18	-	0.31	0.05	0.01	0.01	0.02	0.03	-	-	-	-
B	0.20	-	0.28	0.10	0.01	0.02	-	0.03	-	-	-	-
1	0.30	-	0.31	0.25	0	0.01	0.01	0.01	-	-	-	-
2	0.01	-	0.03	0.01	0.01	0.01	0	0.01	-	-	-	-
3	0.19	-	0.12	0.18	0.01	0.01	0.01	0.01	-	-	-	-
4	0.20	-	0.16	0.23	0.01	0.01	0.01	0.01	-	-	-	-
5	0.20	-	0.20	0.15	0.02	0.01	0.02	0.02	-	-	-	-

1967

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	-	0.20	-	0.20	0	0.01	0.01	-	-	-	-
B	-	-	0.20	-	0.05	0.02	0.02	0.02	-	-	-	-
1	-	-	0.20	-	0.30	0.03	0.03	0.02	-	-	-	-
2	-	-	0.20	-	0.35	0.01	0.02	0.02	-	-	-	-
3	-	-	0.20	-	0.38	0.01	0.02	0.02	-	-	-	-
4	-	-	0.20	-	0.25	0.01	0.02	0.02	-	-	-	-
5	-	-	0.10	-	0.28	0.02	0.02	0.01	-	-	-	-

1968

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	-	0.10	0.30	0.20	0.40	0.40	-	-	0.20	0.70	-
B	-	-	0.20	0.60	0.30	0.50	0.50	-	-	0.50	0.90	-
1	-	-	0.20	0.40	0.20	0.30	0.30	0.60	0.90	0.20	0.30	-
2	-	-	0.10	0.30	0.10	0.30	0.70	0.30	0.30	0.10	0.20	-
3	-	-	0.10	0.20	0.20	0.30	0.40	0.30	0.90	0.20	0.20	-
4	-	-	0.10	0.20	0.30	0.40	0.40	0.40	0.80	0.20	0.10	-
5	-	-	0.10	0.05	0.20	0.30	0.40	0.40	0.30	0.20	0.10	-

Table V. Nitrate nitrogen measurements (ppm, surface) taken at Sherwood Lake, 1965 - 1968

1965

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	0	0.03	0	0	0.03	0.25	-	0	0.01	0	0
B	-	0	0.06	0	0	0.03	0.03	0	0	0.02	0	0
1	0.85	0.08	0.15	0.04	0.02	0	0	0	0.01	0.01	0.02	0
2	-	0.48	0.05	0.01	0.01	0	0	0	0	0.02	0.01	0
3	-	0.33	0.13	0.02	0.01	0.01	0	0.04	0	0.02	0.01	0.02
4	0.51	0.32	0.13	0.03	0	0	0	0.04	0.01	0.02	0.02	0.01
5	-	0.35	0.11	0.02	0	0	0	0.04	0	0.01	0.01	0.01

1966

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	0.02	-	0.03	0	0	0	0.03	0.03	-	-	-	-
B	0.01	-	0.03	0	0.01	0	-	0.03	-	-	-	-
1	0.02	-	0.03	0.01	0.01	0	0.02	0.01	-	-	-	-
2	0.01	-	0.03	0.01	0.01	0.01	0	0.01	-	-	-	-
3	0.02	-	0.02	0.01	0.01	0	0	0.01	-	-	-	-
4	0.02	-	0.03	0.02	0.01	0	0.01	0.01	-	-	-	-
5	0.01	-	0.04	0.02	0.02	0	0.01	0.01	-	-	-	-

1967

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	-	0	-	0	0	0	0.01	-	-	-	-
B	-	-	0	-	0	0	0	0	-	-	-	-
1	-	-	0.01	-	0	0	0	0	-	-	-	-
2	-	-	0.02	-	0.02	0.01	0	0	-	-	-	-
3	-	-	0.03	-	0.03	0	0	0	-	-	-	-
4	-	-	0.02	-	0	0	0	0	-	-	-	-
5	-	-	0.02	-	0.01	0	0	0	-	-	-	-

1968

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	-	0.01	0.01	0.01	0.02	0.04	-	-	0.02	0.01	-
B	-	-	0.03	0.01	0.01	0.02	0.03	-	-	0.02	0.03	-
1	-	-	0.09	0.01	0.01	0.02	0.02	0.02	0.03	0.01	0.04	-
2	-	-	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.01	0.03	-
3	-	-	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.02	-
4	-	-	0.01	0.01	0.01	0.02	0.01	0.15	0.02	0.01	0.02	-
5	-	-	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.04	-

Table VI. Specific conductance measurements (micromhos/cm, surface) taken at Sherwood Lake, 1965 - 1968

1965

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	-	-	5	7	9	16	-	16	10	7	5
B	-	-	-	14	21	23	23	45	27	19	16	12
1	-	-	-	13	21	25	33	32	28	22	18	14
2	-	-	-	13	25	27	25	35	29	21	17	13
3	-	-	-	13	25	27	27	32	28	25	17	13
4	-	-	-	13	22	26	26	32	28	25	17	13
5	-	-	-	13	25	28	33	33	27	25	17	13

1966

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	4	5	7	10	8	9	38	41	11	7	-	-
B	4	11	16	22	25	23	37	41	26	20	-	-
1	12	-	16	20	30	31	34	45	-	-	-	-
2	18	-	16	17	25	29	37	45	-	-	-	-
3	18	-	15	17	25	28	35	50	-	-	-	-
4	18	-	15	17	25	28	36	50	-	-	-	-
5	17	-	14	17	25	28	33	45	-	-	-	-

1967

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	-	8	9	8	10	-	11	8	11	10	5	9
B	-	24	18	13	20	-	24	25	25	22	15	20
1	-	-	16	-	20	25	28	30	-	-	-	-
2	-	-	16	-	20	25	25	28	-	-	-	-
3	-	-	16	-	22	25	27	30	-	-	-	-
4	-	-	15	-	22	22	28	33	-	-	-	-
5	-	-	15	-	20	25	27	30	-	-	-	-

1968

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	4	6	10	5	9	15	21	15	-	12	9	-
B	15	10	27	30	32	29	35	30	-	22	21	-
1	-	-	25	26	24	35	38	31	29	27	22	-
2	-	-	25	25	24	35	38	30	30	27	20	-
3	-	-	22	25	24	34	38	30	29	25	20	-
4	-	-	22	23	24	35	36	35	29	26	20	-
5	-	-	22	25	23	34	36	34	29	26	20	-

Table VII. Secchi disk transparency measurements (cm) taken at Sherwood Lake, 1965 - 1968

1965

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2	-	-	-	274	274	168	244	335	178	178	152	178
3	-	-	-	244	305	178	213	274	178	178	178	198
4	-	-	-	259	351	168	366	274	178	152	178	198
5	-	-	-	290	335	168	305	244	152	178	178	213

1966

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2	152	-	178	152	274	290	229	274	-	-	-	-
3	198	-	152	152	259	305	213	229	-	-	-	-
4	152	-	178	137	274	335	198	259	-	-	-	-
5	152	-	152	137	259	305	198	259	-	-	-	-

1967

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2	-	-	178	-	229	274	320	152	-	-	-	-
3	-	-	178	-	274	305	229	178	-	-	-	-
4	-	-	178	-	244	290	244	178	-	-	-	-
5	-	-	178	-	259	259	244	178	-	-	-	-

1968

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2	-	-	213	254	249	335	274	213	244	229	229	-
3	-	-	213	259	244	366	305	-	229	244	244	-
4	-	-	213	305	274	427	305	229	213	244	244	-
5	-	-	213	305	244	366	274	213	229	244	244	-

Table VIII. Air temperature measurements (°C, surface) taken at Sherwood Lake, 1965 - 1968

1965

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	3.4	6.7	6.1	15.0	15.6	20.6	23.9	-	22.8	15.0	11.1	5.6
1	4.5	5.6	2.8	12.8	17.8	28.9	24.5	27.8	24.5	16.1	12.3	6.7
2	-	5.6	2.8	11.1	18.4	29.5	27.8	29.5	26.1	17.2	10.6	6.1
3	-	5.6	2.8	13.9	21.1	30.6	25.0	30.6	27.8	17.8	11.1	6.1
4	4.5	5.6	2.8	11.1	22.8	27.8	26.1	28.9	24.5	19.5	11.1	6.1
5	-	5.6	2.8	12.3	22.8	33.4	27.8	29.5	27.8	14.5	10.6	6.1

1966

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	1.1	2.8	16.7	22.3	20.0	22.8	32.2	25.0	15.6	16.1	8.4	3.4
1	3.9	-	16.1	22.3	27.8	21.1	26.1	23.4	-	-	-	-
2	3.9	-	17.2	21.1	26.1	22.3	28.4	26.7	-	-	-	-
3	3.9	-	14.5	17.8	26.7	22.3	28.9	23.4	-	-	-	-
4	2.2	-	14.5	17.8	23.4	22.3	28.4	26.7	-	-	-	-
5	3.9	-	14.5	16.7	22.3	23.4	26.1	27.8	-	-	-	-

1967

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	3.9	10.0	21.1	21.1	11.7	19.5	22.3	24.5	19.5	31.1	15.6	10.0
1	-	-	20.0	-	12.8	20.0	25.6	24.5	-	-	-	-
2	-	-	20.0	-	11.1	21.1	24.5	23.4	-	-	-	-
3	-	-	20.0	-	11.7	21.7	25.6	23.4	-	-	-	-
4	-	-	18.9	-	12.2	21.7	25.6	23.4	-	-	-	-
5	-	-	18.9	-	11.7	19.5	25.6	25.6	-	-	-	-

1968

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	6.1	3.4	13.4	23.4	22.3	22.3	27.3	22.3	-	13.4	5.0	-
1	-	-	20.0	16.7	16.7	24.5	23.4	24.5	15.6	18.4	3.9	-
2	-	-	20.0	15.6	16.7	24.5	26.1	23.4	16.7	15.6	4.5	-
3	-	-	21.1	16.1	16.7	25.6	26.7	23.4	20.0	15.6	5.6	-
4	-	-	21.1	17.8	18.9	27.8	26.7	23.9	21.1	15.0	4.5	-
5	-	-	21.1	17.8	21.1	29.5	26.7	23.9	22.3	13.9	4.5	-

Table IX. Water temperature measurements (°C, surface) taken at Sherwood Lake, 1965 - 1968

1965

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	3.9	2.8	2.8	8.4	12.3	14.5	18.9	-	16.1	8.4	5.6	3.4
1	1.1	4.5	5.6	12.3	20.6	22.3	22.8	24.5	20.6	15.0	7.8	5.0
2	-	4.5	3.9	12.3	21.1	22.3	22.3	25.0	20.0	14.5	8.9	5.0
3	-	4.5	3.9	12.3	20.6	22.3	22.3	24.5	20.6	14.5	8.9	5.0
4	1.1	4.5	4.5	12.2	20.6	22.3	28.8	24.5	20.6	14.5	8.9	4.5
5	-	4.5	3.9	12.3	20.0	21.7	23.4	23.9	20.6	14.5	8.9	4.5

1966

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	0	3.9	4.5	8.9	12.8	13.9	22.3	18.4	11.7	10.0	5.6	2.2
1	0	-	8.9	12.8	23.4	20.6	25.0	23.4	-	-	-	-
2	2.2	-	8.9	13.4	22.3	21.1	26.1	23.4	-	-	-	-
3	2.2	-	8.4	12.3	21.7	21.1	26.1	23.4	-	-	-	-
4	2.2	-	7.8	12.2	20.6	22.3	27.2	24.5	-	-	-	-
5	3.4	-	8.4	12.8	21.1	23.4	26.7	24.5	-	-	-	-

1967

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	2.2	1.1	9.5	10.0	10.0	15.0	16.1	15.6	13.4	11.1	5.6	6.7
1	-	-	8.4	-	12.3	15.6	24.5	22.3	-	-	-	-
2	-	-	10.6	-	12.3	16.1	23.9	22.3	-	-	-	-
3	-	-	10.6	-	10.6	16.7	23.9	22.3	-	-	-	-
4	-	-	10.0	-	12.2	17.8	23.4	23.9	-	-	-	-
5	-	-	10.0	-	11.7	16.7	23.9	23.4	-	-	-	-

1968

Sta.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	0	0	2.2	12.3	11.1	16.1	26.1	16.7	-	6.7	3.4	-
1	-	-	10.0	14.5	15.0	25.0	26.1	23.4	18.4	14.5	3.9	-
2	-	-	9.5	14.5	15.0	24.5	26.1	23.9	18.9	14.5	3.9	-
3	-	-	9.5	14.5	15.0	25.0	30.0	24.5	19.5	14.5	3.9	-
4	-	-	9.5	14.5	14.5	25.0	26.1	24.5	18.9	14.5	3.9	-
5	-	-	9.5	14.5	16.1	25.0	26.7	-	18.9	14.5	3.9	-

Table X. Volume of plankton cc/m^3 from Sherwood Lake, 1965 - 1968

Date	Station Number 1	2	3	4	5	Monthly average	Yearly average
5/18/65	5.38	2.91	4.16	3.64	8.27	4.87	3.37
6/23/65	5.01	1.79	2.09	1.01	1.75	2.33	
7/15/65	5.01	5.10	3.80	3.36	5.36	4.53	
9/23/65	7.39	2.15	1.92	2.09	2.50	3.21	
10/19/65	4.63	1.48	1.21	0.80	1.46	1.92	
4/22/66	3.77	0.45	0.89	0.56	0.89	1.31	2.48
5/26/66	6.89	1.79	3.13	1.99	2.24	3.21	
6/21/66	7.51	3.13	2.68	1.42	2.24	3.40	
7/26/66	1.25	1.34	1.12	0.85	0.89	1.09	
8/19/66	5.13	2.46	4.02	1.14	4.25	3.40	
5/3/67	2.63	1.30	-	0.51	0.76	1.30	1.96
6/29/67	6.39	2.24	2.24	1.51	3.67	3.21	
7/31/67	2.13	2.15	2.77	1.05	2.50	2.12	
8/29/67	2.13	0.85	1.43	0.54	1.07	1.20	
3/29/68	0.63	0.27	0.80	0.28	0.67	0.53	1.63
4/26/68	2.13	0.40	0.54	0.40	0.54	0.80	
6/29/68	3.38	1.43	5.81	1.02	4.47	3.22	
7/25/68	1.88	1.30	1.43	0.94	1.30	1.37	
8/30/68	2.88	2.19	2.24	1.05	0.98	1.87	
9/30/60	4.01	1.25	1.88	0.77	2.19	2.02	
10/24/68	2.75	1.03	3.04	0.85	1.43	1.82	
11/26/68	1.50	1.92	1.34	1.05	1.30	1.42	

Table XI. Fish population data from Sherwood Lake, 1965 - 1968

		Fingerlings			Intermediates			Harvestables		
	Fish Species	Size Range (mm)	Number per acre	Weight per acre (kg)	Size Range (mm)	Number per acre	Weight per acre (kg)	Size Range (mm)	Number per acre	Weight per acre (kg)
1965	Largemouth bass	56-102	193	1.11	107-203	25	1.50	206-229	5	0.64
	Bluegill	36-69	95	0.15	-	-	-	191-206	4	0.57
	Black Bullhead	69-94	43	0.30	109-183	30	1.37	-	-	-
1966	Largemouth bass	48-102	219	1.62	107-198	30	1.77	239-267	8	1.56
	Bluegill	20-76	773	4.00	79-152	154	2.50	-	-	-
	Black Bullhead	38-76	40	0.21	79-152	21	0.59	157-191	15	1.07
1967	Largemouth bass	38-102	127	1.18	104-203	8	0.36	234-432	5	2.14
	Bluegill	13-76	695	1.76	79-127	219	2.05	130-183	11	0.74
	Black Bullhead	41-84	14	0.13	140-157	2	0.10	203-264	2	0.75
1968	Largemouth bass	30-102	937	4.09	104-203	46	2.48	206-333	10	2.48
	Bluegill	25-76	1695	9.05	79-152	232	3.43	157-191	4	0.48
	Black Bullhead	38-76	197	0.80	81-152	11	0.23	165-193	3	0.23

WATER QUALITY AND PRODUCTIVITY CHANGES ASSOCIATED WITH THE LIMING OF A SOFT WATER LAKE

by

Robert E. Sumner

ABSTRACT

Sherwood Lake, a 165 acre public fishing impoundment in Greenbrier County, West Virginia, was treated with calcium carbonate for four years. The limestone treatment was done by revolving limestone drums installed above the lake on Meadow Creek. The limestone drum provided continuous treatment throughout the period. Limnological conditions of Meadow Creek and Sherwood Lake were monitored throughout the treatment period. Physicochemical and plankton data were collected monthly and the fish population sampled annually.

The water quality of Sherwood Lake improved gradually during treatment, however, by the end of 1968 the lake could only be classified as a soft water lake.

The growth of *Elodea* was encouraged by the addition of limestone. A lack of available nutrients and decreased productivity at higher trophic levels was attributed to the dense growths of *Elodea*. The mean annual volume of plankton decreased during lime treatment, however, this decrease was attributed to the usurping of available nutrients by higher aquatic plants. Low concentrations of available phosphorus was considered to be the major chemical factor limiting biological production.

No significant growth increments were evident for any species of fish of any age that could be attributed directly to the limestone treatment of Sherwood Lake.

An increase in the standing crop of fish was noted but could not be ascribed entirely to the addition of limestone.