6-1967

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Recommended Citation

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A PRE- AND POST IMPROVEMENT STUDY ON SIX SOUTHEAST KANSAS STRIP-MINE LAKES

A Thesis Submitted to the Graduate Division in Partial
Fulfillment of the Requirements for the
Degree of Master of Science

By 897
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KANSAS STATE COLLEGE OF PITTSBURG
Pittsburg, Kansas
June, 1967

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ACKNOWLEDGEMENTS

The author wishes to express his appreciation for the assistance and guidance given by Dr. J. Carl Bass.

Thanks are also extended to Dr. L. J. Gier, William Jewell College, for keying the specimens of Sphagnum cuspidatum, and to Robert Hartmann of the Kansas Forestry, Fish and Game Commission for his suggestions and aid in field work.

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CHAPTER I

INTRODUCTION

During the last sixty years extensive experimental research has been conducted in an attempt to establish methods of controlling the acid conditions resulting from coal mine operations.

It was the purpose of this research to determine the feasibility of reclaiming acid strip-mine lakes for use as potential fisheries management areas. To accomplish the objectives outlined above a two-phase program was initiated. The first phase involved the physical alteration of the drainage areas of the experimental lakes included in this study in an attempt to divert all visible signs of acid drainage to areas other than those incorporated into the drainage systems of the experimental lakes.

The second phase of this project is to be carried out over a period of three years. The data from the first segment of this three-year project are contained in this thesis and were obtained from July 1966 to June 1967. This research was supported by funds from the Kansas Forestry, Fish and Game Commission and the U.S. Bureau of Sport Fisheries and Wildlife Management D-J Project F-12-R-3, Job 4-3, and involved the quantitative determination of the effects of speeding the natural succession of the acid strip-mine lakes by adding agricultural lime to some of these bodies of water.

Approximately 65,000 acres of land in the Western Interior Coal Province comprised of Arkansas, Kansas, Oklahoma, Missouri, and Iowa have been strip-mined. The highest concentration of strip-mining for coal in the Province was in Southeastern Kansas and Southwestern Missouri (Rogers, 1951).

In a mimeographed report to the Kansas Forestry, Fish and Game Commission, Charles Burner (1953) indicated that information received showed water covers an estimated 8% of the surface of strip-mined land, and approximately 20% of the strip-mine lakes had pH values too low for fish production. The most recent available information showed 39,234 acres of land had been strip-mined in Crawford and Cherokee Counties, Kansas (Kansas Geological Survey, 1966).

"The ultimate source of all coal mine acidity is iron disulfide, FeS_2, which occurs as either pyrite or marcasite" (Temple and Koehler, 1954). Many investigators have studied the reactions involving the oxidation of pyritic sulfur (Stokes, 1901; Winchell, 1907; Sinnatt and Simpkin, 1922; Braley, 1957; Braley, 1960; Temple and Koehler, 1954; Lorenz, 1962; and

Lorenz and Tarpley, 1963). The natural oxidation of pyritic material may be represented by the following chemical equations:

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4$$

$$FeS_2 + 3O_2 = FeSO_4 + SO_2$$

$$FeS_2 + 7Fe_2(SO_4)_3 + 8H_2O = 15FeSO_4 + 8H_2SO_4$$

Secondary reactions take place between ferrous sulfate, sulfuric acid and the compounds in nearby clay, limestones, and various substances that are present in mines or streams and result in the variety of chemicals found in mine drainage. The supplemental reactions represent an explanation of the existence of aluminum, manganese, calcium, magnesium, sodium, potassium, chlorates, nitrates, and silicates (Lorenz, 1962).

Temple and Koehler (1954) further showed that in the presence of certain iron-oxidizing bacteria, <u>Thiobacillus ferrooxidans</u> and <u>Thiobacillus thiooxidans</u>, that the rate of the oxidation of iron disulfide as well as the total amount of sulfuric acid produced from a given amount of iron disulfide was increased. These bacteria were always present in natural systems studied by these investigators.

Further research has revealed that even though both <u>Thiobacillus thiooxidans</u> and <u>Thiobacillus ferrooxidans</u> are probably present under natural conditions, only <u>Thiobacillus ferrooxidans</u> increases the rate of oxidation of iron disulfide (Parsons, 1957).

In strip-mining operations the overburden, that material which overlays the coal, is removed and piled to one side (spoil banks) in an order which is the reverse of that in which it was removed, thus the material immediately overlying the coal forms the surface of the spoil banks. This material, as well as the coal itself, contains the pyritic sulfur responsible for the initial acidity of strip-mine lakes. The degree of acidity is proportional to the amount of pyritic sulfur associated with the coal vein in a given region, and the neutralizing capabilities of the associated strata. Once the coal is removed from a strip-mine it is transported to a centralized processing plant where it is washed, graded, and prepared for shipping. The washings, pyritic sulfur and associated materials, are concentrated in large mounds and represent a potential source of acid to the surrounding areas.

The results of a series of studies carried out in Missouri suggested that an orderly series of predictable changes exists which are associated with aging in strip-mine lakes. These investigators have divided these successional stages into three distinct groups:
1) Youthful, 2) Early Recovery, and 3) Late Recovery.

The Youthful stage was characterized by high acidity, deep red color, pH 3.0 or lower, high total dissolved solids, and distinct thermal and chemical stratification.

The Early Recovery stage was characterized by acidity values of less than 700 ppm., pH values between 3 and 5, decrease in total dissolved solids, deep blue water color, high transparency, and homothermic temperature conditions.

In the Late Recovery stage the effects of acid pollution were no longer apparent. The waters had pH values near 7, acidity was zero, dissolved solids low, thermal stratification occurred during the summer, transparency was low due to clay turbidity and plankton blooms, and there was a definite increase in the biota.

Succession in acid lakes was similar to other successional phenomena in that the direction of succession was predictable but the rate at which succession occurred was not. The persistence of Youthful and Early Recovery stages for 30-45 years was suggested to be due to the presence of waste coal piles in restricted watersheds or the presence of extensive spoil banks within large watersheds (Campbell, Lind, Harp, Geiling, and Letter, 1965).

Many proposals have been made concerning methods of controlling and eliminating mine acid pollution.

Many of the problems have developed from acid drainage into streams causing a complete or nearly complete elimination of fishes and a gross change in the overall biota of the stream. It has long been considered that it is not economically feasible to apply lime to streams as a means of maintaining the normal unpolluted conditions (Ohio River Pollution Survey, 1942; Crichton, 1928; Temple and Koehler, 1954; and Carpenter and Davidson, 1930). Numerous other approaches have been proposed and attempted. One investigator developed an experimental strip-mine which eliminated drainage into stream channels (Braley, 1952). Neutralization basins have been proposed (Baffa, 1960). Treatment plants have been proposed, constructed, and discontinued (Ohio River Pollution Survey, 1942).

Another problem arising from acid mine pollution has resulted from the flow of streams polluted with drainage from acid mines into impoundments. Two lakes in Vinton County, Ohio, have been successfully reclaimed after damage from pollution of this type. The pH in Lake Alma had dropped to pH 4.5 when approximately five tons of hydrated lime was applied to this lake. This resulted in an increase in pH to 6.9 or above for three years (Cole, 1957). Lake Hope was treated with lime in 1954, resulting in correction of increasingly acid conditions (Cole, 1960).

Lime has been used to some extent to adjust the alkaline reserve of impoundments with low acid combining capacity. Lime was effectively applied to hatchery ponds in Murray, Kentucky, which developed low pH and acid combining capacity as a result of the addition of water which had high free carbon dioxide content, low alkalinity, and low pH (Lewis and Summerfelt, 1961).

A study in Wisconsin utilized lime as a means of increasing the productivity of small kettle lakes which had characteristically brown-colored water. The results of lime application to these lakes showed an increase in the trophogenic zone, an increase in methyl-orange alkalinity, and an increase in pH values (Hasler, Brynildson, and Helm, 1951).

A similar experimental study was carried out on two acid bog lakes in Northern Michigan. The application of lime to these lakes at a rate of 100 lbs. per acre-foot resulted in an increase in pH, and total alkalinity. A significantly higher standing crop of phytoplankton and zooplankton occurred during the summer following lime application. There was also a significant increase in the total phosphorous in one of the two limed lakes. These lakes did not, however, show a decrease in the organic colloidal color (Waters, 1957).

Most of the experimental research conducted, after the beginning of large strip-mining operations, which was directly related to the changes in the environment brought about by these operations, was focused on the reclamation of the spoil banks for agricultural and commercial use (Hall, 1940; Rogers, 1949; and Wells, 1953). Because of the high degree of difficulty in cultivation and harvesting, these lands have never been effectively reclaimed for agricultural use (Wells, 1953). They have been, however, successfully managed as wildlife refuges (Riley, 1954).

More recently the trend in research involving strip-mining operations has turned to the lakes formed as a result of the mining operations. The literature contains reports on research concerning management for their fisheries potential, detailed studies on water chemistry, comparative limnological studies, and studies dealing with natural succession.

One of the earliest studies involving a biological approach to the acid conditions in strip-mine lakes showed that under the extremely restrictive conditions of high acid concentrations, there is a group of microorganisms present in abundance which have the potentiality of becoming the first link in the food chain. This study also showed that it was entirely possible to determine the conditions of the acid waters by biological surveys (Lackey, 1938).

Parsons (1952) expressed the need for a coordinated effort relating all physical and chemical influences to a biological approach to the pollution problem resulting from coal mining operations.

Crawford (1942) studied the physical, chemical and biological features of both acid and alkaline waters in strip-mine lakes in Missouri. Another study carried out ten years later on the same strip-mine lakes showed that the greatest change which had taken place was the invasion of fish into two of the study lakes. The presence of fish was apparently correlated with a decrease in acidity (Heaton, 1951).

Schoonover and Coates (1949) carried out one of the first detailed studies of strip-mine lakes in Southeastern Kansas. Their studies on a large number of strip-mine lakes showed them to be less productive than natural bodies of water throughout the state. They attributed this to the lack of large shallow areas, protected water, and an unproductive bottom. The pH of the lakes they tested ranged from 4.0 to 8.2.

A limnological study carried out on the Natural History Reserve operated by Kansas State College of Pittsburg, Kansas, substantiated the conclusions reached by Schoonover and Coates. These results showed this lake possessed favorable carbon dioxide, oxygen, carbonate and bicarbonate alkalinity, benthic and planktonic conditions favorable for good fish production. The absence of such a population in this lake was attributed to the depth and almost vertical position of the banks providing for little or no breeding areas or for protection for fish food organisms (Burner and Leist, 1953).

A limnological study carried out on three alkaline strip-mine lakes in Southeastern Kansas showed that the physico-chemical conditions in two of the strip-mine lakes which were twenty years old varied little from the third lake which was fifty years old, and that all three possessed characteristics which were within the limits necessary for thriving warm water fish populations; however, the lakes did not possess populations which were considered to be thriving (Maupin, Wells and Leist, 1954). The authors offered no explanations as to the reasons for the absence of a well balanced, thriving fish population.

In a growth rate study comparing growth rates of Micropterus salmoides and Lepomis cyanellus from a strip-mine lake in Cherokee County, Kansas, to similar data from several other studies throughout the United States the author found that the species taken from the strip-mine lake showed comparable growth rates to the same species from other bodies of water for the first two years, but after two years of growth the stunting became pronounced. The fish studied were found to be undersized for their age but they were not underweight for their length. The author also pointed out that it should not be assumed that the data presented would necessarily be true in all, or even most, of the strip-mine lakes of Southeastern Kansas, as such lakes vary considerably in physico-chemical properties which affect the biotic conditions (Fuller, 1952).

The results of a physico-chemical study on strip-mine ponds in Southern Illinois showed that the lakes exhibited stratification during the summer months, and that the thermocline possessed high oxygen concentrations. The lakes also showed high values for specific conductance. The authors concluded that the ponds, because of oligotrophic conditions, high salt content, low fertility, steepness of shore line, and inaccessibility, offered poor possibilities for successful fish production. They mentioned, however, that the ponds might support brown trout (Salmo trutta), rainbow trout (S. gairdneri) or smallmouth bass (Micropterus dolomieui) populations because of the high oxygen content in the thermocline and hypolimnion (Lewis and Peters, 1954).

Another research project carried out in Southern

Illinois on aquatic vegetation of strip mine waters indicated that the densities of the submerged and emergent aquatic vegetation indicated a high fertility for the waters, but the steep spoil banks and the resulting narrow favorable zones for plant growth sharply curtailed production (Bell, 1956).

A two-year comparative study of plankton succession in strip-mine ponds in Pennsylvania revealed that below pH 6.8 populations were almost 100% chlorophyllous species, and that the number of animal species decreased with increased acidity. The zooplankters which were found to be most abundant in all waters, even those below pH 6.8, were rotifers. The author noted that planktonic organisms invade strip-mine ponds early and though the number of different species may be few, sometimes the species present are found in large numbers (Dinsmore, 1957).

A detailed study involving the determination of sodium, magnesium, manganese, calcium, iron, aluminum, phosphate, sulfate, pH, bicarbonate alkalinity, free carbon dioxide, and dissolved oxygen, concentrations in three Southeast Kansas strip-mine lakes revealed some of the problems which must be solved to convert some of the lake waters to that kind suitable for supporting fish (Simpson, 1959).

Stockinger and Hays (1960) in comparing plankton, benthos, and fish in three strip-mine lakes of varying H-ion concentrations in Southeastern Kansas found that the plankton population of the highly acid lake (pH 3.2-3.6) was less than that of the marginally acid (pH 6.2-7.4) or the alkaline (pH 7.0-7.8) strip-mine lake. In comparing the benthos of the three lakes these investigators found that the highly acid lake contained the largest number of organisms per square foot of bottom area with the genus Tendipes being the most numerous group. The analysis of the existing fish populations revealed that the highly acid lake was devoid of fish while the population of bluegill from the moderately acid lake indicated pronounced stunting in growth, and that the growth rate of bass in the alkaline body showed favorable growth for the first two years of life with stunting becoming pronounced after two years. The determination of the degree of stunting was made after correlation with some other bodies of water throughout the United States.

An investigation of the components of the watersheds of Ohio strip-mine lakes showed that the type of soil making up the lake basin was highly varied. The basins with clay as the major constituent provided an almost impervious basin, thus reducing the water loss through leakage. The researcher also noted that the type of machine used in overburden removal influenced the physicochemical complex of the impounded water. The stripping shovels generally produced well mixed spoil materials for the watershed, while draglines and scoops tended to place the acid producing materials located directly above the coal on top of the less toxic materials of the watershed. The pH, fertility, and productiveness of the impounded water was greatly influenced by the particular geological strata of the watershed (Riley, 1960).

The studies involving natural ecological succession of strip-mine lakes in Missouri suggested that there was an orderly series of predictable changes associated with aging in strip-mine lakes, and that these stages are closely associated with decreasing acidity (Campbell, Lind, Geiling, and Harp, 1965).

CHAPTER II

DESCRIPTION OF THE STUDY AREAS

The Weir-Pittsburg coal vein, the coal vein which was strip-mined in the six areas included in this study, is a part of the Cherokee shale. This bed crops out from the state line east of Arcadia in Crawford County, Kansas, to two miles north of Columbus in Cherokee County, Kansas, a distance of about fifty miles (Abernathy, Jewett, and Schoewe, 1947). The average thickness of the bed varies from thirty-two inches in the northern part of the field to forty-three inches in the southern part of the field. Those areas which have been stripped were overlain by an average of twenty to thirty feet of finely laminated gray shale. The shale usually contains a sandy zone about three feet thick near the middle, and in some places this zone grades laterally into a thick and prominent sandstone (Pierce and Courtier, 1937).

The strip-mine lakes studied in this project were all located on land owned by the Kansas Forestry, Fish and Game Commission.

The strip-mine lake designated as Cr. #1 (Crawford County Pit No. 1) is located in the S.W. ¼, S.E. ¼, Sec. 11, T. 30 S., R. 25 E., in Crawford County, Kansas. The records in the Bureau of Mines indicated this section was first strip-mined in 1928, by the Simone Bros. Coal Co. (Sherwood, 1928). The first deep-shaft mining operations were begun in 1928 and continued into 1930 (Sherwood, 1930). The Geological Bulletins further indicate that this strip-mine lake is undercut by deep-shaft mines (Pierce and Courtier, 1937).

This lake is bounded on the south and west by county roads, on the north by cultivated fields, and on the east by strip-mined lands.

The Kansas Forestry, Fish and Game Commission constructed a boat ramp in the southern-most portion of this lake at the beginning of this study.

The strip-mine lake has a surface area of 1.4 acres, a maximum depth of three meters and a total volume of 4.8 acre-feet. The major drainage into this lake was from the north and northeast sides.

Cr. #2 (Crawford County Pit No. 2) is located in the N.E. ¼, N.W. ¼, Sec. 13, T. 30 S., R. 25 E., in Crawford County, Kansas. This section was first mined in 1920 by the Reliance Coal and Mining Co. (Sherwood, 1920). Deep-shaft mining was begun in this section in 1928 by the Loan Oak Coal Co. (Sherwood, 1928). There is no indication that the deep-shaft mines of this area undercut the strip-mined areas.

This lake is bordered on the north by a county road, and on the east, south, and west by strip-mined lands.

At about the time this study was started the Kansas Forestry, Fish and Game Commission undertook several steps to increase the accessibility of this lake, and to divert visible signs of acid drainage away from this area. Increased accessibility was accomplished by the construction of a road and boat ramp from the north side of this lake to the county road which borders the lake on the north. The potential maximum volume of the lake was increased by raising the height of the natural dam formed during strip-mining operations. A dike was built in a slough east of this lake in an attempt to divert highly acid materials away from the normal drainage of this lake.

This lake has a surface area of 6.3 acres, a maximum depth of six meters, and a total volume of 55.0 acre-feet.

Cr. #3 (Crawford County Pit No. 3) is located in the N.E. $\frac{1}{4}$, N.W. $\frac{1}{4}$, Sec. 13, T. 30 S., R. 25 E., in Crawford County, Kansas.

This section was first strip-mined in 1920 by the Reliance Coal and Mining Co. (Sherwood, 1920). Deep-shaft operations were begun in this section in 1928 by the Loan Oak Coal Co. (Sherwood, 1928). This lake is bordered on the east by a county road which serves as the boundary line between Kansas and Missouri, and on the north, south, and west by strip-mined lands. Immediately east of this lake, across the county road, stands the remains of an old tipple which served as a pyrite concentrating plant for the mining operations in this area. Drainage into this lake is from the east. The old pyrite concentrating plant is one of the potential acid sources in this area as there are visible signs of drainage from this area to the lakes located to the west.

This lake has a surface area of .7 acres, a volume of 2.1 acre-feet, and a maximum depth of two meters.

This lake served as one of the two controls during this study. No physical alterations of this lake were undertaken.

Ch. #1 (Cherokee County Pit No. 1) is located in the E. ½, S.W. ¼, Sec. 18, T. 32 S., R. 24 E., in Cherokee County, Kansas. Strip-mining operations were started in this section in 1916 by the Skidmore-Patterson Coal Co. (Sherwood, 1916). Deep-shaft operations were started in 1923 by the Big Four Coal Co. (Sherwood, 1923). Mining operations, both deep-shaft and strip-mining, were continued in this section until the early 1930's (Keegan, 1931).

This lake is bordered on the west by a Frisco railroad track, and on the north, east, and south by strip-mine lands.

Drainage into this area is from the west under a trestle of the Frisco Railroad Co., and to a lesser degree from the north.

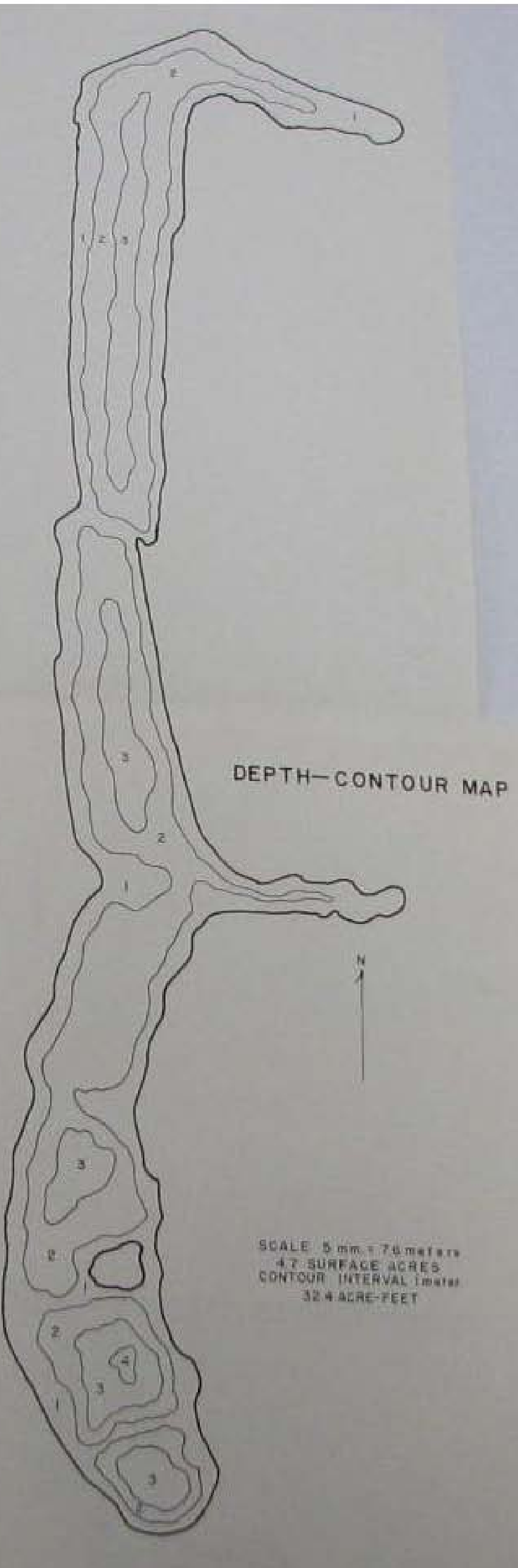
The Kansas Forestry, Fish and Game Commission has constructed a boat ramp and access road to this lake; the access road enters from the south.

This lake has an area of 4.7 surface-acres, a volume of 32.4 acre-feet, and a maximum depth of four meters.

Ch. #2 (Cherokee County Pit No. 2) is located in the N. $\frac{1}{2}$, S.E. $\frac{1}{4}$, Sec. 18, T. 32 S., R. 24 E., of Cherokee County, Kansas. This lake is located in the same section as Ch. #1; the information regarding periods of mining are the same for both lakes. This lake is bordered on the north, south, east, and west sides by strip-mine lands. The land immediately to the east of this lake was once the area of a pyrite concentrating plant. During the period of physical alteration undertaken by the Kansas Forestry, Fish and Game Commission, this area was disc-harrowed, limed, and planted to rye. These steps were taken in an attempt to neutralize the highly acid surface soils, and to decrease the erosion from this area into the strip-mine lake. An access road was also constructed to this lake during the period of rehabilitation. This road served a two-fold function in that it served not only as a ready access to the lake, but it also aided in diverting acid drainage from the area of the old pyrite concentrating plant. Drainage into this lake is almost exclusively from the east-northeast.

This lake has a surface area of 4.0 acres, a maximum depth of six meters, and a volume of 49.7 acre-feet.

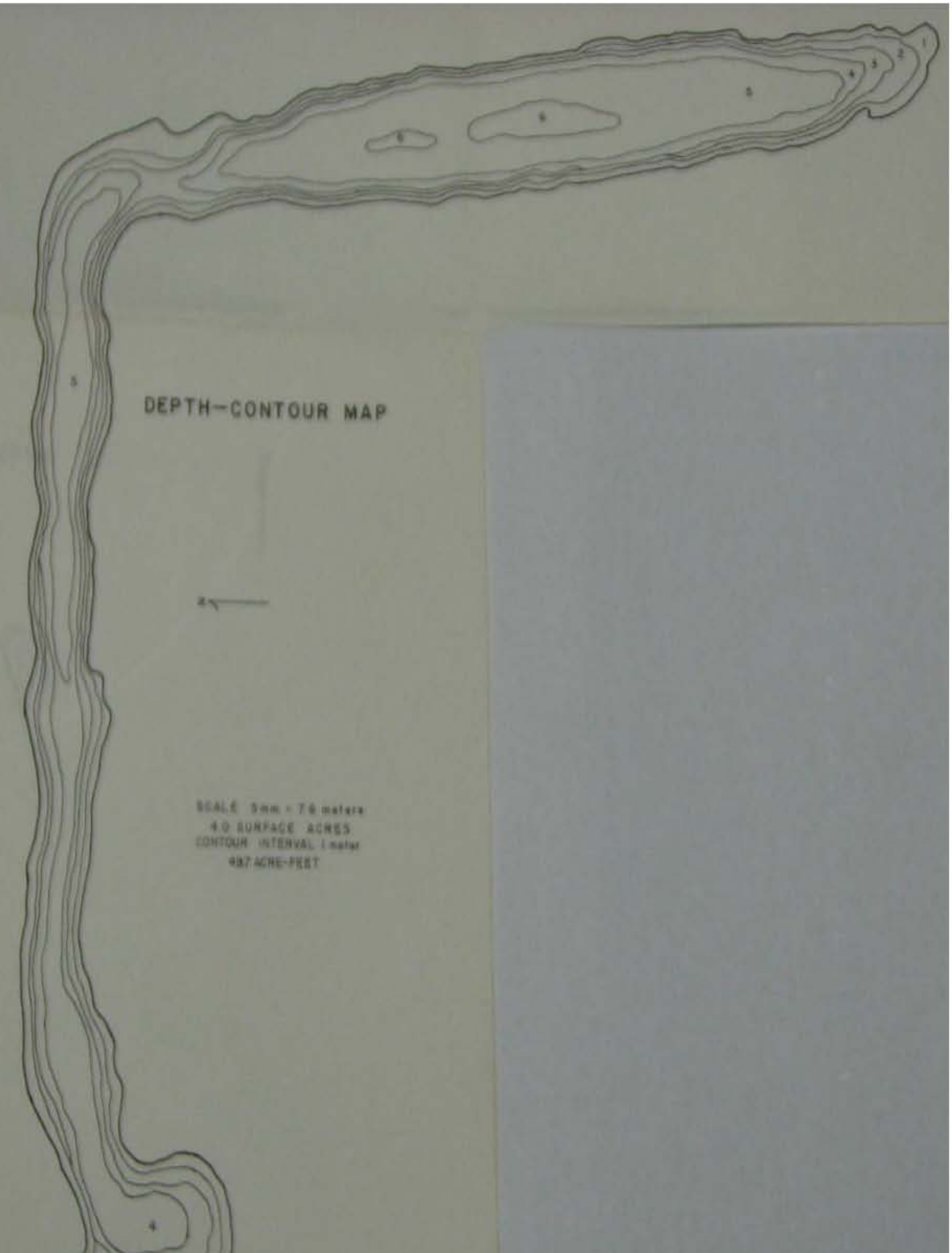
Ch. #3 (Cherokee County Pit No. 3) is located in the S.W. ¼, S.E. ¼, Sec. 18, T. 32 S., R. 24 E., in Cherokee County, Kansas. This strip lake was mined during the same period as Ch. #1 and Ch. #2. This lake is surrounded on all four sides by strip-mined lands and was one of the two control lakes for this study. The lake has a surface area of 1 acre, a volume of 4.0 acre-feet, and a depth of three meters.



DEPTH—CONTOUR MAP

SCALE 5 mm.= 7.6 meters
4.7 SURFACE ACRES
CONTOUR INTERVAL 1 meter
32.4 ACRE-FEET

CH. PIT NO. 1
SEC. 18 T. 32 S. R. 24 E.
CHEROKEE CO., KANSAS

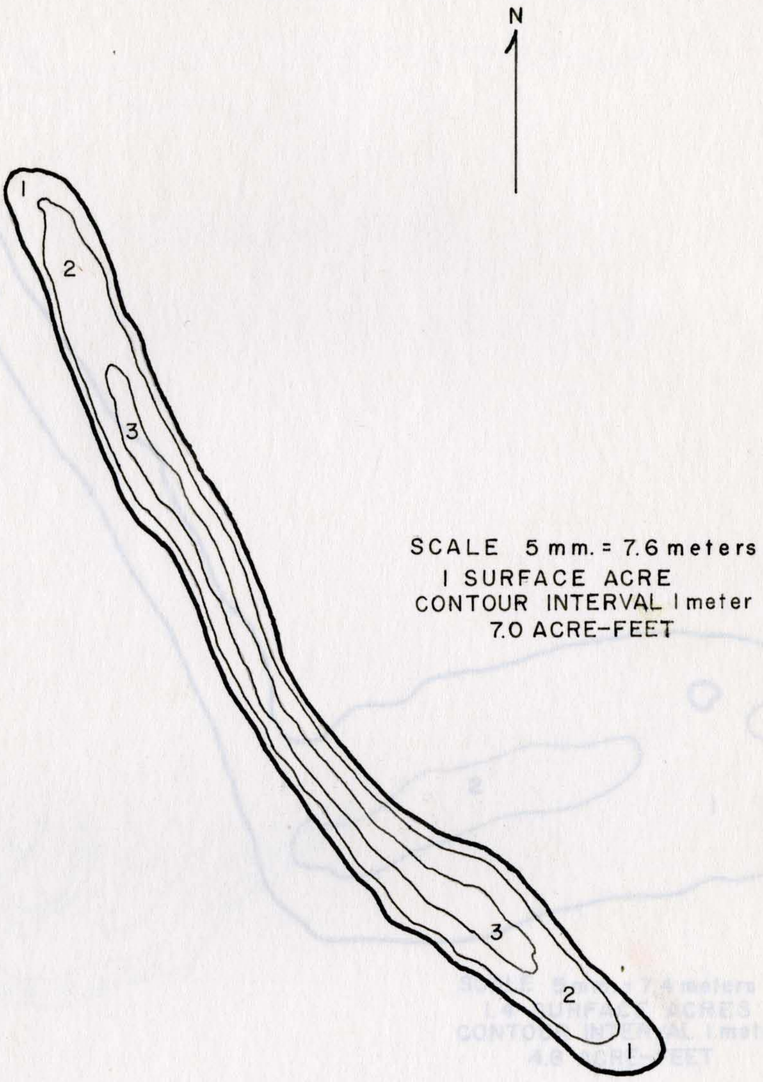


DEPTH—CONTOUR MAP

SCALE 5mm = 7.6 meters
4.0 SURFACE ACRES
CONTOUR INTERVAL 1 meter
48.7 ACRE-FEET

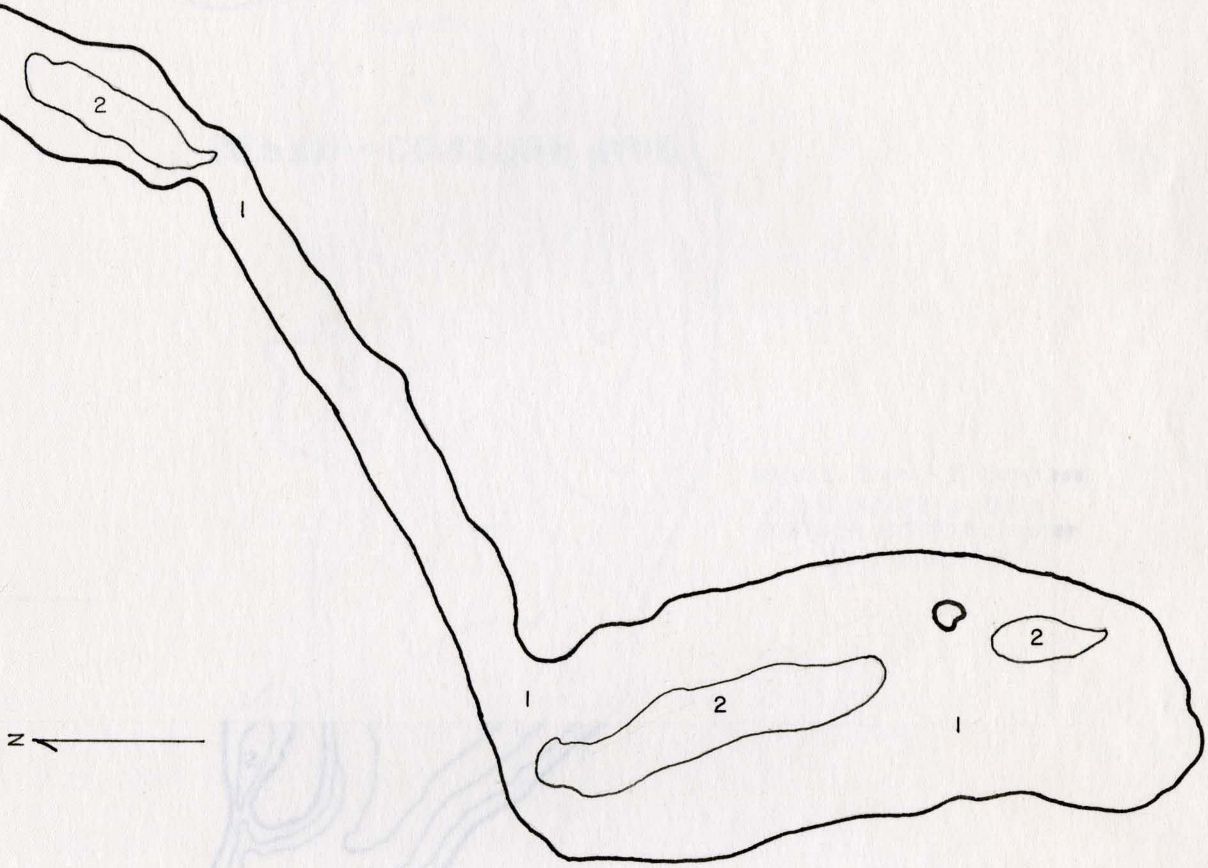
CH. PIT NO. 2
SEC. 18 T. 32 S. R. 24 E.
CHEROKEE CO., KANSAS

DEPTH—CONTOUR MAP



CH. PIT NO. 3
SEC. 18 T. 32 S. R. 24 E.
CHEROKEE CO., KANSAS

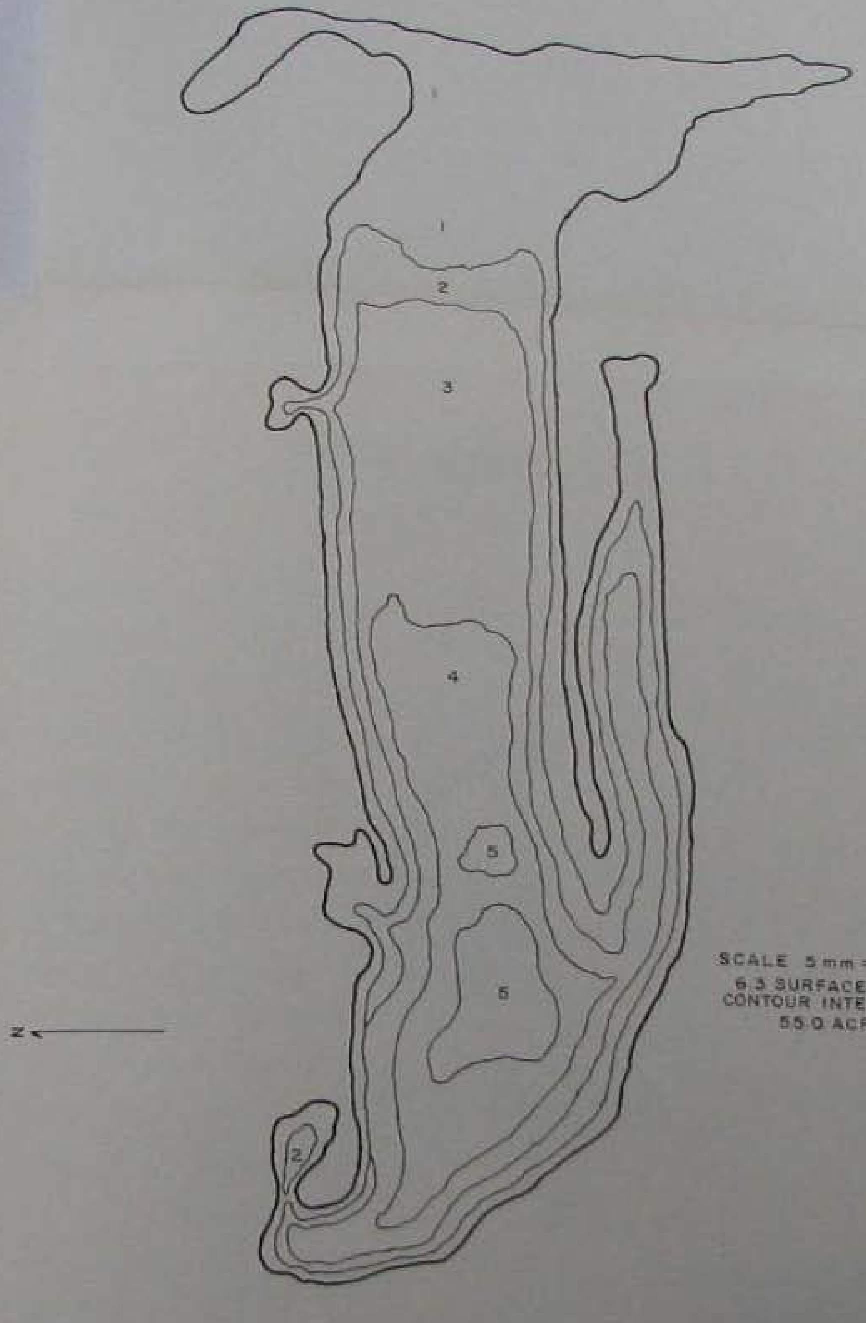
DEPTH—CONTOUR MAP



SCALE 5 mm. = 7.4 meters
1.4 SURFACE ACRES
CONTOUR INTERVAL 1 meter
4.8 ACRE-FEET

CR. PIT NO. 1
SEC. 11 T. 30 S. R. 25 E.
CRAWFORD CO. KANSAS

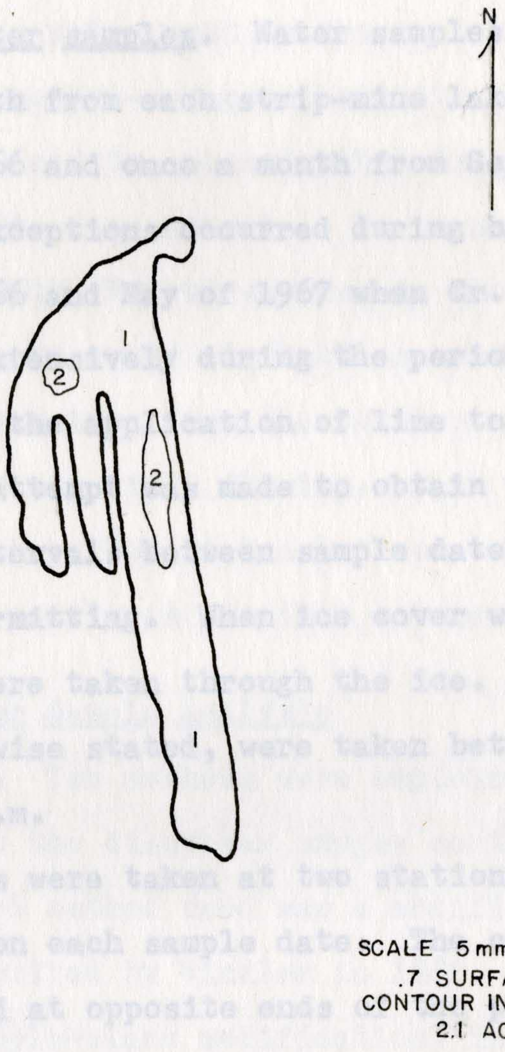
DEPTH—CONTOUR MAP



SCALE 5 mm = 7.4 meters
6.3 SURFACE ACRES
CONTOUR INTERVAL 1 meter
55.0 ACRE-FEET

CR. PIT NO. 2
SEC. 13 T. 30 S. R. 25 E.
CRAWFORD CO., KANSAS

DEPTH—CONTOUR MAP



SCALE 5 mm. = 7.4 meters
.7 SURFACE ACRE
CONTOUR INTERVAL 1 meter
2.1 ACRE-FEET

CR. PIT NO. 3
SEC. 13 T. 30 S. R. 25 E.
CRAWFORD CO., KANSAS

CHAPTER III

MATERIALS AND METHODS

Collection of water samples. Water samples were collected twice a month from each strip-mine lake during July and August of 1966 and once a month from September 1966 to June 1967. Exceptions occurred during brief periods in July of 1966 and May of 1967 when Cr. #2 and Ch. #1 were sampled extensively during the period immediately following the application of lime to these bodies of water. An attempt was made to obtain the samples at monthly intervals between sample dates, weather conditions permitting. When ice cover was present the samples were taken through the ice. All samples, unless otherwise stated, were taken between 6:00 a.m. and 12:00 p.m.

The water samples were taken at two stations in each strip-mine lake on each sample date. The collection stations were selected at opposite ends of the pits and represented a deep and shallow station in each strip-mine lake. The water samples taken were designated as surface and bottom samples for each station. The surface samples were taken within one meter of the surface and the bottom samples within a meter-distance of the bottom. The samples were taken using a three-liter capacity

Foerst modification of the Kemmerer sampler (Welch, 1948).

Glass stoppered bottles, one wide-mouth and one narrow-mouth 250 ml. volume B.O.D. for each test, were used to transport the samples used in the analysis of dissolved oxygen, pH, methyl-orange alkalinity, boiling-point phenolphthalein acidity, phenolphthalein acidity, total phosphate, nitrite, and nitrate. In transferring the water samples from the Foerst sampler to the B.O.D. bottles care was taken to avoid air bubbles, and to withdraw the rubber delivery tube from the bottles while water from the sampler was still flowing. Each sample bottle was allowed to overflow at least three volumes of water to insure as nearly as possible a true sample.

Water Sample Analysis

Dissolved oxygen. Two methods were employed in the field to determine the dissolved oxygen content of the samples. The first method used was a modification of a method first described by Winkler in 1888. This method, called the sample-blank modification, involved the simultaneous analysis of two bottles of the sample to compensate for errors due to various interfering substances so that all the deductible errors occurred in one bottle. The procedure followed for this determination was the same as that given by Ellis, Westfall, and Ellis, (1948).

The second method employed for the determination of dissolved oxygen was a Beckman model 777 Dissolved Oxygen Analyzer. This instrument was used extensively in the initial phases of the study but later became inoperable and its use was discontinued. The instrument was calibrated by multiplying the barometer reading, obtained the morning the samples were taken, by a factor of 20.9% to find the pressure due to the oxygen in the atmosphere. The amount of dissolved oxygen in the water at different temperatures when exposed to an atmosphere containing 20.9% of oxygen was determined from a table given in Whipple, Fair, and Whipple, (1927).

The source of current for the operation of the dissolved oxygen analyzer in the field was a Homelight generator powered by a gasoline engine. The current was stabilized by the use of a rectifier-type voltage stabilizer, Model 301, produced by the Weston Elec. Inst. Corp.

Hydrogen-ion Potential. The pH determinations were made in the field using a Beckman Zeromatic II glass electrode pH meter. The water samples taken for the pH determinations were taken in wide-necked B.O.D. bottles and the electrodes of the pH meter were placed directly into the B.O.D. bottle thus eliminating the transfer of the sample to another container. Temperatures of the samples were measured and the pH meter control adjusted to the sample temperature. The pH meter was calibrated with standard buffer solution before each series of samples was analyzed.

Water temperature. Surface and bottom water temperatures were measured in degrees Centigrade at both stations using a Yellow Springs Instrument Co. battery operated Y.S.I. single channel direct reading telethermometer equipped with a 30 ft. general purpose probe.

Meterological conditions. Air temperature was recorded at the time of sampling using the same thermometer used in establishing water temperatures.

The data concerning wind direction and velocity, and rainfall were obtained from the weather station maintained by Kansas State College of Pittsburg.

Secchi plate (limit of visibility). A Secchi plate was used as a routine method to compare the limits of visibility of the water between the six strip-mine lakes. The data obtained from these measurements cannot be considered to be a measurement of light penetration but rather a rough index of visibility (Welch, 1948). The Secchi plate used was a circular metal plate, 20 cm. in diameter, the upper surface of which was divided into four equal quadrants and so painted that two quadrants directly opposite were black and the intervening ones white. The lower side of the disk was painted black.

The Secchi plate was lowered into the water and the depth at which it was no longer visible was recorded. Then the disk was raised and the depth at which it reappeared was noted. The average of these two readings was considered to be the limit of visibility. The measurement was made on the shaded, protected side of the boat with the eyes at approximately 50 cm. above the water-surface.

Depth measurements. Depth measurements were accomplished by measuring the submerged length of a weighted rope when lowered into the water until the weight struck the bottom.

Total alkalinity. The total alkalinity samples were determined in the field by titration (Ellis, Westfall, and Ellis, 1948). As the alkalinity of natural waters has been considered to be the result of carbonate alkalinity it has been expressed in terms of calcium carbonate. Hence, three kinds of alkalinity have been designated in limnological studies; namely hydroxide (OH), normal carbonate (CO_3), and bicarbonate (HCO_3), and the entire group summed as total alkalinity (Ellis, Westfall, and Ellis, 1948). Since only bicarbonate or methyl-orange alkalinity was found to exist in the strip-mine lakes studied the total alkalinity was an expression of methyl-orange alkalinity alone.

Total acidity. The determinations of total acidity were accomplished in the field by titration (American Public Health Association, 1965).

Phenolphthalein boiling-point acidity. The determination of boiling-point acidity was carried out in the laboratory. No special precautions were taken at the time of collection of the samples used for this analysis (American Public Health Association, 1965).

Nitrite. The samples taken for the determination of the nitrite content of the water were analyzed in the laboratory according to procedures outlined in a manual of the Hach Chemical Company, Ames, Iowa. These procedures employed Hach chemicals purchased in premeasured quantities. Measurement was accomplished with the use of a Bausch & Lomb Model 4 Spectronic 20. The samples were measured using a matched set of Bausch & Lomb ½ inch colorimeter tubes and a wavelength setting of 525 mμ. The values in ppm. of nitrite in the water sample were read directly from the hand book provided by the Hach Chemical Company.

Total phosphate. The procedures followed for the determination of total phosphate were carried out in the laboratory. This procedure, like that for the nitrite determination, was one in which Hach Chemical Company premeasured chemicals were used in conjunction with measurement in a Bausch & Lomb Model 4 Spectronic 20. Measurement was accomplished using a matched set of $\frac{1}{2}$ inch colorimeter tubes, a 1P40 photocell and red color filter at a wavelength setting of 705 mμ. The values in ppm. of phosphate were read directly from the hand book provided by the Hach Chemical Company.

Nitrate. The samples taken for nitrate analysis were processed in the laboratory. The procedure employed was a modification of the brucine method for nitrate determination given by the American Public Health Association, (1965). This method was employed because it represented a method of determining nitrate concentrations below one mg. per liter by controlling the conditions of the reactions (Jenkins and Medsker, 1964).

The samples were compared using a Bausch & Lomb Spectronic 20 equipped with a one-inch adapter and a wavelength setting of 410 mμ. (Jenkins and Medsker, 1964).

The concentration of nitrate was read from a graph of %T vs. concentration of nitrate in ppm. This graph was prepared by running a series of five known nitrate samples of the following concentrations; 0.01, 0.05, 0.3, 0.5, and 0.8 ppm. This series was repeated ten times and the values obtained were averaged and the data plotted on semi-logarithmic paper.

The one-inch test tubes used for this procedure were Kimax tubes which were matched to ± 5% T using the cobalt chloride procedures outlined in the Bausch & Lomb Colorimeter-Spectrophotometer reference manual.

Carbon dioxide. The determination of the free carbon dioxide content of the water was based on information obtained from Moore (1939). This procedure involves the use of the previously determined pH and total alkalinity as a basis for the mathmatical determination of carbon dioxide.

Soil pH. Samples taken for soil pH analysis were chosen from two different types of areas. Samples of normal vegetated spoil banks were taken to determine the degree of acidity attributed to the strip-mine lakes during periods of runoff, and additional samples were taken where visible signs of drainage from areas of potential high pyrite concentration were found. The pH of these samples were taken so corrective measures of diversion could be undertaken where warranted.

The samples taken from the vegetated spoil banks were chosen from areas which appeared to be representative of the strip-mine lake being sampled. Three samples of approximately 316 $cm.^3$ were taken by hand trowel and placed in plastic containers. Upon return to the laboratory the samples were thoroughly mixed and spread for drying. After the samples had dried they were crushed with a wooden rolling pin. A 1:2.5 soil/water ratio was used to determine the pH. (10 gm. of soil to 25 ml. of deionized distilled water.) The water soil mixture was stirred every ten minutes for a thirty minute period and the pH was read using a Beckman Zeromatic II glass electrode pH meter (jackson, 1958).

Collection and analysis of bottom samples. The bottom samples were collected once a month for the twelve month period. Two samples were chosen at random for each strip-mine lake during each sample period. The samples were taken using a Petersen dredge of the type described by Welch (1948). This method is suitable for qualitative and quantitative work on macroscopic animals, but is not practical for quantitative work on microscopic fauna (Welch, 1948). After securing the sample it was transferred to an open pan, thoroughly mixed by hand, and divided into fourths. One-fourth of the sample was retained for analysis. Upon returning to the laboratory the sample was washed through a series of two sieves. The two sieves had U.S. sieve series mesh numbers of 10 (diameter, 2.00 mm.), and 35 (diameter, 0.500 mm.). Only those organisms which were retained in the two sieves were analyzed.

The screenings were treated in two ways depending on the time allotable to the analysis of the samples. If enough time was available the screenings were placed in shallow white porcelain pans and surveyed for organisms present. This survey involved both sight and binocular scope survey to insure a complete and standard method of analysis. In preparing the samples for survey under a binocular scope small portions of the screenings were placed in petri dishes which had been marked off in one centimeter squares and each square was systematically surveyed under the scope. Only those organisms which were alive at the time of collection were included in the calculations.

Where there was not enough time to analyze the samples on the date of collection the screenings were preserved in 10 per cent formalin and analyzed according to the procedure outlined above. This procedure of preserving screenings for later analysis is not recommended as it involves the determination of the animals which were alive when the samples were taken. This procedure was avoided when possible.

A modification of the survey count method was used to determine the number of macroscopic animals in one square meter of bottom (Welch, 1948). The modification employed was one in which the number of organisms actually counted in the sample was multiplied by a factor of four for ease in analysis.

The following taxonomic keys were used in the identification of the various benthic organisms collected; Ward & Whipple (1959), Usinger (1956), Needham and Needham (1941), Eddy and Hodson (1955), Needham and Westfall (1955), and Pennak (1953).

Collection and analysis of net plankton. Plankton samples were collected once a month during the twelve month period. Both surface samples, within one meter of the surface, and bottom samples, within one meter of the bottom, were collected for each station.

The samples were taken using the pump and hose method (Welch, 1948). The pump was a 36 inch stroke lift type, hand operated barrel pump purchased from the Sears, Roebuck and Co. Plastic hose of half-inch diameter was cut to one meter and one-half meter lengths so that reasonable accuracy could be employed in selecting samples of desired depths. The terminal section of hose was fitted with a 14 cm. diameter plastic funnel to increase the area of sampling and decrease the currents within the immediate vicinity of the sampling device. This was done to increase the validity of the sample as it has been estimated that without such a device as much as 10% of the plankters which manifest avoiding reactions to such currents might be lost in the process of sampling (Welch, 1948).

Approximately fifty liters of strip-mine water was pumped and allowed to flow through a plankton net similar to the Wisconsin plankton net described by Welch (1948). The plankton net framework and trap were covered with No. 25 silk bolting cloth. Upon processing the fifty-liter sample the net and trap were washed with distilled water and the contents transferred to a concentrate bottle and preserved with 5% formalin. Only those organisms which did not pass through the plankton trap were analyzed. No attempt was made to survey the nannoplankton or periphyton.

The total count procedure for analyzing plankton samples was employed to determine the number of plankters per liter of orininal water (Welch, 1948).

The planktonic organisms counted were placed in the following taxa; copepoda, cladocera, rotifer, flagellate, desmid, diatom, sarcodina, and filamentous green algae. The following keys were used to identify the plankters; Ward & Whipple (1959), Pennak (1953), Smith (1950), Prescott (1951), and Needham and Needham (1941).

Morphometry. Hydrographic maps of the six strip-mine lakes were constructed using a combination of several methods outlined by various authors (Welch, 1948; Lagler, 1956; and Hutchinson, 1957).

The shore-line features of the maps were enlarged from aerial photographs by means of a pantograph manufactured by the Lutz Co. The aerial photographs were obtained from the Kansas Forestry, Fish and Game Commission.

The surface area of each of the strip-mine lakes was determined from the enlarged drawings by use of a Keuffel & Esser, 620015 Compensating Polar Planimeter.

The data used in the construction of the bottom contours was collected by survey methods. A point of origin was chosen at one end of a strip-mine lake and twenty meter intervals were staked out along each bank. In order to maintain parallel transects between the twenty meter stakes more than one measurement was taken from a given point where warranted. A transect divided into meter distances was sighted between the twenty meter stakes. Measurements were taken at one and two meters from the point of reference and then two meter intervals were used to complete the distance necessary to reach the opposite bank. The point of reference originated from the same bank for each measurement. The actual depths were measured by use of a depth pole fitted with a metal "boot" to retard the sinking of that end of the pole into the softer bottom deposits (Welch, 1948).

<u>Collection</u> <u>of</u> <u>fishes</u>. On April 22, 1967, <u>Derris</u> root poison (rotenone) was administered to Cherokee Co. Pit No. 1. Upon the recommendation of Robert Hartmann, Fisheries Biologist, Kansas Forestry, Fish and Game

Commission, the rotenone (Pro-noxfish Fish Toxicant, 5% emulsified rotenone) was applied at a concentration of 1 ppm. Dispersal of the rotenone was accomplished by spraying.

The fishes were collected from the waters throughout the afternoon of April 22, and additional collections were made on April 23, 24, and 26.

The processing of the fish included the determination of weight, standard length, sex, and the taking of scale samples. Weight was taken in ounces by use of a spring balance. Standard length, total length, and sex determination was accomplished by methods outlined by Lagler (1956). Scale samples were taken as described by Lagler (1956) from an area on the left side of the body below the origin of the dorsal fin and just above the lateral line. Approximately twenty scales were taken from each specimen and were placed in collection envelopes.

Application of lime. On June 23, 1966, the initial project of applying lime to Cr. #2 was undertaken. Approximately one ton of lime was distributed in the area of station no. 1 from a barge constructed from two twelve foot aluminum boats. The boats were fastened together with a frame constructed from 2 x 4's, with 1 x 8 foot planks nailed to this frame serving as the surface of the barge. The lime was distributed from the barge by shovel.

On June 24, 1966, the remaining lime, approximately 5.2 tons, was distributed throughout the lake in the manner outlined above.

After the application of the 6.2 tons of lime on the 23rd and 24th of June, the liming procedures were stopped.

On July 15, 1966, the liming operations were resumed and a total of 15.8 tons of lime was distributed throughout the strip-mine lake according to the above outlined procedures.

On May 2, 1967, the initial project of applying lime to Ch. #1 was undertaken. On this date 1.1 tons of lime were spread throughout the lake.

On May 11, 1967, an additional 2.5 tons of lime were spread throughout this lake.

On May 27, 1967, a final dosage of 5.0 tons of lime was applied to this lake.

All of the lime used during these procedures was purchased from the John Stark Quarry, located southwest of Girard, Kansas, at a cost of $1.80 a ton. An analysis of the lime showed it contained 92% $CaCO_3$ equivalent.

CHAPTER IV

RESULTS AND DISCUSSION

At the beginning of this study four of six strip-mine lakes selected for analysis (Ch. #1, Ch. #2, Cr. #2, and Cr. #3) possessed characteristics which placed them in the category of Early Recovery lakes. The characteristics of the other two lakes placed them in the Late Recovery category. This classification was based on that given by Campbell, Lind, Geiling, and Harp (1965).

Before the application of lime to Ch. #1 in May, the lake showed no thermal stratification, had a pH range of 4.2 to 5.4, a boiling-point acidity range of 4.0 ppm. to 10.0 ppm., and the water was turquoise blue in color. This lake did not, however, exhibit the degree of transparency possessed by the other Early Recovery lakes included in the study. This lake, even though it possessed low pH values, had a fish population. After the application of a total of 8.6 tons of lime to this body in May the pH reached a high of 7.0, the boiling-point acidity was reduced to a range of 0.0 to 0.5 ppm., the total alkalinity rose from a previous high of 5.0 ppm. to 10.0 ppm., and the water color changed from turquoise blue to dark green.

The lake which was designated Ch. #2 exhibited no thermal stratification, had a pH range of 3.6 to 4.9, a boiling-point acidity range of 38 to 84 ppm., turquoise blue water color, and very transparent water conditions.

Before the application of lime to Cr. #2, no thermal stratification was recorded, pH ranged from 3.4 to 4.6, the water was extremely transparent and the lake was turquoise blue in color. No boiling-point acidity values were obtained for any of the lakes before October of the study so these values are not available for this lake for the period before lime application. The lake was homothermic throughout this period. This lake possessed a massive bed of Sphagnum cuspidatum Ehrh. (identified by L. J. Gier, PhD., William Jewell College) which was found to be present from the maximum recorded depths to depths of one meter throughout the lake. After the application of lime to this lake the pH rose to a maximum of 7.9, total alkalinity rose from a previous zero to a high of 20 ppm., boiling-point acidity ranged from 0.0 to 10.0 ppm., the transparency values were greatly reduced, and the water color changed from the pre-liming color of turquoise to a dark green.

The lake designated as Cr. #3, the control lake for the acid lakes utilized in this study, showed a pH range of 2.6 to 3.0, boiling-point acidity range of 440 to 568 ppm., transparency values which equalled the depth

TABLE I

MONTHLY DATA OF SECCHI PLATE TRANSPARENCY
(METERS)
1966-1967

LAKE	CHEROKEE CO. PIT #1				CHEROKEE CO. PIT #2				CHEROKEE CO. PIT #3			
STATION	STA. #1		STA. #2		STA. #1		STA. #2		STA. #1		STA. #2	
	DEPTH	TRANS.	DEPTH	TRANS.	DEPTH	TRANS.	DEPTH	TRANS.	DEPTH	TRANS.	DEPTH	TRANS.
JULY	3.55	.88	2.13	2.13	5.02	5.02	3.60	3.60	3.09	1.83	2.62	1.31
AUG.	3.54	1.19	----	----	5.05	5.05	3.34	3.34	3.35	1.73	2.24	1.72
SEPT.	2.80	1.73	1.85	1.85	4.95	4.95	3.00	3.00	3.25	1.00	1.98	.86
OCT.	3.31	1.11	1.83	1.34	4.88	4.88	3.24	3.24	3.32	.98	2.10	2.10
NOV.	3.28	1.04	1.83	1.50	5.11	5.11	3.00	3.00	3.25	1.68	2.00	1.76
DEC.	3.07	.90	1.64	.60	4.98	3.50	2.92	2.92	3.24	2.98	2.08	2.08
JAN.	3.00	1.00	1.70	1.10	4.90	3.50	3.00	3.00	3.20	2.50	2.00	2.00
FEB.	3.16	1.16	1.72	1.20	4.77	2.23	2.48	1.45	2.98	2.86	2.10	2.10
MAR.	4.74	1.50	1.68	1.12	5.00	1.50	2.98	1.86	3.00	2.80	2.00	2.00
APR.	3.53	1.17	1.95	.70	5.09	1.27	4.49	1.22	3.46	1.16	3.80	1.09
MAY	3.90	1.31	1.87	1.63	5.62	2.61	4.87	2.94	3.64	1.65	2.82	1.20
JUNE	4.31	1.75	2.28	1.96	3.66	3.66	5.75	5.32	3.11	2.53	3.00	1.56

TABLE II

MONTHLY DATA OF SECCHI PLATE TRANSPARENCY
(METERS)
1966-1967

LAKE	CRAWFORD CO. PIT #1				CRAWFORD CO. PIT #2				CRAWFORD CO. PIT #3			
STATION	STA. #1		STA. #2		STA. #1		STA. #2		STA. #1		STA. #2	
	DEPTH	TRANS.	DEPTH	TRANS.	DEPTH	TRANS.	DEPTH	TRANS.	DEPTH	TRANS.	DEPTH	TRANS.
JULY	2.45	1.18	2.60	1.44	4.54	3.32	3.30	3.30	2.05	2.05	1.68	1.68
AUG.	2.65	1.01	2.51	1.06	4.56	1.60	3.00	1.47	1.91	1.75	1.50	1.50
SEPT.	1.84	1.04	2.44	1.28	4.21	1.56	2.95	2.62	2.09	2.09	1.21	1.21
OCT.	2.46	1.63	2.41	2.00	4.83	2.30	2.90	2.70	1.60	1.60	1.12	1.12
NOV.	2.27	1.42	2.32	1.38	4.23	2.74	2.58	2.58	1.49	1.49	1.07	1.07
DEC.	2.48	1.45	2.31	1.53	4.63	1.28	2.60	2.60	1.46	1.46	1.02	1.02
JAN.	2.50	1.50	2.40	1.50	4.96	1.54	2.90	1.54	1.50	1.50	1.00	1.00
FEB.	2.50	1.38	2.55	1.50	4.90	2.45	3.34	1.05	1.46	1.46	1.05	1.05
MAR.	2.55	1.45	2.45	1.50	5.08	1.63	2.77	1.65	1.48	1.48	.98	.98
APR.	2.25	1.15	2.21	1.72	5.09	2.22	3.35	2.00	1.10	1.10	1.15	1.15
MAY	2.53	1.48	2.33	1.95	4.95	1.63	1.41	1.41	1.75	1.75	1.25	1.25
JUNE	1.67	1.52	2.20	1.82	5.18	3.11	1.40	1.40	1.76	0.71	1.38	0.70

in nearly every case, homothermic temperature conditions, and turquoise blue water color.

Ch. #3, a Late Recovery lake, exhibited a pH of from 6.9 to 8.3, possessed no boiling-point acidity, was thermally stratified from May to mid-November, was much more turbid than the Early Recovery lakes, and was dark green in color. This lake possessed a well established fish population.

Cr. #1 had a pH range of from 6.9 to 8.4, had no boiling-point acidity, was more turbid than the Early Recovery lakes, showed thermal stratification from May to late September, and was dark green in color. This lake had a fish population. This body of water also possessed a dense growth of water lilies, _Nymphaea ordorata_ Ait. and _Nuphar advena_ Ait. (as described by Fernald, 1950). This vegetational growth formed a mat which covered the water surface except in those areas which exceeded two meters in depth.

The rate of natural succession of strip-mine lakes from acid to alkaline conditions must be based on the amount of pyritic sulfur associated with a given body of water. Although the direction of this succession may be predicted, the rate at which it occurs cannot. The rate of succession may, however, be retarded by the presence of a source of pyritic sulfur in the drainage basin associated with a given lake (Campbell, Lind, Geiling, and Harp, 1965).

It was on this basis that attempts were made to speed the ecological succession of two of the acid strip-mine lakes included in this study. These lakes had been acid for thirty to forty years. By eliminating the source or sources of sulfuric acid, which result from the oxidation of pyritic sulfur, and by diverting the potential sources of this acid and applying agricultural lime to these bodies it was felt that the succession to the alkaline state would be accomplished. Theoretically, the elimination of the sources of acid drainage causing the retardation of natural succession would result in a natural succession to the alkaline state. The addition of lime served only to accomplish a more rapid succession to the alkaline state.

Crawford (1942), working in Missouri on the natural succession of strip-mine lakes, attempted to neutralize a 0.01 surface acre pond with a maximum depth of four feet and a pH of 2.4. Three tons of lime ($CaCO_3$) were added to this lake. This resulted in an increase of pH to 4.3, but within one week the pH returned to its original value. Additional lime (the amount was not given) was added but the pH was never raised to a value of pH 5. Because no apparent attempts were made to divert any source of acid drainage, and no values as to the boiling-point acidity or age of this lake are given, it is not possible to draw conclusions as to the reason for failure in the attempt to reclaim this lake. Crawford (1942) also mentions in discussing the methods of neutralization that other attempts to reclaim acid strip-mine waters in Missouri and other states have failed, but he gives no references as to his source of this information.

The strip-mine spoil dumps forming the banks of the lakes were probably initially responsible for a degree of acidity due to the oxidation of the pyritic sulfur exposed during mining operations. Because of the degree of mixed vegetation covering these banks and the values recorded for soil pH (4.8-6.2), this is no longer felt to be a significant source of acid.

The reaction of lime (calcium carbonate) with the sulfuric acid has resulted in deleterious effects to benthic populations when this method of neutralization was carried out in streams of the eastern United States (Lorenz, 1962). The calcium sulfate which is formed in this chemical reaction in only slightly soluble and precipitates out forming a sludge which tends to smother the benthic organisms present. This problem was not encountered during the neutralization of the strip-mine lakes in this study in that the source of the sulfuric acid in the lakes was not a constant source like that in streams which flow through the coal mine areas of the east. Therefore, the quantity of lime required to neutralize the waters of the acid lakes was considerably less than that required to neutralize a stream with a constant source of the acid. The chemical reaction which takes place in neutralization is as follows:

$$H_2SO_4 + CaCO_3 \rightleftharpoons CaSO_4 + CO_2 + H_2O$$

Boiling-point acidity is a measure of the hydrolyzable salts of mineral acids (American Public Health Association, 1965). It is an indication of the chemical conditions of the water which gives it the capacity to resist changes to the alkaline state. This is felt to be one of the most significant characteristics which must be considered when attempting to reclaim acid strip-mine lakes.

The boiling-point acidity values for Cr. #3 (Figure 8) are higher than those recorded for any of the other lakes. This is probably the result of its close proximity to an abandoned pyrite-concentrating plant located immediately to the east of this lake. The boiling-point acidity values for Ch. #2 were the second highest values recorded for the lakes in this study (Figure 7). This lake, like Cr. #3, was located close to an old pyrite-concentrating plant. No boiling-point acidity values were recorded for the two lakes which were alkaline at the beginning of the study, Ch. #3 and Cr. #1. The reasons for the residual amounts of boiling-point acidity in Cr. #2 after liming and attainment of pH values greater than pH 7 (Figure 11), are not known.

Of the acid lakes, Ch. #1 had the lowest boiling-point acidity values (Figure 7). These values decreased to a low of 0-0.5 ppm. after the liming operations were concluded during May.

The hydrogen ion concentration, although it is an indication of the fitness of the water, does not give any information as to the actual amount of acid present in a given body of water. This may be exemplified by the following table given by Braley (1954). This table compares the pH values with the amounts of sulfuric acid present in mine water samples.

pH	Acidity (ppm.)
5.85	302
3.75	4,253
3.39	120
3.29	1,046
2.64	944
2.63	1,245

As can be seen from the table, the sample of pH 3.39 contains a considerably smaller amount of available acid (120 ppm.) when compared to the sample of higher pH 3.75

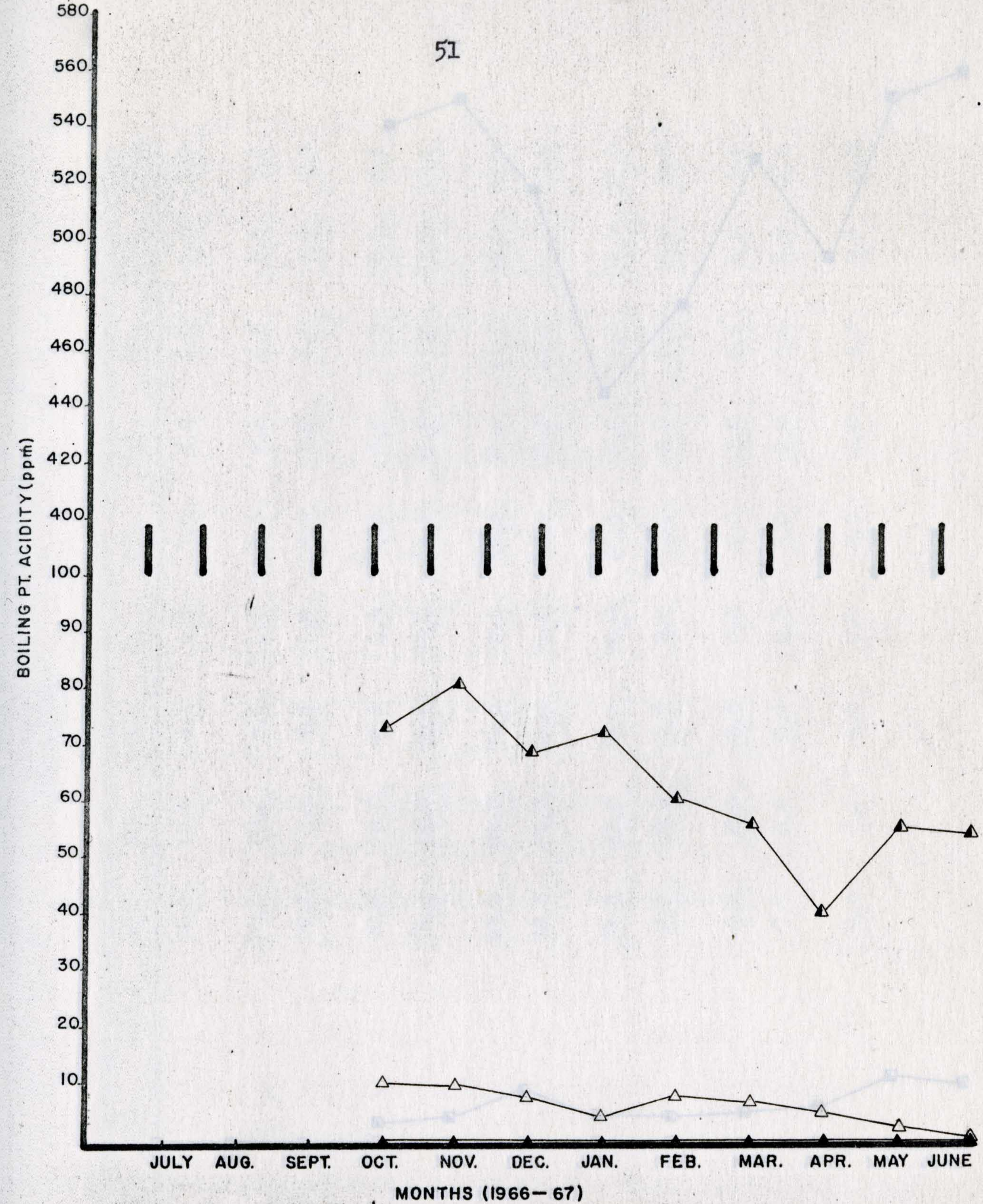


Fig. 7 Concentration of boiling point acidity versus time in months taken once each month from October 1966 to June 1967. All points are the average of four determinations. Ch. #1—△—, Ch. #2—◭—, Ch. #3 —▲—.

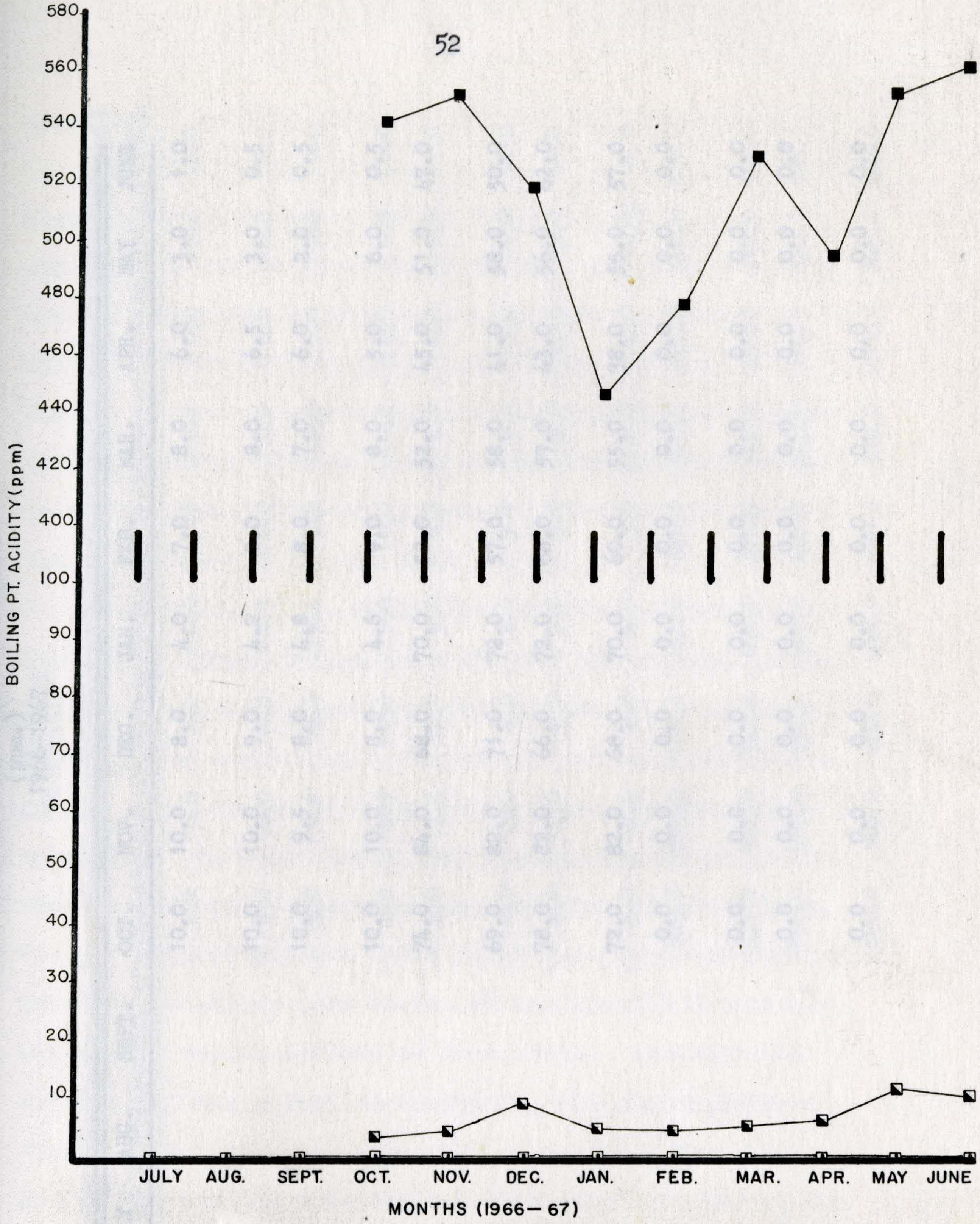


Fig. 8 Concentration of boiling point acidity versus time in months taken once each month from October 1966 to June 1967. All points are the average of four determinations. Cr. #1 -□-, Cr. #2 -◪-, Cr. #3 -■-.

TABLE III

MONTHLY DATA OF BOILING PT. ACIDITY
(ppm.)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Ch. #1 Sta. #1				10.0	10.0	8.0	4.0	7.0	8.0	6.0	3.0	1.0
Bottom				10.0	10.0	9.0	4.2	8.0	8.0	6.5	3.0	0.5
Surface Ch. #1 Sta. #2				10.0	9.5	8.0	4.8	8.0	7.0	6.0	2.0	0.5
Bottom				10.0	10.0	8.0	4.6	9.0	8.0	5.0	6.0	0.5
Surface Ch. #2 Sta. #1				74.0	84.0	68.0	70.0	58.0	52.0	45.0	51.0	47.0
Bottom				69.0	82.0	71.0	72.0	57.0	58.0	41.0	58.0	50.0
Surface Ch. #2 Sta. #2				78.0	82.0	66.0	72.0	68.0	59.0	43.0	56.0	62.0
Bottom				72.0	82.0	68.0	70.0	60.0	55.0	38.0	55.0	57.0
Surface Ch. #3 Sta. #1				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bottom				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Ch. #3 Sta. #2				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bottom				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE IV

MONTHLY DATA OF BOILING-PT. ACIDITY

(ppm.)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Cr. #1 Sta. #1				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bottom				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Cr. #1 Sta. #2				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bottom				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Cr. #2 Sta. #1				0.0	2.0	10.0	5.0	4.0	5.0	6.0	9.0	11.0
Bottom				2.0	3.0	8.0	4.0	3.0	4.0	6.0	6.0	12.0
Surface Cr. #2 Sta. #2				4.0	4.0	6.0	3.0	5.0	5.0	7.0	13.0	10.0
Bottom				4.0	3.0	8.0	4.0	3.0	6.0	9.0	16.0	7.0
Surface Cr. #3 Sta. #1				540.0	545.0	556.0	440.0	480.0	528.0	495.0	544.0	570.0
Bottom				536.0	542.0	542.0	452.0	472.0	542.0	490.0	560.0	544.0
Surface Cr. #3 Sta. #2				560.0	560.0	486.0	448.0	482.0	525.0	500.0	530.0	565.0
Bottom				540.0	568.0	492.0	446.0	480.0	534.0	510.0	564.0	562.0

which had a boiling-point acidity of 4,253 ppm.

The application of lime to the acid waters in Ch. #1 resulted in an increase in the total or methyl-orange alkalinity, and increase in pH values, and a decrease in the boiling-point acidity as can be seen in Figure 9. The values for boiling-point acidity are not available for Cr. #2 for the period before the application of lime. The application of lime to this body did, however, result in an increase in the methyl-orange alkalinity, and pH values determined (Figure 10).

The choice of Cr. #2 as the first lake to be limed was, as it turned out, a poor choice. During the initial physical renovation and diversion period the water level of this lake was raised in an attempt to make passable a slough which connected to a second lake. Before the raising of the water level only a small amount of drainage occurred from this secondary lake to the study lake, Cr. #2. By raising the water level the degree of drainage from the secondary lake to Cr. #2 was greatly increased, especially during periods of heavy rain. Although the water level was raised considerably, the slough between the two lakes remained impassable throughout the study, and it was not possible to lime this secondary body. For this reason, the secondary lake serves as a source of acid waters which have low pH values 3.5 and high boiling-point acidity values, 150 ppm. It is felt that drainage from this secondary lake is the most probable cause for the drop in pH values and alkalinity and the increase in boiling-point acidity during the months of May and June (Figure 11). The sample date for May was preceded by four days during which a total of 1.14 inches of rain fell. This immediate rainfall plus a total rainfall of 9.01 inches for the months of April and May resulted in increased drainage from the secondary lake. The increased drainage from the secondary lake did not result in a return to conditions which existed in the lake before the application of lime to this lake (Figure 13). If the rainfall pattern follows that which is most common for Southeast Kansas, the rainfall for July and August should be low enough to decrease the drainage from the secondary lake, and give the remaining alkalinity a period during which the excess boiling-point acidity may be neutralized. It must also be pointed out, however, that this does not account for the possibility of acidic subterranean drainage into the lake, but it is felt that if this drainage did occur in quantities sufficient enough to result in significant damage to the lake, this would have been indicated by the samples taken before the heavy rains.

The sample date for June shows a continued drop in pH, alkalinity, and shows an increase in values for boiling-point acidity. Samples taken near the influx of this acid to the main body of the lake shows a lower pH (5.2), and higher boiling-point acidity (20 ppm.) than either of the two stations normally sampled.

The massive bed of Sphagnum cuspidatum associated with Cr. #2 cannot be disregarded as a source of acid for this lake, as it has been shown that Sphagnum accumulates sulfur from the atmosphere and releases it as sulfuric acid (Reid, 1961). This was, however, felt to be a minor problem and since the application of lime to this body the Sphagnum has undergone definite decomposition.

During this same period of heavy rainfall in May, the application of lime to Ch. #1 was being accomplished (Figure 9). The last lime application to this lake occurred on May 27, 1967. The following four days resulted in a total rainfall of 1.14 inches and yet as can be seen from Figure 9 the boiling-point acidity values continued to drop and the alkalinity values increased. The pH values fluctuated during this period but this might have been a normal fluctuation resulting from increased carbonic acid content due to the rains, as during this same period the alkaline lakes of the study showed lower pH values.

The value of the data obtained from the lime application to Cr. #2, as far as developing a theory as to the amount of lime required to reclaim acid strip-mine lakes, was very limited because the values for boiling-point acidity were not determined. The amount of lime initially applied to this lake was determined from a chart prepared by Dr. L. C. Heckert in 1956, which was based on the amount of lime ($CaCO_3$) required to neutralize a given volume of water of a certain pH. This value was calculated to be three tons for Cr. #2. The amount in excess of the calculated value (3.2 tons) was included in the initial application to aid in the development of a carbonate buffering system. The pH value initially rose to a high of 6.0, but then fell to near its pre-liming value (Figure 10).

The complexity of the system (reserve acidity) was still not understood but because this lake possessed a large shallow area for spawning, a characteristic lacking in most strip-mine lakes, an additional 15.8 tons of lime was applied. This resulted in the attainment of the desired goals.

It is now felt, after the realization of the complexity of the problem involved, that a systematic approach to the reclamation of acid strip-mine lakes may be set forth. The following factors should be determined before attempting to reclaim acid strip-mine lakes:

(1) Characteristics of spoil banks--The complete oxidation of pyritic sulfur exposed during mining

operations is desirable. This may be indicated by moderate pH values for the spoil banks and dense vegetational growth. These characteristics can generally be correlated with the age of the strip-mine lakes. No definite standards have been set as to the limit of lower pH values of the soil banks which might limit the success of reclamation.

(2) Visible signs of surface drainage serving as sources of acid--These sources must be eliminated before liming will be successful. The lack of visible sources of drainage and retention of acid characteristics by a lake probably indicate subterranean drainage. If subterranean drainage exists, liming application will probably not correct this problem.

(3) Physical-chemical conditions--The boiling-point acidity of the lake waters and volume of water present must be established as the degree of treatment necessary for reclamation will be based on these values.

Based on the results obtained from the application of lime to Ch. #1 (Figure 9), it is felt that an application rate of 68.4 pounds of lime for each ppm. boiling-point acidity per acre foot should be utilized as guidelines for lime application. It must be realized that this application rate is based on the success obtained on one strip-mine lake and these values will be subject to change as more data concerning lime application is accumulated.

Several problems can be forseen in future work. The liming of lakes which have extremely high boiling-point acidity values may result in the formation of $CaSO_4$ sludge and render the bottoms of the lakes unfit for benthic organisms.

The chemical fitness of the water for fish production upon completion of renovation has not been determined. Leitch (1931) concluded that chemical neutralization may cause increased hardness in direct proportion to the original acidity. Froemming (1940) showed that the growth of fish in aquaria may be limited by the hardness of the water. The possibility of additive of synergistic reactions as a result of chemical treatment may exist but cannot be predicted. Of vital interest as to the success of the reclamation process future studies, some of which have already been planned, should include a pre- and post-liming determination of the major chemical constituents of strip-mine lake waters. Simpson (1959) has laid the groundwork for a study of this nature. A study involving the length of time required for the establishment of planktonic and benthic populations of numbers and structure comparable to productive strip-mine lakes of the area, and a controlled study involving the survival growth rates, and population structure of fishes introduced into reclaimed strip-mine

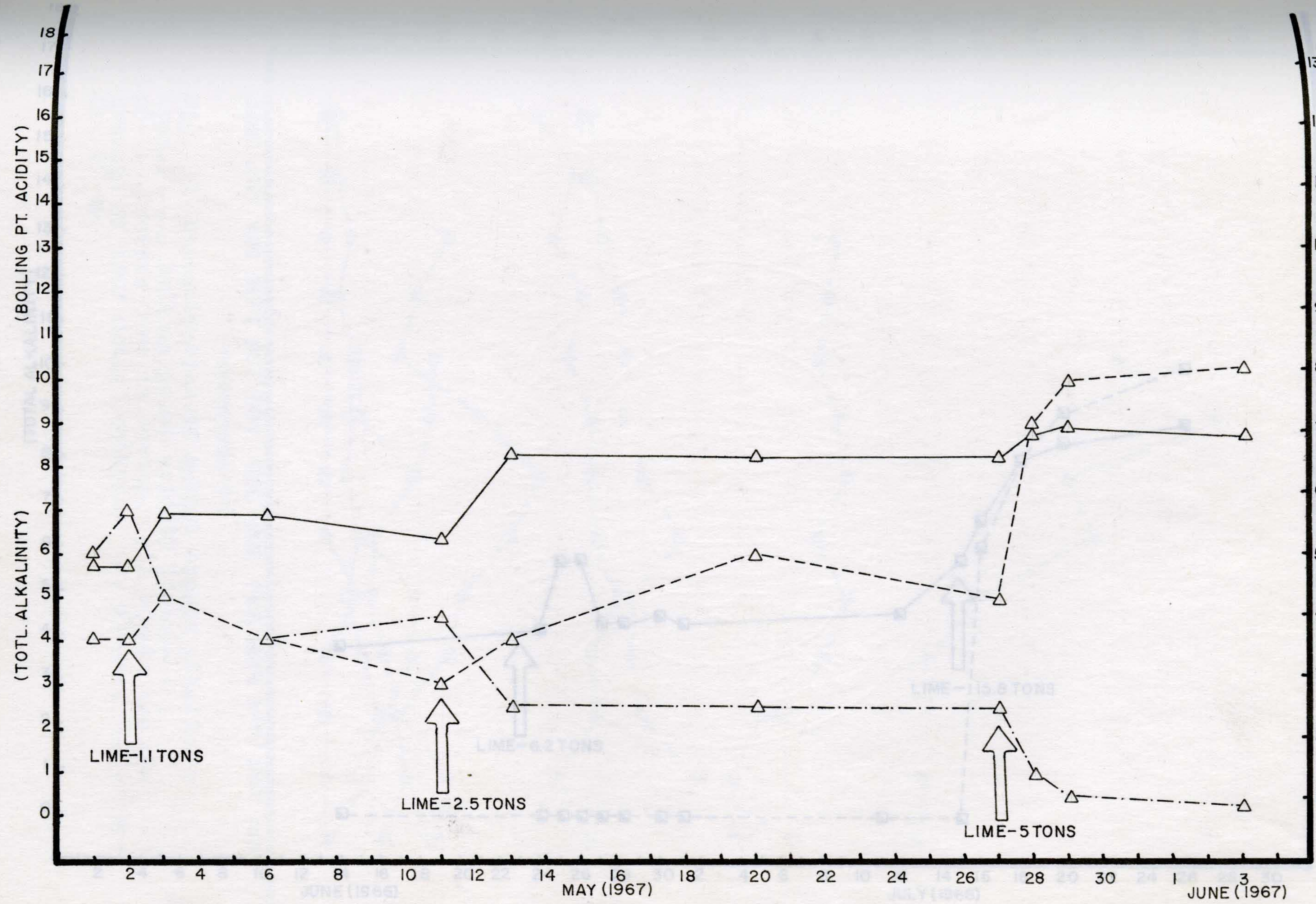


Fig. 9 Concentration of methyl orange alkalinity (ppm.)— —, boiling point acidity —·— (ppm.)—·—, pH——, versus time in days. All points are the average of four determinations. Ch. #1 △ .

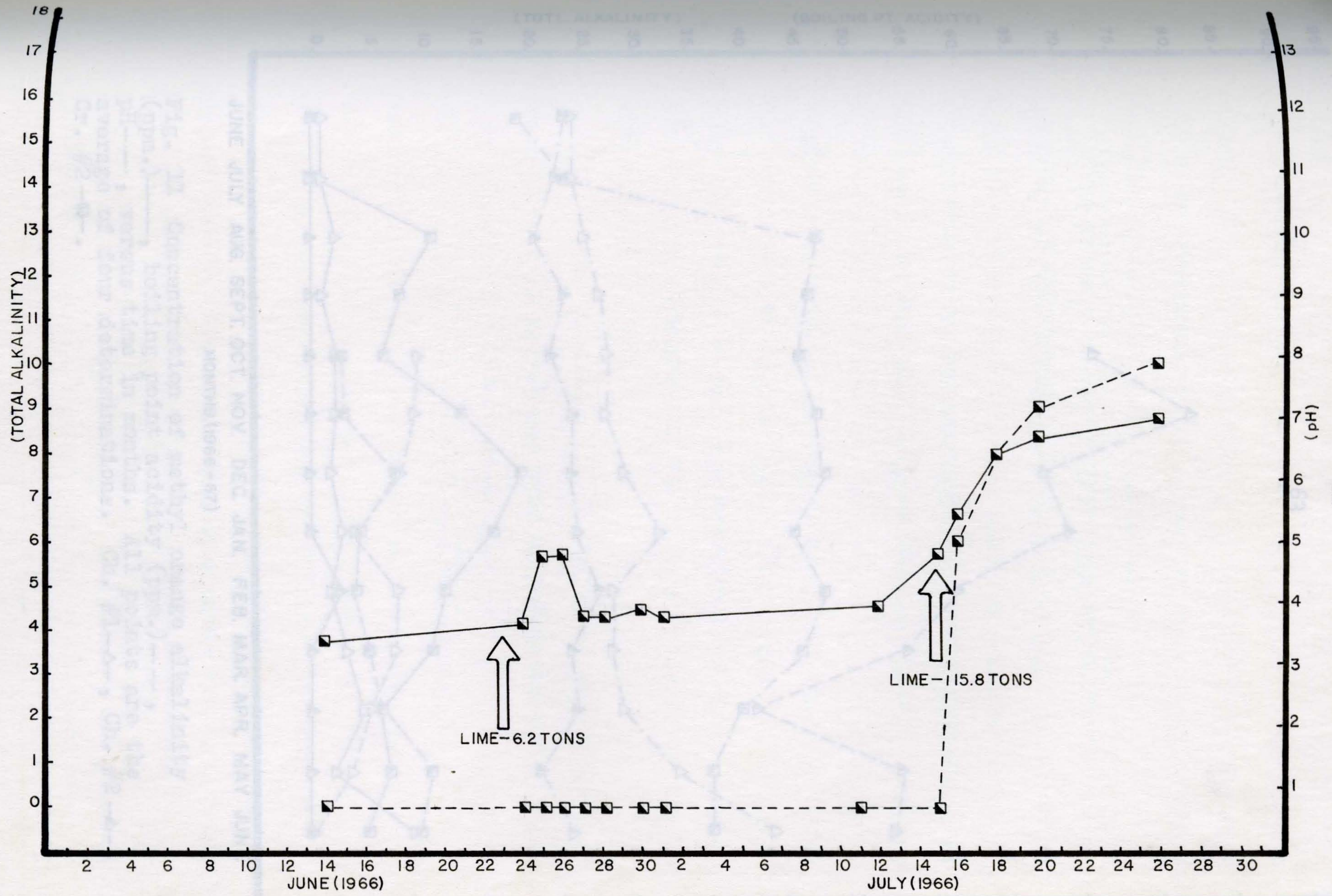


Fig. 10 Concentration of methyl orange alkalinity (ppm.)— — , pH ——, versus time in days. All points are the average of four determinations. Cr. #2 ◪ .

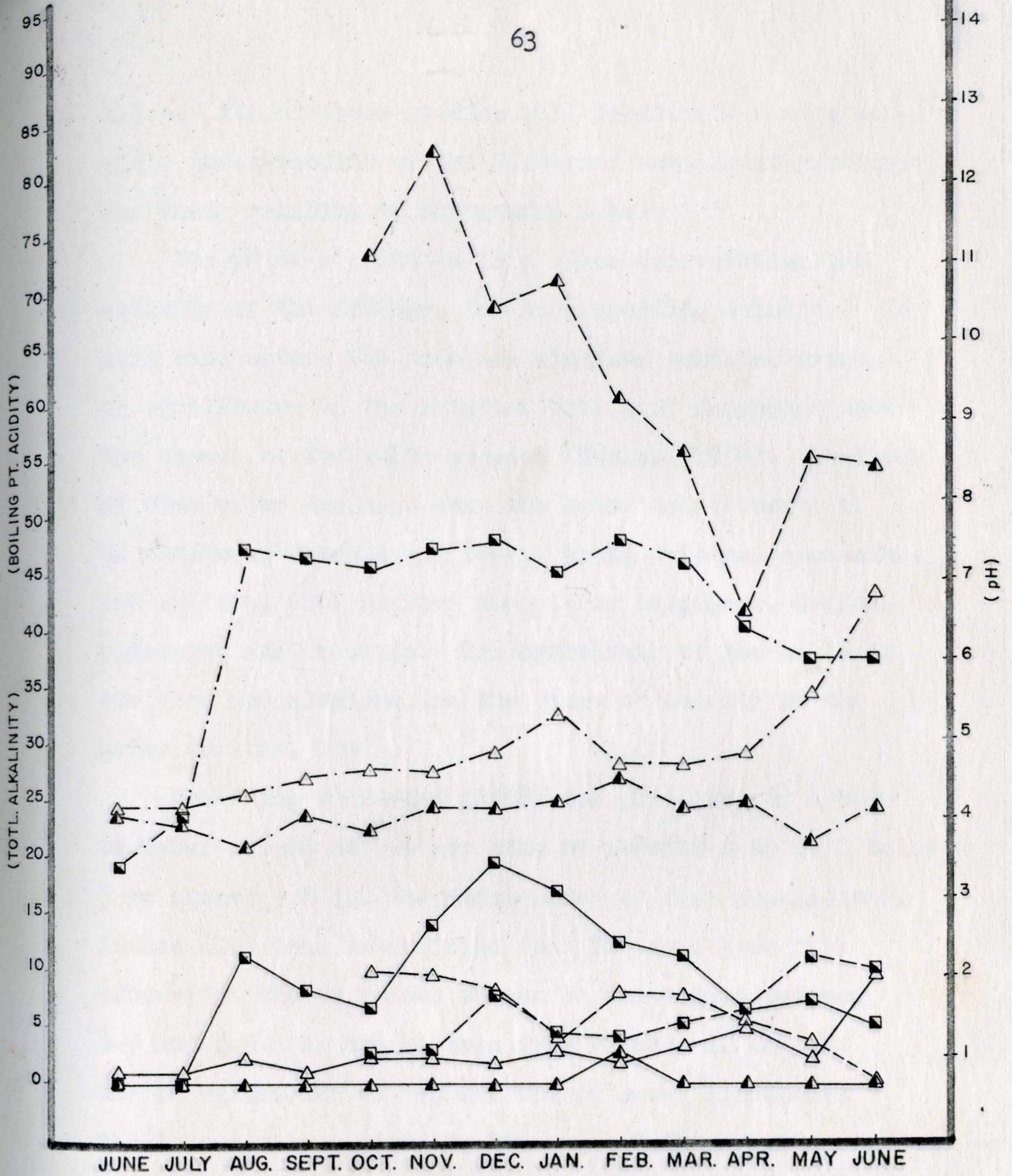


Fig. 11 Concentration of methyl orange alkalinity (ppm.)——, boiling point acidity (ppm.)– – –, pH—·—·, versus time in months. All points are the average of four determinations. Ch. #1—△—, Ch. #2—▲—, Cr. #2—■—.

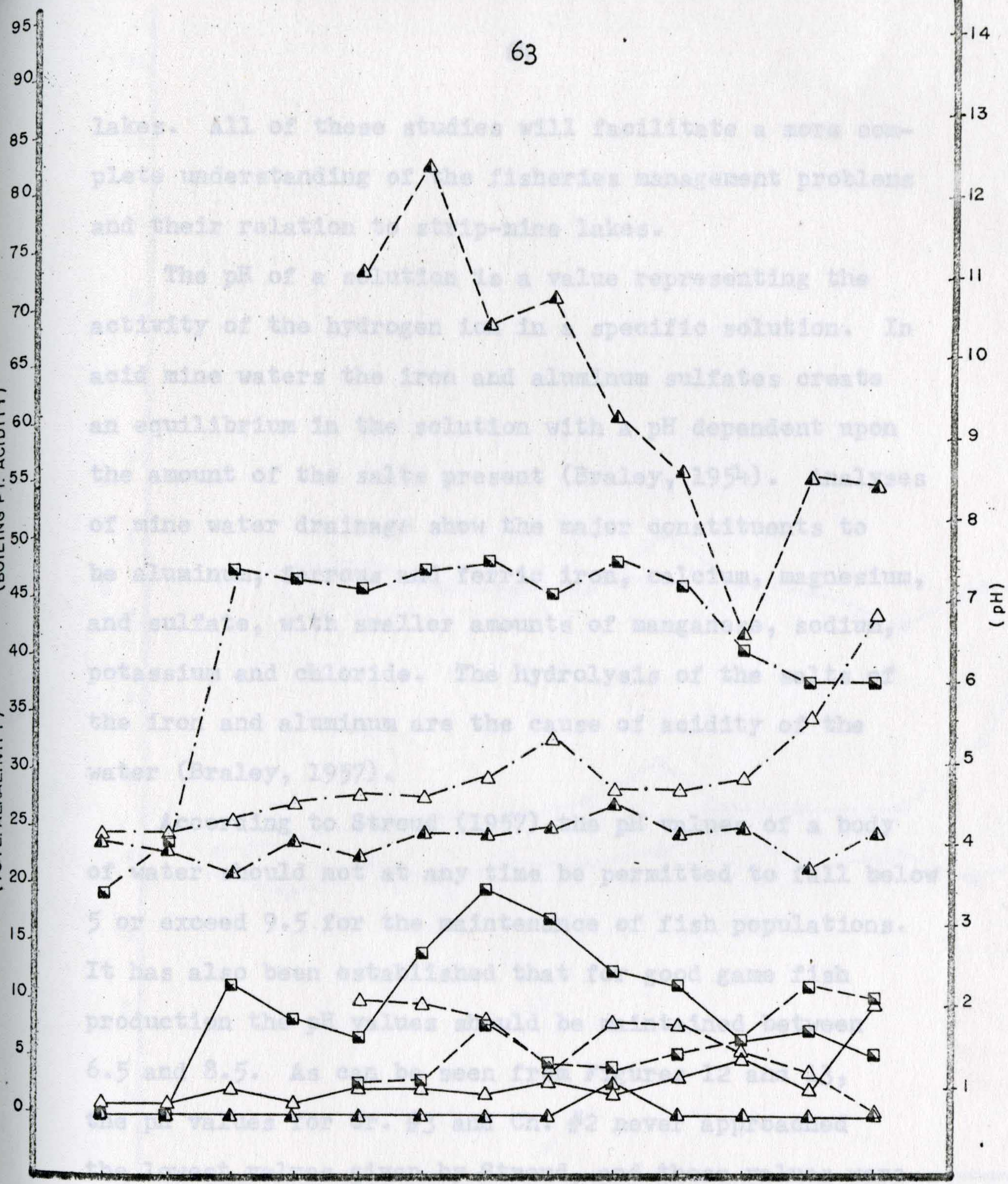


Fig. 11 Concentration of methyl orange alkalinity (ppm.)———, boiling point acidity (ppm.)— — —, pH—·—·, versus time in months. All points are the average of four determinations. Ch. #1—△—, Ch. #2—▲—, Cr. #2—■—.

lakes. All of these studies will facilitate a more complete understanding of the fisheries management problems and their relation to strip-mine lakes.

The pH of a solution is a value representing the activity of the hydrogen ion in a specific solution. In acid mine waters the iron and aluminum sulfates create an equilibrium in the solution with a pH dependent upon the amount of the salts present (Braley, 1954). Analyses of mine water drainage show the major constituents to be aluminum, ferrous and ferric iron, calcium, magnesium, and sulfate, with smaller amounts of manganese, sodium, potassium and chloride. The hydrolysis of the salts of the iron and aluminum are the cause of acidity of the water (Braley, 1957).

According to Stroud (1957) the pH values of a body of water should not at any time be permitted to fall below 5 or exceed 9.5 for the maintenance of fish populations. It has also been established that for good game fish production the pH values should be maintained between 6.5 and 8.5. As can be seen from Figures 12 and 13, the pH values for Cr. #3 and Ch. #2 never approached the lowest values given by Stroud, and these values were achieved in Cr. #2 and Ch. #1, only after the application of lime to these lakes. The pH values of the two alkaline lakes Ch. #3 (Figure 12), and Cr. #1 (Figure 13), were within the range of values established for

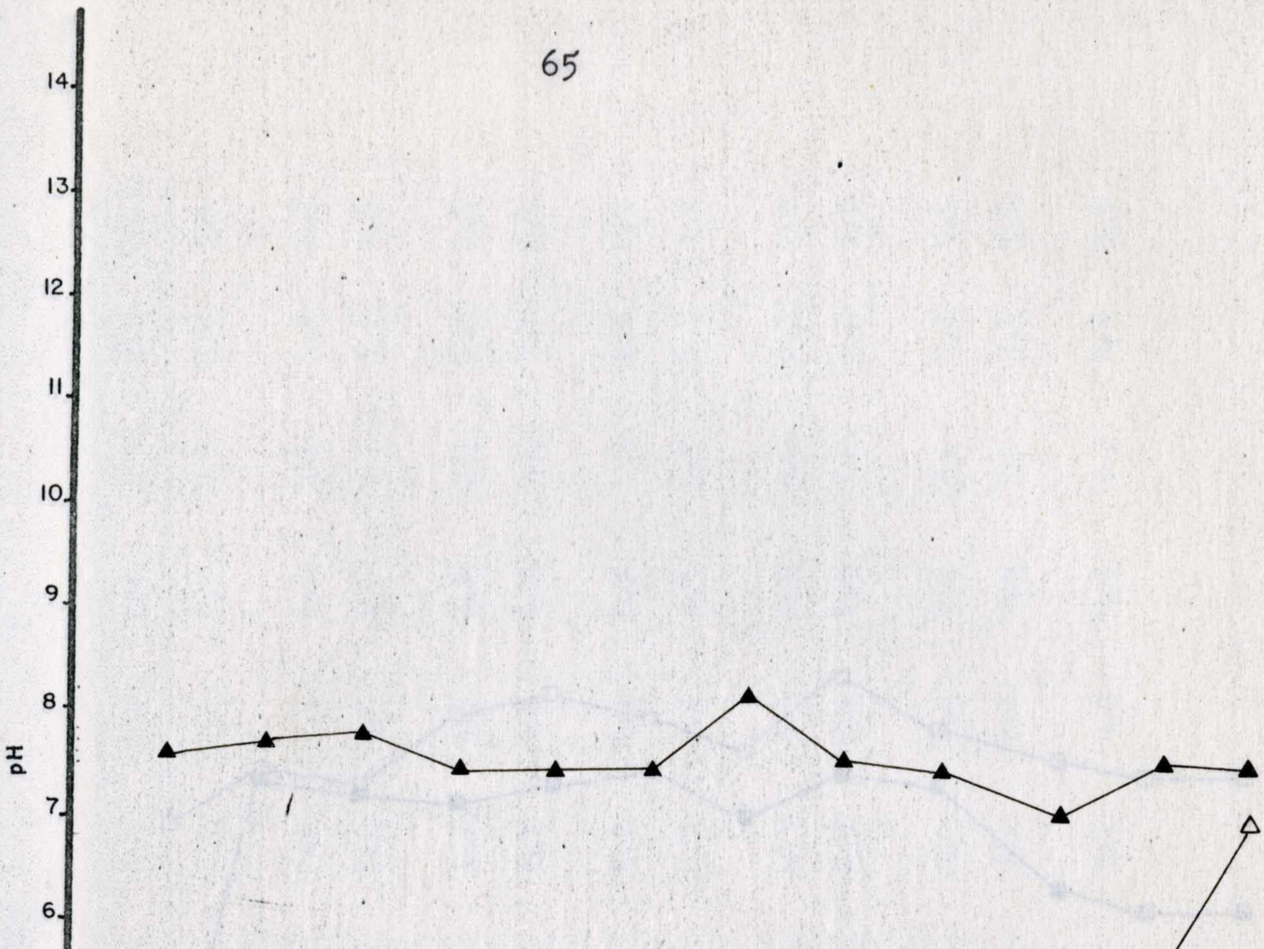


Fig. 12 Concentration of hydrogen ion versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Ch. #1 —△—, Ch. #2 —▲—, Ch. #3 —▲— .

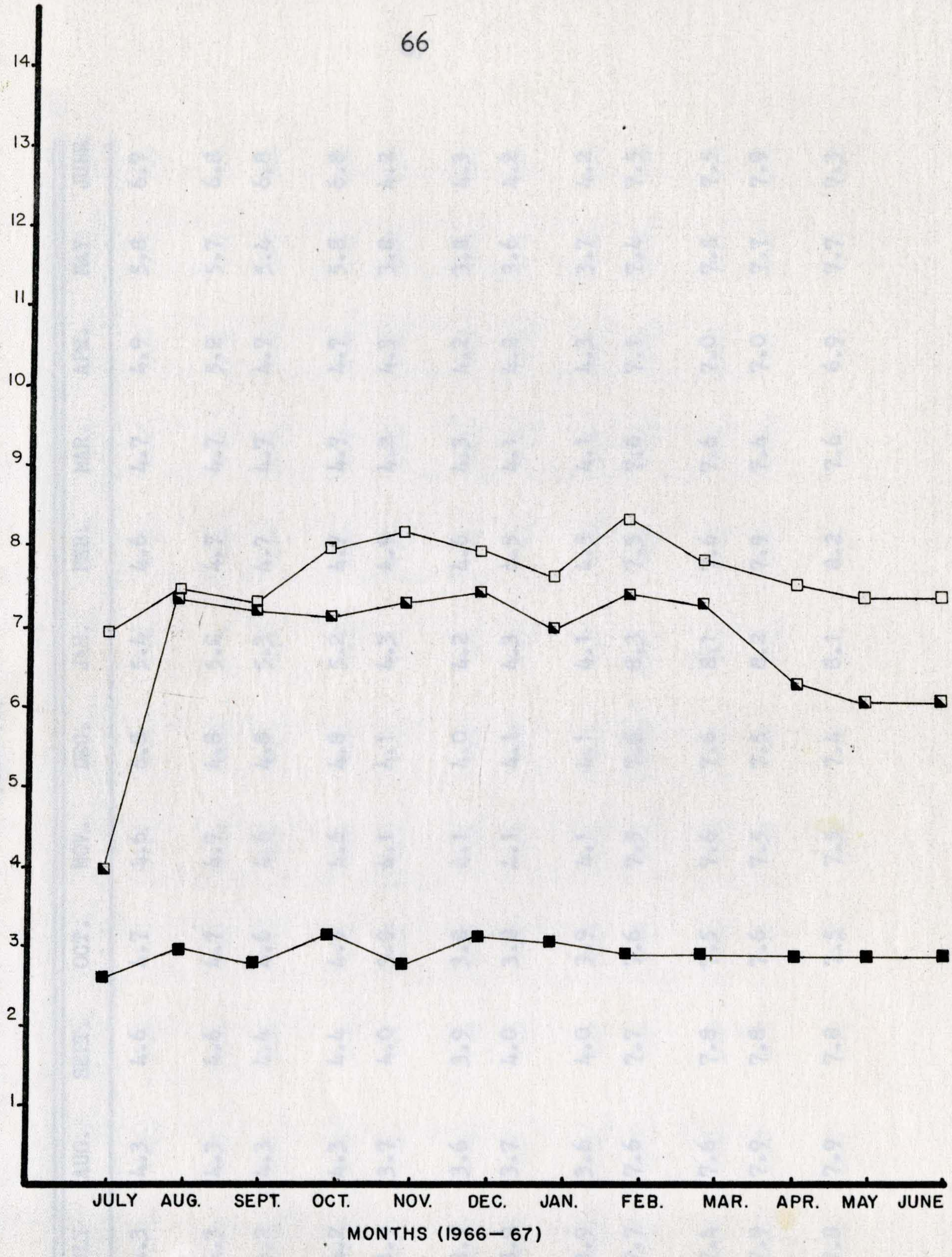


Fig. 13 Concentration of hydrogen ion versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Cr. #1 —□—, Cr. #2 —◪—, Cr. #3 —■—.

TABLE V

MONTHLY DATA OF HYDROGEN ION CONCENTRATION
(pH)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Ch. #1 Sta. #1	4.3	4.3	4.6	4.7	4.6	4.8	5.4	4.6	4.7	4.9	5.8	6.7
Bottom	4.3	4.3	4.6	4.7	4.7	4.8	5.2	4.7	4.7	5.2	5.7	6.8
Surface Ch. #1 Sta. #2	4.2	4.3	4.4	4.6	4.6	4.8	5.3	4.7	4.7	4.7	5.4	6.8
Bottom	4.2	4.3	4.4	4.5	4.6	4.8	5.2	4.7	4.7	4.7	5.8	6.8
Surface Ch. #2 Sta. #1	3.9	3.7	4.0	3.9	4.1	4.1	4.3	4.9	4.2	4.3	3.8	4.2
Bottom	3.9	3.6	3.9	3.8	4.1	4.0	4.2	4.6	4.3	4.2	3.8	4.3
Surface Ch. #2 Sta. #2	3.9	3.7	4.0	3.8	4.1	4.1	4.3	4.5	4.1	4.2	3.6	4.2
Bottom	3.9	3.6	4.0	3.9	4.1	4.1	4.1	4.5	4.1	4.3	3.7	4.2
Surface Ch. #3 Sta. #1	7.7	7.6	7.7	7.6	7.5	7.6	8.3	7.3	7.6	7.1	7.4	7.5
Bottom	7.4	7.6	7.8	7.5	7.6	7.6	8.1	7.6	7.6	7.0	7.5	7.5
Surface Ch. #3 Sta. #2	7.9	7.9	7.8	7.6	7.5	7.5	8.2	7.9	7.4	7.0	7.7	7.9
Bottom	7.8	7.9	7.8	7.5	7.5	7.4	8.1	8.2	7.6	6.9	7.7	7.3

TABLE VI

MONTHLY DATA OF HYDROGEN ION CONCENTRATION
(pH)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Cr. #1 Sta. #1	7.2	7.5	7.3	8.0	8.2	8.1	7.8	8.3	8.0	7.0	7.7	7.5
Bottom	6.9	7.5	7.4	8.0	8.2	8.0	7.6	8.4	7.9	7.6	7.7	7.4
Surface Cr. #1 Sta. #2	7.3	7.5	7.4	8.0	8.2	8.1	7.8	8.4	7.9	7.6	7.3	7.4
Bottom	6.9	7.5	7.4	7.9	8.2	8.0	7.7	8.4	7.9	7.6	7.3	7.2
Surface Cr. #2 Sta. #1	4.0	7.3	7.1	7.3	7.4	7.9	7.1	7.4	7.1	6.3	6.8	5.8
Bottom	4.0	7.4	7.4	7.3	7.5	7.6	7.1	7.5	7.1	6.5	6.4	6.3
Surface Cr. #2 Sta. #2	4.0	7.5	7.5	7.0	7.4	7.5	7.1	7.4	7.2	6.5	6.2	6.1
Bottom	4.0	7.5	7.5	7.3	7.5	7.3	7.1	7.6	7.4	6.5	5.6	5.8
Surface Cr. #3 Sta. #1	2.7	3.0	2.9	3.2	2.9	3.1	3.1	3.0	2.9	3.1	3.0	2.8
Bottom	2.6	3.0	3.0	3.2	2.9	3.2	3.1	3.0	3.0	3.0	3.1	2.9
Surface Cr. #3 Sta. #2	2.6	3.0	2.9	3.2	3.0	3.2	3.1	3.0	3.0	3.1	2.9	3.0
Bottom	2.6	3.0	3.0	3.2	3.0	3.2	3.1	3.0	3.0	3.0	2.9	2.9

good fish production.

The presence of a fish population, see Table XXVI, in Ch. #1 before the application of lime to this lake can be accounted for by the fact that the permissible range of pH for fish is dependent upon many factors such as temperature, dissolved oxygen, and prior acclimatization. According to a table compiled by McKee and Wolf (1963), the most resistent fish can tolerate such extreme pH values of 4.0 and 10.0 indefinitely after acclimatization. This table also shows that fish eggs could be hatched, but abnormal young were produced at extreme pH values of 3.8 and 10.0.

The water temperatures of the six strip-mine lakes never exceeded the TLm (tolerance limit median, the concentration required to kill 50% of the test organisms) for adult _Micropterus_ _salmoides_ (TLm 36.4°C) or _Lepomis_ _macrochirus_ (TLm 35°C). The temperature of all the lakes did exceed the optimum or preferred temperature for _M._ _salmoides_ (TLm 22-25°C) (McKee and Wolf, 1953). See Tables VII and VIII.

The alkalinity of waters generally refers to the quantity and kinds of compounds present which collectively shift the pH to the alkaline side of neutrality (Ellis, Westfall and Ellis, 1948).

When alkalinity is the result of bicarbonate

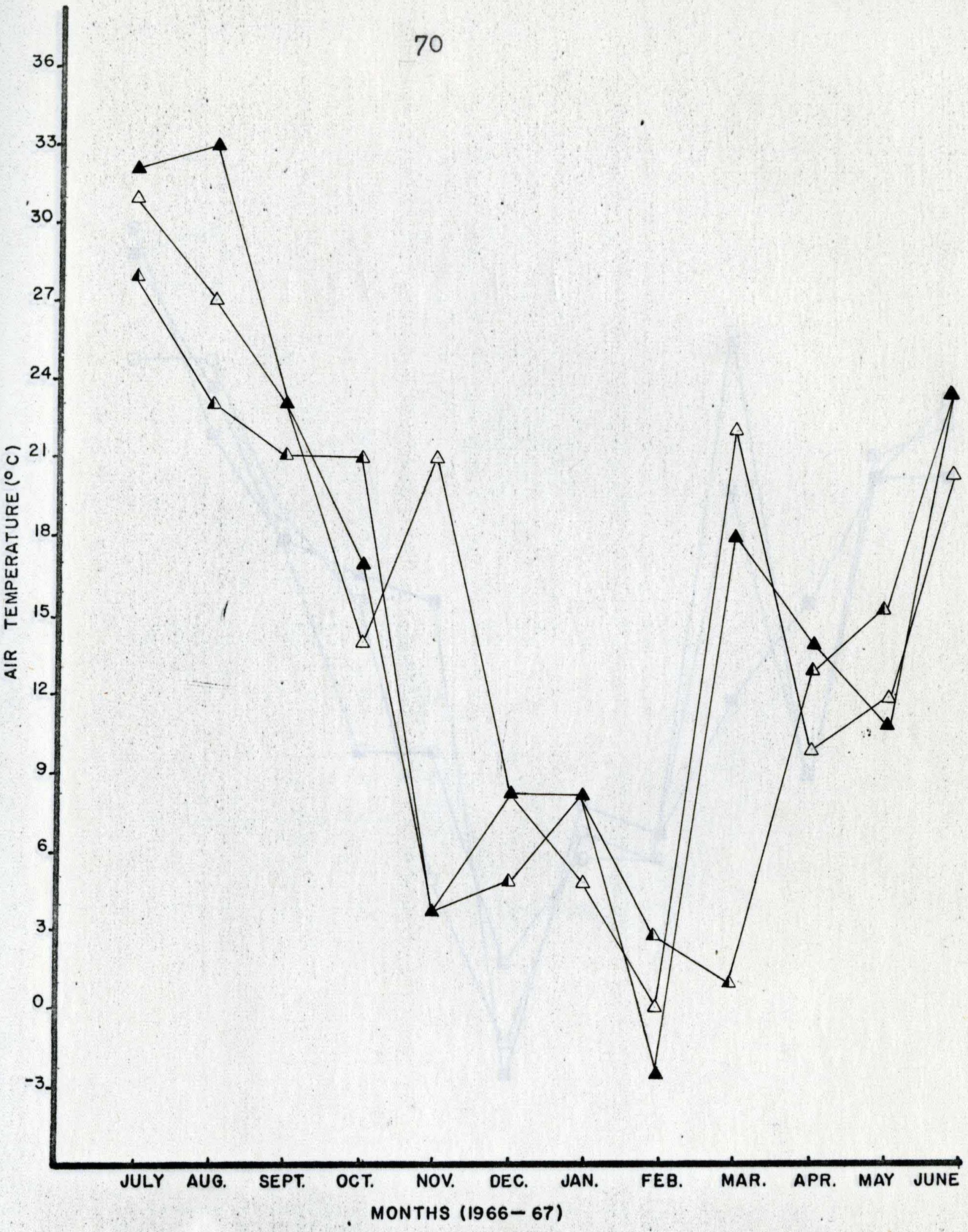


Fig. 14 Air temperature versus time in months taken once each month from July 1966 to June 1967. All points are the average of two determinations. Ch. #1 —△— , Ch. #2 —◭—, Ch. #3 —▲— .

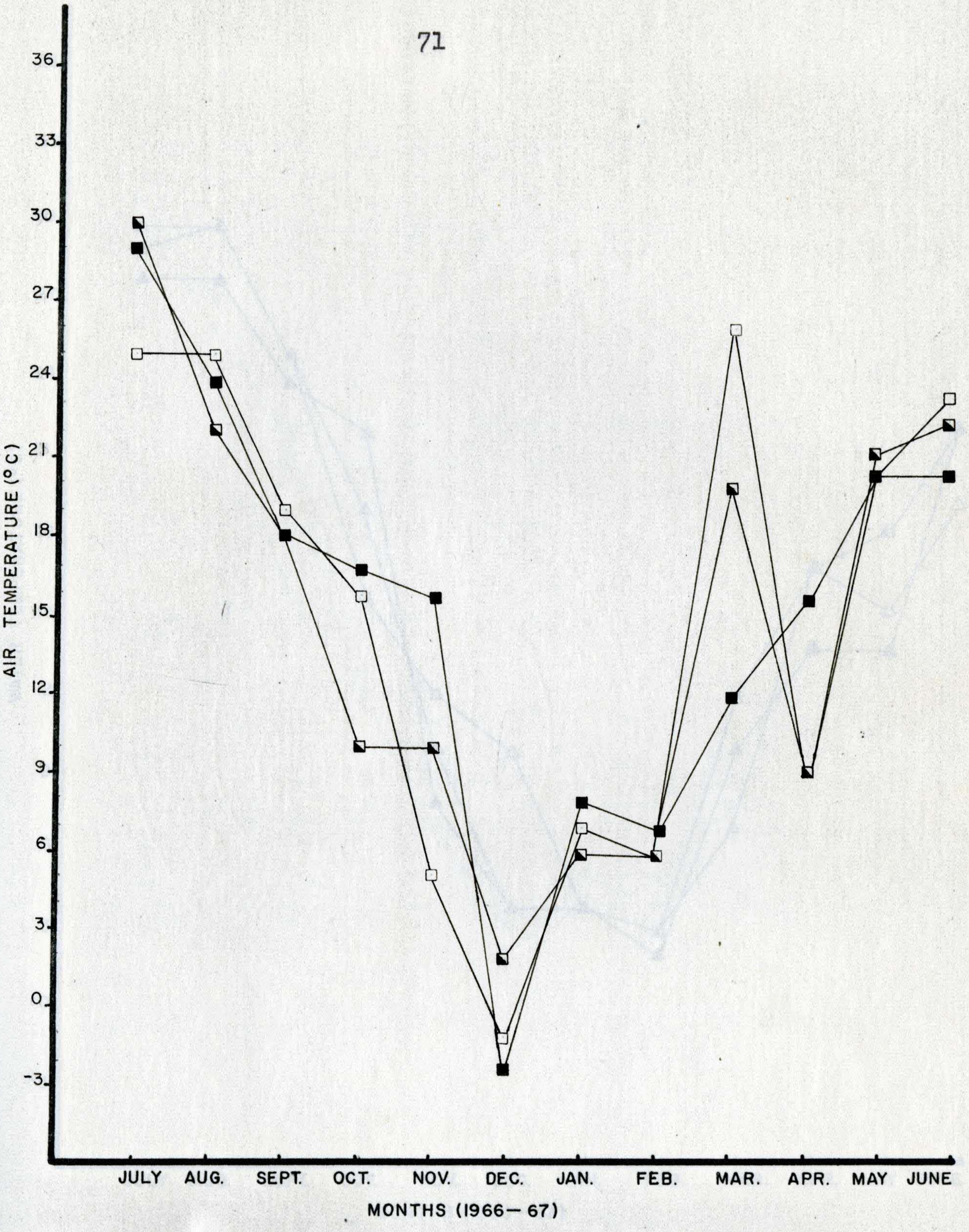


Fig. 15 Air temperature versus time in months taken once each month from July 1966 to June 1967. All points are the average of two determinations. Cr. #1 —□—, Cr. #2 —◩—, Cr. #3 —■—.

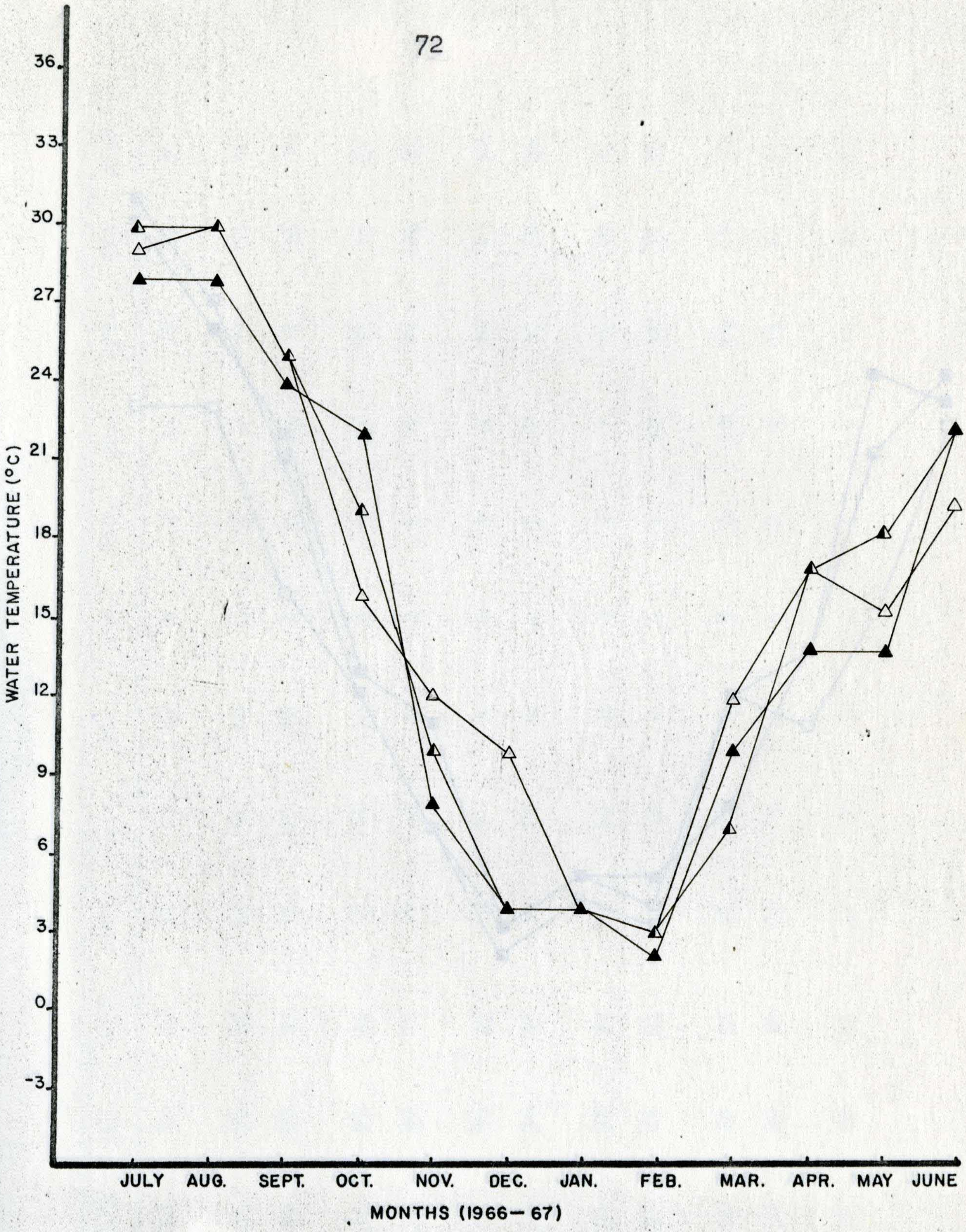


Fig. 16 Water temperature versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Ch. #1 —△—, Ch. #2 —◭—, Ch. #3 —▲—.

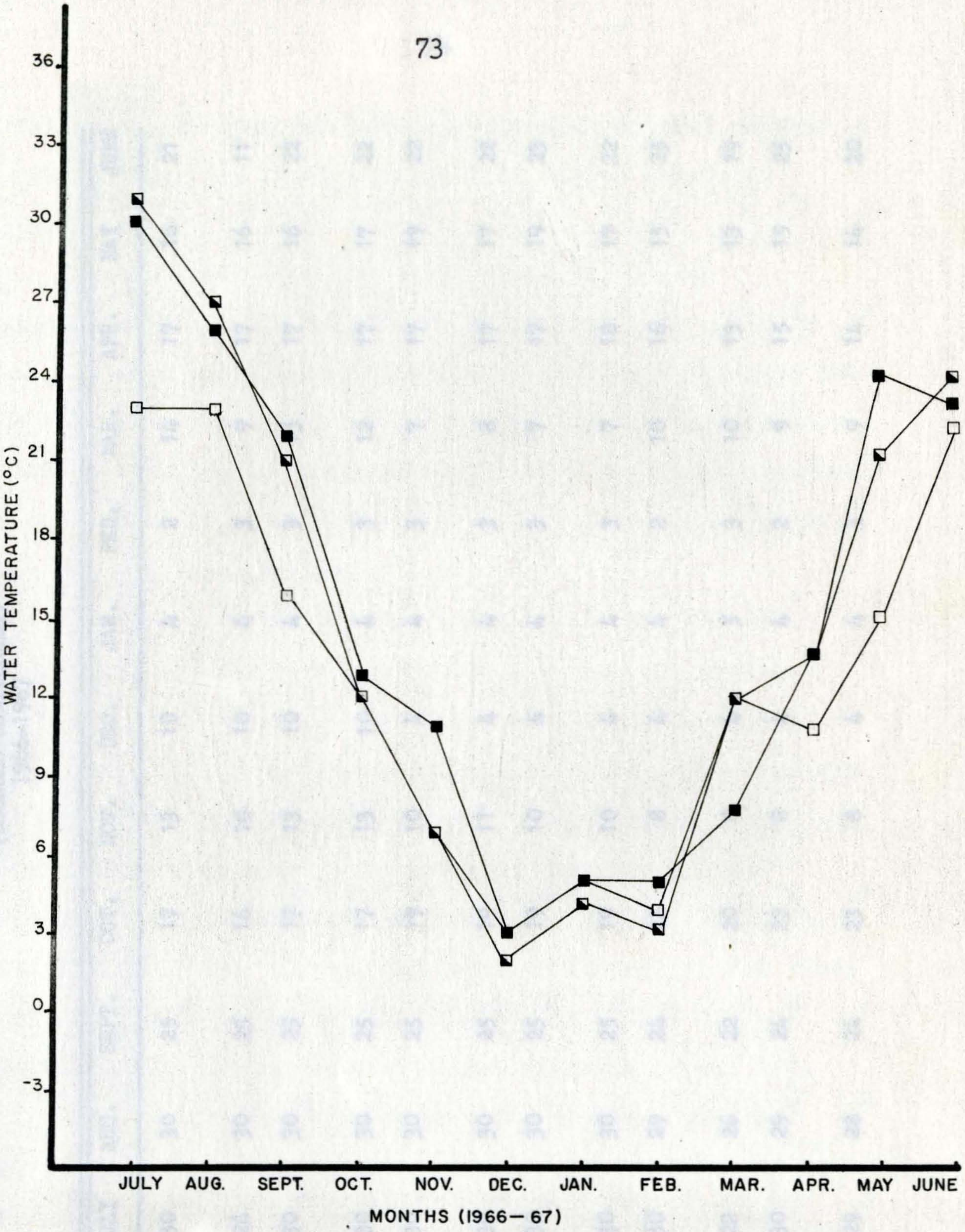


Fig. 17 Water temperature versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Cr. #1—□—, Cr. #2—◪—, Cr. #3 —■— .

TABLE VII

MONTHLY DATA OF WATER TEMPERATURE
(DEGREES CENTIGRADE)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Ch. #1 Sta. #1	30	30	25	17	13	10	4	2	14	17	16	21
Bottom	26	30	25	16	10	10	4	3	9	17	16	11
Surface Ch. #1 Sta. #2	30	30	25	17	13	10	4	3	13	17	16	22
Bottom	30	30	25	17	13	10	4	3	12	17	17	22
Surface Ch. #2 Sta. #1	30	30	25	19	10	4	4	3	7	17	19	22
Bottom	30	30	25	19	11	4	4	3	8	17	17	22
Surface Ch. #2 Sta. #2	30	30	25	19	10	4	4	3	7	17	19	23
Bottom	30	30	25	19	10	4	4	3	7	18	17	22
Surface Ch. #3 Sta. #1	30	29	24	22	8	4	4	2	10	16	15	25
Bottom	22	26	22	20	8	4	5	3	10	13	13	19
Surface Ch. #3 Sta. #2	30	29	24	23	8	4	4	2	9	15	15	25
Bottom	29	28	24	23	8	4	4	3	9	14	14	20

TABLE VIII

MONTHLY DATA OF WATER TEMPERATURE
(DEGREES CENTIGRADE)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Cr. #1 Sta. #1	27	25	15	12	8	2	4	4	16	12	20	23
Bottom	21	22	15	11	8	3	6	3	9	11	11	20
Surface Cr. #1 Sta. #2	26	26	17	12	8	2	4	4	16	12	19	23
Bottom	17	20	17	11	8	4	5	3	8	10	11	23
Surface Cr. #2 Sta. #1	31	27	21	12	9	2	4	3	14	14	24	26
Bottom	31	27	21	12	8	3	4	3	8	12	12	18
Surface Cr. #2 Sta. #2	32	27	21	13	8	2	4	3	15	14	24	26
Bottom	31	27	21	12	8	3	4	3	9	14	24	26
Surface Cr. #3 Sta. #1	30	26	22	13	11	3	5	4	8	14	24	23
Bottom	30	26	22	13	11	4	5	4	8	14	25	23
Surface Cr. #3 Sta. #2	30	26	22	13	11	3	4	4	8	14	24	23
Bottom	31	26	22	13	11	3	4	4	8	14	24	23

alkalinity, it does not have any apparent harmful effects upon plankton and other aquatic life (McKee and Wolf, 1963).

As alkalinity does not exist below pH 4.4, no alkalinity was recorded for Cr. #3 (Figure 19). On only one occasion was alkalinity recorded for Ch. #2 (Figure 18). No alkalinity was recorded for Cr. #2 before the application of lime, but after lime application alkalinity reached a maximum of 20 ppm. in December and January and a low of 4.0 ppm. in June (Figure 19).

The values of methyl-orange alkalinity for Ch. #1 ranged between 1.0 ppm. and 3.0 ppm. before the application of lime. After the application of lime the values rose to a high of 11.0 ppm. (Figure 9). The carbonates and bicarbonates in natural unpolluted waters having a good fish fauna range from 0- to 350 ppm. with the usual expected values between 45 and 200 ppm. (Ellis, Westfall, and Ellis, 1948). The values obtained throughout the study for alkalinity in Cr. #1 and Ch. #3 were within the expected values for unpolluted waters (Figures 18 and 19).

The acidity of water is a measure of the presence of uncombined carbon dioxide, mineral acids, and salts of strong acids and weak bases. A fading and impermanent endpoint is characteristic of the phenolphthalein acidity titration carried out at room temperature. Samples

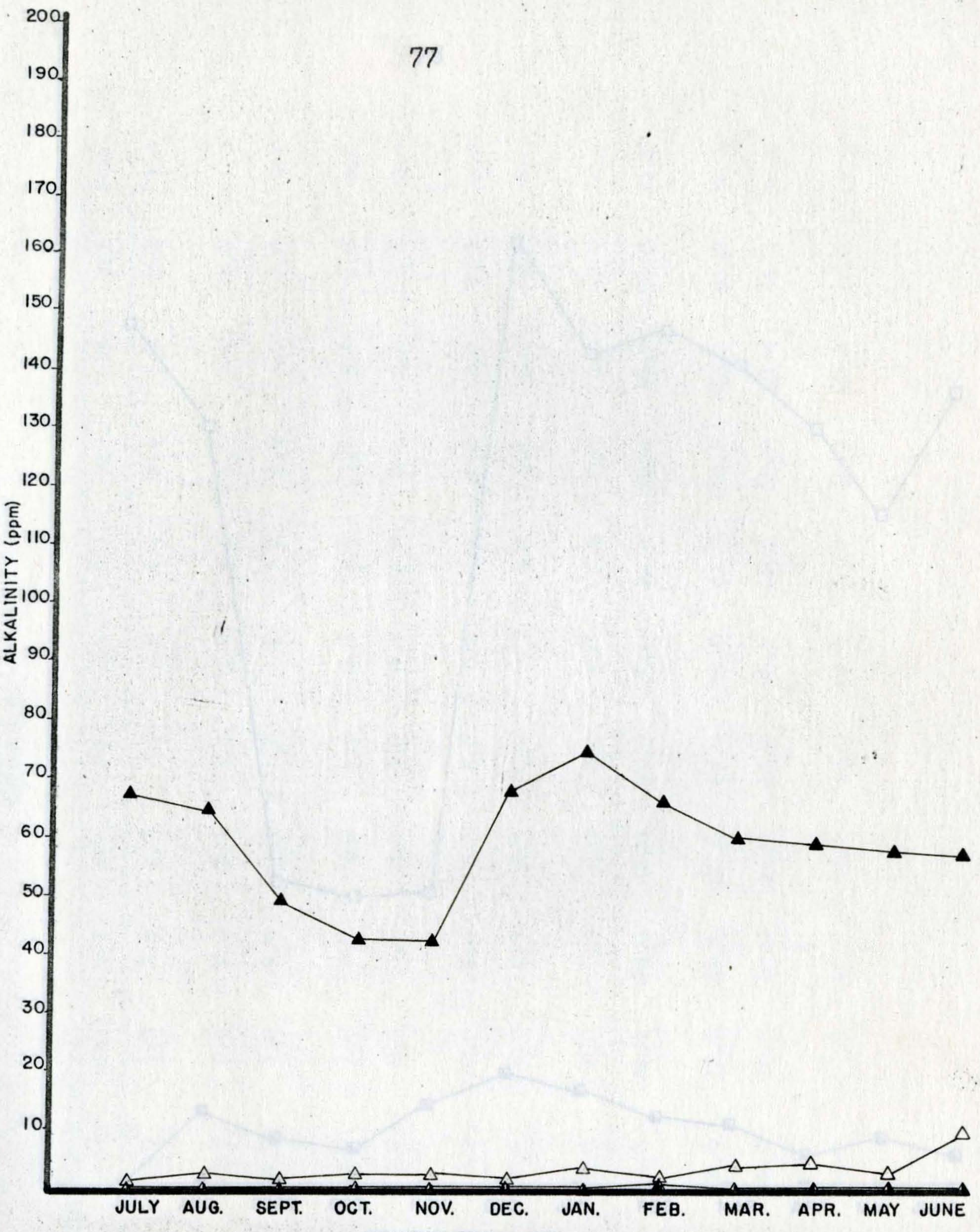


Fig. 18 Concentration of methyl orange alkalinity versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Ch. #1—△—, Ch. #2—◭—, Ch. #3—▲—.

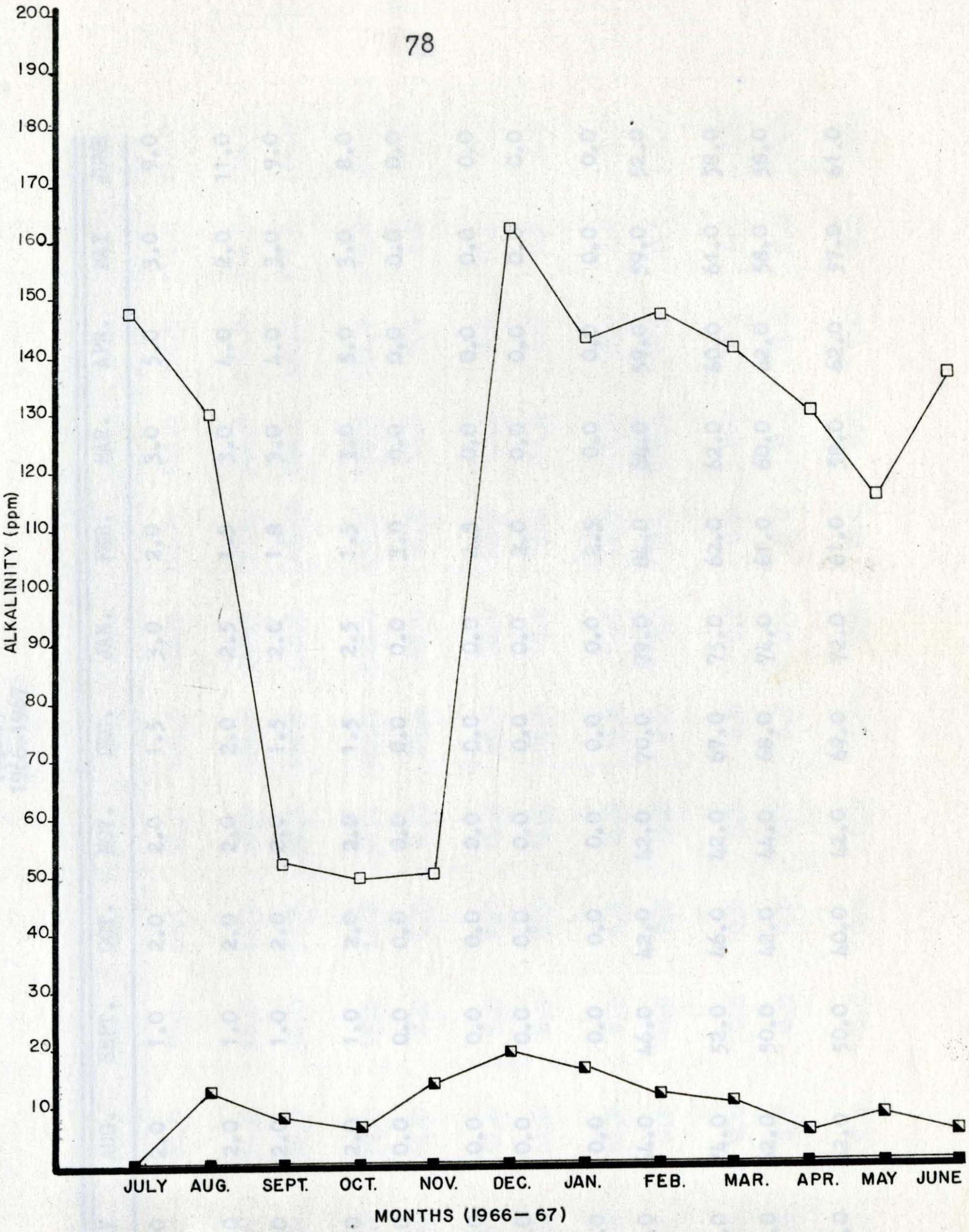


Fig. 19 Concentration of methyl orange alkalinity versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Cr. #1 —□— , Cr. #2 —◪— , Cr. #3 —■— .

TABLE IX

MONTHLY DATA OF TOTAL ALKALINITY
(ppm.)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Ch. #1 Sta. #1	1.0	2.0	1.0	2.0	2.0	1.5	3.0	2.0	3.0	5.0	3.0	9.0
Bottom	1.0	2.0	1.0	2.0	2.0	2.0	2.5	1.5	3.0	4.0	2.0	11.0
Surface Ch. #1 Sta. #2	1.0	2.0	1.0	2.0	2.0	1.5	2.0	1.8	3.0	4.0	3.0	9.0
Bottom	1.0	2.0	1.0	2.0	2.0	1.5	2.5	1.5	3.0	5.0	3.0	8.0
Surface Ch. #2 Sta. #1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0
Bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0
Surface Ch. #2 Sta. #2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
Bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0
Surface Ch. #3 Sta. #1	61.0	64.0	46.0	42.0	42.0	70.0	79.0	84.0	64.0	59.0	59.0	52.0
Bottom	90.0	74.0	52.0	46.0	42.0	67.0	75.0	62.0	62.0	60.0	61.0	58.0
Surface Ch. #3 Sta. #2	60.0	62.0	50.0	42.0	44.0	68.0	74.0	61.0	60.0	62.0	58.0	58.0
Bottom	60.0	62.0	50.0	40.0	42.0	69.0	72.0	61.0	58.0	62.0	57.0	61.0

TABLE X

MONTHLY DATA OF TOTAL ALKALINITY
(ppm.)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Cr. #1 Sta. #1	132.0	120.0	50.0	48.0	49.0	164.0	144.0	146.0	145.0	134.0	114.0	137.0
Bottom	144.0	136.0	49.0	48.0	49.0	154.0	140.0	139.0	146.0	131.0	114.0	138.0
Surface Cr. #1 Sta. #2	128.0	132.0	54.0	51.0	52.0	170.0	148.0	132.0	140.0	132.0	117.0	138.0
Bottom	188.0	132.0	55.0	51.0	51.0	164.0	142.0	133.0	138.0	134.0	118.0	133.0
Surface Cr. #2 Sta. #1	0.0	14.0	8.0	6.0	14.0	19.0	18.0	12.0	10.0	5.0	5.0	5.0
Bottom	0.0	12.0	8.0	8.0	14.0	20.0	20.0	12.0	11.0	8.0	10.0	6.0
Surface Cr. #2 Sta. #2	0.0	12.0	8.0	6.5	14.0	19.0	15.0	12.0	11.0	6.0	10.0	4.0
Bottom	0.0	12.0	9.0	6.5	14.0	19.0	14.0	12.0	11.0	7.0	6.0	5.0
Surface Cr. #3 Sta. #1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Cr. #3 Sta. #2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

containing iron and aluminum sulfate are responsible for the fading endpoint (American Public Health Association, 1965). The acidity values obtained for five of the six strip-mine lakes are shown in Figures 20 and 21. The absence of data for Cr. #3 is due to the inability of this worker to determine a satisfactory endpoint during titration. Some doubt exists as to the validity of the values obtained for the acid strip-mine lakes shown, as difficulty was encountered in obtaining a stable, permanent endpoint in samples from all of the acid strip-mine lakes.

Moore's (1939) mathematical method for the determination of the free carbon dioxide content of water is based on values determined for the hydrogen ion concentration and total alkalinity. The values obtained for free carbon dioxide can only be as accurate as those obtained for total alkalinity and the hydrogen ion concentration. This method cannot be employed where alkalinity determinations are zero, but in this case the values for carbon dioxide are not as important as they are in relationship to the carbonate carbon dioxide buffer system of a lake (Table XIII).

The dissolved oxygen requirements for a good warm-water fish population should not be below 5 ppm. (Stroud, 1967).

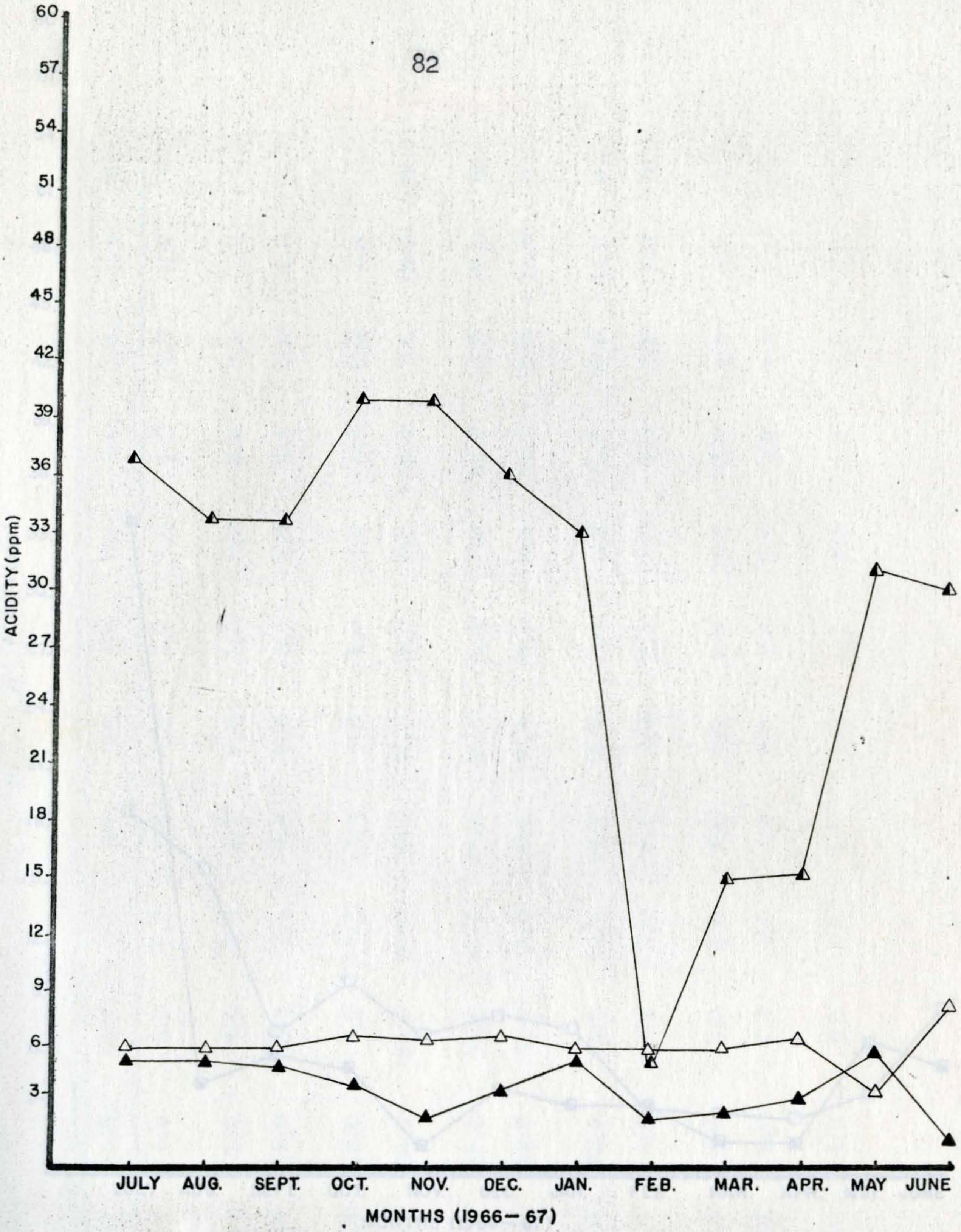


Fig. 20 Concentration of phenolphthalein acidity versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Ch. #1 —△—, Ch. #2 —◭—, Ch. #3 —▲—.

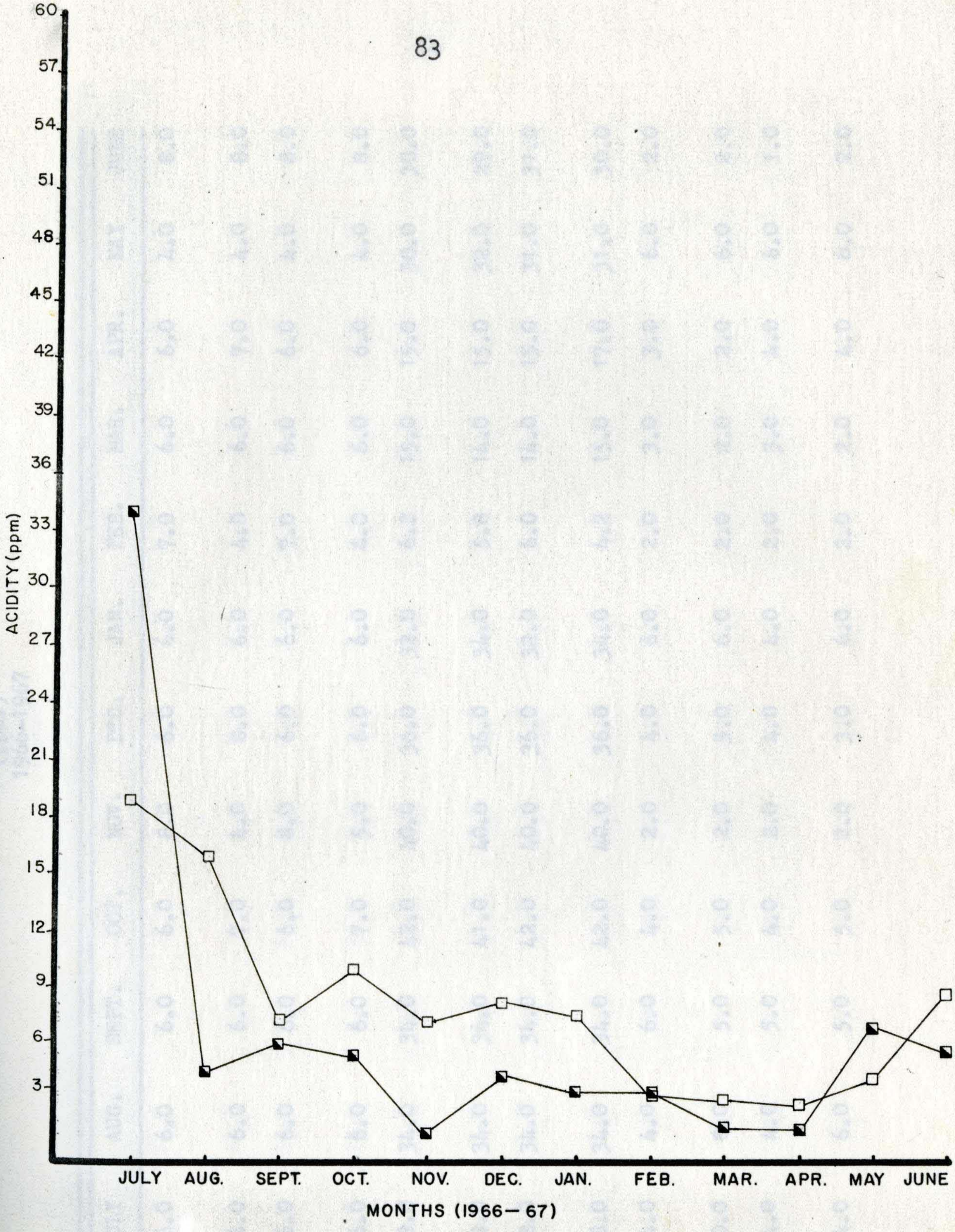


Fig 21 Concentration of phenolphthalein acidity versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Cr. #1 —□—, Cr. #2 —◪—, Cr. #3 —■—, (Undetermined).

TABLE XI

MONTHLY DATA OF TOTAL ACIDITY
(ppm.)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Ch. #1 Sta. #1	6.0	6.0	6.0	6.0	8.0	6.0	6.0	7.0	6.0	6.0	4.0	8.0
Bottom	6.0	6.0	6.0	7.0	4.0	8.0	6.0	4.0	6.0	7.0	4.0	8.0
Surface Ch. #1 Ch. #2	6.0	6.0	6.0	6.0	8.0	6.0	6.0	7.0	6.0	6.0	4.0	8.0
Bottom	6.0	6.0	6.0	7.0	5.0	6.0	6.0	6.0	6.0	6.0	4.0	8.0
Surface Ch. #2 Sta. #1	38.0	34.0	34.0	42.0	40.0	36.0	32.0	6.2	15.0	15.0	30.0	30.0
Bottom	38.0	34.0	34.0	41.0	40.0	36.0	34.0	5.8	14.0	15.0	32.0	29.0
Surface Ch. #2 Sta. #2	38.0	34.0	34.0	42.0	40.0	36.0	32.0	6.0	14.0	15.0	31.0	31.0
Bottom	38.0	34.0	34.0	42.0	40.0	36.0	34.0	4.2	15.0	17.0	31.0	30.0
Surface Ch. #3 Sta. #1	4.0	4.0	6.0	4.0	2.0	4.0	6.0	2.0	3.0	3.0	6.0	2.0
Bottom	10.0	8.0	5.0	5.0	2.0	3.0	6.0	2.0	2.0	2.0	6.0	2.0
Surface Ch. #3 Sta. #2	4.0	4.0	5.0	4.0	2.0	4.0	4.0	2.0	3.0	4.0	6.0	1.0
Bottom	4.0	6.0	5.0	5.0	2.0	3.0	6.0	2.0	2.0	4.0	6.0	2.0

TABLE XII

MONTHLY DATA OF TOTAL ACIDITY
(ppm.)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Cr. #1 Sta. #1	12.0	16.0	7.0	8.0	5.0	8.0	7.2	2.0	3.0	3.0	5.0	10.0
Bottom	20.0	16.0	8.0	8.0	8.0	8.0	7.6	3.0	2.8	3.0	3.0	8.0
Surface Cr. #1 Sta. #2	12.0	16.0	7.0	12.0	8.0	7.5	7.6	3.0	3.0	2.8	4.0	8.0
Bottom	32.0	16.0	8.0	12.0	8.0	8.5	7.4	3.0	2.0	2.0	4.0	5.0
Surface Cr. #2 Sta. #1	34.0	4.0	6.0	5.0	2.0	4.0	3.0	3.0	2.5	2.0	4.0	5.0
Bottom	34.0	4.0	6.0	5.0	2.0	5.0	3.0	3.0	2.5	3.0	8.0	---
Surface Cr. #2 Sta. #2	34.0	4.0	6.0	5.0	2.0	4.0	3.0	3.0	2.5	3.0	6.0	---
Bottom	34.0	4.0	5.0	5.0	2.0	4.0	3.0	3.0	2.5	2.0	8.0	---
Surface Cr. #3 Sta. #1	---	---	---	---	---	---	---	---	---	---	---	---
Bottom	---	---	---	---	---	---	---	---	---	---	---	---
Surface Cr. #3 Sta. #2	---	---	---	---	---	---	---	---	---	---	---	---
Bottom	---	---	---	---	---	---	---	---	---	---	---	---

TABLE XIII

AVERAGE MONTHLY DATA OF CARBON DIOXIDE (ppm.)

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Ch. #1	99.4	196.0	157.9	158.5	158.5	73.1	48.5	103.0	154.2	161.8	14.2	2.8
Ch. #2	----	----	----	----	----	----	----	182.5	----	----	----	----
Ch. #3	5.2	2.5	1.5	2.6	2.6	4.2	0.9	3.2	3.7	11.8	2.8	4.2
Cr. #1	28.7	7.8	6.1	0.9	0.6	3.1	5.5	1.0	2.4	6.4	8.6	10.1
Cr. #2	----	.96	.79	.83	1.1	1.2	2.5	.73	1.3	5.0	15.0	9.8
Cr. #3	----	----	----	----	----	----	----	----	----	----	----	----

The amount of dissolved oxygen in water at equilibrium with a normal atmosphere is a function of the temperature and salinity of the water, the ability of water to hold oxygen decreases with increasing temperatures (McKee and Wolf, 1963). The lethal effects of low concentrations of dissolved oxygen is apparently increased in the presence of toxic substances. Since so many factors influence the lethal concentrations of dissolved oxygen it is difficult to estimate the minimum safe concentrations at which fish will be unharmed under natural conditions.

McKee and Wolf (1963) in quoting other authorities report that sustained dissolved-oxygen concentrations of 2.0 mg./l will kill all kinds of fish, 3.5 mg./l will be lethal to most species and few fish will be found under 4.5 mg./l.

The average values obtained for dissolved oxygen for Ch. #1, Ch. #2, and Ch. #3 (Figure 22) remained above 6.0 ppm. During the period of thermal stratification in Ch. #3 station number 1 bottom samples showed values consistently below 3.0 ppm. The oxygen deficit below the thermocline is probably due to the oxidation of organic matter (Hutchinson, 1957).

The average dissolved oxygen concentrations for Cr. #2 remained above 6.0 ppm. until March when the

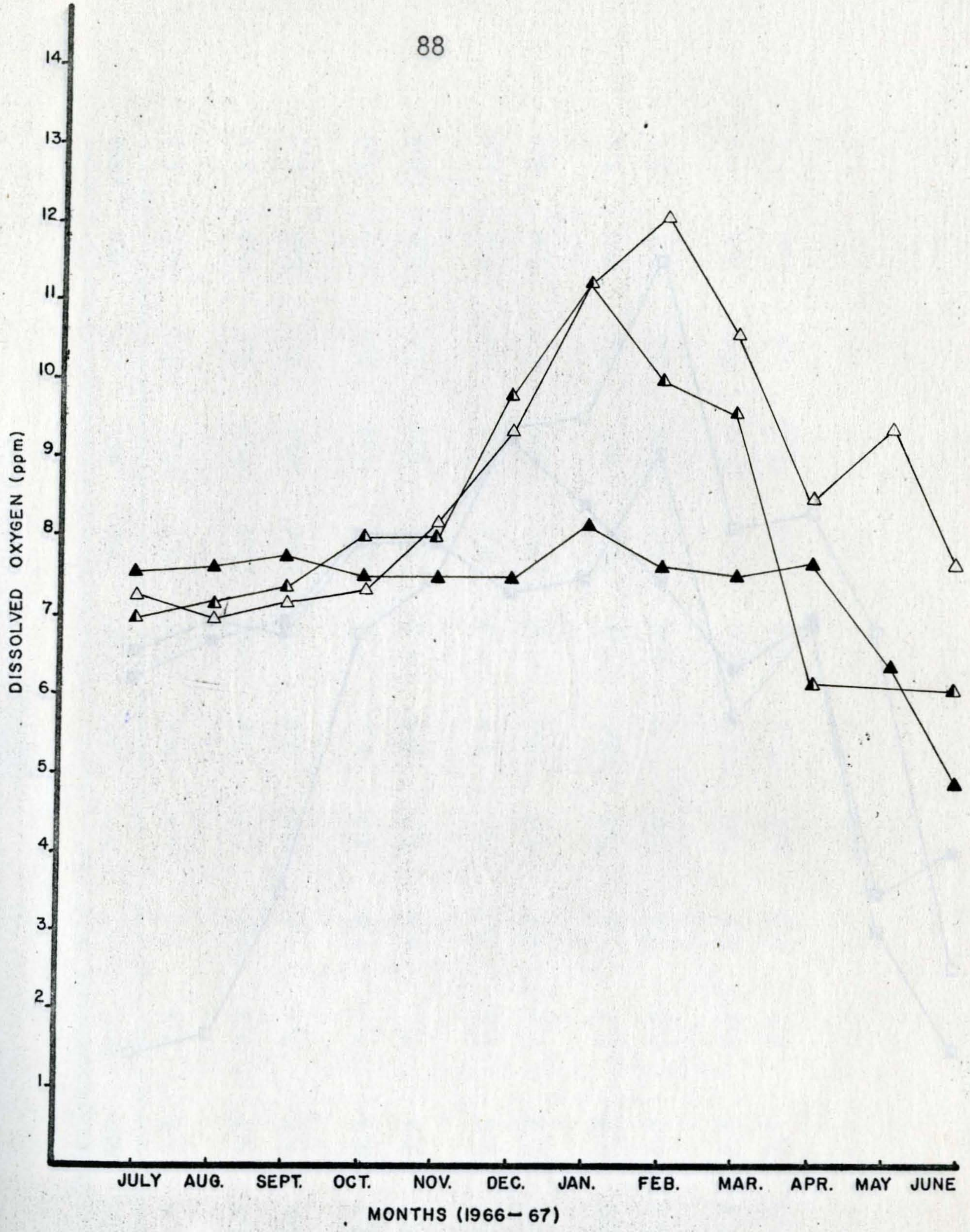


Fig. 22 Concentration of dissolved oxygen versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Ch. #1 —△—, Ch. #2 —▲—, Ch. #3 —▲— .

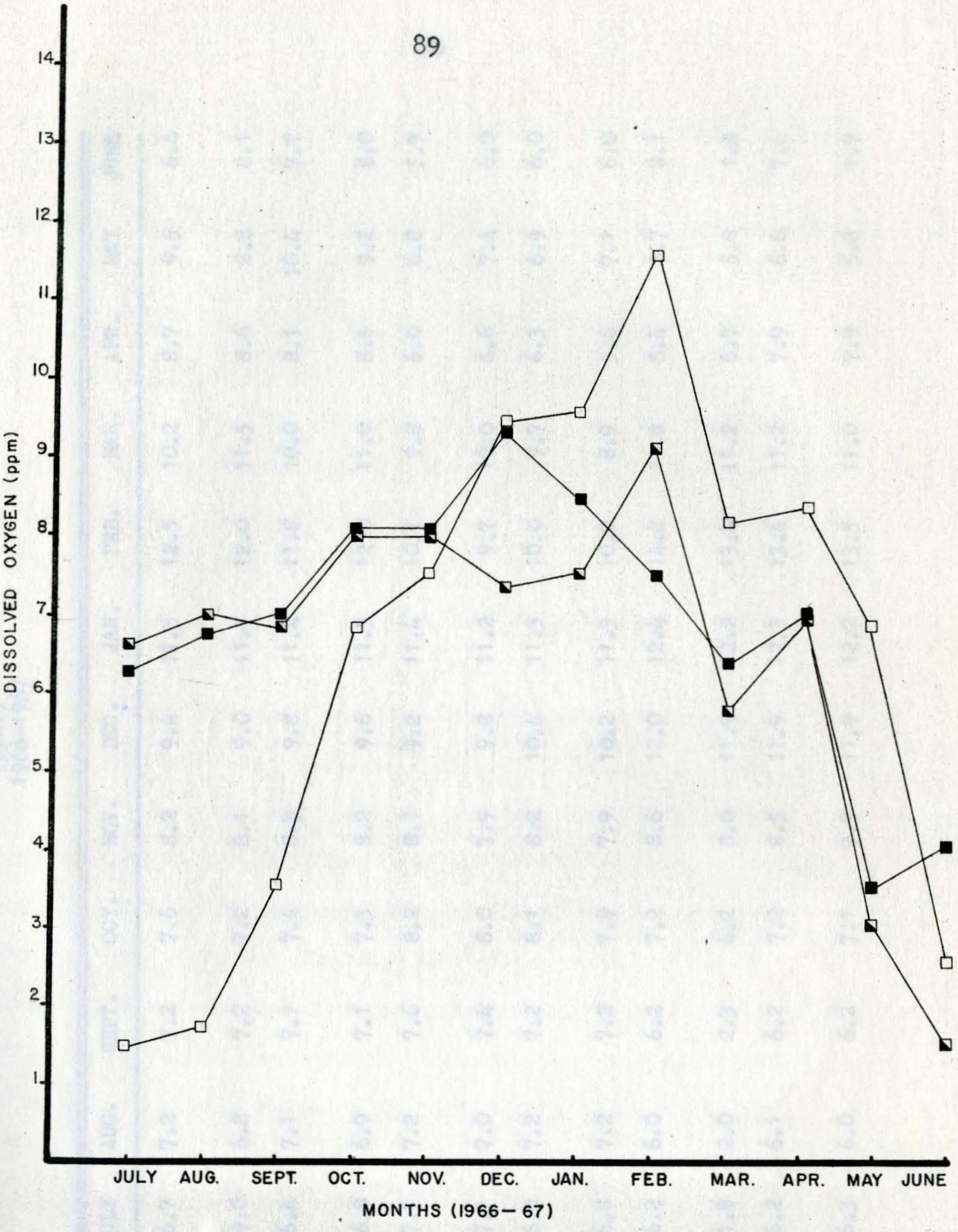


Fig. 23 Concentration of dissolved oxygen versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Cr. #1 —□— , Cr. #2 —◩—, Cr. #3 —■— .

TABLE XIV

MONTHLY DATA OF DISSOLVED OXYGEN
(ppm.)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Ch. #1 Sta. #1	6.7	7.2	7.2	7.6	8.2	9.4	11.3	12.5	10.2	8.7	9.5	6.6
Bottom	9.0	6.8	7.2	7.2	8.1	9.0	11.1	12.0	11.5	8.6	8.8	8.1
Surface Ch. #1 Sta. #2	6.4	7.1	7.1	7.4	8.3	9.8	11.4	11.8	10.0	8.1	10.4	7.7
Bottom	6.8	6.9	7.1	7.3	8.2	9.6	11.3	12.0	11.0	8.5	9.2	8.0
Surface Ch. #2 Sta. #1	7.1	7.2	7.6	8.2	8.1	9.2	11.4	10.1	9.8	6.0	6.8	5.9
Bottom	7.1	7.0	7.4	8.0	7.9	9.8	11.2	9.7	10.0	6.6	7.4	6.0
Surface Ch. #2 Sta. #2	6.8	7.2	7.2	8.1	8.2	10.4	11.3	10.0	9.7	6.3	6.9	6.0
Bottom	6.8	7.2	7.2	7.9	7.9	10.2	11.3	10.0	8.9	5.6	7.1	6.0
Surface Ch. #3 Sta. #1	6.2	6.0	6.2	7.2	8.6	12.0	12.4	14.2	11.8	8.4	7.7	8.1
Bottom	1.9	2.0	2.3	4.2	8.0	11.9	12.2	13.4	11.2	6.7	5.0	1.8
Surface Ch. #3 Sta. #2	6.2	6.1	6.2	7.2	8.5	11.9	12.3	13.4	11.2	7.9	6.6	7.6
Bottom	6.3	6.0	6.2	7.1	7.9	11.9	12.2	13.5	11.0	7.9	5.8	1.9

TABLE XV

MONTHLY DATA OF DISSOLVED OXYGEN
(ppm.)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Cr. #1 Sta. #1	2.0	3.1	5.2	7.6	8.0	11.4	9.8	12.3	8.5	8.0	9.2	3.2
Bottom	0.7	1.1	2.1	6.0	7.4	9.2	9.4	12.2	8.0	8.8	7.3	1.8
Surface Cr. #1 Sta. #2	2.5	1.9	5.4	7.9	7.6	8.8	9.9	10.8	8.3	8.4	6.7	3.3
Bottom	0.8	0.9	1.8	6.2	7.4	8.6	9.6	11.6	7.9	8.7	4.6	1.7
Surface Cr. #2 Sta. #1	6.9	7.2	7.0	8.2	8.4	7.8	8.0	9.2	5.6	7.2	2.7	1.2
Bottom	6.4	6.8	6.8	7.9	7.2	6.5	7.4	9.4	6.1	7.0	0.1	0.0
Surface Cr. #2 Sta. #2	6.7	7.2	7.0	8.1	8.2	8.0	7.4	9.2	5.5	7.1	4.7	2.6
Bottom	6.7	7.0	6.8	7.9	8.4	7.1	7.4	9.2	6.4	7.1	4.6	2.2
Surface Cr. #3 Sta. #1	6.3	7.1	7.1	8.1	8.6	9.3	8.5	7.8	6.2	7.2	3.7	4.0
Bottom	6.3	6.8	7.0	8.1	8.0	9.3	8.4	7.6	6.8	7.0	3.7	4.0
Surface Cr. #3 Sta. #2	6.3	6.9	7.0	8.2	7.8	9.5	8.5	7.8	6.4	7.4	3.5	4.0
Bottom	6.3	6.6	6.9	8.1	8.0	9.4	8.5	7.6	6.6	7.4	3.3	4.0

average value for Cr. #2 was 5.9 ppm., and during May and June when the average dropped well below 6.0 ppm. The average values for Cr. #3 were above 6.0 ppm. throughout the study period except during May and June. The reason for the drop in dissolved oxygen for Cr. #2 and Cr. #3 are not known (Figure 23).

It is felt that the extremely low values obtained for Cr. #1 during July, August and September (Figure 23) were due to two reasons. First the lake showed thermal stratification during this period and the low values obtained for waters below the thermocline resulted from organic oxidation. Secondly, shallow lakes filled with dense vegetation show low oxygen content in surface waters during early morning hours as a result of several factors. Periods of windless, cloudy days, and high air temperatures both day and night will result in normal or near-normal dissolved oxygen values during afternoon hours, but with the onset of darkness photosynthesis ceases, and respiration continues so that through the night the dissolved oxygen content is depleted (Bennett, 1962). Dissolved oxygen values obtained during the afternoon from this same lake on the same dates the early samples were taken showed average values of 5.3 ppm. for July, 5.8 ppm. for August, and 6.4 ppm. for September.

Nitrites are generally formed as a result of the

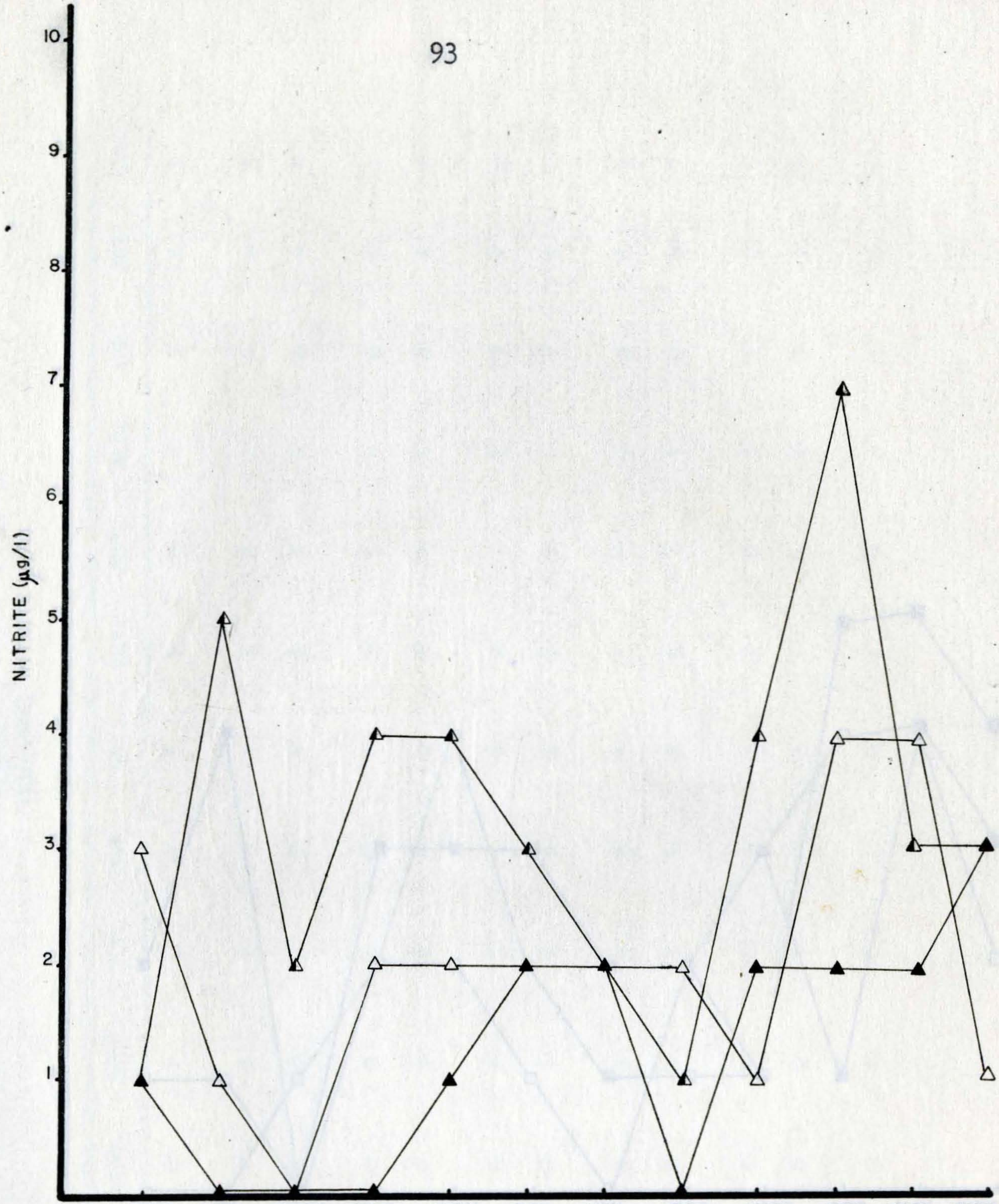


Fig. 24 Concentration of nitrite versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Ch. #1 —△—, Ch. #2 —◭—, Ch. #3 —▲—.

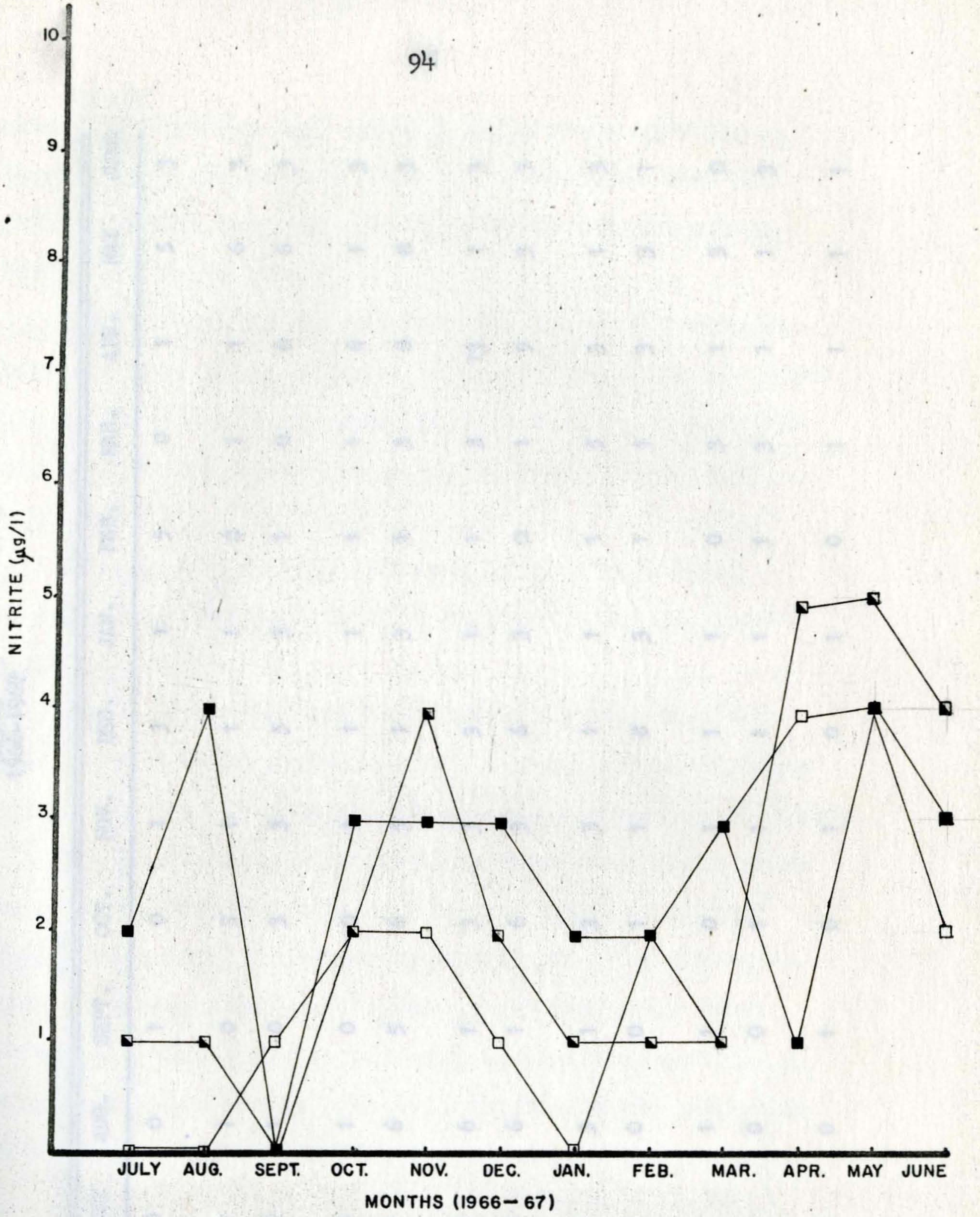


Fig. 25 Concentration of nitrite versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Cr. #1—□—, Cr. #2—◪—, Cr. #3—■—.

TABLE XVI

MONTHLY DATA OF NITRITE
(μg/l)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface	0	0	1	0	1	3	1	5	0	1	5	3
Ch. #1												
Sta. #1												
Bottom	3	1	0	3	1	1	1	0	1	1	6	3
Surface	5	1	0	3	3	5	3	1	0	6	6	3
Ch. #1												
Sta. #2												
Bottom	3	1	0	0	1	1	1	1	1	6	1	3
Surface	1	6	5	6	5	1	3	1	3	8	8	3
Ch. #2												
Sta. #1												
Bottom	1	6	1	3	3	3	1	1	3	13	1	3
Surface	1	6	1	6	3	6	3	0	1	5	3	3
Ch. #2												
Sta. #2												
Bottom	1	3	1	3	3	1	1	1	5	3	1	3
Surface	1	0	0	1	1	8	3	1	1	3	3	1
Ch. #3												
Sta. #1												
Bottom	1	1	1	0	1	1	1	0	3	1	3	0
Surface	1	0	0	1	1	1	1	1	3	1	1	3
Ch. #3												
Sta. #2												
Bottom	1	0	1	0	1	0	1	0	1	1	1	1

TABLE XVII

MONTHLY DATA OF NITRITE
($\mu g/l$)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Cr. #1 Sta. #1	0	0	3	3	3	1	0	3	1	5	6	3
Bottom	1	1	1	1	0	1	1	3	1	1	0	1
Surface Cr. #1 Sta. #2	0	0	0	1	0	1	0	1	1	3	6	3
Bottom	0	0	0	1	3	0	1	1	1	5	5	3
Surface Cr. #2 Sta. #1	1	0	0	3	3	3	1	0	1	6	5	3
Bottom	1	3	0	1	3	1	0	1	0	5	5	1
Surface Cr. #2 Sta. #2	1	0	1	5	5	3	3	0	3	3	5	1
Bottom	1	0	1	1	3	1	1	3	1	5	5	3
Surface Cr. #3 Sta. #1	3	3	0	3	3	3	1	1	3	1	3	1
Bottom	1	5	0	0	3	3	3	3	5	1	6	3
Surface Cr. #3 Sta. #2	3	3	0	6	5	3	1	3	1	1	5	3
Bottom	3	3	0	3	1	3	3	3	3	1	3	5

action of bacteria upon ammonia and organic nitrogen. Because they are quickly oxidized to nitrates they are seldom present in waters in significant concentrations (McKee and Wolf, 1963).

The nitrite values obtained for the six strip-mine lakes of this study (Figures 24 and 25) were all far below values which have been shown to be lethal to minnows (50 mg./l of sodium nitrite fatal in 14 days) (McKee and Wolf, 1963).

The reasons for the extremes in fluctuations of nitrite concentration shown in Figures 24 and 25 is unknown to this writer.

The values obtained for nitrites do show that the acid lakes contain amounts equal to or in excess of those values recorded for the alkaline lakes included in the study.

In the presence of oxygen and under conditions which seem to be satisfied in most lakes, a large portion of the ammonia which is formed is nitrified. The nitrification processes involve two stages, nitrite being first formed and then nitrate. In acid waters the reaction between ammonia and nitrous acid might liberate molecular nitrogen (Hutchinson, 1957).

The world average for nitrate nitrogen in unpolluted fresh waters is approximately 0.30 ppm. This is the form of nitrogen that is most readily taken up by green plants rooted in the substrate or floating in the water (Reid, 1961).

McKee and Wolf (1963) report references which show that among United States waters supporting good fish life, ordinarily 5 per cent have less than 0.2 mg./1 of nitrates; 50 per cent have less than 0.9 mg./1; and 95 per cent have less than 4.2 mg./1.

It has also been shown that high nitrate concentrations in waters will stimulate the growth of plankton and aquatic weeds and that nitrates indirectly foster increased fish production by facilitating plankton growth and the development of fish-food organisms (McKee and Wolf, 1963).

The values obtained for nitrate concentrations in this study show that the nitrate concentration decreases with increase in pH (Figures 26 and 27).

Crawford (1942) found that the concentration of inorganic nitrogenous compounds increases steadily as the H-ion concentration becomes lower.

Figures 26 and 27 also show that the average nitrate concentrations in the two bodies of water supporting fish populations (Ch. #3 and Cr. #1) are far below the values given for that 5 per cent of lakes having good fish populations which contain less than 200 μg/1.

The presence of higher nitrate concentrations in

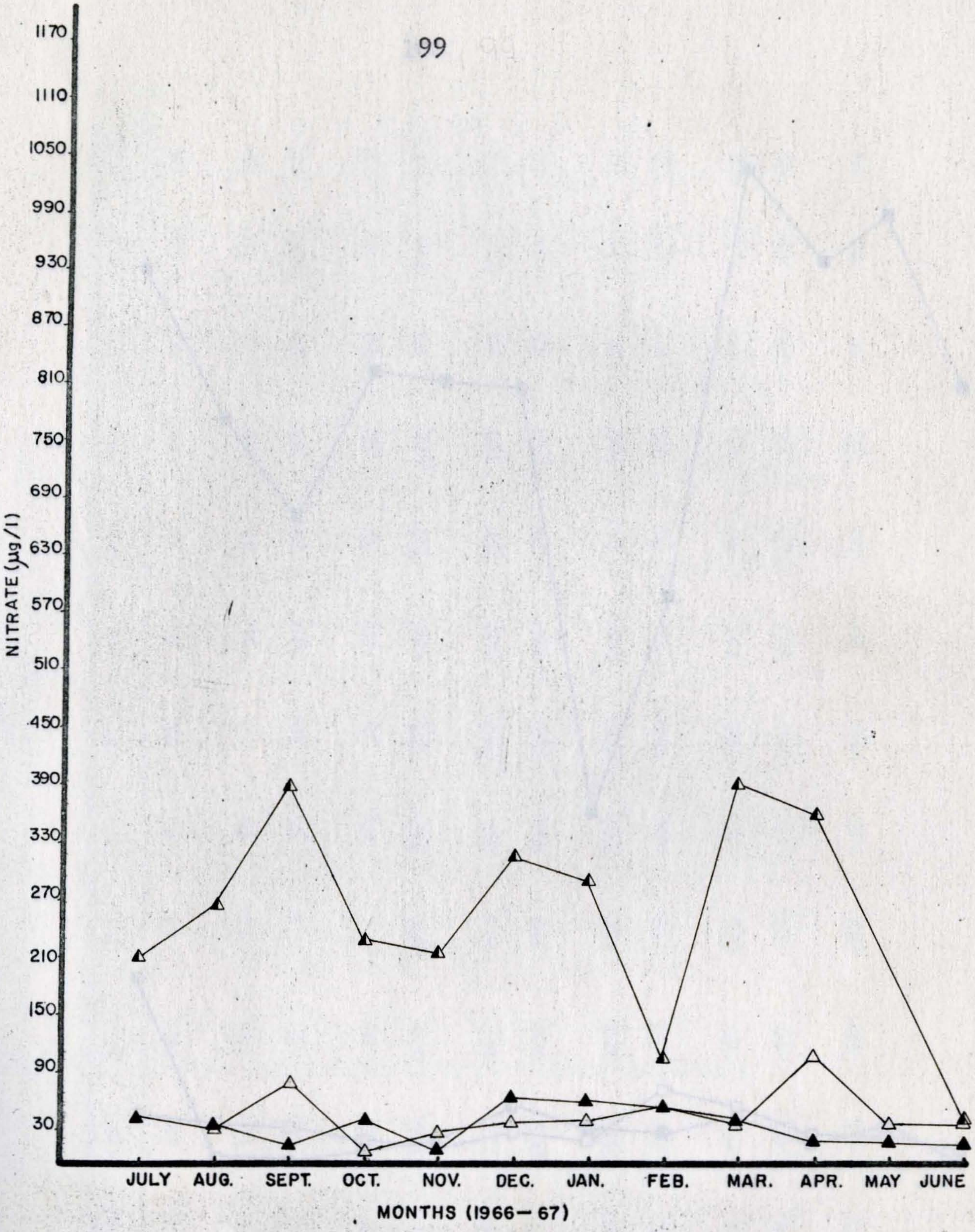


Fig. 26 Concentration of nitrate versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Ch. #1—△—, Ch. #2—◭—, Ch. #3—▲—.

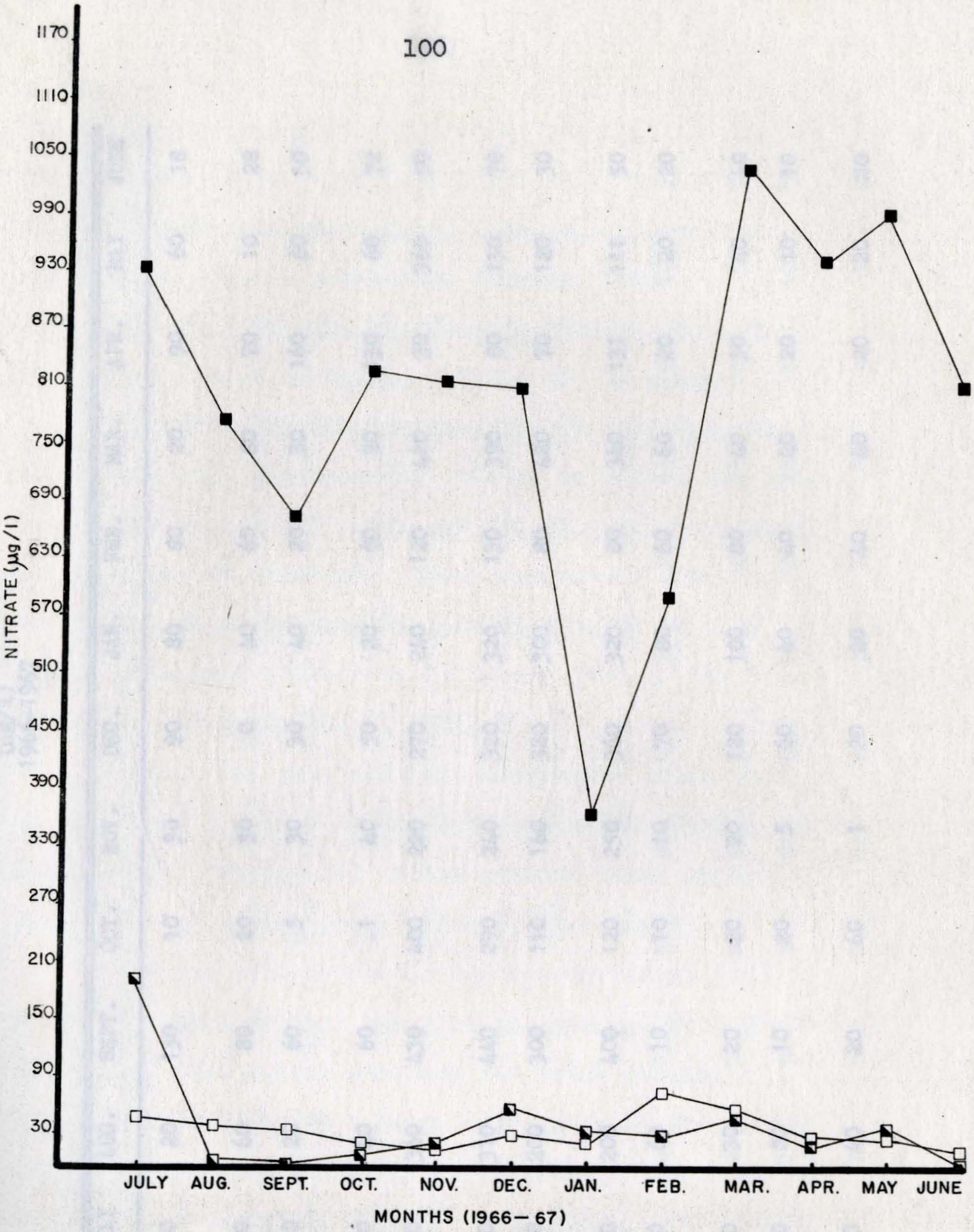


Fig. 27 Concentration of nitrate versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Cr. #1—□—, Cr. #2—◪—, Cr. #3—■—.

TABLE XVIII

MONTHLY DATA OF NITRATE
(µg/l)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Ch. #1 Sta. #1	30	20	130	10	30	90	80	80	20	90	60	18
Bottom	80	60	80	20	30	0	40	60	80	70	10	28
Surface Ch. #1 Sta. #2	30	20	60	5	30	30	40	20	30	160	60	50
Bottom	30	40	60	1	40	50	20	60	20	130	60	72
Surface Ch. #2 Sta. #1	160	360	430	400	220	270	240	120	420	30	360	50
Bottom	240	310	440	290	240	320	320	130	390	80	150	70
Surface Ch. #2 Sta. #2	220	200	300	110	160	320	300	80	420	70	120	30
Bottom	220	200	400	120	250	360	320	80	340	131	111	50
Surface Ch. #3 Sta. #1	80	60	10	10	10	70	80	60	60	20	20	20
Bottom	30	30	20	20	20	120	100	80	40	30	40	40
Surface Ch. #3 Sta. #2	30	20	10	80	5	60	40	40	40	20	10	10
Bottom	30	40	20	60	1	20	20	40	40	20	20	20

TABLE XIX

MONTHLY DATA OF NITRATE
(µg/l)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Cr. #1 Sta. #1	20	30	30	20	20	40	30	50	50	30	10	33
Bottom	70	60	40	10	20	20	30	80	80	40	10	0
Surface Cr. #1 Sta. #2	30	40	30	40	0	30	20	50	60	40	50	0
Bottom	80	40	50	40	20	30	30	120	40	60	10	15
Surface Cr. #2 Sta. #1	100	5	5	10	70	40	20	40	60	20	50	0
Bottom	140	5	0	0	5	70	50	20	70	30	30	0
Surface Cr. #2 Sta. #2	270	0	0	30	20	60	20	20	40	30	40	0
Bottom	270	5	5	5	5	80	70	40	50	20	40	0
Surface Cr. #3 Sta. #1	960	840	730	780	800	780	360	580	1160	960	1000	750
Bottom	1000	820	710	840	820	800	380	620	1160	940	960	849
Surface Cr. #3 Sta. #2	780	710	640	860	840	840	380	600	1120	980	1040	774
Bottom	1000	740	640	840	820	840	360	600	730	960	960	848

the more acid bodies of water might possibly be due to the reaction of ferrous sulfate and sulfuric acid with the compounds in nearby clays, limestones, sandstones, and various organic substances (Lorenz, 1962).

The reason for the decrease in nitrate concentration after liming in Cr. #2 (Figure 27) is unknown.

In general limnological studies it is necessary to report total phosphorous. The pH of waters determines to a great extent the nature of the phosphate compound as it exists in solution. Under moderately alkaline conditions calcium phosphate prevails while in acid waters phosphate attraction is toward iron in the form of ferric phosphate (Reid, 1961).

In water the meta and pyro phosphoric acids tend to change to the more stable ortho condition (McKee and Wolf, 1963). Phosphates seldom exhibit toxic effects upon fish and other aquatic life (Vivier, 1935).

According to Reid (1961) the average total phosphorous content of most lakes ranges from about 0.010 to 0.030 ppm. The values obtained for total phosphate during this study show a range comparable to the values given by Reid, and these values are also in close agreement with those values obtained by Simpson (1959).

According to Lorenz (1962) the variety of chemicals found in acid mine drainages are; aluminum, manganese,

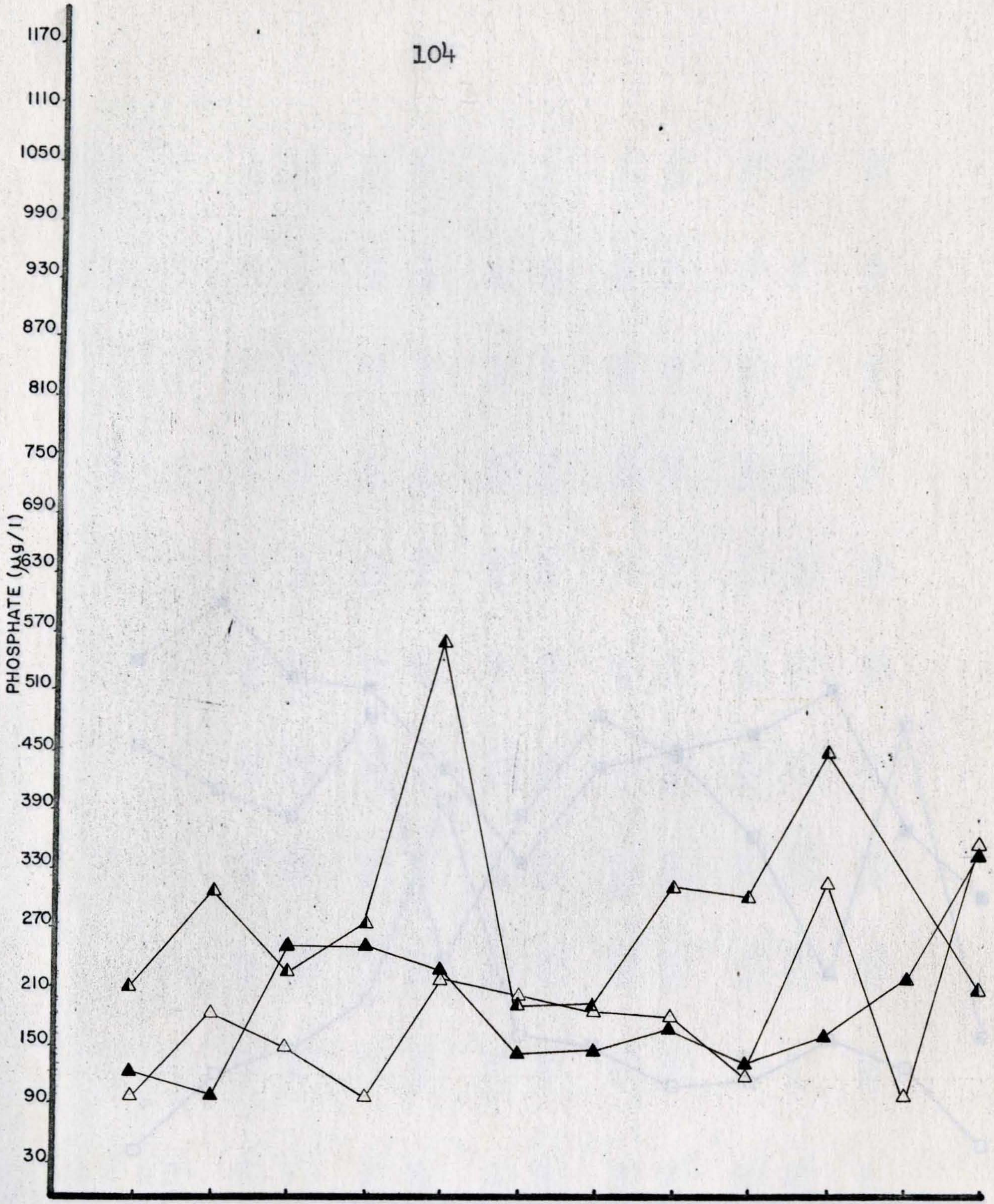


Fig. 28 Concentration of total phosphate versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Ch. #1 —△—, Ch. #2 —◭—, Ch. #3 —▲—.

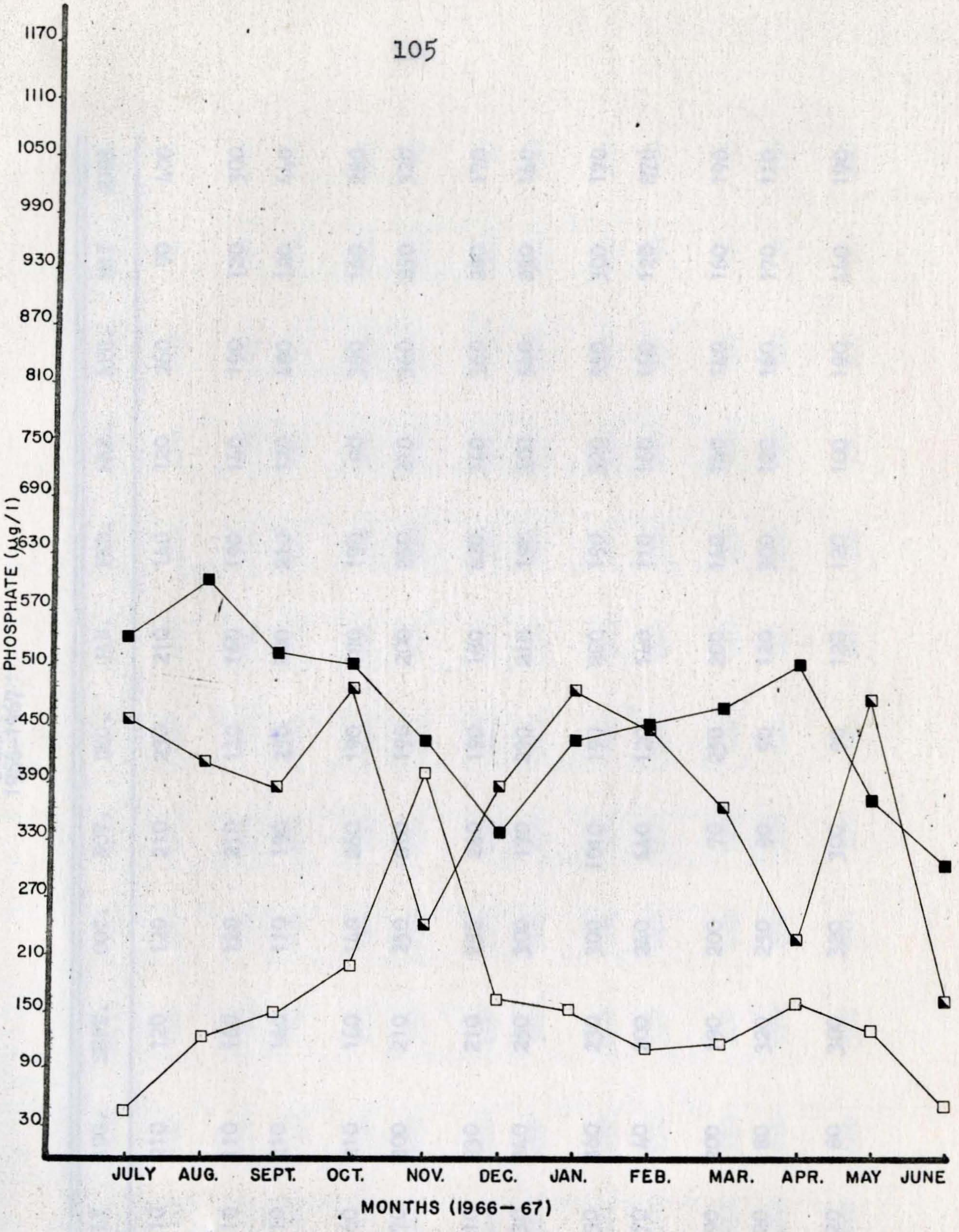


Fig. 29 Concentration of total phosphate versus time in months taken once each month from July 1966 to June 1967. All points are the average of four determinations. Cr. #1—□—, Cr. #2—◪—, Cr. #3—■—.

TABLE XX

MONTHLY DATA OF PHOSPHATE
($\mu g/l$)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Ch. #1 Sta. #1	110	210	120	120	210	230	210	140	120	260	90	400
Bottom	110	110	160	120	210	120	160	190	140	190	120	300
Surface Ch. #1 Sta. #2	110	210	160	110	190	250	200	210	120	480	120	440
Bottom	60	210	160	140	260	190	180	190	90	380	160	280
Surface Ch. #2 Sta. #1	170	300	210	250	810	190	200	250	210	360	250	320
Bottom	210	230	210	250	260	190	180	620	340	360	280	170
Surface Ch. #2 Sta. #2	230	340	250	300	170	230	210	190	300	540	230	160
Bottom	230	360	230	300	1010	190	200	190	320	550	300	170
Surface Ch. #3 Sta. #1	70	40	200	240	440	120	140	110	160	160	120	870
Bottom	190	200	190	200	70	250	200	140	140	140	160	190
Surface Ch. #3 Sta. #2	120	80	320	250	90	90	120	300	120	160	170	110
Bottom	120	80	300	320	300	90	120	120	100	190	440	190

TABLE XXI

MONTHLY DATA OF PHOSPHATE
(μg/l)
1966-1967

LAKE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
Surface Cr. #1 Sta. #1	40	100	160	320	320	140	160	110	120	380	90	90
Bottom	40	120	120	170	320	200	140	110	100	70	120	60
Surface Cr. #1 Sta. #2	40	140	110	160	810	160	160	120	140	90	170	20
Bottom	70	140	210	160	160	160	160	120	120	120	170	90
Surface Cr. #2 Sta. #1	460	400	380	530	230	380	400	420	340	210	1340	90
Bottom	460	440	400	570	260	480	620	530	250	110	160	90
Surface Cr. #2 Sta. #2	460	400	380	500	230	360	530	480	530	480	210	250
Bottom	460	420	400	380	260	340	420	460	360	140	210	210
Surface Cr. #3 Sta. #1	550	550	530	440	440	400	440	460	620	580	40	280
Bottom	530	590	500	480	420	420	420	480	530	480	40	19
Surface Cr. #3 Sta. #2	550	640	530	660	460	420	440	440	680	520	40	530
Bottom	550	640	550	480	420	480	440	440	550	500	30	440

calcium, magnesium, sodium, potassium, chlorates, nitrates, silicates, iron and sulfates.

Simpson (1959) in his research on Southeast Kansas strip-mine lakes included in his study all of the above except nitrates and silicates. Nitrates have been analyzed in this present study.

Two of the same strip-mine lakes included in Simpson's (1959) work have been included in this present study.

Aluminum is one of the most abundant elements on the face of the earth, but never as a pure metal in nature. Although the metal itself is insoluble, many of the aluminum salts are not (McKee and Wolf, 1963).

Simpson (1959) reported a range of 0.60 to 3.11 ppm. aluminum for the most acid strip-mine lake (3.6 to 4.2) included in his study. This lake is the same as the lake designated as Ch. #2 in the present study and will be referred to as such throughout this discussion.

The range of values reported for the moderately acid lake in Simpson's (1959) work (pH 4.6 to 5.6) was 0 to .500 ppm. This lake corresponds to the lake designated as Ch. #1 in this present study and will be referred to as such throughout the discussion.

The range of aluminum concentrations for the alkaline lake (7.6 to 8.2) was .011 to .355 ppm.

According to data compiled by McKee and Wolf (1963), aluminum, as aluminum sulfate, has been fatal to Fundulus within five days at a concentration of 7 mg./1 and within thirty-six hours at a concentration of 14 mg./1. The values recorded by Simpson (1959) were below the 7 mg./1 concentration in every sample. Simpson's (1959) data also shows a decrease in aluminum with an increase in pH values.

The ranges of manganese presented by Simpson (1959) are as follows: Ch. #1, .30 to 13.3 ppm.; Ch. #2, 2.0 ppm. to 35.1 ppm.; alkaline lake, .30 to 13.5 ppm. The toxicity of manganese to Fundulus in fresh water as manganese chloride has been shown to be 12 mg./1 in six days. Other fish have been shown to be much more tolerant. Manganese nitrate has been shown to be fatal to some fish at concentrations (measured as manganese) of 50 mg./1 for one week's exposure. As manganese sulfate 50 mg./1 for three days' exposure did not kill young sticklebacks (McKee and Wolf, 1963).

The moderately acid lake, Ch. #1, showed values of manganese comparable to the alkaline lake. The highly acid lake had maximum values 2.5 times that of the other two lakes, indicating a decrease of manganese with decrease in acidity. All the values were below lethal concentrations except those given for Fundulus exposed to manganese chloride.

The calcium ion concentrations found in natural fresh waters range from 10-50 ppm. The toxicity of sodium, magnesium, and potassium ions and cations of lead, zinc and cupric ions is counteracted by the presence of calcium (Doudoroff, 1957).

The range of calcium ions found in the three strip-mine lakes studied by Simpson (1959) showed Ch. #1, the moderately acid lake, had the least amount of calcium (0.49 to 28.7 ppm.), the alkaline lake had the second lowest concentration (124 to 219 ppm.) and the highly acid lake had the highest concentration of calcium (176 to 472 ppm.).

According to the references cited by McKee and Wolf (1963) it was shown that fish have survived for up to three days at concentrations of 2500 to 4000 mg./l of calcium. It was further shown that in waters supporting good mixed fish fauna 5 per cent have less than 15 mg./l of calcium; 50 per cent less than 28 mg./l; and 95 per cent less than 52 mg./l.

Simpson's (1959) data shows the range of magnesium for the three strip-mine lakes to be as follows: Ch. #2, 96-156 ppm.; Ch. #1, 8.0-108 ppm.; and the alkaline lake, 5.0-112 ppm.

McKee and Wolf (1963) cite a reference which suggests that waters supporting a good fish fauna, ordinarily 5 per cent have less than 3.5 mg./l of magnesium; 50 per cent have less than 7 mg./l and 95 per cent have less than 14 mg./l. They also indicate that magnesium chloride, nitrate, and sulfate, at concentrations between 1000 and 3000 mg./l as magnesium have been tolerated by fish.

Jones (1939) reported that sodium was toxic to fish in distilled and soft waters in concentrations of 500-1000 mg./l when sodium chloride or nitrate were used.

The range of values for sodium reported by Simpson were Ch. #1, 30.7 to 36.2 ppm.; Ch. #2, 77.0 to 99.8 ppm.; and the alkaline lake 34.2 to 77.2 ppm.

Doudoroff (1957) reports that potassium should be classed as a metal of relatively low toxicity to fish. Potassium has been shown to be more toxic to fish and shellfish than calcium, magnesium, or sodium (Brandt, 1946).

The range of concentrations for potassium given by Simpson (1959) was as follows: Ch. #1, 0.96-3.06 ppm.; Ch. #2, 4.06-6.06 ppm.; alkaline lake, 1.68-5.06 ppm.

With the addition of iron to water in the form of chlorides, sulfates or nitrates, the salts dissociate. The resulting ferric or ferrous ions combine with hydroxyl ions to form precipitates with very little iron remaining in solution. If the dosage is sufficient and the water is not strongly buffered, the addition of a soluble iron salt may lower the pH of the water to a toxic level. In the United States, 95 per cent of waters supporting good fish populations have less than 0.7 mg./l iron (McKee and Wolf, 1963).

Simpson (1959) gives the following ranges of iron concentrations for the three strip-mine lakes included in his study: Ch. #1, 0-.126 ppm.; Ch. #2, .018-3.78 ppm.; alkaline lake, 0-.068 ppm. These values indicate a marked decrease with increasing pH values.

In reference to work done on the concentration of sulfate in United States waters supporting good fish fauna McKee and Wolf (1963) show 5 per cent of the waters contain less than 11 mg./l sulfate; 50 per cent less than 32 mg./l, and 95 per cent less than 90 mg./l. The sulfates of aluminum and iron in relation to lethal concentrations has already been discussed.

Simpson (1959) reports the following range of concentrations of sulfate for strip-mine lakes: Ch. #1, 78.7-389.0 ppm.; Ch. #2, 998.8-1653 ppm.; alkaline lake, 532.8-1070 ppm.

There is a marked decrease in values of sulfate concentration from the most acid lake, Ch. #2, to the alkaline lake. There is also, however, a marked decrease in values from the alkaline lake to the moderately acid lake, Ch. #1. This degree of variation is probably a result of variations in the initial conditions of the lakes after mining which would in turn probably be dependent upon variations in geology of the area.

The limitations of the applications of lethal concentrations from laboratory tests to field conditions must be considered. The setting of these values does not in any way account for the possibility of the interactions of the various chemicals resulting in additive, or synergistic reactions, nor does it in any way show the limitations of fish growth before concentrations reach lethal dosages. Consideration must be given to the fact that different test fishes show large variations in the concentrations which are lethal. Considerations must also be given to the possibility of the limitations placed on essential food chain organisms which would directly affect fish growth and production below concentrations which are lethal to fishes.

The data show that there is a definite decrease in the concentration of aluminum, manganese, calcium, and iron between the highly acid (3.6-4.2 pH) Ch. #2, and the alkaline lake (7.6-8.2 pH), and that there is a slight decrease in concentrations of magnesium, sodium, and potassium between Ch. #1 and the alkaline lake.

It has also been shown that for the test fish indicated aluminum, manganese (as manganese nitrate), calcium, magnesium, sodium, potassium and iron do not exceed the lethal limits of tolerability. Manganese, as manganous chloride, did exceed the limits of lethal tolerability for Fundulus, but this excess was present in the already productive alkaline lake as well as the two acid lakes.

The data also show that calcium, magnesium, and iron are in greater concentration, even in the alkaline lake, than 95 per cent of the fresh water lakes of the United States supporting good fish populations.

The literature concerning the number of benthic organisms per unit area of bottom shows some disagreement when comparisons are made between acid and alkaline strip-mine lakes.

Stockinger and Hays (1960), based on the results obtained from a study made on one highly acid lake (pH 3.2-3.6), a moderately acid lake (pH 6.2-7.4), and an alkaline lake (pH 7.0-7.8), indicate the highly acid lake showed a greater number of benthic organisms per unit area of bottom than the moderately acid or alkaline lake. They indicated that dipteran larvae (Tendipes) comprised the bulk of the benthic organisms in the acid lake. Coleoptera, Odonata, Megaloptera, and additional dipteran larvae were also collected.

Heaton (1951) reported finding a greater number of benthic organisms per unit area in the highly acid lake of his study. He attributed this to the presence of large numbers of midge fly larvae. He found only three other benthic forms to be present; additional dipteran, Coleoptera, and Megaloptera larvae. These additional forms did not contribute significantly to the number of organisms per unit area.

The results of this present study indicate that there are a greater number of benthic organisms per unit area of bottom in the alkaline lakes than in any of the acid lakes studied. The results also show a marked decrease in benthic organisms per unit area with increasing depth in the alkaline lakes, a tendency which is not apparent in the acid lakes (Tables XXII and XXIII).

The peaks which are observed for November and January in samples from Ch. #1 are due to the presence of a large number of larvae of the family Tendipedidae (Chironomidae). The peak observed in Ch. #2 in November is due to the presence of a large number of Tendipedidae larvae, while the December peak is due to larvae of the family Culicidae.

The peaks in Ch. #3 in November and May are due to mayfly larvae of the family Baetidae, while the December peak is due to an oligochaete of the family Naididae.

The peaks observable in Cr. #1 in January and June are due to oligochaetes of the family Naididae. The peak in January in Cr. #2 is due to the presence of a mite of the family Oribatidae, while the October peak in Cr. #3 is due to larvae of the family Tendipedidae.

There is no value in attempting to correlate the time of year a peak occurred between the various lakes as some dates have samples which exclude various depths and for this reason some of the organisms are probably selected against because of the type of sampling employed.

It is felt that the major differences found between this study and the previously mentioned studies involve sampling techniques. Although each study indicates distinct tendencies none of the studies actually contain all the factors which should be considered before definite conclusions can be drawn as to the relative abundance of organisms or the comparative community structure between acid and alkaline strip-mine lakes. Before these comparisons can be made with some degree of confidence it is evident that the following factors must be included. The lakes chosen should have equal or nearly equal basins, including total area and contours. The lakes should be divided into meter contour intervals and the sampling should be designed so that random samples, at least two, are taken for each contour interval for each sample date. Consideration should also be given to the presence of fish in alkaline lakes, or the absence of fish in acid lakes. It has been shown that in lakes which do not have fish populations there is reduction in the production of benthic organisms but a higher standing crop, when compared to a lake with fish which shows a higher production of organisms but a lower standing crop (Hayne and Ball, 1956).

The notable differences between the acid and alkaline, as far as families of organisms present, varies widely from lake to lake in this study. Cr. #3, the most acid lake of the study, contained the smallest number of families with four. This figure compares favorably with those figures obtained by Heaton (1951) and Stockinger and Hays (1960). The second lake Ch. #2 (rating in order of decreasing acidity) showed a total of eleven families, while Cr. #2 showed eleven families and Ch. #1 showed sixteen different families. The two alkaline lakes showed the following number of families; Ch. #3, fourteen families, and Cr. #1, thirteen families.

The most notable differences in comparison of families show the lack of the family Oribatidae from either of the alkaline lakes, and the absence of pelecypods and gastropods from the acid lakes. Although the oligochaete family Naididae was found in three of the acid lakes studied it was never found in numbers comparable to those numbers which were found in the alkaline lakes.

TABLE XXII
NUMBER OF BENTHIC ORGANISMS PER SQ. METER

LAKE	CHEROKEE CO. PIT #1				CHEROKEE CO. PIT #2						CHEROKEE CO. PIT #3		
DEPTH (M.)	1	2	3	4	1	2	3	4	5	6	1	2	3
JULY	2,370		4,350			1,930			750				$\frac{180}{6}$
AUG.	1,560		1,240			1,620		2,860			5,660	3,890	
SEPT.	560	500					620		2,970			1,000	1,990
OCT.	3,340	1,370				560	680						$\frac{1,180}{1,560}$
NOV.	120	8,150					7,780		370		$\frac{7,780}{6,900}$		
DEC.	930			4,230	180				4,290		11,320	9,390	
JAN.	$\frac{9,580}{5,230}$				$\frac{1,430}{180}$						$\frac{6,840}{1,310}$		
FEB.	310			2,610			3,110		2,670			2,860	1,700
MAR.		$\frac{1,370}{1,990}$				$\frac{500}{560}$						1,120	620
APR.	680	3,170					500			620	1,620	1,000	
MAY	2,970			3,480	810	500					7,220	4,170	
JUNE	180			1,180	620				500		$\frac{1,930}{1,120}$		
(AVE.)	2,319	2,758	2,795	2,875	644	945	2,538	2,860	1,925	620	5,170	3,347	1,034
(YEAR-AVE.)		2,687					2,519					3,184	

TABLE XXIII
NUMBER OF BENTHIC ORGANISMS PER SQ. METER

LAKE	CR. #1		CR. #2					CR. #3	
DEPTH (M.)	1	2	1	2	3	4	5	1	2
JULY		120 180	1,310				5,190	60	180
AUG.		180 750		4,850			2,610	680 310	
SEPT.		500 310	2,180			2,610			680 120
OCT.	1,800	250	1,560 310						5,160 310
NOV.	7,470 1,680		250	620				930 440	
DEC.	1,370	620	680				8,150	560 1,870	
JAN.	25,190 39,070			250	23,080			250 2,740	
FEB.	2,970	750	150			680		750	1,180
MAR.		560 440	1,300	1,240				1,060 1,740	
APR.	4,290	370	120		750			440	680
MAY	2,610 2,970		250			1,300		871 0	
JUNE	4,290 20,715			180			370	250	3,732
(AVE.)	9,535	419	821	1,428	11,915	1,530	4,080	809	1,482
(YEAR-AVE.)	4,997				3,955			1,145	

The results indicate a gradual decrease in numbers of benthic organisms in Cr. #2 after liming. This can be attributed to the decomposition and disappearance of the _Sphagnum_ _cuspidatum_. According to Ward and Whipple (1963) many of the genera of Orabatei contain species that are found on _Sphagnum_ and it is sometimes difficult to tell whether a particular species is to be regarded as an inhabitant of the water or whether it is more correctly regarded as an inhabitant of the plant itself.

A detailed study of the benthic organisms at the species level would be helpful in determining the changes which occur in the benthic community after liming. The length of time elapsed since lime application to Ch. #1 has not been great enough to determine any gross changes in the benthic population at the family level.

The appendix includes the classification of the benthic organisms found in each of the strip-mine lakes studied.

It has been fairly well established through studies dealing with the numbers and species of planktonic organisms inhabiting strip-mine lakes that the acid lakes show smaller numbers of fewer species than do alkaline lakes (Dinsmore, 1957; Stockinger and Hays, 1960; Crawford, 1942; and Heaton, 1951).

Net plankton analysis in this present study was included in an attempt to establish the effects of liming on the planktonic community as related to numbers of organisms present per liter of sample. The results indicate that liming has no immediate effect on the number of planktonic organisms present (Tables XXIV and XXV).

According to Whipple (1927) free mineral acidity apparently acts directly and prejudicially upon the cells of plankton. This might account for the restricted numbers of planktonic organisms present in the acid strip-mine lakes. Heaton (1951) suggests that upon the removal of the limiting factor of high acidity the plankton population of an acid lake was characterized by great diversity of species in place of a restricted few species. These comments were made in reference to natural succession from the acid to the alkaline state.

The reasons for the lack of apparent changes in numbers of planktonic organisms after lime application and establishment of pH values greater than 7 is unknown. This is, however, a factor which would probably limit the success of a well balanced fish population.

The results show a definite restriction in average numbers of planktonic organisms between the acid and alkaline lakes included in this study except for the average value obtained for the bottom samples in Ch. #1. This comparatively high value can be attributed to the bottom sample taken during March (Table XXIV). The

TABLE XXIV

NUMBER OF NET PLANKTON PER LITER OF WATER

LAKE	CHEROKEE CO. PIT #1		CHEROKEE CO. PIT #2		CHEROKEE CO. PIT #3	
	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM
JULY	210	346	745	547	1,515	1,077
AUG.	183	419	519	424	8,787	7,342
SEPT.	293	349	537	179	1,226	765
OCT.	284	1,843	502	200	3,599	3,275
NOV.	787	304	436	222	1,549	2,283
DEC.	179	248	152	91	360	284
JAN.	44	60	490	331	112	271
FEB.	76	0	122	364	714	840
MAR.	202	159,260	248	126	10,354	11,542
APR.	1,874	4,131	85	132	11,614	14,980
MAY	1,374	12,528	1,315	1,373	51,081	53,266
JUNE	161	665	417	895	28,652	39,605
AVERAGE	472	15,012	464	407	7,575	11,294

TABLE XXV

NUMBER OF NET PLANKTON PER LITER OF WATER

LAKE	CRAWFORD CO. PIT #1		CRAWFORD CO. PIT #2		CRAWFORD CO. PIT #3	
	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM
JULY	2,376	1,662	53	185	75	700
AUG.	3,279	1,328	308	625	121	116
SEPT.	1,367	1,006	377	322	98	187
OCT.	1,460	661	444	875	909	966
NOV.	23,075	4,148	160	66	286	597
DEC.	8,986	9,538	143	453	247	171
JAN.	668	1,301	63	119	169	126
FEB.	3,868	2,698	93	253	354	246
MAR.	3,508	3,672	94	98	84	0
APR.	3,482	3,468	329	341	452	417
MAY	6,117	3,987	445	384	765	8,273
JUNE	23,083	12,738	755	815	44	41
AVERAGE	6,772	3,850	272	317	296	983

bloom or pulse was due to a large number of diatoms collected during this sample. The peak sample for Ch. #2 and Ch. #3 during May can be attributed to increased numbers of rotifers of the genus Keratella sp. and increased numbers of the mastigophora Ceratium sp.

The peak observed in Cr. #1 during November was due to the presence of large numbers of Keratella sp., while the June peak was due to increased numbers of Ceratium sp. The June peak in Cr. #2 was also due to increased numbers of the mastigophora Ceratium sp. The May peak (Table XXV) in Cr. #3 was due to increased numbers of diatoms.

Table XXVI represents an analysis of the numbers of fish and the pounds of per volume and area of water recovered from Ch. #1 after the application of rotenone to this lake. The average weight per fish included in this table was as follows; Chaenobryttus gulosus (Cuvier), 2.28 oz./fish; Lepomis cyanellus Rafinesque, 4.60 oz./fish; Lepomis macrochirus Rafinesque, 5.50 oz./fish; Micropterus salmoides (Lacepede), 3.60 oz./fish; and Notemigonus crysoleucas (Mitchill), 0.5 oz./fish.

The standing crop of fish in a given body of water is the total weight of fish present in the area at the time of observation (Rounsefell and Everhart, 1953). According to this definition the standing crop of this strip-mine lake at the time of sampling would be 35.7

pounds. This value would be somewhat higher as it includes only those fish given in Table XXVI.

The pounds of fish obtained from this lake per surface acre (7.57) compared with those values compiled from several sources by Rounsefell and Everhart (1953) will give an indication as to the paucity of the population recovered after rotenone application.

POUNDS OF FISH PER ACRE OF POND

Pounds per Acre	Locality
138 (28-370)	Iowa
100-200	Virginia
71-1145	Illinois
45 (game fish); 100-300 (coarse)	Indiana
657 (fertilized); 100-300 (unfertilized)	Alabama
17-36	Nova Scotia

A comparative growth rate study to be included in the second setment of this project will be carried out on the fish collected during this survey and the values obtained will be compared with those obtained after rotenone application to Ch. #3, during the summer of 1967.

TABLE XXVI

FISH RECOVERED FROM CH.#1 AFTER ROTENONE APPLICATION

Fish*	Number	Lbs./Acre Foot	Lbs./Surface Acre
Chaenobryttus gulosus	30	.13	.91
Lepomis cyanellus	30	.26	1.84
Lepomis macrochirus	26	.28	1.90
Micropterus salmoides	61	.42	2.92
Notemigonus crysoleucas	3	.003	.006
Totals	150	1.093	7.57

*An additional total of 3 Micropterus salmoides, 20 Lepomis cyanellus, 16 Chaenobryttus gulosus, and 58 Lepomis spp. were collected and preserved but not included in this table.

CHAPTER V

SUMMARY AND CONCLUSIONS

1. Six Southeast Kansas strip-mine lakes, four of which were acid, two alkaline at the beginning of the study, were sampled once a month for a period of one year. The following factors were determined on these sample dates; water temperature, air temperature, depth, turbidity, pH, total alkalinity, carbon dioxide, phenolphthalein acidity, boiling-point acidity, total phosphate, nitrate and nitrite concentrations. Periodic soil pH determinations were made.
2. Benthic and net plankton samples were obtained once a month and comparisons made between acid and alkaline lakes on numbers of individuals obtained.
3. Depth-contour maps of the six strip-mine lakes were constructed.
4. Physical alterations on the drainage systems of four of the six lakes were accomplished using heavy equipment. This was done under the direction of the Kansas Forestry, Fish and Game Commission.
5. Lime, as agricultural lime at 92% $CaCO_3$, was applied to two of the acid strip-mine lakes.

6. Fish were removed from one of the lakes by rotenone application. Weight, sex, and standard length were recorded for the fish collected. A growth rate study of these fishes will be included in the second segment of this project.

The results of this study indicate the following conclusions. Agricultural lime application to acid strip-mine lakes, whose rate of natural succession has been retarded by the presence of acid surface drainage, results in speeded succession to the alkaline state at costs which are not prohibitive providing the following criteria are met:

1. The spoil banks, forming the banks of the lakes, must be free from acid drainage.

2. Visible signs of surface drainage with low pH values, and high boiling-point acidity values must be eliminated.

A rate of 68.4 pounds of agricultural lime for each ppm. of boiling-point acidity per acre foot of water is suggested as a tentative rate of application.

No data have been obtained which suggest the minimum boiling-point acidity values which might limit successful lime application due to the formation of calcium sulfate sludge.

The first visible signs of changes which occur after liming are the change in water color from turquoise blue to dark green. A subsequent increase in turbidity occurs. As a result of increased turbidity thermal stratification occurs with a concurrent reduction in dissolved oxygen taking place at maximum depths.

As a result of liming the values obtained for pH rose and boiling-point acidity values decreased substantially. No apparent changes in concentrations of nitrite and total phosphate were observed, while there was a marked decrease in nitrate values of one of the strip-mine lakes limed.

No appreciable changes in numbers of planktonic or benthic organisms were noted during the study period in those lakes which were limed.

A comparison of the metallic constituents analyzed by Simpson (1959) with lethal concentrations reported by various authors showed that in the lakes studied these elements would not be a limiting factor for fish survival before lime application. No values were obtained concerning changes in these constituents after lime application, nor was any attempt made to analyze these substances for the possible occurrence of synergistic or additive reactions which might occur as a result of lime application.

Assuming time is the factor limiting the development of total alkalinity values, and planktonic and benthic community structure in numbers comparable to established alkaline strip-mine lakes, the boiling-point acidity pH relationship appears to be the only factor which must be controlled before acid strip-mine lakes can be reclaimed.

APPENDIX

APPENDIX

A listing of the benthic organisms collected from each of the six strip-mine lakes for the period from July 1966 to June 1967.

Cherokee Co. Lake No. 1

CLASS	ORDER	FAMILY	GENUS	SPECIES
Insecta	Diptera	Culicidae	Chaoborus	sp.
Insecta	Diptera	Tendipedidae	---------	---
Insecta	Diptera	Ceratopagonidae	---------	---
Insecta	Diptera	Sciomyzidae	---------	---
Insecta	Diptera	Tabanidae	---------	---
Insecta	Trichoptera	Hydroptilidae	---------	---
Insecta	Trichoptera	Limnephilidae	---------	---
Insecta	Coleoptera	Hydrophilidae	Berosus	sp.
Insecta	Odonata	Libelluidae	Pachydiplax	longipennis
Insecta	Odonata	Coenagrionidae	Ischnura	sp.
Insecta	Odonata	Agrionidae	---------	---
Insecta	Megaloptera	Sialidae	Sialis	sp.
Oligochaeta	Plesiopora	Naididae	---------	---
Oligochaeta	Plesiopora	Aelosomatidae	---------	---
Nematoda	---------	----------	---------	---

Cherokee Co. Lake No. 2

CLASS	ORDER	FAMILY	GENUS	SPECIES
Insecta	Diptera	Culicidae	Chaoborus	sp.

CLASS	ORDER	FAMILY	GENUS	SPECIES
Insecta	Diptera	Tendipedidae	---------	---
Insecta	Diptera	Ceratopagonidae	---------	---
Insecta	Trichoptera	Hydroptilidae	---------	---
Insecta	Coleoptera	Dytiscidae	*Dytiscus*	*sp.*
Insecta	Coleoptera	Hydrophilidae	*Berosus*	*sp.*
Insecta	Odonata	Coenagrionidae	*Argia*	*sp.*
Insecta	Odonata	Coenagrionidae	*Amphiagrion*	*sp.*
Insecta	Odonata	Coenagrionidae	*Ischnura*	*sp.*
Insecta	Odonata	Libelluidae	*Plathemis*	*sp.*
Insecta	Odonata	Coenagrionidae	*Anomalagrion*	*sp.*
Insecta	Odonata	Libelluidae	*Pachydiplax*	*sp.*
Insecta	Megaloptera	Sialidae	*Sialis*	*sp.*
Insecta	Ephemeroptera	Ephemeridae	*Hexagenia*	*sp.*
Oligochaeta	Plesiopora	Naididae	---------	---
Nematoda	---------	---------	---------	---
Acari	Oribatei	Oribatidae	*Hydrozetes*	*sp.*

Cherokee Co. Lake No. 3

Insecta	Diptera	Culicidae	*Chaoborus*	*sp.*
Insecta	Diptera	Tendipedidae	---------	---
Insecta	Diptera	Ceratopagonidae	---------	---
Insecta	Diptera	Tabanidae	---------	---
Insecta	Diptera	Sciomyzidae	---------	---
Insecta	Trichoptera	Limnephilidae	---------	---

CLASS	ORDER	FAMILY	GENUS	SPECIES
Insecta	Odonata	Coenagrionidae	*Anomalagrion*	*sp*.
Insecta	Odonata	Coenagrionidae	*Amphiagrion*	*sp*.
Insecta	Odonata	Coenagrionidae	*Ischnura*	*sp*.
Insecta	Odonata	Coenagrionidae	*Argia*	*sp*.
Insecta	Odonata	Libelluidae	*Pachydiplax*	*sp*.
Insecta	Odonata	Libelluidae	*Somatochlora*	*sp*.
Insecta	Megaloptera	Sialidae	*Sialis*	*sp*.
Insecta	Ephemeroptera	Ephemeridae	*Hexagenia*	*sp*.
Insecta	Ephemeroptera	Baetidae	*Caenis*	*sp*.
Insecta	Ephemeroptera	Baetidae	*Neocleon*	*sp*.
Oligochaeta	Plesiopora	Naididae	---------	---
Hirudinea	Rhynchobdellida	Glossiphoniidae	---------	---
Gastropoda	Pulmonata	Physidae	---------	---

Crawford Co. Lake No. 1

Insecta	Diptera	Culicidae	*Chaoborus*	*sp*.
Insecta	Diptera	Tendipedidae	---------	---
Insecta	Diptera	Ceratopagonidae	---------	---
Insecta	Diptera	Tabanidae	---------	---
Insecta	Coleoptera	Chrysomelidae	---------	---
Insecta	Odonata	Coenagrionidae	*Amphiagrion*	*sp*.
Insecta	Ephemeroptera	Baetidae	*Caenis*	*sp*.
Insecta	Lepidoptera	Pyralididae	---------	---
Oligochaeta	Plesiopora	Naididae	---------	---

CLASS	ORDER	FAMILY	GENUS	SPECIES
Nematoda	---------	---------	---------	---
Gastropoda	Pulmonata	Physidae	---------	---
Pelecypoda	---------	---------	---------	---

Crawford Co. Lake No. 2

CLASS	ORDER	FAMILY	GENUS	SPECIES
Insecta	Diptera	Culicidae	*Chaoborus*	*sp.*
Insecta	Diptera	Tendipedidae	---------	---
Insecta	Diptera	Ceratopagonidae	---------	---
Insecta	Coleoptera	Hydrophilidae	*Berosus*	*sp.*
Insecta	Coleoptera	Dytiscidae	*Dytiscus*	*sp.*
Insecta	Odonata	Coenagrionidae	*Amphiagrion*	*sp.*
Insecta	Odonata	Agrionidae	*Ischnura*	*sp.*
Insecta	Megaloptera	Sialidae	*Sialis*	*sp.*
Oligochaeta	Plesiopora	Naididae	---------	---
Acari	Oribatei	Oribatidae	*Hydrozetes*	*sp.*

Crawford Co. Lake No. 3

CLASS	ORDER	FAMILY	GENUS	SPECIES
Insecta	Diptera	Tendipedidae	---------	---
Insecta	Diptera	Ceratopagonidae	---------	---
Insecta	Megaloptera	Sialidae	*Sialis*	*sp.*
Acari	Oribatei	Oribatidae	*Hydrozetes*	*sp.*

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