This is to certify that the

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A LIMNOLOGICAL-BIOLOGICAL INVESTIGATION OF SPRING LAKE, MICHIGAN

By

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ABSTRACT

A LIMNOLOGICAL-BIOLOGICAL INVESTIGATION OF SPRING LAKE, MICHIGAN

By

Robert W. Bentz Jr.

This study provides background information on the physical, chemical, and biological parameters of Spring Lake, Michigan, gathered from March to October, 1976. Spring Lake has a surface area of 172,572 square meters with a maximum depth of 9.75 meters.

Thermal stratification was observed at the two deep-water stations from June through October. A clinograde oxygen curve appeared after thermal stratification was established.

Chemical characteristics were: total alkalinity, 152-196 mg/l; pH, 7.3-8.4; total hardness, 160-200 mc/l; Kjeldahl nitrogen, 0.47-0.55 mg/l; total phosphorus, 0.026-0.042 mg/l; calcium, 33.0-50.0 mg/l; and chlorides, 4.0-5.5 mg/l.

Seasonal distribution of phytoplankton was characteristic of medium hardwater lakes in the temperate region. Zooplankton populations were limited to nine genera. Of the aquatic insects, mayflies were most numerous in shallow water while chironomids were most abundant in deep water. Distribution and abundance of aquatic macrophytes were influenced by wave action and sediment characteristics. Bluegills exhibited a slower growth rate and lower coefficient of condition than the state average.

ACKNOWLEDGMENTS

I wish to express my appreciation to the property owners of Spring Lake for funding this research. I would like to acknowledge Michigan State University, Department of Fisheries and Wildlife for the use of their facilities and equipment.

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INTRODUCTION

Within the past decade a large number of lake surveys and water quality investigations have been conducted across the United States. The vast majority of these investigations have dealt with eutrophication or pollution problems occurring in lakes and streams with a resulting lack of good "background" water quality determinations (Edmondson, 1970). In many instances, we do not know what the lake conditions were before they became objectionable. This gap in our understanding makes it difficult to evaluate long-term water quality trends as they occur.

The purpose of this study is an attempt to provide such background information from one of the many small lakes located throughout Michigan. Physical, chemical, and biological parameters of Spring Lake, Montcalm County, were monitored extensively over a seven-month period from the vernal mixing period through summer stratification to the onset of fall overturn. The major objectives of this study are:

1. to provide a morphological description of Spring Lake;
2. to evaluate important chemical parameters of Spring Lake and record temporal and spatial deviations;
3. to describe the relative abundance, distribution, and diversity of aquatic macrophytes, plankton, invertebrates, and fish in Spring Lake.

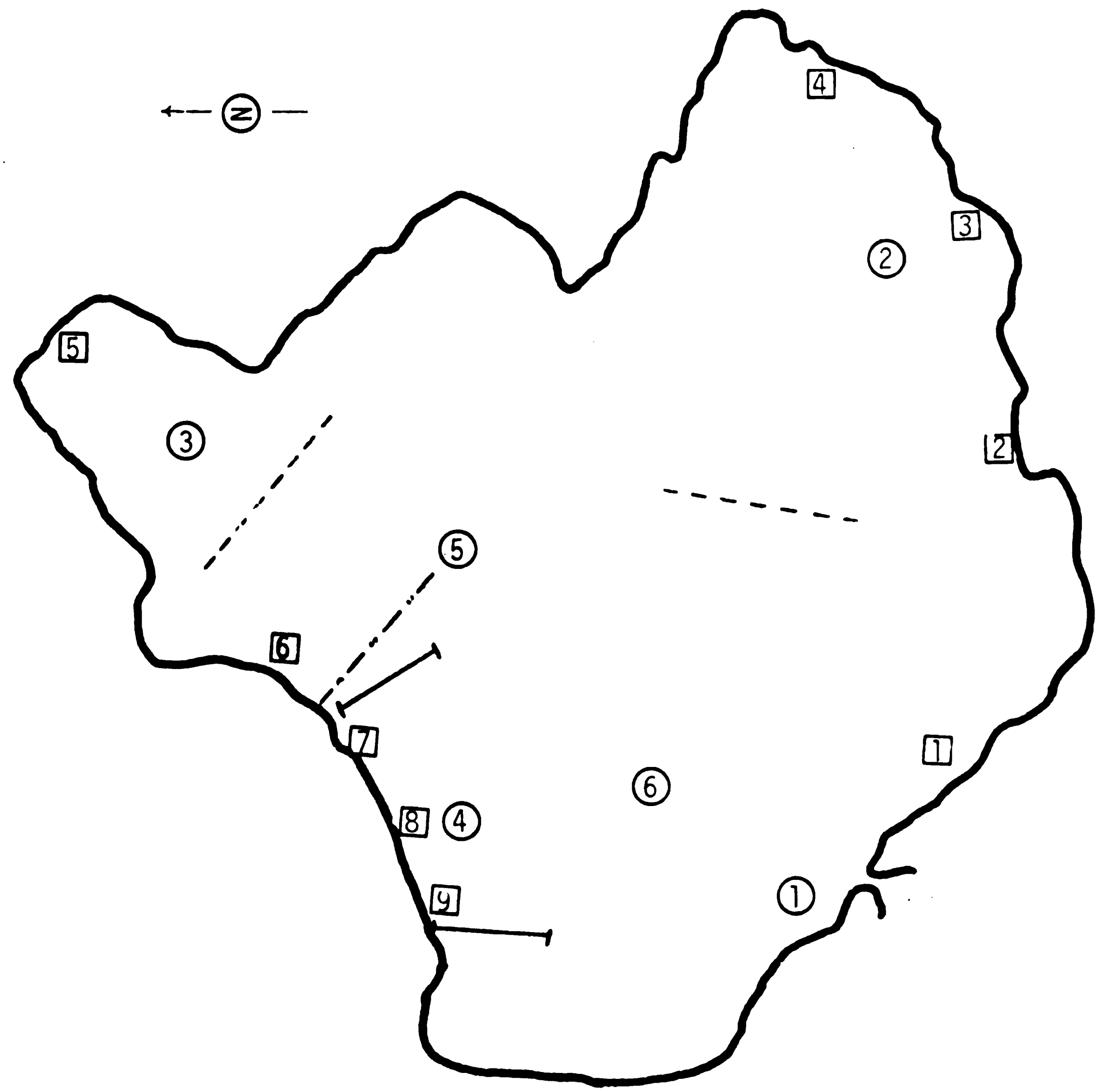
This study was initiated on March 24, 1976, and terminated October 24, 1976.

DESCRIPTION OF STUDY AREA

Spring Lake is located in the drainage basin of the Flat River (T11N, R8W, Sec. 22, Pine Township, Montcalm County). The Lake has a surface area of 172,572 square meters, and a mean and maximum depth of 2.19 meters and 9.75 meters respectively. The lake is fed by springs which emerge from the lake bottom. There are no inlets, and only one small outlet which connects Spring Lake with West Lake. Thirty-five summer cottages have been established around the lakeshore.

Six sampling stations within the lake were determined and permanently marked with anchored buoys (Figure 1). Stations 1, 2, 3, and 4 were situated in near-shore areas ranging in depth from .91 to 4.57 meters. Stations 1 and 4 had steeply sloped, predominantly marl bottoms with limited aquatic macrophyte colonization. The mud bottoms at Stations 2 and 3 were flat with an abundance of macrophytes. Stations 5 and 6 had depths of 8.0 and 9.14 meters respectively, and were located in the deepest portions of the central lake basin. No aquatic macrophytes were found at these stations.

Approximately 80% of the shoreline area consists of Rifle and Tawas peats (U. S. Department of Agriculture, 1960). These poorly drained organic soils are composed of woody and fibrous plant remains. The watertable is near the surface and the spongy soil is moderately



○ Major Sampling Stations

□ Chloride Sampling Stations

———— Experimental Gill Nets

-------- Horizontal Zooplankton Tows

—·—·—· Benthic Invertebrate Transect

Figure 1.--Locations of sampling stations, gill nets, zooplankton tows, and invertebrate transect on Spring Lake, Michigan.

acidic. Vegetation includes tamarack, red maple, and oak. Cleared areas support a dense growth of sedges and grasses.

The remainder of the lake's shoreline area is composed of Montcalm and McBride loamy sands. These well drained soils support a mixed hardwood and conifer forest with oak and maple dominating.

PHYSICAL AND CHEMICAL PARAMETERS

I. Morphology

A shoreline map of Spring Lake was constructed on March 24, 1977, using the plane-table survey method (Welsh, 1948). Nineteen stations around the lakeshore were selected to determine the shore configuration. Shoreline details were drawn in by walking around the lake. Hydrographic contours were determined with a Ray Jefferson Model 6010 Depth Finder and Precision Optical Range Finder.

Measurements of the lake map were made with a Dietzen Compensating Polar Planimeter and Dietzen Model 1718 Map Measurer. Methods used in calculating the areas, volumes, and various morphometric parameters are those given by Welsh (1975) and Cole (1975).

The areas and volumes within each contour stratum are shown in Figure 2 and are listed in Table 1. Other morphological parameters are listed in Table 2. Extensive shallows along the north and northwestern shores result in nearly 50% of the total lake surface area to be 3.05 meters (10 feet) deep or less which is equivalent to 60% of the total lake volume. Hard, compacted sediments with a high marl content and little vegetation characterized the shallow areas along the wave swept eastern shoreline. Shallow areas along the protected western shore had soft, organic sediments that supported large numbers of macrophytes.

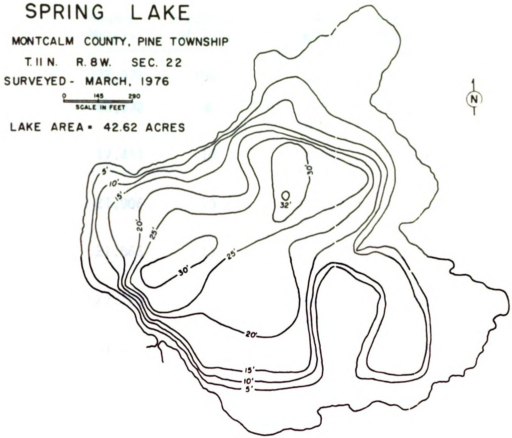


Figure 2.--Hydrographic map of Spring Lake, Montcalm County, Michigan.

TABLE 1.--Areas and volumes of water at various levels in Spring Lake.

Depth Feet (Meters)	Areas		Depth Stratum Feet (Meters)	Volumes	
	Square Meters	Percentage of Total		Cubic Meters	Percentage of Total
Surface	172,572	100	0-32	378,329	100
5 (1.52)	62,032	36	0-5 (0-1.52)	171,988	45
10 (3.05)	17,411	10	5-10 (1.52-3.05)	57,148	15
15 (4.57)	21,906	13	10-15 (3.05-4.57)	29,937	8
20 (6.10)	21,865	13	15-20 (4.57-6.10)	33,391	9
25 (7.62)	23,120	13	20-25 (6.10-7.62)	34,316	9
30 (9.14)	19,274	11	25-30 (7.62-9.14)	32,306	9
32 (9.75)	6,964	4	30-32) (9.14-9.75)	19,243	5

TABLE 2.--Morphometric features of Spring Lake.

Item	Value
Volume	378329 m^3
Surface Area	172572 m^2
Maximum Depth	9.75 m
Mean Depth	2.19 m
Maximum Length	565 m
Maximum Width	557 m
Average Width	305 m
Total Shorelength	1945 m
Shore Development	1.32
Water Exchange Rate	108 days

Discharge from the outlet channel was measured once in September, 1976, using the Embody float method (Kevern, 1973). The discharge from Spring Lake into West Lake was 0.04 cubic meters per second.

Rawson (1955) has stated that there is a definite correlation between mean depth and the standing crops of plankton, bottom fauna, and the sustained production of fish. Shallow lakes exhibit a higher carrying capacity than deep lakes. With a mean depth of only 2.19 meters, Spring Lake has the potential to be highly productive, based on its morphological characteristics.

Hooper (1955) studied the influence of alkalinity on lake basin shape in eight southern Michigan lakes. When the alkalinity exceeded 105 mg/l the marl precipitation and sedimentation rates increased greatly, forming sharp drop-offs into deep water.

This type of marl bench formation is found frequently in Spring Lake which has alkalinity values ranging from 150 to 180 mg/l. Perhaps the chemical mechanisms described by Hooper led to these formations.

II. Transparency

Water transparency was measured with a 20-cm Secchi disk approximately every two weeks at all sampling stations from April 10 to October 24, 1976. Exact sampling dates are listed in the Appendix, Table A1. The data are shown in Figure 3.

Average Secchi disk values for Spring Lake ranged from 2.07 to 3.78 meters during the sampling period. No significant differences in transparency were noted between any of the sampling stations. Early spring and late fall transparency values were higher than midsummer values although phytoplankton concentration (as measured by chlorophyll _a_) which usually lowers transparency, (Hutchinson, 1957) decreased throughout the sampling period. These low summer values may have been due to the frequent high winds. Heavy wave action can stir up and distribute decomposition products and debris from shallow areas throughout the water mass (Tressler and Domogalla, 1931). Another possible explanation for low transparency values may be the presence of suspended solids. Hooper and Ball (1964) found low

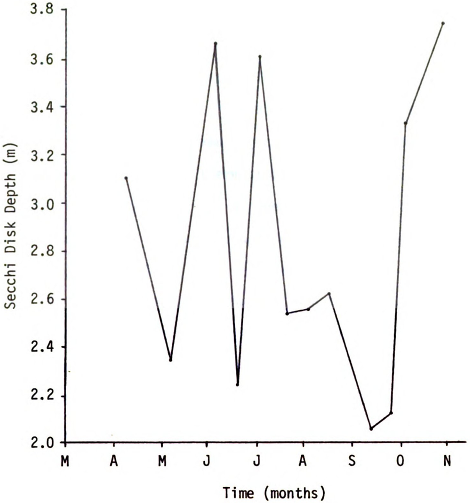


Figure 3.--Average Secchi disk transparency values for Spring Lake, Michigan.

transparency values in marl lakes was due to large amounts of suspended marl.

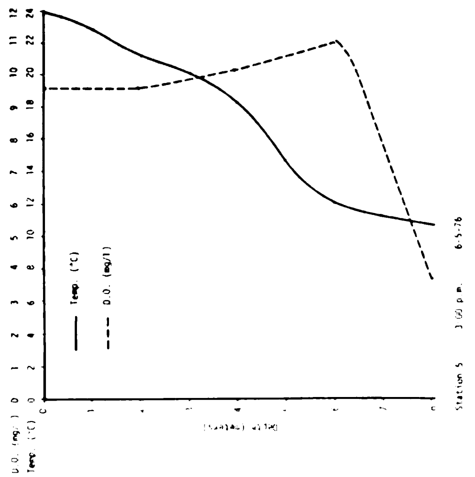
III. Temperature and Dissolved Oxygen

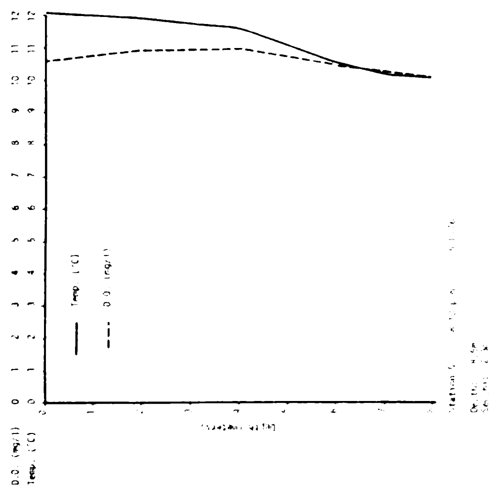
Water temperature was measured monthly from April 10 to October 23, 1977 (Appendix Table A1) at one-meter intervals from surface to bottom at all six sampling stations using a portable Y.S.I. telethermometer with a thermistor.

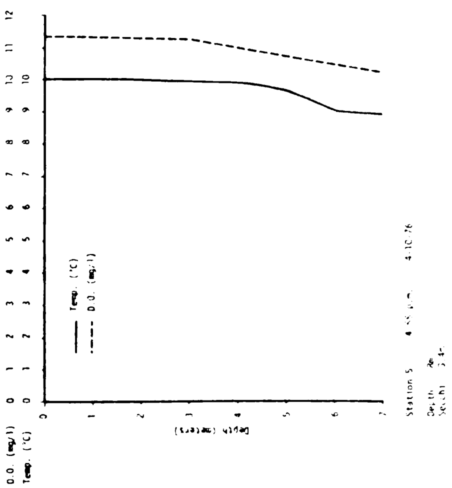
Dissolved oxygen profiles at one-meter intervals from surface to bottom were conducted simultaneously with temperature profiles at all stations (Appendix Table A1). Dissolved oxygen was measured in the field titrimetrically, using the azide modification of the Winkler iodemetric method (A.P.H.A., 1970), on samples collected with a one-liter Kemmerer bottle. Samples were allowed to overflow for 10 seconds before reagents were added, so that any bubbles which might have formed would be removed.

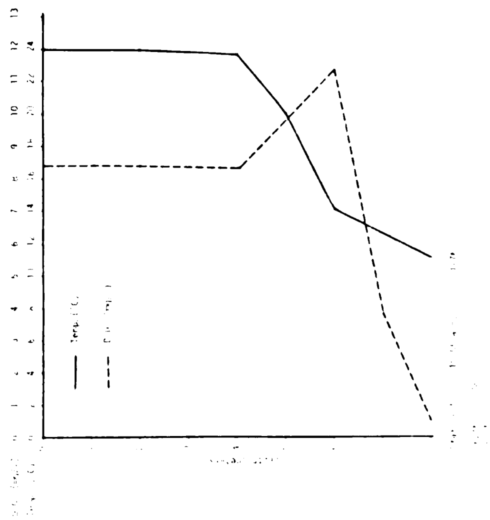
Spring Lake was dimictic, with complete mixing periods in mid-March and late October of 1975. Thermal stratification occurred between early June and late October (Figure 4). Only the deep-water Stations 5 and 6 became thermally stratified during the sampling period. Littoral Stations 1, 2, 3, and 4 exhibited uniform temperature profiles from surface to bottom. There were no observed horizontal variations in temperature between the deep-water and littoral stations.

Surface temperature varied from 10°C to 25°C during the sampling period. The upper four meters of water, or epilimnion, were









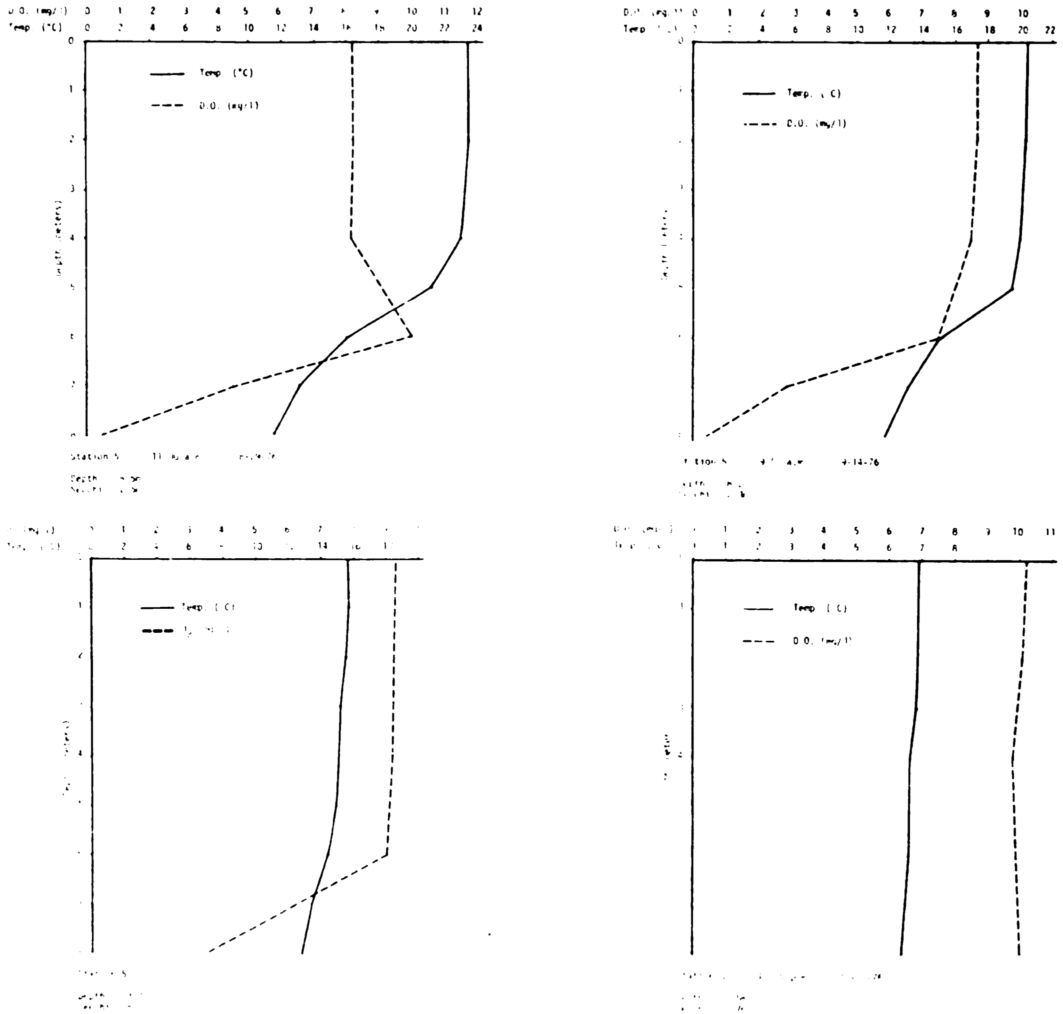


Figure 4.--Temperature (°C; solid line) and dissolved oxygen (mg/l; broken line) profiles at Station 5, Spring Lake from April through October, 1976.

homothermal for most of the summer. The temperature dropped sharply from four meters to six meters, the metalimnion, and the change was accentuated as the season progressed. At five meters the temperature varied from 9.7°C in early April to 22.3°C in late September. The temperature in the hypolimnion, near the bottom at eight meters, increased gradually from 8.8°C in April to 12.7°C in October. Hutchinson (1957) attributes this increase in hypolimnetic temperatures to a downward turbulent conduction of heat from warmer upper waters and to heating by chemically produced density currents.

Stratification of the vertical distribution of dissolved oxygen occurred at the two deep-water stations while uniform distributions were observed at the four littoral stations throughout the sampling period. No horizontal variations in oxygen concentrations were noted between the deep-water and littoral stations.

The dissolved oxygen distribution at the deep-water stations stratified by June 5, and established a clinograde curve with a metalimnetic maximum of 11.0 mg/l at six meters (Figure 4). Metalimnetic maxima are nearly always the result of oxygen produced by algal populations that are concentrated in this zone of high density water which retards the algal sinking rate (Wetzel, 1975). This maximum increased to 12.3 mg/l in July and then gradually decreased until a typical clinograde curve developed in September. The clinograde curve disappeared in October due to the autumn turnover and complete mixing of the lake water.

A maximum oxygen concentration of 10.1 mg/l occurred in the bottom water during the spring turnover in April. Depletion of oxygen in the hypolimnion began immediately after the lake stratified thermally. Dissolved oxygen concentrations within one-meter of the bottom dropped below 1.0 mg/l during a three month period from July through September. With the breakdown of thermal stratification and resultant mixing of the entire water column in late October, oxygen concentrations near the bottom increased to 10.0 mg/l.

IV. Alkalinity, pH, and Hardness

Values for alkalinity, pH, and hardness were determined in the field three times during the study period (Appendix Table A1). Samples were collected with a one-liter Kemmerer bottle. Water samples were taken just below the surface at all six sampling stations, with additional samples taken at the mid-depth and bottom levels of the two deep-water stations. Water entering the lake from one of the lake bottom springs was also sampled once during the study.

A Beckman portable pH meter was used to determine the pH. Total alkalinity (phenolphthalein alkalinity plus Bromcresol green alkalinity) was analyzed by the acid titration method (APHA, 1970). The EDTA titration method (Kevern, 1973) was employed to calculate hardness.

Spring Lake was consistantly alkaline, with pH values ranging from 7.3 to 8.4 during the study period (Figure 5; Appendix Table A2). Horizontal variations in pH between the different stations were small.

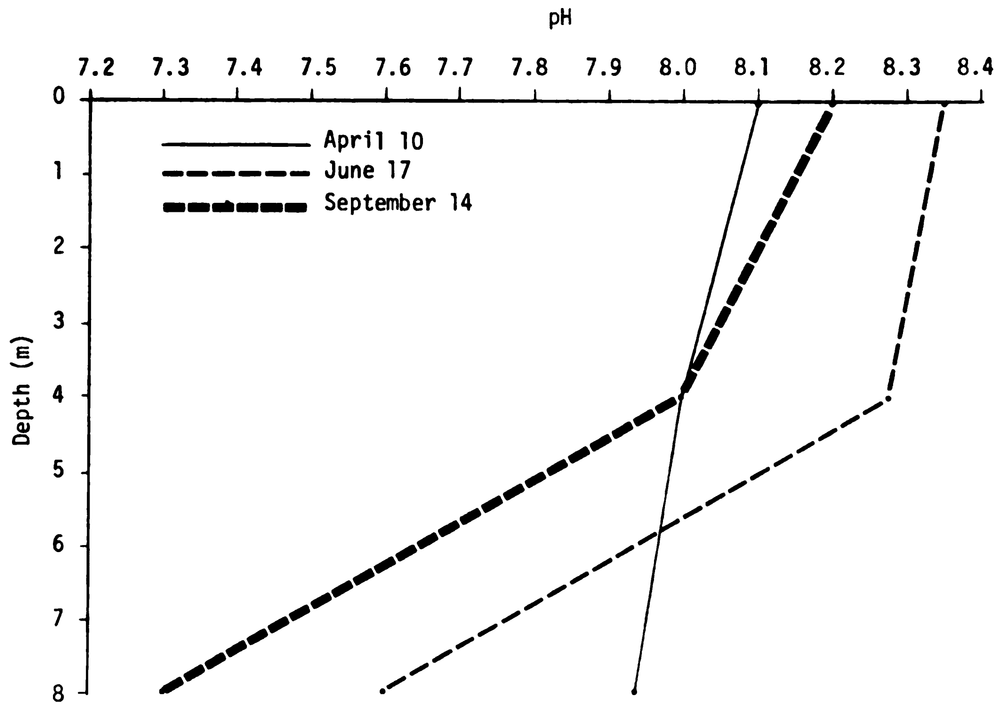


Figure 5.--Depth-pH curves for Station 5, Spring Lake, Michigan.

The surface was generally more alkaline than the mid-depth and bottom values although vertical differences at the two deep-water stations never exceeded 0.9 standard units. This observed decrease in pH at the lower depths has been attributed by Wetzel (1975) to respiratory generation of carbon dioxide in the tropholytic zone and sediments. Similar patterns of decreasing pH with increasing depth were reported in studies involving five Michigan lakes by Tucker (1957). The pH of the spring water was 7.5.

Total alkalinity as calcium carbonate ranged from 152 to 196 mg/l during the study period (Figure 6; Appendix Table 3A) with slight horizontal variations. Alkalinity values were fairly uniform throughout the water column during the spring mixing period. However, as thermal stratification developed and continued throughout the summer months, a decrease in alkalinity in the epilimnion with a concomitant increase in the hypolimnion was observed. Cole (1975) explains this increase in hypolimnetic alkalinity as the result of photosynthetic activity in the trophogenic zone which causes the precipitation of calcium carbonate. The sinking carbonate is redissolved in the hypolimnion by the carbonic acid formed from hydration of the carbon dioxide of decay. An alkalinity concentration of 180 mg/l was determined for the spring water.

Water hardness values ranged from 160 to 210 mg/l during the study period (Figure 7; Appendix Table 4A) and exhibited similar spatial and temporal characteristics to those of alkalinity. A slight decrease in hardness concentrations was observed during the

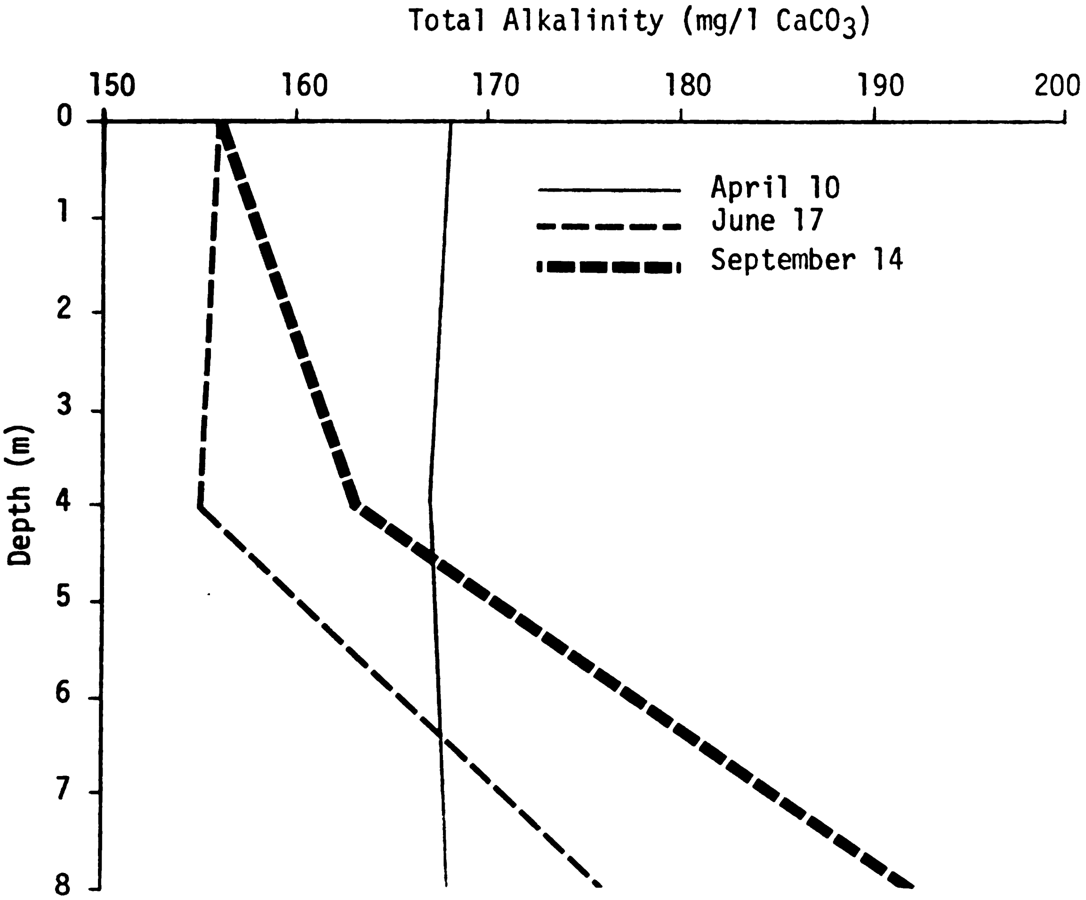


Figure 6.--Depth-total alkalinity curves for Station 5, Spring Lake, Michigan.

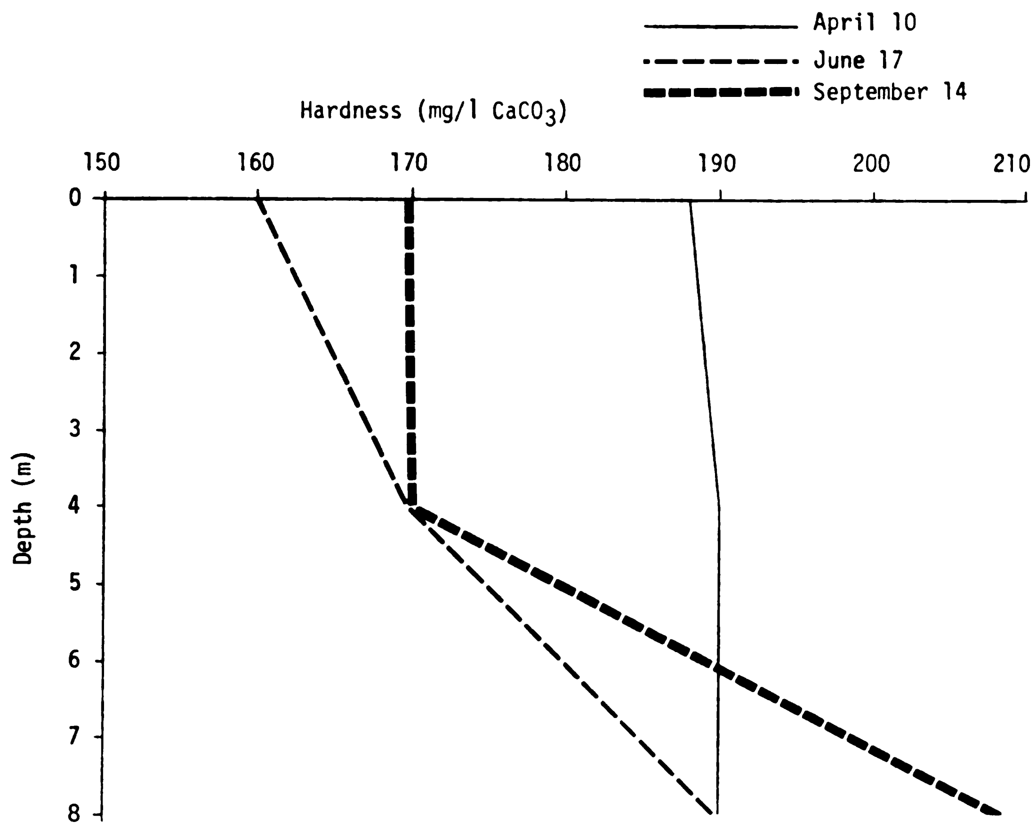


Figure 7.--Depth-hardness curves for Station 5, Spring Lake, Michigan.

study period. Spring Lake would be classified as a hard water lake (Kevern, 1973) based on an average hardness concentration of 163 mg/l. A hardness value of 200 mg/l was determined for the spring water.

V. Nitrogen and Phosphorus

Water samples for nitrogen and phosphorus determinations were collected concurrently with water samples for alkalinity, pH, and hardness (Appendix, Table 1A) and were taken to the Water Quality laboratory of the Institute of Water Research for analysis. Total phosphorus and total Kjeldahl nitrogen were determined on the Technician Auto-analyzer with the block digestion technique (U.S.E.P.A., 1974).

Total Kjeldahl nitrogen determines organically bound nitrogen and ammonia nitrogen (APHA, 1970). Average nitrogen concentrations decreased during the study period, ranging from 0.55 mg/l in April to 0.47 mg/l in September (Figure 8; Appendix Table A5). These nitrogen values would place Spring Lake into the meso-eutrophic category of Wetzel's (1975) classification.

Nitrogen concentrations in surface samples, which are dominated by dissolved organic nitrogen (Birge and Juday, 1922), exhibited little horizontal variation. Average nitrogen concentrations measured at the surface varied from 0.56 mg/l in April to 0.38 mg/l in September. Manny (1972) points out that algae and macrophytes are the major contributors to the dissolved organic nitrogen pool in the trophogenic zone.

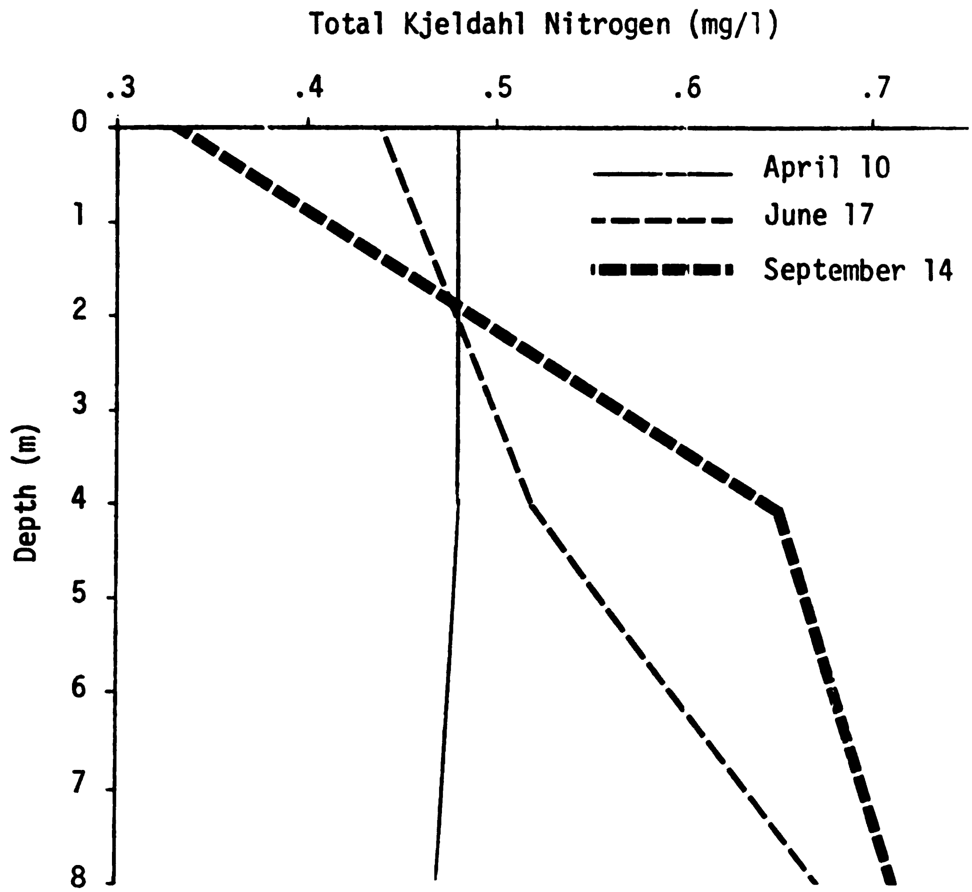


Figure 8.--Depth-total Kjeldahl nitrogen curves for Station 5, Spring Lake, Michigan.

Nitrogen concentrations near the bottom at the two deep-water stations were similar to surface concentrations during the vernal mixing period. As thermal stratification developed in June and continued through October, a concurrent increase in nitrogen to 0.71 mg/l was observed in the hypolimnion as nitrogen concentrations decreased in the epilimnion. Ruttner (1963) states that when oxygen concentrations in the hypolimnion decrease to less than 1.0 mg/l, denitrifying bacteria break down the organic nitrogen received from the epilimnion and convert it to ammonia nitrogen. Since the hypolimnetic oxygen concentrations in Spring Lake were below .5 mg/l for a three-month period, it seems likely that ammonia nitrogen was the dominant component in the bottom samples during this period. The nitrogen concentration in the spring water was 0.17 mg/l.

Total phosphorus includes soluble and insoluble; organic and inorganic forms (APHA, 1970). Average total phosphorus concentrations in Spring Lake ranged from 0.026 mg/l in April to 0.042 mg/l in June (Figure 9; Appendix Table 6A). These values slightly exceed the total phosphorus average of 0.023 determined by Juday and Birge (1931) for 479 lakes in northeastern Wisconsin, and are much greater than the 0.008 mg/l reported by Hooper and Ball (1964) from a marl lake in northern Michigan. In a study of 13 marl lakes in northern Indiana, Wetzel (1966) reported an average total phosphorus concentration of 0.018 mg/l. According to the lake classification table developed by Wetzel (1975), Spring Lake would be categorized as meso-eutrophic based on the total phosphorus concentrations.

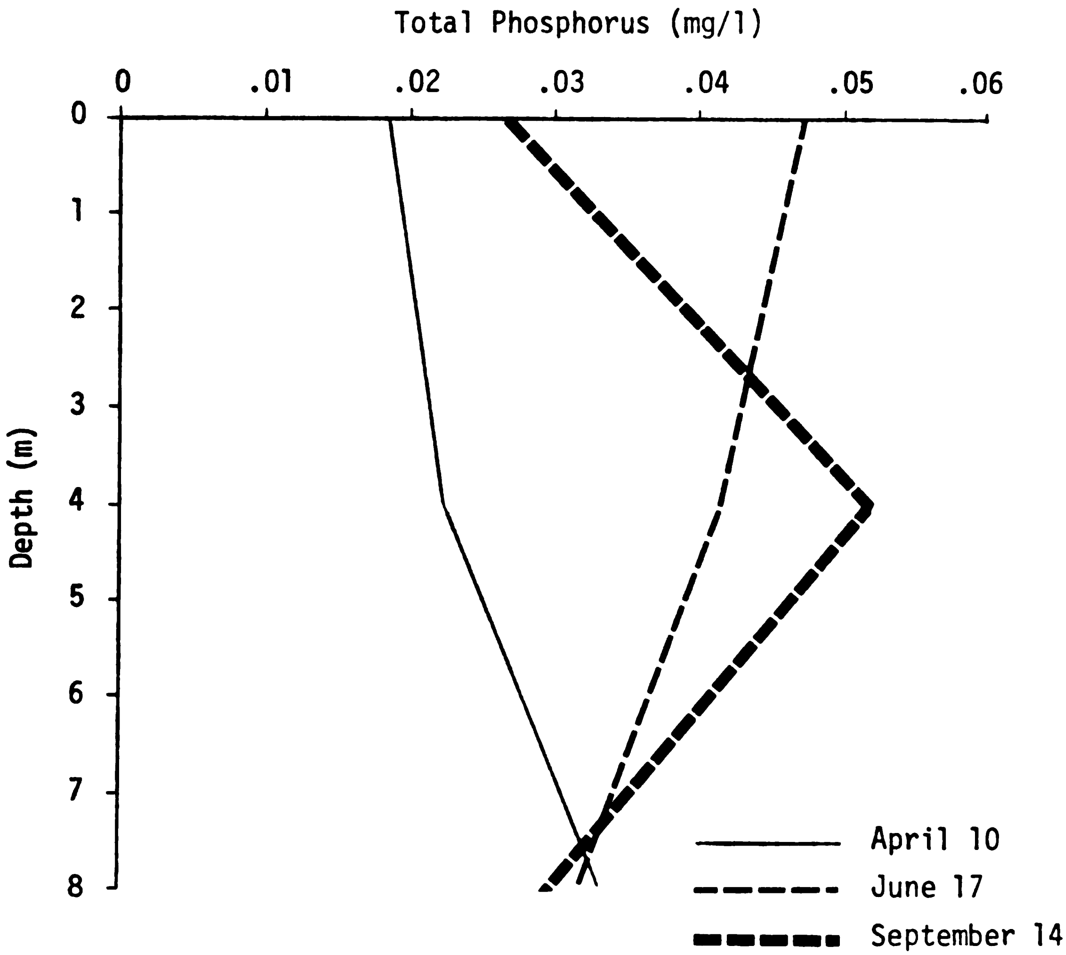


Figure 9.--Depth-total phosphorus curves for Station 5, Spring Lake, Michigan.

Phosphorus concentrations during the spring mixing period exhibited uniform vertical distribution which is characteristic of most lakes (Wetzel, 1975). In June, shortly after thermal stratification developed, a twofold increase in average phosphorus concentrations was observed. The cause of this increase in unknown.

Totla phosphorus concentration had become stratified by September. Surface concentrations averaged 0.023 mg/l which is identical to surface values determined in April. A marked increase in the quantity of total phosphorus was noted in the deeper waters of the lake where phosphorus values averaged 0.034 mg/l. This increase of phosphorus in the tropholytic zone has been documented in numerous studies (Juday and Birge, 1931; Hutchinson, 1941; Tucker, 1957; Wetzel, 1975). Two processes contribute to the increase. The first process is the constant transfer of phosphorus rich plankton and other organic material from the trophogenic zone (Juday and Birge, 1931; Wetzel, 1975). The second involves the release of phosphorus from the sediments during near anaerobic conditions (Hutchinson, 1941) which were observed in Spring Lake during this period. During periods of severe oxygen depletion, substantial quantities of phosphate, ammonia, and iron are released into the water from the sediments (Mortimer, 1971). The phosphorus concentration of the spring water was 0.010 mg/l.

VI. Calcium

Water samples for calcium determinations were collected concurrently with water samples for alkalinity, pH, and hardness

(Appendix Table 1A) and were taken to the Water Quality Laboratory of the Institute of Water Research for analysis. Calcium was determined with a Jarrell Ash Model 800 Atomic Absorption Spectrophotometer.

Calcium concentrations ranged from 33.0 to 50.0 mg/l during the study period (Figure 10; Appendix Table 7A). An average concentration of 46.2 mg/l was observed uniformly throughout the water column during the spring mixing period. Calcium stratitifcation occurred shortly after thermal stratification developed in June. Epilimnetic values decreased to 42.0 mg/l while hypolimnetic calcium concentrations increased to 50.0 mg/l. This calcium stratification became more pronounced in September as trophogenic values decreased to 33.0 mg/l while tropholytic values remained at 50.0 mg/l. Otsuki and Wetzel (1974) determined that the epilimnetic decalcification and concomitant increases in the hypolimnion were directly related to rapid increases in the photosynthetic rates of phytoplankton and littoral macrophytes, resulting in the precipitation of calcium carbonate. A calcium concentration of 46 mg/l was observed in the spring water.

Calcium values for Spring Lake were significantly higher than those reported by Hooper (1955) for eight southern Michigan lakes, but were slightly lower than the average calcium concentration in 13 marl lakes in northeastern Indiana (Wetzel, 1966).

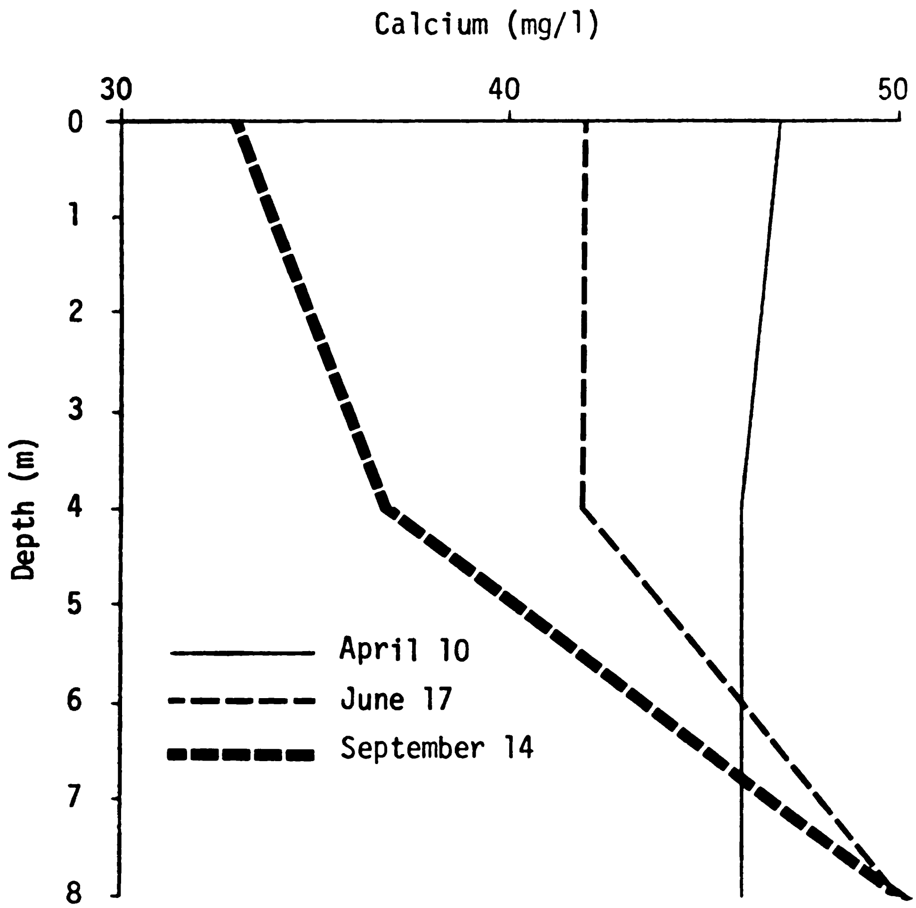


Figure 10.--Depth-calcium curves for stations, Spring Lake, Michigan.

VII. Chlorides

Water samples for chloride determinations were collected monthly from June through September (Appendix, Table 1A) at nine locations (Figure 1) along the lakeshore in shallow water less than one foot deep. Stations 2, 3, 4, 6, 7, 8, and 9 were located in areas with cottages while stations 1 and 5 were in undeveloped areas. The mercuric nitrate titration method (APHA, 1970) was used to determine chloride concentrations.

Chloride concentrations in Spring Lake ranged from 4.0 to 5.5 mg/l during the study period. High concentrations can indicate that the lake is receiving sewage wastes from faulty septic tank systems or municipal wastewater (Wetzel, 1975; Cole, 1975). Kevern (1973) states that cholride concentrations over 50 mg/l probably represent some type of human contamination. With the low chloride concentrations observed during the study period, it seems likely that Spring Lake receives no appreciable septic tank seepage from the cottages surrounding the lake.

BIOLOGICAL PARAMETERS

Phytoplankton, zooplankton, aquatic insect, aquatic macrophyte, and fish communities of Spring Lake were analyzed during the seven-month study period. The following sections deal with the methods used in collection and identification, and the results obtained.

I. Phytoplankton

Qualitative phytoplankton samples were taken with a one-liter Kemmerer bottle at all six sampling stations (Figure 1) approximately every two weeks from April through September, 1976 (Appendix, Table A1). Additional samples were collected at a depth of six meters at the two deep-water stations during the observed metalimnetic oxygen maximum. When brought to the surface, a 1% solution of Lugol's killing and preserving liquid was added to 0.5 liter. Samples were taken to the laboratory and allowed to settle. Each sample was reduced to 50 ml and centrifuges at 1400 R.P.M. for 20 minutes. The condensed algae were then transferred to a slide for identification and counting. Keys of Prescott (1951, 1970) were utilized in identifying the algae to the generic level.

Water samples for chlorophyll a determinations were collected once a week from May through September (Appendix, Table 1A) at Station 5 between 10 a.m. and 1 p.m. to estimate quantitative seasonal variations. Secchi disk transparency was first determined, after which a continuously-sampling weighted sample bottle was lowered to twice the Secchi disk depth. This procedure ensured a composite sample of the trophogenic water column. Samples were preserved with calcium carbonate to prevent the breakdown of chlorophyll a into pheophytin, and mailed to the Michigan Department of Natural Resources, Environmental Services, Environmental Support Laboratory in Lansing, Michigan, for analysis. The samples were filtered with an acetone soluble Millipore filter and analyzed according to Standard Methods (APHA, 1970).

Numerous studies have reported on the seasonal variation or periodicity of phytoplankton in freshwater lakes (Bozniak and Kennedy, 1968; Klak, 1937; Kraatz, 1941; Hutchinson, 1944, 1967; Lund, 1964, 1965; and Fogg, 1965). The phytoplankton of Spring Lake exhibited a characteristic seasonal variation which corresponds with many of these reports. A total of 34 genera were identified from the samples. A list of the phytoplankton found, with their relative abundance, is given in Table 3. A phytoplankton study conducted by Raymond (1937) on a marl lake in Michigan with chemical conditions similar to Spring Lake reported many of the genera observed in Spring Lake.

Diatoms, with Asterionella spp., Cyclotella spp., and Fragilaria spp. dominating, comprising 78% of the phytoplankton samples during April (Figure 11). This spring maximum by the Bacillariophyceae has been observed by Klak (1937) in 21 lakes in Minnesota and Kraatz (1941) in lakes of northern Ohio. Diatoms

TABLE 3.--List of phytoplankton collected in Spring Lake from April through September, 1976. Genera are listed in order of decreasing abundance within each phylum or subphylum

Chlorophyta

- *Oocystis spp.*
- *Gloeocystis spp.*
- *Spondylosium spp.*
- *Ankistrodesmus spp.*
- *Scenedesmus spp.*
- *Eudorina spp.*
- *Pandorina spp.*
- *Mougeotia spp.*
- *Pediastrum spp.*
- *Spirogyra spp.*
- *Zygnema spp.*
- *Cosmarium spp.*
- *Staurastrum spp.*

Chrysophyta:Chrysophyceae

- *Dinobryon spp.*
- *Chrysosphaerella spp.*
- *Synura spp.*

Chrysophyta:Bacillariophyceae

- *Cyclotella spp.*
- *Fragilaria spp.*
- *Asterionella spp.*
- *Navicula spp.*
- *Cymbella spp.*
- *Diatoma spp.*
- *Synedra spp.*
- *Tabellaria spp.*
- *Gomphonema spp.*

Cryptophyta

- *Cryptomonas spp.*

Cyanophyta

- *Microcystis spp.*
- *Aphanothece spp.*
- *Chroococcus spp.*
- *Merismopedium spp.*
- *Anabaena spp.*

Euglenophyta

- *Trachelomonas spp.*

Pyrrophyta

- *Ceratium spp.*
- *Gonyaulax spp.*

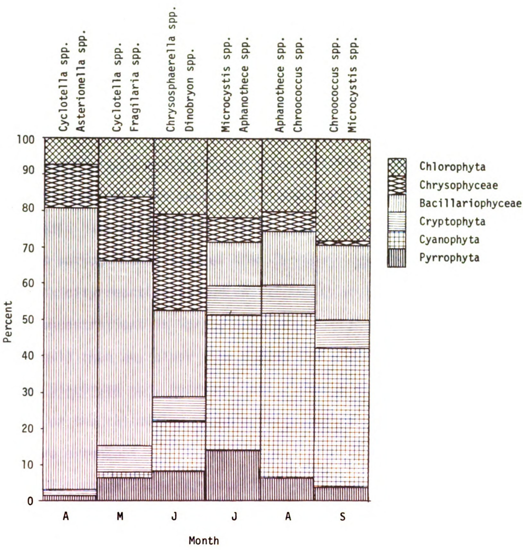


Figure 11.--Distribution of the major groups of phytoplankton and the dominant genera in Spring Lake based on monthly numerical averages of samples collected from April to September, 1976.

continued to dominate the phytoplankton community through May and early June, although they comprised only 32% of the total in June as members of the Cyanophyta, Chlorophyta, and Chrysophyceae increased numerically.

In mid-June the Chrysophyceae exhibited a large increase in numbers and became the dominant group with 33% of the total. Chrysophaerella spp. and Dinobryon spp. were the predominant genera during this period. The substantial numerical increase of Dinobyron spp. at this time is atypical. Lund (1965) states from his observations and various other studies that Dinobyron spp. exhibit a phosphorus toxicity reaction at concentrations above 0.030 mg/l. Phosphorus concentrations in Spring Lake were higher during this period (0.046 mg/l) than any other time during the study period. Thus, the observed Dinobryon spp. increases are either a clear exception to the rule or the calculated phosphorus concentrations during this period are erroneous.

Blue-green algae (Cyanophyta) became dominant in early July and remained so for the remainder of the study period. Microcystis spp., Aphanothece spp., and Chroococcus spp. were the predominant genera. This increase in the blue-green algae coincides with the maximum surface temperature observed during the study period which Fogg (1965) cites as a decisive factor in determining the seasonal occurrence of the Cyanophyta. The period of maximum development in the blue-green algae occurred in early August when they composed over 52% of the total sample. This predominance began to decrease shortly thereafter, until the Cyanophyta constituted only 39% of the total in mid-September.

The phytoplankton community responsible for the metalimnetic oxygen maximum described earlier had a similar composition to that of the surface waters. Blue-green algae were the dominant group at the six meter level with concentrations nearly identical to those at the surface. Genera of the Chrysophyceae, Cryptophyta, and Chlorophyta were more numerous in the metalimnetic samples than those at the surface.

Chlorophyll a has been shown to provide quantitative measurements of total organic material in the water (Ryther, 1956; Bachman and Jones, 1974). Raymont (1963) states that 1.0 μg of chlorrophyll a is approximately equal to 35.0 μg of dry organic matter. Chlorophyll a concentrations were used to estimate seasonal variations of the phytoplankton populations in Spring Lake.

Chlorophyll a concentrations based on vertical tows described above, ranged from 0.72 to 4.1 μg/l, or 25.2 to 143.5 μg.l dry organic matter during the study period (Figure 12). Chlorophyll values were high, averaging 2.61 μg/l during the vernal phytoplankton maximum period of May and early June with a steep drop to 0.72 μg/l observed in late June. This decrease in phytoplankton after the spring maximum is characteristic of lakes in the temperate region (Moss, 1972; Wetzel, 1975). Although the chlorophyll a concentration increased rapidly after the sudden decrease in June, a gradual decline was noted through the summer months of July, August, and

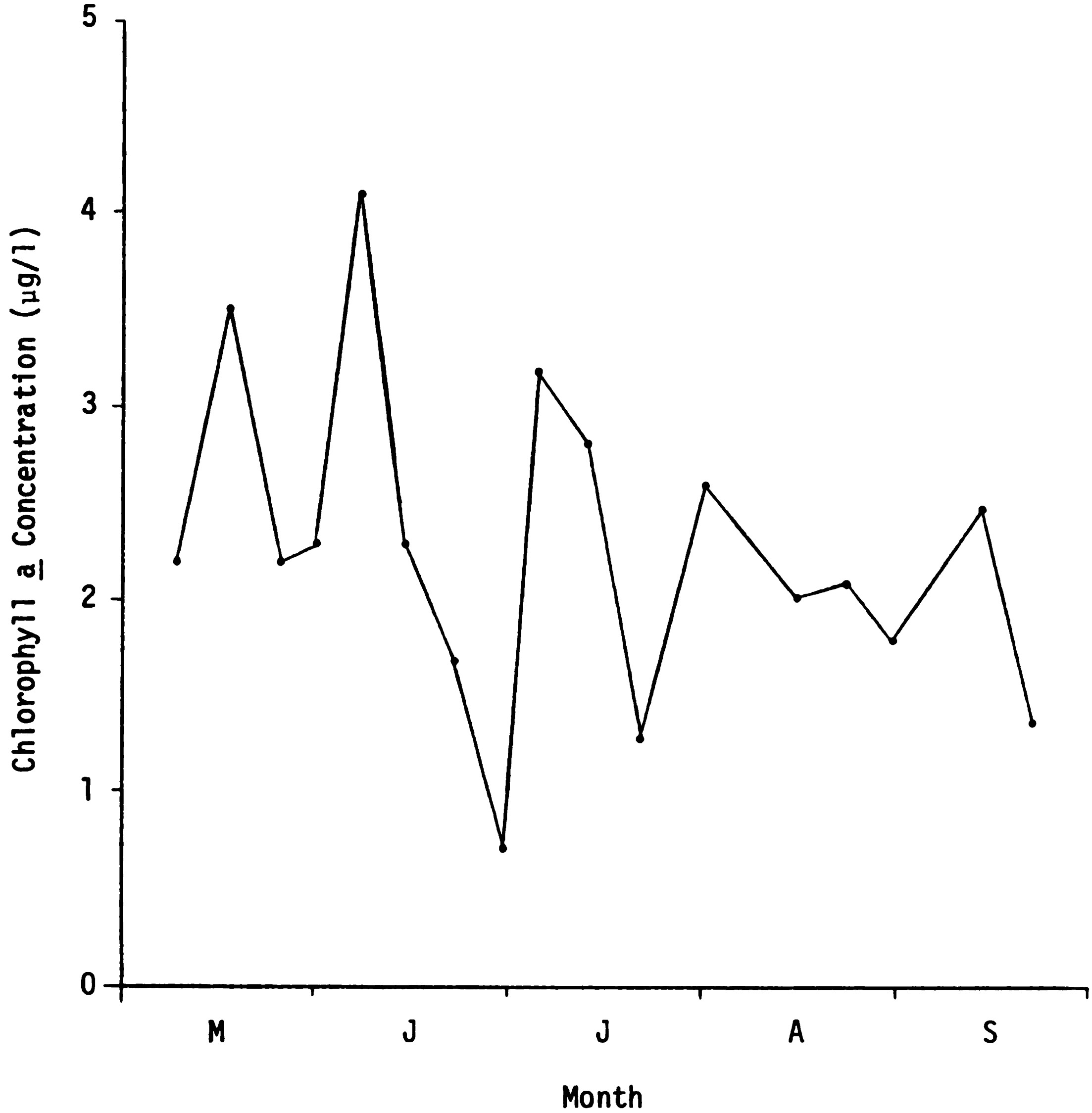


Figure 12.--Chlorophyll a concentrations at Station 5, Spring Lake from May through September, 1976.

September. This decline in chlorophyll would indicate a concomitant decline in the phytoplankton populations in Spring Lake. Lund (1965) explains that this decline in phytoplankton populations during the summer months is characteristic of most lakes except those that are highly eutrophic.

II. Zooplankton

Zooplankton populations were sampled monthly from April through September, 1976 (Appendix, Table 1A). Vertical samples were collected at Stations 5 and 6 and horizontal samples were obtained in two littoral areas exhibiting an abundance of aquatic macrophytes (Figure 1). Samples were collected in a Wisconsin style plankton net with a mesh size of 80 microns. The zooplankters were preserved with 37% formaldehyde and taken to the laboratory. Identifications were made from the keys in Pennak (1953) and Eddy and Hodson (1961).

The entomostracan populations in Spring Lake were confined to seven genera in the order Cladocera and two in the order Copepoda (Table 4). The genera observed are common to many lakes in North America. The number of cladoceran genera in Spring Lake is slightly higher than the average of two to four limnetic cladocerans reported by Pennak (1957) for small to medium-sized lakes of the world. The higher number of cladoceran genera may be due to the fact that littoral areas were also sampled. Pennak (1955) states that littoral populations of zooplankton are composed of more species and are less constant that limnetic populations.

Table 4 lists the distribution of zooplankton in Spring Lake based on the percentage of the total sample. Sida sp. and Bosmina sp. were found predominantly in the littoral area. Quade (1969) reports that aquatic macrophytes can control the distribution of littoral Cladocera. Daphnia sp., Diaphanosoma sp., and Simocephalus sp. were much more abundant in the limnetic samples.

The cladoceran populations exhibited one small increase in abundance in mid-June and another larger increase in late August and early September. These increases in abundance correspond with those reported by Pennak (1946) for seven lakes in Colorado and Hall (1964) for a lake in Michigan, although seasonal abundance of zooplankters is quite variable among different lakes and within lakes during different years (Wetzel, 1975).

The copepod Diaptomus sp. was observed more frequently than Cyclops sp. in the limnetic samples while the reverse occurred in the littoral areas. Studies by McQueen (1969) have shown that adult Cyclops sp. prey heavily on Diaptomus sp. nauplii. Predation of Diaptomus sp. by large numbers of Cyclops sp. in the littoral zones could have resulted in the low numbers of Diaptomus sp. found in these areas.

III. Aquatic Insects

Aquatic insects were sampled at 1.5 meter depth intervals on October 9, 1976, along a trasect from shore to Station 5 (Figure 1). Two samples were collected at each station with an Eckman dredge (6cm x 6cm) and washed in a No. 30 U. S. Standard Sieve with a mesh

TABLE 4.--Seasonal distributon of zooplankton genera in Spring Lake from April through September, 1976. Vertical and horizontal values listed are percentages of total sample based on four and two tows respectively (V=Vertical Tows, H=Horizontal Tows)

		April 10		May 8		June 17		July 19		August 15		September 12	
		H*	V	H	V	H	V	H	V	H	V	H	V
Cladocera													
Sididae	Diaphanosoma sp.	--	16.9	5.2	8.3	12.1	6.9	.9	6.4	3.0	1.6	0.8	3.5
	Sida sp.	--	--	1.3	--	--	--	.9	3.5	9.9	5.2	3.2	2.7
Bosminidae	Bosmina sp.	--	10.4	42.6	26.8	--	3.1	--	--	--	--	0.8	--
Daphnidae	Daphnia sp.	--	--	1.3	2.7	5.2	17.4	--	4.6	14.9	26.7	7.3	15.4
	Ceriodaphnia sp.	--	--	--	--	--	1.6	--	--	--	--	--	--
	Scaphloberis sp.	--	--	0.7	--	--	3.2	--	--	--	--	--	--
	Simocephalus sp.	--	--	--	--	--	--	--	--	3.5	19.5	2.4	9.8
Chydordae	Pleuroxus sp.	--	0.9	--	--	1.7	--	--	--	--	--	--	--
Copepoda:Calanoida													
Diaptomidae	Diaptomus sp.	--	4.2	7.7	15.7	12.1	22.9	8.9	12.9	24.4	13.0	13.0	14.5
Copedoda:Cyclopoida													
Cyclopidae	Cyclops sp.	--	25.9	8.4	15.2	37.9	23.5	43.4	31.4	17.9	21.4	32.5	32.3
Nauplii†		--	41.6	32.9	31.4	31.0	21.8	46.0	41.3	26.4	12.5	39.8	21.7

†Immature members of both suborders were added together.

*No horizontal samples were collected on this date.

size of 0.595 mm. The residue containing organisms and debris was preserved in a 37% formaldehyde solution and taken to the laboratory. The organisms were removed by careful picking and identified with the aid of Usinger (1956) and Hilsenhoff (1975).

The order Ephemeroptera is represented by four families which were found predominantly in shallow water less than 3.0 meters in depth. The sediments of this zone consisted of marl, sand, and organic material which formed a cohesive substrate. A list of aquatic insects collected and their depth distribution is given in Table 5.

TABLE 5.--Number of aquatic insects collected in two Eckman Dredge samples on October 9, 1976, along a transect from shore to Station 5 on Spring Lake

Order	Family	Genus	Depth of Water		
			0-3 Meters	4-6 Meters	7-9 Meters
Anisoptera	Gomphidae		2		
Diptera	Ceratopogonidae		1		
	Chaoboridae				27
	Chironomidae		1	21	301
Ephemeroptera	Caenidae		1		
	Ephemerellidae		4		
	Ephemeridae	Hexagenia	28	2	
	Heptageniidae			1	
Trichoptera	Leptoceridae		9	7	1

Caddisflies of the family Leptoceridae were located exclusively on the various aquatic macrophytes rooted in the bottom. The number of Leptoceridae declined rapidly below a depth of 6.0 meters. This decline may have been due to the decrease in macrophyte abundance which occurred at the 7.5 meter level.

The Diptera exhibited a marked increase in numbers with depth. The largest concentrations were recorded at the 7.0 to 9.0 meter level where the sediment ooze was composed of organic particles and decaying leaves. A large percentage of the total Chironomidae population probably excaped capture due to the large mesh size of the seive used. Studies by Jonasson (1955) indicate that mesh sizes above 0.4mm capture only a fraction of the chironomids present during a period from July to November.

IV. Aquatic Macrophytes

The aquatic macrophyte distribution in Spring Lake was surveyed qualitatively in early September, 1976. Plants were collected by hand and a weed grapple along numerous transects from shore to deep water around the lake. Identification was conducted in the field with the aid of Fassett (1957).

A list of the aquatic macrophytes and macroalgae identified is given in Table 6. The distribution of aquatic plants in Spring Lake at depths up to 3.0 meters was greatly influenced by the degree of exposure and resulting sediment characteristics of the area. Macrophyte zonation due to sediment type in Wisconsin lakes is discussed in detail by Wilson (1935). Hutchinson (1975) states that

TABLE 6.--List of aquatic macrophytes and macroalga in Spring Lake, September, 1976

Brasenia Schreberi	Gmel.
Chara spp.	
Elodea canadensis	Michx.
Najas flexilis	(Willd.)
Nitella spp.	
Nymphaea odorata	Ait.
Polygonum coccineum	Muhl.
Pontederia cordata	L.
Potamogeton lucens	L.
Potamogeton natans	L.
Potamogeton pectinatus	L.
Potamogeton pusillus	L.
Potamogeton Richardsonii	(Benn.)
Scirpus americanus	Pers.
Typha latifolia	L.
Utricularia spp.	

sediment characteristics may be the controlling factor in macrophyte distribution.

Shallow areas along the western and northwestern shores, which were protected from the prevailing westerly winds, exhibited a soft, highly organic bottom as reported in the morphology section. The greatest concentrations and most diverse populations of macrophytes were observed in these shallows from shore to a depth of 1.0 meter. Potamogeton pectinatus, P. lucens, P. natans, Elodea canadensis, Utricularia sp., Brasenia Schreberi, and Polygonum coccineum were found sparingly with Chara spp. and Najas flexilis dominating. With an increase in depth to 2.0 meters the various species of pondweed observed in the shallow water became much more abundant as the amount of Chara spp. decreased. Najas flexilis remained the predominant species. The four small groups of Nymphaea odorata situated along the western shore were located within the 2.0 to 3.0 meter contour. Potomogetan pusillus and Chara spp. became the dominant submerged macrophytes at these depths as Najas decreased in abundance.

The eastern shores presented a contrasting type of flora due to constant exposure to the westerly winds and the resulting dense, coarse sediments of intermixed sand and marl. From the shore to a depth of 1.0 meter the bottom was nearly barren. The only macrophyte growing in abundance was the bulrush Scirpus americanus, which was observed in large numbers along most of the shoreline and upon an extensive sandbar, with a few scattered specimens of Chara supp. and

Utricularia spp. Rich, et al., (1971) states that sparse vegetation on shallow marl benches is characteristic of marl lakes in the Great Lakes region.

Macrophyte zonation between 1.0 and 3.0 meters was similar to that found on the western shore. However, the Potamogeton spp. which were much less abundant and Chara spp. which dominated, were both smaller in stature than their counterparts of the western shore. Najas flexilis was rarely observed on the eastern shore.

At depths below 4.0 meters the macroalgae Nitella spp. were the only plants observed. It formed dense, continuous beds over most of the bottom to a depth of 8.0 meters. This complete take-over by Nitella spp. at lower depths was also observed in four medium hardwater lakes in Wisconsin (Wilson, 1935, 1941). Below 8.0 meters the sediments were soft and composed of partially decomposed oak and maple leaves. No macrophytes were found at these depths.

V. Fish

A total of 163 bluegill sunfish (Lepomis macrochirus) were collected throughout the summer of 1976. Five additional species, Micropterus salmoides, Pomoxis nigromaculatus, Amploplites rupestris, Perca Flavescens and Esox lucius were collected in small numbers. Collections were made with two experimental gill nets, 5.5 feet by 200 feet, with four sections of different mesh sizes (1, 2, 3, and 4 inches stretched mesh respectively, as manufactured), a "common sense" minnow seine, and by angling. Each fish was measured to the nearest millimeter for total and standard length. Weight was measured to the nearest gram for fish larger than 20 grams and to the nearest tenth of a gram for fish under 20 grams.

The scale method as described by Lagler (1956) and validated by Regier (1962) was employed in assessing age and growth characteristics. Scale samples were collected by removing approximately 10 to 20 scales from the area below the origin of the dorsal fin and just below the lateral line. After drying, 5 to 10 scales from each fish were placed between pieces of cellulose acetate and impressions were made with a roller press as described by Smith (1954). These impressions were then enlarged and examined on a Bausch and Lomb microprojector.

From magnified impressions of the scales, positions of the annuli in relation to the scale focus were measured to the nearest millimeter along the scale radius on scale cards. The back-calculated total lengths at each annulus was determined by a nomograph as described by Carlander and Smith (1944).

To estimate the length of a fish at the time of previous annuli formation, a regression must be calculated between the length of the fish and its scale radius. The regression equation representing the body-scale relationship is:

$$TL = a + b\,(SR)$$

where TL is the total length of the fish in millimeters

a is equal to the total length intercept when the scale radius equals 0

b is equal to the close of the regression line

SR is the scale radious magnified 22 times and measured in millimeters (Armstrong, 1973).

The body-scale relationship was determined from 80 fish. A straight line having the equation:

$$TL = 18 + 10.8\ SR$$

best describes the relationship.

The back-calculated total length at each annulus for 163 bluegills is presented in Table 7. Very little incremental growth was observed during the second year while growth rates increased during the third, fourth, and fifth years. A decrease in growth was again noted in the sixth year.

A comparison of the growth rates for bluegills in Spring Lake and a state average established by the Research and Development Division of the Michigan Department of Natural Resources is presented in Figure 13. Bluegills in Spring Lake exhibit a very low growth rate during their first two years. Their rate of growth parallels the state average beyond the second year, and is slightly higher beyong the fourth year, but is never able to overcome the deficit created during the initial two years of growth. Growth rates determined for bluegills in Spring Lake were significantly lower than those reported by Carlander (1953) for 21 lakes througout the United States.

Age and growth characteristics determined for largemouth bass, black crappie, rockbass, yellow perch, and northern pike are given in Appendix Tables 8A, 9A, 10A, 11A, and 12A respectively.

TABLE 7.--Number, ages, mean weights, mean calculated total lengths, mean total lengths at capture, mean growth increments, and mean coefficient of condition factors of bluegills from Spring Lake, Michigan

Age Group	Number in Sample	Mean Weight (gm)	Mean Total Length at Capture (mm)	Mean Calculated Length (mm) at Ages						Coefficient of Condition
				1	2	3	4	5	6	
1	3	3.2	61	48						2.98
2	28	5.3	70	37	57					3.19
3	32	14.0	94	37	56	78				3.55
4	51	40.8	133	37	53	78	108			3.62
5	44	81.5	166	37	53	72	102	138		3.59
6	5	99.8	178	36	53	71	96	122	153	3.59
Mean Total Length (mm) at each annulus				37	54	76	105	136	153	
Mean growth increment				37	17	22	29	31	17	

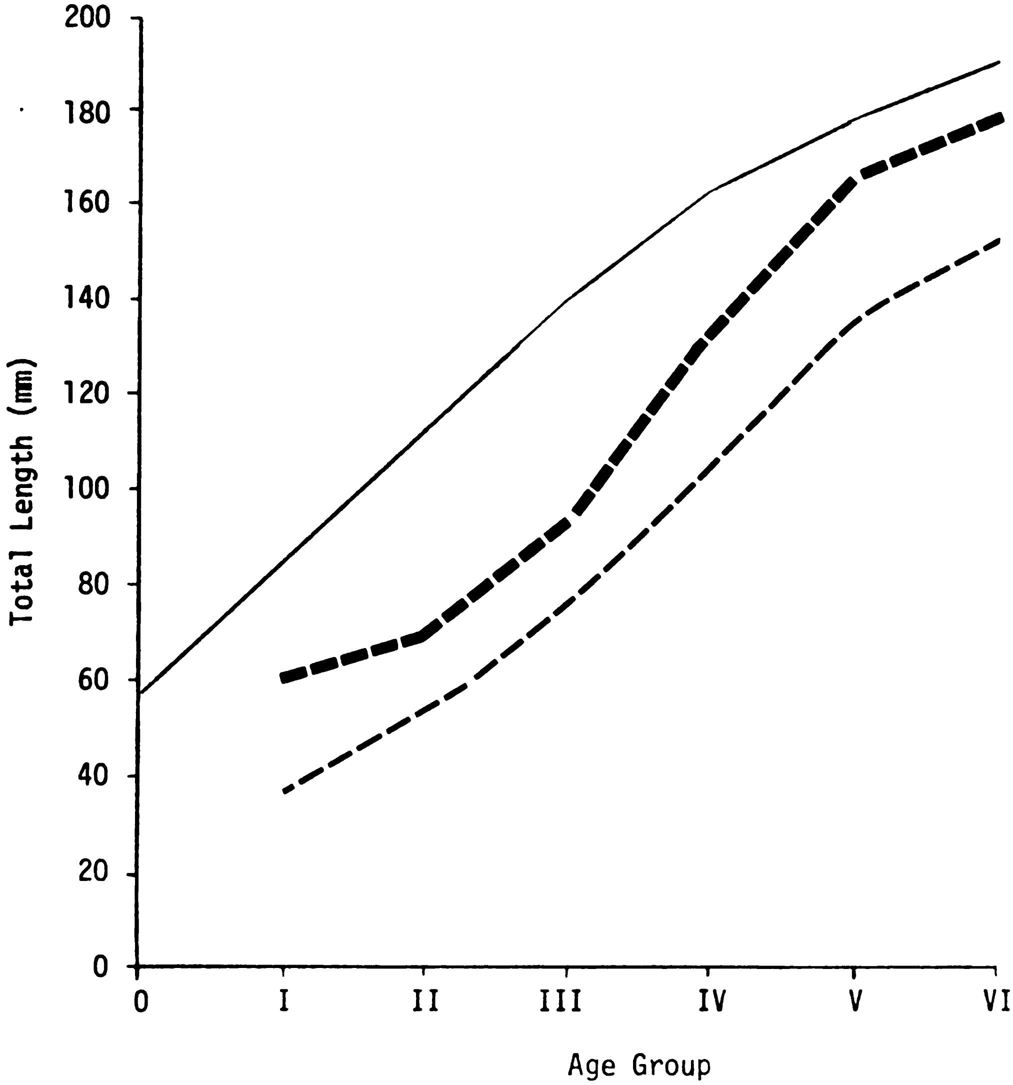


Figure 13.--Mean calculated total length for bluegills in Spring Lake (dashed line). Mean total length at capture for bluegills in Spring Lake (thick dashed line) and Michigan State average (solid line).

The length-weight relationship is described by the formula:

$$\text{Log } w = \log a + b \text{ Log SL}$$

where b represents the slope of the line

a represents its "y" intercept

w equals the weight

SL equals the standard length.

In determining the length-weight relationship for bluegills, a scatter diagram was constructed by plotting the standard length in millimeters and weight in grams for each fish. The logs of ten equidistant points on this graph were determined and plotted in Figure 14. Calculations indicated that the equation:

$$\text{Log } W = -4.6405 + 3.0857 \text{ Log SL}$$

best described the length-weight relationship for bluegills in Spring Lake.

The coefficient of conditon, K, is an index of the general plumpness or robustness of fish. The formula used to determine "K" values is:

$$K_{TL} = \frac{W \times 10^5}{TL^3}$$

where K_{TL} is the condition factor based on total length

W is the weight in grams

TL is the total length in millimeters (DiCostanzo, 1975).

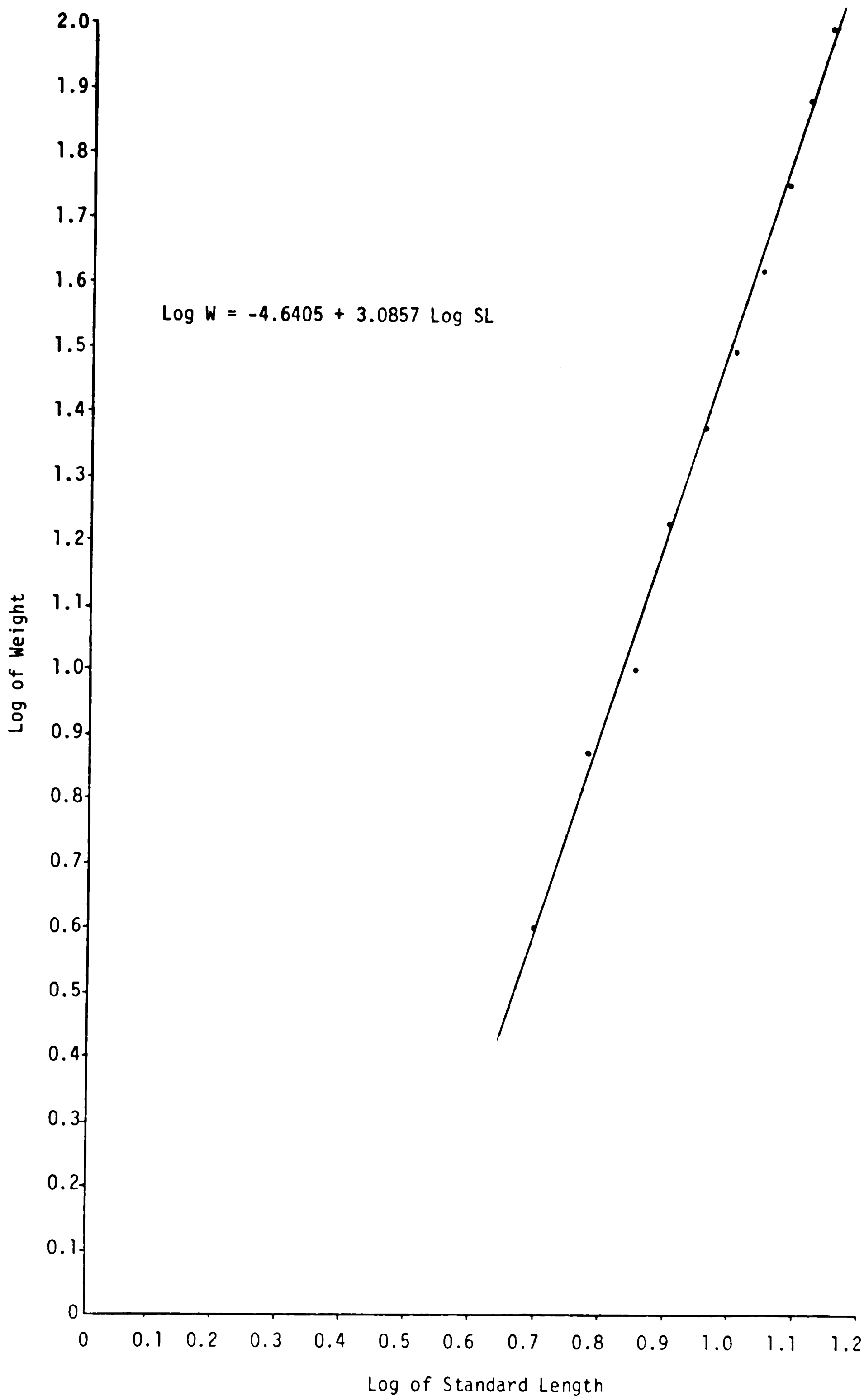


Figure 14.--Length-weight relationship for 163 bluegills from Spring Lake, Michigan.

The condition value for each age group of bluegill is given in Table 7. Condition values ranged from 2.89 for age 1 bluegills, increasing to 3.59 for ages 5 and 6.

Carlander (1944) states that condition values of 3.3 to 4.0 were average for bluegills in Minnesota lakes. In a survey of over 500 Michigan lakes, Beckman (1948) reported mean condition factors ranging from 3.42 to 3.88 for bluegills of sizes comparable to those found in Spring Lake.

SUMMARY

1. This study was initiated to provide background information on Spring Lake, Montcalm County, Michigan. Physical, chemical, and biological parameters were monitored over a seven-month period from March 24, 1976, to October 23, 1976.

2. The shoreline area was predominantly composed of Rifle and Tawas peats with a small amount of Montcalm loamy sand. These soils supported a mixed hardwood and conifer forest.

3. A hydrographic map was constructed and used to determine various morphological statistics. The surface area was 172,572 square meters with a maximum depth of 9.75 meters. Total volume equaled 378,328 cubic meters.

4. Thermal stratification was only observed at the two deep-water stations and occurred between early June and late October. Surface temperature varied from 10° to 25°C during the sampling period. The metalimnion was located between four and six meters. A clinograde oxygen curve appeared after thermal stratification was established. A metalimnetic oxygen maxima occurred at six meters during July and August. Dissolved oxygen concentrations in the hypolimnion fell to less than 1.0 mg/l during a three month period from July to September.

5. Total alkalinity ranged from 152 to 196 mg/l as $CaCO_3$; pH ranged from 7.3 to 8.4; total hardness varied from 160 to 210 mg/l as $CaCO_3$. Average total Kjeldahl nitrogen concentrations ranged from 0.55 to 0.47 mg/l while the average total phosphorus concentrations varied from 0.026 to 0.042 mg/l. Calcium ranged from 33.0 to 50.0 mg/l, and chlorides varied slightly from 4.0 to 5.5 mg/l.

6. Thirty-four phytoplankton genera were identified. Seasonal distribution of phytoplankton was characteristic of medium hardwater lakes located in the temperate region. Diatoms dominated in the spring and then exhibited a steady decline in abundance. Blue-green algae increased in abundance as the summer progressed and constituted the major component of the phytoplankton population from early July until mid-September. Chlorophyll a values varied from 0.72 to 4.1 μg/l which is equivalent to 25.2 to 143.5 μg/l dry organic weight.

7. Zooplankton populations collected were confined to seven genera in the order Cladocera and two in the order Copepoda. Two peaks in abundance were observed; one in mid-June, and another in late August.

8. Nine families of aquatic insects were collected. Mayflies were the most numerous and also restricted to shallow, well oxygenated sediments while members of the Chironomidae were most abundant in the deeper water where oxygen concentrations were low during thermal stratification.

9. Thirteen species and three genera of aquatic macrophytes and macroalgae were identified. Distribution at depths up to three meters was greatly influenced by the degree of exposure and resulting sediment characteristics.

10. Bluegill sunfish, largemouth bass, black crappie, rock bass, yellow perch, and northern pike were collected by a variety of methods. Bluegills exhibited a very slow growth rate during the first two years and never equaled the state average. Coefficient of condition values were also less than a state-wide average.

LITERATURE CITED

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American Public Health Assocation, American Water Works Association, Water Pollution Control Federation. 1970. Standard methods for the examination of water and wastewater. Amer. Publ. Health Assoc. New York. 874 pp.

Armstrong, J. W. 1973. Age, growth and food habits of the round whitefish, Prosopium cylindraceum (Pallus), in central Lake Michigan. M.S. Thesis, Michigan State University, East Lansing, 76 pp.

Bachmann, R. W., and J. R. Jones. 1974. Phosphorus inputs and algal blooms in lakes. Iowa St. J. Res., 49: 155-160.

Beckman, W. C. 1948. The length-weight relationship, factors for conversion between standard and total lengths, and coefficients of condition for seven Michigan fishes. Trans. Amer. Fish. Soc., 75: 237-256.

Birge, E. A., and C. Juday. 1922. The inland lakes of Wisconsin. The plankton, its quantity and composition. Bull. Wisc. Geol. Nat. Hist. Surv. 64, 1-222.

Bozniak, E. G., and L. L. Kennedy. 1968. Periodicity and ecology of the phytoplankton in an oligotrophic and eutrophic lake. Can. J. Bot. 46: 1259-1271.

Carlander, K. D. 1944. Notes on the coefficient of condition, K, of Minnesota fishes. Minn. Bur. Fish. Res. Invest. Rept. 41, revised, 40 pp., typed. In Carlander, K. D. 1953. Handbook of freshwater fishery biology. Wm. C. Brown Co., Dubuque, Iowa. 429 pp.

________. 1953. Handbook of freshwater fishery biology. Wm. C. Brown Co., Dubuque, Iowa. 429 pp.

________, and L. L. Smith, Jr. 1944. Some use of nomographs in fish growth studies. Copeia, 3: 137-162.

Cole, G. A. 1975. Textbook of limnology. C. V. Mosby Co. St. Louis, Mo. 283 pp.

DiCostanzo, C. J. 1957. Growth of bluegill, Lepomis macrochirus, and pumpkinseed, L. gibbosus, of Clear Lake Iowa. Iowa St. Coll. J. Sci. 32: 1-34.

Eddy, S., and A. C. Hodson. 1961. Taxonomic keys to the common animals of the north central states exclusive of the parasitic worms, insects and birds. Burgess Pub. Co. Minneapolis. 162 pp.

Edmondson, W. T. 1970. Eutrophication in North America. In Eutrophication: causes, consequences, correctives. Washintong, D. C., National Academy of Sciences, pp. 124-150.

Fassett, N. C. 1957. A manual of aquatic plants. U. of Wisc. Press, Madison. 405 pp.

Fogg, G. E. 1965. Algal cultures and phytoplankton ecology. U. of Wisc. Press, Madison. 126 pp.

Hall, D. J. 1964. An experimental approach to the dynamics of a natural population of Daphnia galeata mendotae. Ecology, 45: 94-112.

Hilsenhoff, W. L. 1975. Aquatic insects of Wisconsin with generic keys and notes on biology, ecology, and distribution. Tech. Bull. 89, Dept. of Nat. Res., Madison. 52 pp.

Hooper, F. F. 1955. Some chemical and morphometric characteristics of southern Michigan lakes. Mich. Acad. Sci., Arts, and Let., Pap., 41: 109-130.

Hooper, F. F., and R. C. Ball. 1964. Responses of a marl lake to fertilization. Trans. Amer. Fish. Soc., 93: 164-173.

Hutchinson, G. E. 1941. Limnological studies in Connecticut. IV. The mechanisms of intermediary metabolism in stratified lakes. Ecol. Monog., 11: 21-60.

________. 1944. Limnological studies in Connecticut. VII. A critical examination of the supposed relationship between phytoplankton periodicity and chemical changes in lake waters. Ecology, 25: 3-25.

________. 1957. A treatise on limnology. I. Geography, physics, and chemistry. John Wiley and Sons, Inc., New York, 1015 pp.

________. 1967. A treatise on limnology. II. Introduction to lake biology and the limnoplankton. John Wiley and Sons, Inc., New York, 1115 pp.

Hutchinson, G. E. 1975. A treatise on limnology. III. Limnological botany. John Wiley and Sons, Inc., New York, 660 pp.

Jonasson, P. M. 1955. The efficiency of sieving techniques for sampling bottom freshwater fauna. Oikos, 6: 183-207.

Juday, C., and E. A. Birge. 1931. A second report on the phosphorus content of Wisconsin lake water. Trans. Wisc. Acad. Sci., Arts, and Let., 26: 353-382.

Kevern, N. R. 1973. A manual of limnological methods. Department of Fisheries and Wildlife, Michigan State University. East Lansing. 157 pp.

Klak, G. E. 1937. A comparative study of summer plankton from twenty-one bodies of water in the vicinity of Minneapolis and St. Paul, Minnesota. Amer. Micros. Soc. Trans., 56: 196-202.

Kraatz, W. C. 1941. Quantitative plankton studies of Turkeyfoot Lake, near Akron, Ohio. Ohio J. Sci., 41: 1-22.

Kagler, K. F. 1956. Freshwater fishery biology. Wm. C. Brown Co. Dubuque, Iowa. 421 pp.

Lund, J. W. G. 1964. Primary production and periodicity of phytoplankton. Verh. Int. Ver. Limnol., 15: 37-56.

________. 1965. The ecology of the freshwater phytoplankton. Biol. Review, 40: 231-293.

McQueen, D. J. 1969. Reduction of zooplankton standing stocks by predaceous _Cyclops bicuspidatus thomasi_ in Marion Lake, British Columbia. J. Fish. Res. Bd. Canada, 26: 1605-1618.

Manny, B. A. 1972. Seasonal changes in dissolved organic nitrogen in six Michigan lakes. Verh, Int. Ver. Limnol., 18: 147-156.

Mortimer, C. H. 1971. Chemical exchanges between sediments and water in the Great Lakes-speculations on probable regulatory mechanisms. Limnol. Oceanogr., 16: 387-404.

Moss, B. 1972. Studies on Gull Lake, Michigan. I. Seasonal and depth distribution of phytoplankton. Freshwat. Biol., 2: 309-320.

Otsuki, A., and R. G. Wetzel. 1974. Calcium and total alkalinity budgets and calcium carbonate precipitation of a small hardwater lake. Arch. Hydrobiol., 73: 14-30.

Pennak, R. W. 1946. The dynamics of fresh-water plankton populations. Ecol. Monogr., 16: 341-355.

________. 1953. Fresh-water invertebrates of the United States. Ronald Press Co., New York. 769 pp.

________. 1955. Persistent changes in the dominant species composition of limnetic entomostracan populations in a Colorado mountain lake. Amer. Micros. Soc. Trans., 74: 116-118.

________. 1957. Species composition of limnetic zooplankton communities. Limnol. Oceanogr., 2: 222-232.

Prescott, G. W. 1951. Algae of the western Great Lakes area exclusive of desmids and diatoms. Cranbrook Press, Bloomfield Hills, Michigan. 945 pp.

________. 1970. How to know the freshwater algae. Wm. C. Brown Co., Dubuque, Iowa. 348 pp.

Quade, H. W. 1969. Cladoceran faunas associated with aquatic macrophytes in some lakes in northwestern Minnesota. Ecology, 50: 170-179.

Rawson, D. S. 1955. Morphometry as a dominant factor in the productivity of large lakes. Verh. Int. Ver. Limnol., 12: 164-175.

Raymond, M. R. 1937. A limnological study of the plankton of a concretion-forming marl lake. Amer. Micros. Soc. Trans., 56: 405-430.

Raymont, J. E. G. 1963. Plankton and productivity in the oceans. Pergamon Press Ltd., Oxford. 660 pp.

Reiger, H. A. 1962. Validation of the scale method for estimating age and growth of bluegills. Trans. Amer. Fish. Soc., 91: 362-374.

Rich, P. M., R. G. Wetzel, and N. Van Thuy. 1971. Distribution, production, and role of aquatic macrophytes in a southern Michigan marl lake. Freshwat. Biol. 1: 3-21.

Ruttner, F. 1963. Fundamentals of limnology. U. of Toronto Press, Toronto. 295 pp.

Ryther, J. H. 1956. The measurement of primary production. Limnol. Occanogr., 1: 72-84.

Smith, S. H. 1954. Method of producing plastic impressions of fish scales without using heat. Prog. Fish-Cult., 16: 75-78.

Tressler, W. L., and B. P. Domogalla. 1931. Limnological studies of Lake Wingra. Trans. Wisc. Acad. Sci., Arts, and Let., 26: 331-351.

Tucker, A. 1957. The relation of phytoplankton periodicity to the nature of the physio-chemical environment with special reference to phosphorus. Amer. Mid. Nat., 57: 300-333.

U. S. Department of Agriculture, Soil Conservation Service. 1960. Soil Survey of Montcalm County, Michigan. In cooperation with Michigan Agriculture Experiment Station, U. S. Government Printing Office, Washington, D. C. Series 1949, No. 11. 61 pp.

U. S. Environmental Protection Agency. 1974. Methods for chemical analysis of water and waste. Office of Technology Transfer, Washington, D. C. 298 pp.

Usinger, R. L. 1956. Aquatic insects of California with keys of North American genera and California species. U. of Calif. Press, Berkeley. 508 pp.

Welsh, P. S. 1948. Limnological methods. McGraw Hill Co., Inc., New York. 381 pp.

Wetzel, R. G. 1966. Productivity and nutrient relationships in marl lakes of northern Indiana. Verh. Int. Ver. Limnol., 16: 321-332.

________. 1975. Limnology. W. B. Saunders Co., Philadelphia. 741 pp.

Wilson, L. R. 1935. Lake development and plant succession in Vilas County, Wisconsin. Part I, the medium hardwater lakes. Ecol. Monogr., 5: 207-247.

________. 1941. The larger aquatic vegetation of Trout Lake, Vilas County, Wisconsin. Trans. Wisc. Acad. Sci., Arts, and Let., 33: 135-146.

APPENDIX

TABLE A1.--Sampling schedule by date (month/day) for varous chemical and biological parameters on Spring Lake from April through October, 1976

Date	Secchi disk	Temperature	Dissolved Oxygen	pH	Total Alkalinity	Total Hardness	Total Kjeldahl Nitrogen	Total Phosphorus	Calcium	Chlorides	Photoplankton	Chlorophyll a	Zooplankton
4/10	x	x	x	x	x	x	x	x	x		x		x
4/25											x		
5/8	x	x	x							x	x	x	x
5/16												x	
5/22	x										x	x	
5/30												x	
6/5	x	x	x							x	x	x	
6/13												x	
6/17	x			x	x	x	x	x	x		x		x
6/20												x	
6/27												x	
7/4	x	x	x							x	x	x	
7/11												x	
7/19	x										x	x	x
8/1	x	x	x								x	x	
8/15	x									x	x	x	x
8/22												x	
8/29	x	x	x								x	x	
9/12	x										x	x	x
9/14	x	x	x	x	x	x	x	x	x			x	
9/9												x	
10/2	x	x	x										
10/23	x	x	x										

TABLE A2.--Summary of pH values of Spring Lake measured at all sampling stations from April through October, 1976

Sampling	Station	Date		
		April 10, 1976	June 17, 1976	Sept. 14, 1976
Surface	1	7.99	8.30	8.10
	2	7.99	8.25	8.10
	3	7.95	8.30	8.00
	4	8.00	8.38	8.10
	5	8.10	8.35	8.20
	6	8.00	8.40	8.20
Mid-Depth	5	8.00	8.28	8.00
	6	7.99	8.40	8.10
Bottom	5	7.94	7.60	7.30
	6	7.90	7.60	7.30
Spring				7.50

TABLE A3.--Summary of total alkalinity concentrations (mg/l $CaCo_3$) of Spring Lake measured at all sampling stations from Spril through October, 1976

Sampling	Station	Date		
		April 10, 1976	June 17, 1976	Sept. 14, 1976
Surface	1	170.0	155.0	154.0
	2	169.0	155.0	157.0
	3	167.0	157.0	155.0
	4	168.0	157.0	152.0
	5	168.0	156.0	156.0
	6	168.0	156.0	157.0
Mid-Depth	5	167.0	155.0	163.0
	6	168.0	155.0	144.0
Bottom	5	168.0	176.0	192.0
	6	167.0	180.0	196.0
Spring				180.0

TABLE A4.--Summary of total hardness concentrations (mg/l $CaCO_3$) of Spring Lake measured at all sampling stations from April through October, 1976

Sampling	Station	Date		
		April 10, 1976	June 17, 1976	Sept. 14, 1976
Surface	1	190.0	170.0	166.0
	2	190.0	170.0	164.0
	3	188.0	170.0	164.0
	4	186.0	169.0	162.0
	5	188.0	170.0	160.0
	6	188.0	170.0	163.0
Mid-Depth	5	190.0	170.0	170.0
	6	190.0	170.0	170.0
Bottom	5	190.0	190.0	208.0
	6	188.0	196.0	210.0
Spring				200.0

TABLE A5.--Summary of total Kjeldahl mitrogen (mg/1N) of Spring Lake measured at all sampling stations from April through October, 1976

Sampling	Station	Date		
		April 10, 1976	June 17, 1976	Sept. 14, 1976
Surface	1	0.88	0.53	0.46
	2	0.59	0.46	0.34
	3	0.46	0.48	0.36
	4	0.44	0.49	0.45
	5	0.48	0.44	0.33
	6	0.52	0.42	0.36
Mid-Depth	5	0.48	0.52	0.65
	6	0.48	0.54	0.37
Bottom	5	0.47	0.67	0.71
	6	0.67	0.67	0.68
Spring				0.17

TABLE A6.--Summary of total phosphorus concentrations (mg/l P) of Spring Lake measured at all sampling stations from April through October, 1976

Sampling	Station	Date		
		April 10, 1976	June 17, 1976	Sept. 14, 1976
Surface	1	0.006	0.046	0.020
	2	0.062	0.056	0.029
	3	0.012	0.042	0.021
	4	0.017	0.041	0.020
	5	0.019	0.047	0.028
	6	0.021	0.042	0.022
Mid-Depth	5	0.022	0.042	0.030
	6	0.016	0.032	0.032
Bottom	5	0.033	0.032	0.052
	6	0.051	0.040	0.020
Spring				0.010

TABLE 7A.--Summary of calcium concentrations (mg/l Ca) of Spring Lake measured at all sampling stations from April through October, 1976

Sampling	Station	Date		
		April 10, 1976	June 17, 1976	Sept. 14, 1976
Surface	1	46.0	43.0	33.0
	2	46.0	42.0	33.0
	3	47.0	42.0	33.0
	4	46.0	42.0	33.0
	5	47.0	42.0	33.0
	6	46.0	41.0	33.0
Mid-Depth	5	46.0	42.0	37.0
	6	46.0	43.0	34.0
Bottom	5	46.0	50.0	50.0
	6	46.0	50.0	49.0
Spring				46.0

TABLE A8.--Mean calculated total length at each annulus for 25 large-mouth bass from Spring Lake, Michigan

Age Group	Number in Sample	Mean Calculated Length (mm) at Ages							Coefficient of Condition
		1	2	3	4	5	6	7	
1	6	92							2.72
2	6	89	174						2.07
3	5	86	148	222					2.53
4	2	87	149	204	258				2.27
5	3	88	154	203	255	310			2.63
6	2	71	123	182	237	289	335		2.37
7	1	62	104	136	187	270	314	374	2.39
Mean Total Length (mm) at each annulus		86	152	208	243	296	328	374	
Mean growth increment		86	66	56	35	53	32	46	

TABLE A9.--Mean calculated total length at each annulus for 29 black crappie from Spring Lake, Michigan

Age Group	Number in Sample	Mean Calculated Length (mm) at Ages							Coefficient of Condition
		1	2	3	4	5	6	7	
1	0								
2	0								
3	15	54	95	146					2.55
4	12	48	78	130	181				2.62
5	2	53	85	123	165	193			2.75
Mean Total Length (mm) at each annulus		51	87	138	179	193			
Mean growth increment		51	36	51	41	14			

TABLE A10.--Mean calculated total length at each annulus for 24 rockbass from Spring Lake, Michigan

Age Group	Number in Sample	Mean Calculated Length (mm) at Ages							Coefficient of Condition
		1	2	3	4	5	6	7	
1	0								
2	0								
3	11	41	59	93					4.18
4	7	39	56	83	127				4.14
5	6	40	59	86	122	173			4.1
6	0								
7	0								
Mean Total Length (mm) at each annulus		40	58	89	124	173			
Mean growth increment		40	18	31	35	49			

TABLE A11.--Mean calculated total length at each annulus for 18 yellow perch from Spring Lake, Michigan

Age Group	Number in Sample	Mean Calculated Length (mm) at Ages 1	2	3	4	5	6	7	Coefficient of Condition
1	1	62							1.75
2	6	64	97						1.79
3	4	68	95	137					1.80
4	3	63	86	130	168				1.84
5	2	67	91	119	160	206			1.88
6	0								
7	2	73	102	144	189	230	263	294	1.85
Mean Total Length (mm) at each annulus		66	94	133	172	218	263	294	
Mean growth increment		66	28	39	39	46	45	31	

TABLE A12.--Mean calculated total length at each annulus for 11 northern pike from Spring Lake, Michigan

Age Group	Number in Sample	Mean Calculated Length (mm) at Ages								Coefficient of Condition
		1	2	3	4	5	6	7	8	
1	0									
2	0									
3	2	132	236	328						.61
4	1	105	177	336	424					.73
5	4	137	224	294	418	492				.88
6	2	98	172	263	368	468	516			.81
7	1	126	195	288	361	463	516	542		
8	1	152	231	384	487	575	650	690	758	1.1
Mean Total Length (mm) at each annulus		126	210	306	409	493	550	616	758	
Mean growth increment		126	84	96	103	84	57	66	142	