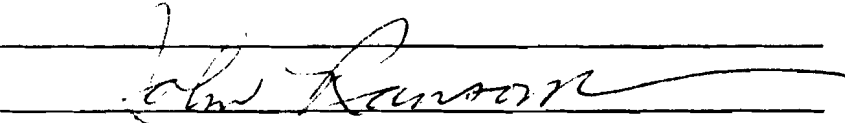


AN ABSTRACT OF THE THESIS OF

Burt E. Eustace for the Master of Science Degree
in Biology presented on 8 August 1980
Title: The Limnology of Wyandotte County Lake, Kansas

Abstract approved: 

A limnological study was conducted on the 135 ha Wyandotte County Lake, located in the County Park at 91st Street and Leavenworth Road in Kansas City, Kansas. Water quality data were established by determining physicochemical parameters and by sampling the benthic macroinvertebrate community from 1 June 1977 and 18 November 1977 and from 30 March 1978 to 5 May 1978. Seven stations were established over the lake at depths ranging from one to 15 meters. A total of 28 taxa consisting of 11,897 individuals of benthic macroinvertebrates was collected. Eight taxa of zooplankton were collected. Individual species diversity indices (\bar{d}) for benthic macroinvertebrates were calculated for each station by depth and mean monthly variations in \bar{d} were calculated with all depths combined. Annual \bar{d} values ranged from 1.0 to 1.9, with an annual mean of 1.4, indicating moderate stress in the aquatic system. Coliform counts averaged 62/100 ml. Thermal conditions were in line with expected seasonal variations for a moderately-deep temperate lake with a spring and fall holomixis and a well-established direct stratification in mid-summer. Oxygen was present in the summer at concentrations from 2.5 to 7.7 mg/liter and at depths from 8 to 15 meters, oxygen was likely to be depleted. Secchi disc transparency varied from 0.53 to 2.50 meters. The mean

lake euphotic zone was 4.66 meters. Nitrate was high, ranging from 6.0 to 17.0 mg/liter, with an annual mean of 11.41 mg/liter. Phosphate ranged closer to normal, with a minimum of 0.06 and a maximum of 0.23 mg/liter. Mean annual phosphate was 0.16 mg/liter. The nitrate : phosphate ratio was 70 : 1, suggesting an important outside source of nitrate. Ammonia nitrogen had a yearly mean of 0.73 mg/liter, within the limits for unpolluted water. Sulfate was low, ranging from 12.0 to 22.0 mg/liter, with an annual mean to six meters of 17.8 mg/liter. Nitrate was slightly above unpolluted standards, ranging from 0.001 to 0.260 mg/liter, with an annual mean of 0.026 mg/liter. Trace metals were measured at the beginning and end of the study. Copper ranged from 1.09 to 1.95 mg/liter. Iron ranged from 0.06 to 0.10 mg/liter. Wyandotte County Lake appeared to be a moderately enriched system.

THE LIMNOLOGY OF
WYANDOTTE COUNTY LAKE, KANSAS

A Thesis
Submitted to
the Division of Biological Sciences
Emporia State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Burt E. Eustace
July, 1980

Thesis
1980
E

John Ransom
Approved for Major Department

Michael E. Dunt
Approved for Graduate Council

416078

~~UNIVERSITY OF CALIFORNIA~~

NO. 20 '80

ACKNOWLEDGMENT

I express my appreciation to Dr. John Ransom for stimulating my interest in aquatic biology which led in turn to the decision to conduct this study, for his support and direction throughout the project, and for his role as my graduate committee chairman. My thanks to Dr. Robert Boles for being a committee member and technical illustrator. My thanks to Dr. Richard Keeling for being a committee member and technical consultant. Mr. Lawrence Nieman of the Wyandotte County Soil Conservation District provided access to maps and aerial photographs. Thanks to the Wyandotte County Park Administrators for granting permission to conduct the study and, particularly, to the staff at 3500 Old Highway 5 for their interest and aid in providing historical data. Finally, a special heart-felt thanks to my wife, Linda, whose support at home, in the field, and at the laboratory made this study possible.

TABLE OF CONTENTS

	PAGE
INTRODUCTION.....	1
DESCRIPTION OF THE STUDY AREA.....	2
MATERIALS AND METHODS.....	5
RESULTS AND DISCUSSION.....	8
Biological.....	8
Benthic Macroinvertebrates.....	8
Distribution and Seasonal Changes in Numbers of Benthic Organisms.....	14
Species Diversity Background.....	18
Zooplankton.....	25
Coliform Bacteria.....	29
Physicochemical.....	30
pH.....	30
Thermal Conditions.....	30
Transparency.....	34
Dissolved Oxygen.....	34
Nitrate and Phosphate.....	37
Ammonia Nitrogen.....	40
Sulfate.....	42
Nitrate.....	43
Trace Metals.....	43
SUMMARY.....	44
LITERATURE CITED.....	46

LIST OF TABLES

TABLE	PAGE
I. Taxa List and Total Number of Benthic Invertebrates Collected.....	9
II. Total Number of Individuals Vs Number of Species of Benthic Macroinvertebrates by Depth.....	12
III. Seasonal Changes of Selected Benthic Macroinvertebrates.....	16
IV. Relative Abundance of Benthic Macroinvertebrates by Depth.....	19
V. Diversity Indices by Station and Date.....	22
VI. Results of Test of Significance by Station.....	26
VII. Zooplankton.....	27
VIII. Monthly Ortho-phosphate and Nitrate Nitrogen by Depth.....	38
IX. Monthly Sulfate and Ammonia Nitrogen by Depth.....	41

LIST OF FIGURES

FIGURE	PAGE
1. Wyandotte County Lake, Kansas.....	3
2. Seasonal Variations in Population Density of Two Benthic Invertebrates.....	15
3. Mean Annual Variation in Density per Individual (\bar{d}) by Depth.....	23
4. Mean Monthly Variation in Density per Individual (\bar{d}) All Depths Combined.....	24
5. Mean Monthly Zooplankton Population Densities per Liter.....	28
6. Mean Temperatures.....	31
7. Mean Dredge Haul Temperatures.....	32
8. Mean Monthly Secchi Disc Transparency.....	33
9. Mean Monthly Concentrations of Dissolved Oxygen.....	36

INTRODUCTION

At the time of this study, Wyandotte County Lake had been in existence for approximately 30 years. The close proximity of the Lake to a large metropolitan area and its resulting recreational pressure, and its proximity to the researcher's residence and place of employment, resulted in the decision to select it for this environmental inventory. In the process of completing the study, the researcher would enhance his field and laboratory skills, satisfy the curiosity of himself and others in regard to conflicting statements of habitat quality, and provide established data for comparisons in future studies.

A primary objective of this study was to characterize the environmental quality of Wyandotte County Lake using species diversity indices calculated on benthic macroinvertebrates collected from various depths and locations and relating those indices to physicochemical features. A community of benthic macroinvertebrates contains species with various ranges of tolerance for organic and inorganic pollutants (Edwards, 1970; Ransom and Dorris, 1972; Ransom and Prophet, 1973). The extent of stress in aquatic systems can be assessed by examination of benthic community structure through information theory (Margalef, 1956) and by developing an index of density per individual (\bar{d}) (Ransom, 1969; Ransom and Dorris, 1972).

DESCRIPTION OF THE STUDY AREA

Wyandotte County Lake was formed by impounding Marshall Creek, approximately 1.3 km from its confluence with the Missouri River at Pomeroy Bend, mile 382 (Figure 1). It is located in the 607 ha Wyandotte County Park, with an entrance at 91st Street on Leavenworth Road, Kansas City, Kansas. The geology of the region consists of limestone, shale, and chert of the Pennsylvanian period. The topography is hilly and rolling, stabilized by mixed hardwoods, primarily of the oak-hickory association. The impoundment, a WPA project constructed with federal and county funds, was begun 17 December 1935. On 19 September 1937, as dam height was within three m of completion, the structure collapsed. Reconstruction began 11 May 1938 under plans prepared by the U. S. Army Corps of Engineers. The dam proper was completed on 7 August 1941. Final work on the dam and spillway was completed on 9 December 1943 and the lake reached overflow capacity on 5 June 1947. At full capacity, the lake covers 135 ha at 820 MSL. At that elevation, the lake has approximately 21 km of shoreline. The long axis of the lake measures approximately 2.85 km, lying mainly in a direction from northeast to southwest. Marshall Creek Cove runs directly north for approximately one km, the axis of the lake then bends northeast and a straight line of 1.85 km will reach the face of the dam near its center. The basin receives drainage from Marshall Creek, several springs, and 2,023 ha of hilly, hardwood-covered watershed. The shoreline is precipitous around much of the basin, resulting in no littoral zone for those areas. An extensive growth of emergent, floating, and submerged vegetation occurred in Marshall Creek Cove,

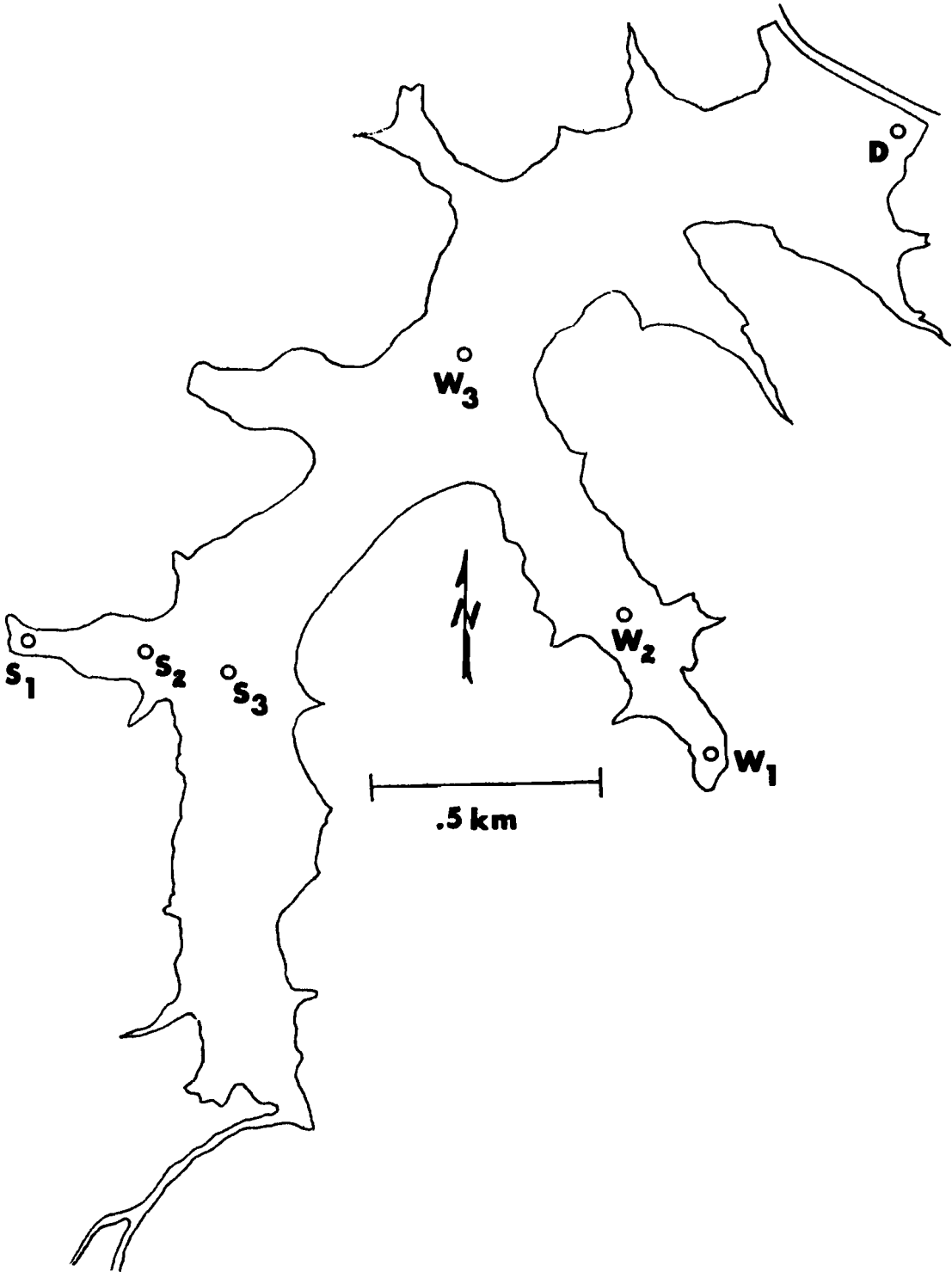


Figure 1. Wyandotte County Lake, Kansas. Circles indicate locations of stations.

dominated by common cattail (Typha latifolia L.), American lotus (Nelumbo lutea (Willd.) Pers.), and pondweeds (Potamogeton spp.). That portion of the basin received the bulk of allochthonous sediment and near-ideal conditions existed for these plants. Limited vegetation existed in the upper end of Wilson Cove and scattered growth of pondweed occurred at various shoaling areas. But, for the most part, the shoreline was not characterized by aquatic vegetation. In much of the lake basin, depth increased rapidly with distance from shore, with parts of the main channel and major coves achieving depths greater than 15 m. The long axis of the lake is oriented such that prevailing winds have an uninterrupted approach to much of the surface. The long fetch results in sufficient eddy diffusion to help maintain oxygen at depths that would otherwise be anoxic during the summer, although a stable stratification develops in deeper waters. Based on data compiled by the Kansas Water Resources Board (1967), the region of Wyandotte County Lake receives a yearly mean precipitation of 89 cm. The mean annual lake evaporation in Wyandotte County is 101.6 cm, increasing to 114.3 cm under drought conditions. Due to continual flow of Marshall Creek and the several springs draining into the basin the water level usually fluctuates very little, remaining reasonably close to overflow depth throughout most of the year.

METHODS AND MATERIALS

Biological

Three stations were established along transects in each of Wilson and Stotler coves, with a seventh station located near the dam (Figure 1). Depths among the stations varied from 1 to 15 m. Sampling began on each date by 0800 hours and was complete by 1200 hours. Benthic macroinvertebrates were obtained with a 15-cm Ekman dredge, washed free of sediment over a 30-mesh brass field screen, transferred to plastic jars, and set aside for final screening, concentration, and preservation. Zooplankton were taken in vertical hauls at each station and transferred to labeled jars for later concentration and preservation. All biological material was refrigerated as soon as possible after collection. Benthic macroinvertebrates and zooplankton were sorted, picked, and concentrated in the laboratory and then preserved in a 80% isopropanol and 1.5% glycerin mixture. Identifications and density determinations were made at later dates using Pennak (1953), Edmondson (Ward and Whipple, 1966), Lind (1974), and Mason (1968). Coliform counts were obtained using Millipore media and apparatus. Bacterial counts were made only at the beginning and at the end of the study. With the exception of trace metals, all other data were collected on a monthly basis except during the summer. In the summer, sampling was at approximately two-week intervals. Benthic macroinvertebrates were recorded as numbers of individuals per dredge haul and per m^2 . Zooplankton were expressed as numbers of individuals per species per liter. Coliform counts were calculated as organisms per 100 ml in each of two coves

both from the surface and from six meters.

Physicochemical

Air and water temperatures were taken at each station at each sampling interval. Water temperatures were recorded at one, six, and 15 meters and were taken from below the surface from water obtained by use of a modified Kemmerer water sampler. Temperature of the samples was determined by thermometer placed in a flooding 300-ml B.O.D. bottle. Dredge haul temperatures were determined by thermometer inserted in the dredge cargo before screening. Dissolved oxygen concentrations were determined by the Alsterberg (azide) modification of the Winkler Method (APHA, 1961). Samples of 300 ml were fixed on the lake, and a 100-ml sample was titrated in the laboratory with 0.025 N phenylarsene oxide. Water samples for all other chemical determinations were collected at the surface and at six meters from station two in alternate coves. Nitrate, phosphate, sulfate, ammonia, nitrite, iron, and copper were determined by using Hach Chemical Company procedures on the Bausch and Lomb Spectronic-20 spectrophotometer. Hydrogen ion concentration was determined using a Cenco No. 21660-6 pH meter.

Statistical

Species diversity indices (\bar{d}) were calculated for benthic macro-invertebrates using the Shannon-Weaver (1949) equation where N is the

$$\bar{d} = - \sum_{i=1}^s \left[\frac{n_i}{N} \log_2 \frac{n_i}{N} \right]$$

total number of individuals and n_i is the number of individuals of species i . An annual mean diversity index (\bar{d}) was calculated for each station by date and depth. Variations in individual species diversity (\bar{d}), oxygen concentrations, and concentrations of nitrate, phosphate, sulfate, and ammonia were evaluated using a Student t-test at $p = .05$ level of significance.

RESULTS AND DISCUSSION

Biological

Benthic Taxa Collected

A total of 11,897 individuals representing 28 taxa of benthic macroinvertebrates was collected (Table I). Sixteen taxa were collected at W_1 , 12 taxa at W_2 , 6 taxa at W_3 , 24 taxa at S_1 , 17 taxa at S_2 , 11 taxa at S_3 , and 6 taxa at D. The total number of individuals collected at each station was 769, 645, 2,812, 639, 1,022, 2,335, and 3,675, respectively (Table II). The station providing the greatest species diversity produced the smallest number of individuals, and the station with the fewest species produced the greatest redundancy and the highest total count.

Nineteen of the 28 taxa (12% of the total number of individuals collected) were midges of the family Chironomidae. According to Mason (1968), these organisms are of major consequence in the food chain between algae and macroinvertebrates, and between the larger macroinvertebrates and fishes. Chironomid larvae are chiefly herbivorous and feed on algae, higher aquatic plants, and organic detritus (Pennak, 1953). The pinkish-to-very-deep-red coloration of most of the more abundant species is caused by dissolved erythrocrucorin in the blood, providing the basis for the common appellation "bloodworm". This substance acts as a respiratory pigment similar to hemoglobin and may be of special significance to larvae living in water with very low levels of dissolved oxygen. In Wyandotte County Lake, however, only 158 of a total of 1,161 chironomids (13.6%) were collected at depths greater than 6 m. It was found that 96 (60%) of the chironomids

TABLE I. Taxa list and total number of benthic invertebrates collected.

Organisms	Station						
	W ₁	W ₂	W ₃	S ₁	S ₂	S ₃	D
ANNELIDA							
OLIGOCHAETA							
<u>Branchiura sowerbyi</u> Bedd.	27	1	-	31	4	-	-
<u>Limnodrilus</u> sp.	105	150	1681	163	410	1520	839
MOLLUSCA							
GASTROPODA							
<u>Physa</u> sp.	-	-	-	1	1	-	-
<u>Gyraulus</u> sp.	-	-	-	1	1	1	-
ARTHROPODA							
INSECTA							
Diptera							
Ceratopogonidae							
<u>Palpomyia</u> sp.	31	28	-	187	38	9	1
Culicidae							
<u>Chaoborou</u> <u>punctipennis</u> Say	11	275	1098	23	298	685	2828

TABLE I. (Continued)

Organisms	Station						
	W ₁	W ₂	W ₃	S ₁	S ₂	S ₃	D
Orthocladinae							
<u>Psectrocladius</u> sp.	7	4	-	61	1	-	-
Ephemeroptera							
Baetidae							
<u>Ephemerella</u> sp.	-	-	-	1	-	-	-
<u>Caenis</u> sp.	3	-	-	10	1	-	-
Ephemeridae							
<u>Hexagenia</u> sp.	-	3	-	3	1	1	-

TABLE II. Total number of individuals vs number of species of benthic macroinvertebrates by depth.

	W ₁ (1m)	W ₂ (6m)	W ₃ (15m)	S ₁ (1m)	S ₂ (6m)	S ₃ (9m)	D (15m)	Total
Species	16	12	6	24	17	11	6	28
Individuals	769	645	2812	639	1022	2335	2675	11897

collected below 6 m were of the genus Chironomus, a taxa characterized by the most brilliant erythrocrucorin color. Procladius sp. formed 21% of the chironomids from below 6 m, although that species was absent when the environment was anoxic at 15 m. Cole (1975) asserts that Procladius sp. is not a permanent member of the profundal benthic community because it is absent during the period of summer anoxia in dimictic temperate lakes.

The greatest abundance and diversity of taxa among chironomids occurred at different stations at a depth of 1 m. The greatest density was 9,553 individuals per m^2 , the combined populations of 5 taxa. This occurred in a soft substrate, mixed with a heavy burden of fine-textured organic detritus. The greatest diversity was reached with 11 taxa producing a combined density of 3,954 individuals per m^2 in a fine sandy-silt substrate mixed with a large proportion of finely-divided organic material. In both cases, the organic component appeared to be primarily of allochthonous origin, the bulk of which seemed to consist of leaf material from the mixed hardwoods rooted over most of the adjacent watershed. A considerable quantity of filamentous algae was also present over the substrate at the one-meter depth. Pennak (1953) stated that certain genera within the chironomid family have adapted well to living in water where concentrations of dissolved oxygen are low and where lake bottoms are composed of fine silt. The distribution of chironomids and other macroinvertebrates collected in this study seemed to bear this out. The exception occurred at those depths where the sediment became sapropel and the oxygen tension reached zero during the summer stagnation. At such times and

places, the lake became the exclusive domain of the vertically-migrating "phantom midge", Chaoborus punctipennis Say, and the highly-tolerant oligochaete, Limnodrilus sp.

The single most abundant organism collected was Chaoborus punctipennis Say, forming 44% of the total collection. Although 88% of the individuals of this species were taken in dredge hauls from at least 15 m below the surface, some were found at all depths.

Two species of oligochaetes, Limnodrilus sp. and Branchiura sowerbyi Bedd., were collected. Limnodrilus sp. was the most abundant, representing 41% of the total macroinvertebrates collected throughout the study. This organism occurred at all depths, but was most abundant at the three 15-m stations. B. sowerbyi Bedd. contributed only 0.5% of the total collection, with 58 of the 63 specimens collected being taken at a depth of one m.

The larvae of the biting midge, Palpomyia sp. formed only 2% of the total collection, occurring almost exclusively (97%) at depths of 6 m or less.

Two species of pelecypods and three species of ephemeropterans were collected, both in extremely small numbers.

Distribution and Seasonal Changes in Numbers of Benthic Organisms

Only two benthic species were collected in sufficient numbers to establish a pattern of seasonal changes in numbers (Figure 2). Seasonal trends of selected organisms are shown in Table III. Limnodrilus sp. demonstrated a seasonal population trend of decrease through the summer and increase through fall, winter, and spring. Pennak (1953) reported tubificids able to endure summer and winter periods of stagnation, and one-third of a group of test Tubifex worms surviving

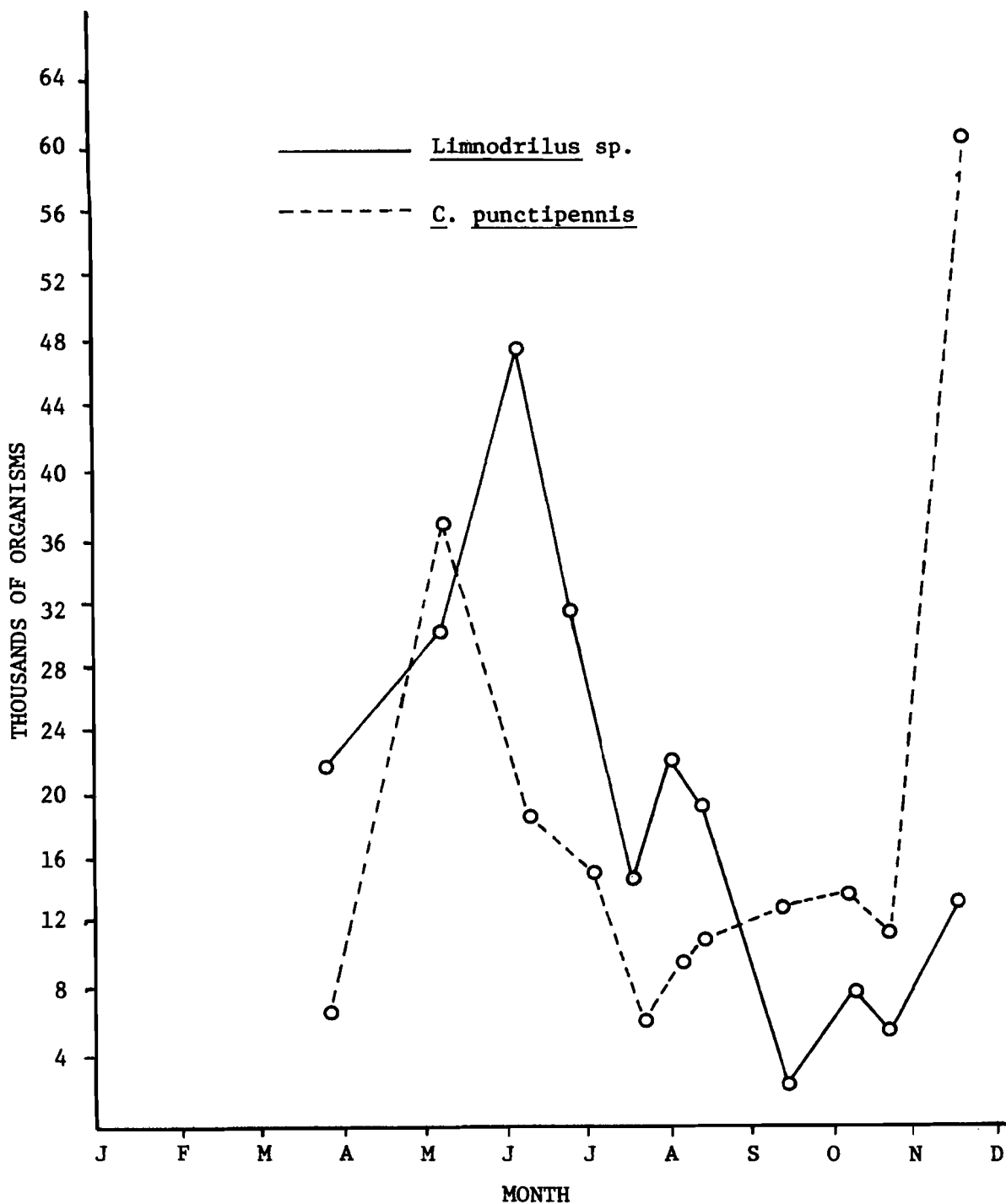


Figure 2. Seasonal variations in population density of two benthic invertebrates. Individuals per M^2 .

TABLE III. Seasonal changes by selected benthic macroinvertebrates expressed as individuals per m² on each sampling date.

Organisms	Date										
	3/30	5/4	6/2	6/20	7/12	7/26	8/10	9/17	10/8	10/28	11/18
OLIGOCHAETA											
<u>Limnodrilus</u> sp.	22175	30352	47908	31286	15021	21777	19904	3555	9511	7821	12312
DIPTERA											
CULICIDAE											
<u>C. punctipennis</u> Say	7265	36173	18132	14577	6622	9821	13243	12044	12976	10843	60527
CHIRONOMIDAE											
<u>Procladius</u> sp.	1866	1911	488	88	133	-----	178	933	-----	132	399
<u>Coelotanypus</u> sp.	622	132	222	132	710	355	88	711	622	1556	578
<u>Chironomus</u> sp. 1	2755	1066	1599	1155	800	1866	444	133	44	3511	5154
<u>Chironomus</u> sp. 2	222	844	133	1555	355	222	44	44	-----	266	489
<u>Cryptochironomus</u> sp. 1	311	978	-----	1022	3733	1955	2977	133	356	177	222

anoxic conditions for 48 days at 0 to 2 C. At higher temperatures the fraction was progressively smaller. When the hypolimnion was anoxic in Wyandotte County Lake, temperatures ranged from 12.5 to 16 C. The higher temperature might easily make anoxic conditions lethal for a great number of these hardy organisms. Most likely the population was not subjected to anoxic conditions during the winter because measurements taken near the end of November disclosed a minimum of 6.8 mg/liter dissolved oxygen at 15 m.

The other species exhibiting a definite seasonal trend was C. punctipennis Say. Numbers of this organism increased during the spring and fall and decreased during the summer and winter. Ransom (1969) noted that midge eggs that had fallen to the bottom did not hatch if the bottom water was anoxic. They remained dormant until oxygen was available. Likewise, low temperature delayed hatching. The combined effects of variations in oxygen tension and temperature suggest an explanation for the presence of spring and fall concentrations of C. punctipennis larvae. The decrease in larval numbers during the summer undoubtedly reflected emergence as adults and agreed with Horner (1977). Probably there was an increase in predation and cannibalism, too. The latter may be of considerable significance, for many of the individuals examined were found to have been in the process of consuming members of earlier instars when collected. The cannibalistic propensity of C. punctipennis and its predator role in the larval state is well known (Reid, 1961; Ransom, 1969).

Species distribution by depth is most readily demonstrated by calculating their relative abundance at depths of one, six, and 15 meters

(Table IV). This was done by obtaining the total number of individuals of each species at a given depth and dividing that total by the number of stations at that depth. This indicated a definite depth preference for most species collected. Fifteen species were most abundant at one m, two were equally abundant at one and six m, nine were most abundant at six m, and two species steadily increased in population density with depth, reaching their maximum at 15 m.

Species Diversity Background

The species diversity index (\bar{d}) is a statistical tool of universal acceptance among aquatic biologists as a means of evaluating water quality or habitat fitness. The use of \bar{d} has superseded the reliance upon one or two "indicator organisms" as stress indicators which was proposed by Richardson (1928), Beck (1955), and Gaufin and Tarzwell (1952). Patrick (1949) was one of the first researchers to show that an approach to combining the number of species of plants and animals, with the numbers of individuals of each, could be a more accurate means of assessing water quality. Many aquatic macroinvertebrates are sub-adult insects who spend a year or more in close proximity to where they were hatched. Their relatively long life span as a completely aquatic organism and their lack of mobility make them natural monitors of physical and chemical conditions in aquatic systems (Pennak, 1953; Tarzwell, 1965; Mathis, 1968). Shannon and Weaver (1949) developed an index equation based on mathematical theory for use in forming decisions regarding water quality based on collections of benthic macroinvertebrates. Diversity indices have been developed, modified, and used by Patten (1962), Wilhm and Dorris (1966), Harrel and

TABLE IV. Relative abundance of benthic macroinvertebrates by depth.

Organism	Depth in meters		
	1	6	15
<u>Branchiura</u> sp.	29.0	2.5	0.0
<u>Limnodrilus</u> sp.	134.0	280.0	1347.0
<u>Physa</u> sp.	0.5	0.5	0.0
<u>Gyraulus</u> sp.	0.5	0.5	0.3
<u>Caenis</u> sp.	6.5	0.5	0.0
<u>Ephemerella</u> sp.	0.5	0.0	0.0
<u>Hexagenia</u> sp.	1.5	2.0	0.3
<u>Chaoborous</u> sp.	23.0	287.0	1537.0
<u>Procladius</u> sp.	17.0	37.0	11.0
<u>Coelotanypus</u> sp.	26.0	34.0	3.0
<u>Tanypus</u> sp.	1.5	2.0	0.0
<u>Ablabesmyia</u> sp.	2.5	0.0	0.0
<u>Chironomus</u> sp. 1	50.0	76.0	29.0
<u>Chironomus</u> sp. 2	1.5	29.0	7.3
<u>Cryptochironomus</u> sp. 1	116.0	43.0	1.3
<u>Cryptochironomus</u> sp. 2	0.0	4.0	0.0
<u>Cryptochironomus</u> sp. 3	2.0	0.0	0.0
<u>Polypedilum</u> sp.	23.0	0.0	0.3
<u>Einfeldia</u> sp.	117.0	1.0	0.3
<u>Stenochironomus</u> sp.	0.0	1.0	0.0
<u>Paralauterborniella</u> sp.	6.0	0.0	0.0

TABLE IV. (Continued)

Organism	Depth in meters		
	1	6	15
<u>Microtendipes</u> sp.	8.0	0.0	0.0
<u>Tribelos</u> sp.	0.0	0.5	0.0
<u>Glyptotendipes</u> sp.	0.5	0.5	0.0
<u>Dicrotendipes</u> sp.	0.5	0.0	0.0
<u>Tanytarsus</u> sp.	2.0	0.0	0.3
<u>Psectrocladius</u> sp.	34.0	2.5	0.0
<u>Palpomyia</u> sp.	109.0	33.0	3.3

Dorris (1968), Mathis (1968), Mathis and Dorris (1968), Wilhm (1970), Ransom (1969) Ransom and Dorris (1972), and Ransom and Prophet (1974) to analyze community structure in streams and reservoirs.

The species diversity index (\bar{d}) reflects the manner in which individuals are distributed among species in a community. Assuming a community to be entirely free of pollution stress, a collection of benthic macroinvertebrates would be found to contain a wide diversity of species, each represented by relatively few individuals. At the other extreme, a community under intense stress would be devoid of many of the intolerant species or, at best, be represented by very few individuals. A community exposed to pollution may be dominated by only one or two species whose numbers may reach tremendous proportions, either from lack of competition or from an ability to thrive under the precise

kind and level of pollution that proved limiting to many others. As pollution increases from zero to high levels, the probability of collecting a species decreases and \bar{d} decreases. It is not necessary that any species disappear in order for the value of \bar{d} to decrease, only that they fail to flourish while a few other species do. In water containing pollutants, the probability is high that an individual in a sample will be of a species already collected, causing \bar{d} to drop. The opposite is true in unpolluted water. The range of \bar{d} values is from zero to five in aquatic environments. Values less than one represent grossly polluted streams or lakes. Values from one to three represent areas of moderate pollution. Values greater than three are found in clean water environments (Wilhm and Dorris, 1966; Wilhm, 1970).

Species Diversity Analyses

A diversity index (\bar{d}) was calculated for each station and for each sampling date (Table V). Mean annual indices were calculated for each station, by depth (Figure 3), and mean monthly variations in \bar{d} were calculated, all depths combined (Figure 4). The annual values ranged from 1.0 to 1.9, with a mean value of 1.43, indicating that Wyandotte County Lake contains moderately-polluted water. The annual \bar{d} values by depth ranged from 0.8 to 2.1, with a mean of 1.39, again indicating a moderate pollution level. Depth values, however, covered stations ranging from one to 15 m, the deeper stations frequently having very low oxygen tension, or being anoxic. Throughout the study, the highest single \bar{d} value was 3.08 and the lowest was 0.27.

The species diversity values of individual stations were subjected

TABLE V. Diversity indices by station and date.

Date	D	S ₁	S ₂	Station S ₃	W ₁	W ₂	W ₃	Mean for Month
3/30	0.80	1.96	2.16	1.58	1.77	2.35	0.64	1.61
5/4	0.79	1.66	1.70	1.60	2.18	1.44	1.03	1.49
6/2	0.75	1.13	0.93	0.56	1.20	1.71	0.83	1.02
6/22	0.90	3.08	1.74	0.34	2.80	0.41	0.85	1.45
7/12	1.00	2.31	2.10	0.27	2.11	0.58	0.29	1.24
7/26	0.97	1.84	1.30	0.54	2.36	0.30	0.44	1.11
8/10	0.98	2.78	0.78	1.05	2.29	0.17	0.36	1.20
9/17	0.74	2.70	2.52	----	2.40	1.17	----	1.91
10/8	0.87	2.24	1.44	1.79	----	----	----	1.59
10/28	0.93	1.97	2.43	0.98	1.50	1.61	0.73	1.45
11/8	0.29	1.49	1.69	0.91	2.66	2.89	1.41	1.62

to a Student t-test at $p = .05$ level of significance. This was first done by dates, producing 55 combinations for comparison. Among these, there was but on significant difference and that occurred between the samples obtained in June and September. Another set of comparisons was made by pairing \bar{d} values by station. Since these comparisons were made on data from stations as shallow as 1 m and as deep as 15 m, significant differences were expected. Comparing the data by stations

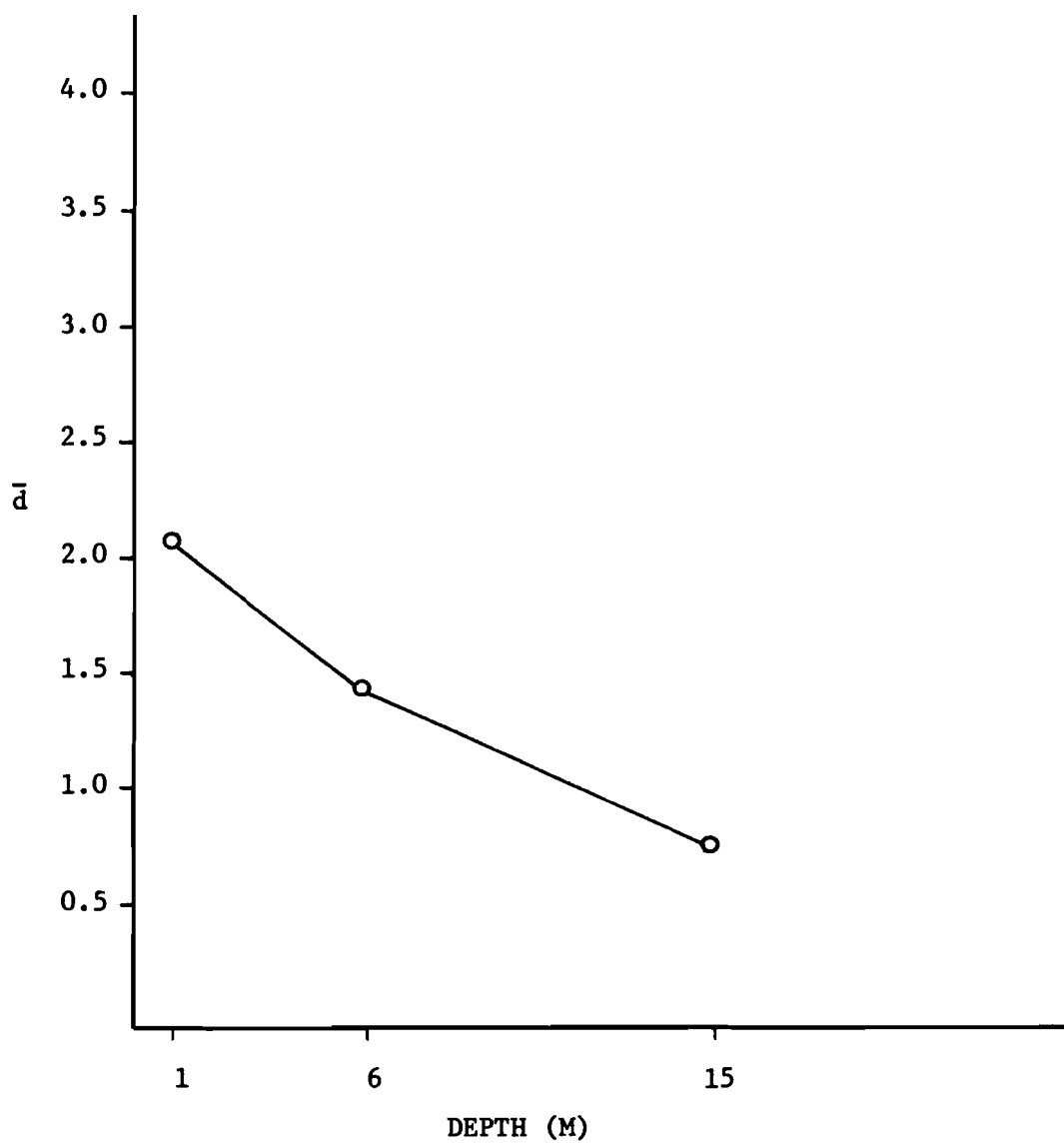


Figure 3. Mean Annual Variation in Diversity per Individual (\bar{d}) by Depth.

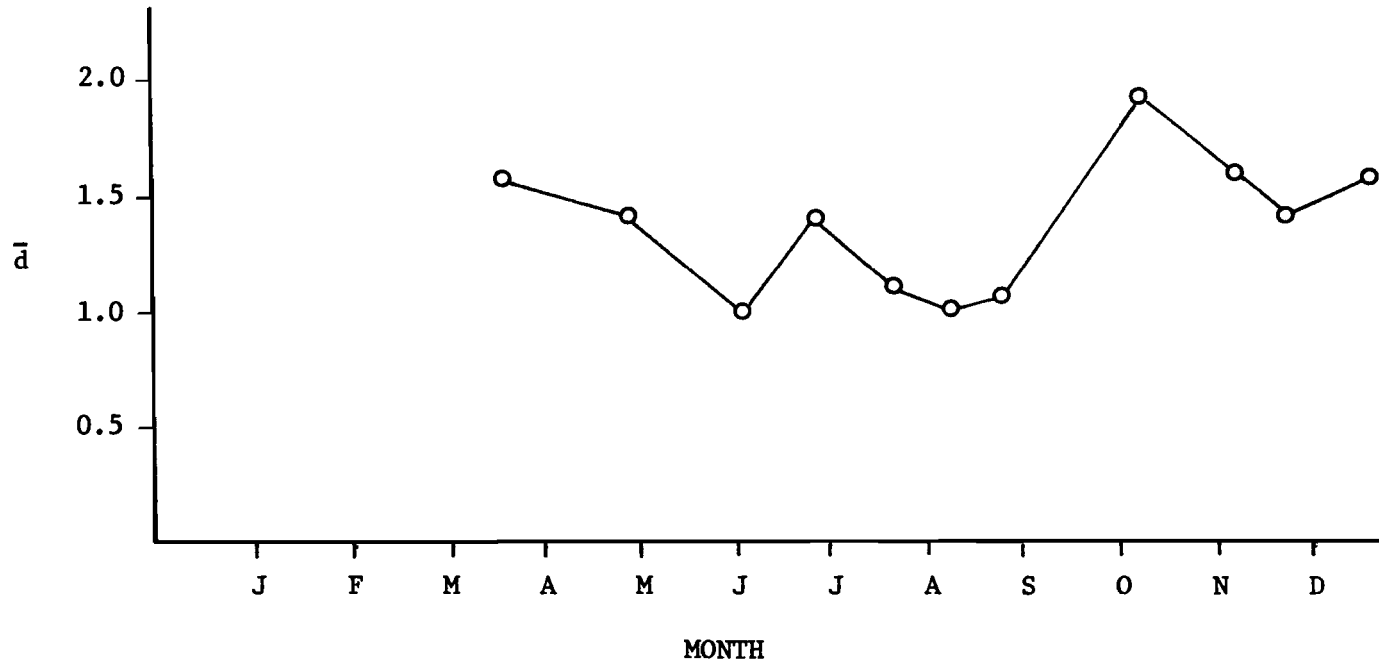


Figure 4. Mean Monthly Variations in Diversity per Individual (\bar{d}). All Depths Combined.

produced 21 combinations, 11 of which revealed \bar{d} values of significant differences (Table VI).

Zooplankton

Two genera of copepods, five genera of cladocerans, and a single genus of ostracod were observed in plankton samples (Table VII). The dynamics of the zooplankton community are shown as mean monthly values for each sampling date (Figure 5). The two genera of copepods, Cyclops sp. and Diaptomus sp., were present in all samples. Cyclops sp. reached a maximum density of 60 individuals per liter in June and Diaptomus sp. reached a maximum density of 30 individuals per liter in early October. Throughout the study, however, Cyclops sp. exceeded Diaptomus sp. by only 10%. This order of abundance was the inverse of that reported by Prophet (1965) from Lyon County, Kansas State Lake. In that study, Diaptomus siciloides was the most characteristic copepod with D. pallidus never abundant, but generally present. Cyclops bicuspidatus tended to be more numerous in Lyon County State Lake during the cooler months but absent during the warmer periods, July through October. At the time of the Lyon County study, however, the lake was much smaller than its 55-ha spillway level, with a maximum reported depth at that time of only 3.96 m. During August, the water was homothermous for all depths at approximately 25.6 C. In Wyandotte County Lake, when the surface temperature was at a maximum of 27.9 C, it was 25.7 C at 6 m, and 19.0 C at 15 m. The opportunity to avoid the higher temperature and related stress may be sufficient to explain the

TABLE VI. Results of test of significance by station using the Student t-test at $p = .05$ level of significance. Significant difference (X); no significant difference, (0).

Station	S ₂	S ₃	W ₁	W ₂	W ₃	D
S ₁	0	X	0	X	X	X
S ₂		X	0	0	X	X
S ₃			X	0	0	0
W ₁				X	X	X
W ₂					0	0
W ₃						0

TABLE VII. Zooplankton. Mean number of individuals per liter.

Organisms	3/30	5/4	6/2	6/20	7/12	7/26	8/10	9/17	10/8	10/28	11/18
COPEPODA											
<u>Diaptomus</u> sp.	16	18	11	17	15	16	7	12	30	26	21
<u>Cyclops</u> sp.	12	10	60	25	9	7	23	13	16	16	19
CLADOCERA											
<u>Daphnia</u> sp.	7	24	13	15	20	30	46	38	36	16	17
<u>Bosmina</u> sp.	6	9	10	2	--	--	61	73	23	14	5
<u>Diaphanosoma</u> sp.	--	--	--	15	--	12	--	--	5	--	--
<u>Simocephalus</u> sp.	--	--	--	--	--	21	40	15	--	--	--
<u>Ceriodaphnia</u> sp.	--	--	--	--	--	--	--	19	--	--	--
OSTRACODA											
<u>Darwinula</u> sp.	--	--	--	--	4	--	--	--	--	--	--

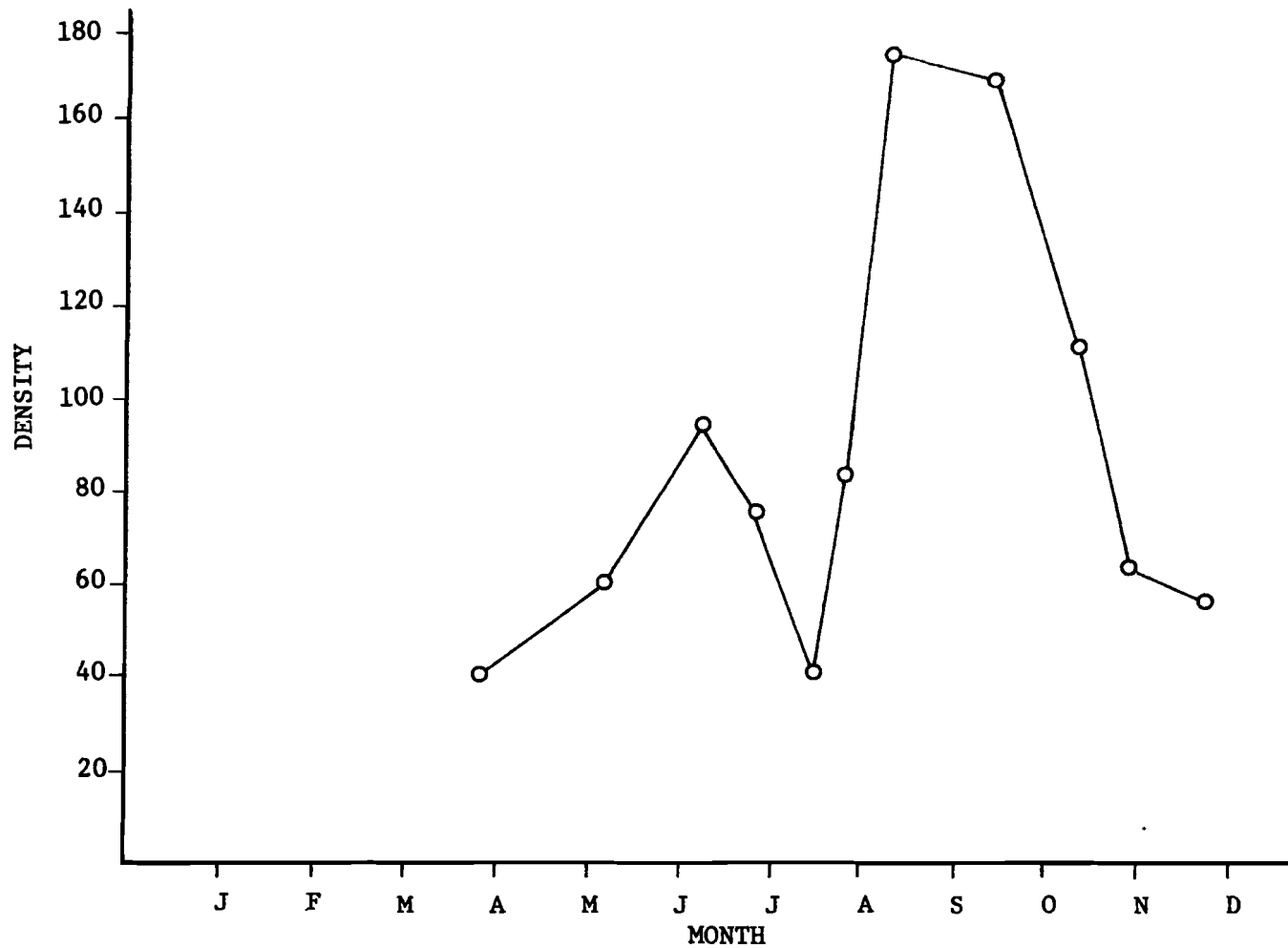


Figure 5. Mean Monthly Zooplankton Population Densities per Liter.

dominance of Cyclops sp. in Wyandotte County Lake. The two studies show Diaptomus sp. present in all months.

Among the Cladocera, Daphnia sp. was present in all samples reaching a maximum density of 46 individuals per liter in August. Bosmina sp., present in all samples except those taken in July, reached a maximum density of 73 individuals per liter in mid-September. Diaphanosoma sp. was collected only three times, occurring from June to early October. Simocephalus sp. was taken in three consecutive samples from July to mid-September. Ceriodaphnia sp. was scarce, taken only once in mid-September. The frequency of Daphnia sp. and Bosmina sp. on a regular basis throughout the year and the occurrence of Diaphanosoma sp. only during the period of June through October, is in agreement with the data for these species reported by Prophet (1965) on Lyon County Lake.

Coliform Bacteria

Coliform bacteria densities were surveyed twice during the study, using Millipore membrane filters and EMB broth. Water samples were taken from the surface and at 6 m, from stations in opposite coves. Dilutions were made with autoclaved lake water. The mean count from 5 plates was used as a density measure at each location. Densities were higher at 6 m than at the surface, and higher in Wilson Cove than in Stotler Cove. Mean coliform counts in Wilson Cove were 22.5/100 ml at the surface and 116.0/100 ml at 6 m. In Stotler Cove, the counts averaged 14.5/100 ml and 97.0/100 ml, respectively. Mean count for all dates and depths, combined, was 62/100 ml.

Physicochemical

pH

Two stations were sampled at both the surface and the bottom in alternate coves on alternate sampling dates. Little difference was observed in pH when comparisons were made by depth or date. The 11 readings taken from the surface ranged from 7.4 to 8.6, with a mean of 8.06. Those from 6 m ranged from 6.4 to 8.3, with a mean of 7.63. Only one measurement dropped into the acid range. The reading of 6.4 was obtained at 6 m in mid-September. The dissolved oxygen at that depth and date was 3.9 mg/liter. The lowest combination of dissolved oxygen and pH was 0.5 mg/liter at pH 7.4. With low dissolved oxygen, one would expect high CO_2 and a corresponding low pH. Apparently a high level of natural buffering occurs due to the predominance of calcareous rock in the lake basin and watershed. The abundance of CO_3^{--} prevents any prolonged or rapid shift of pH into the acid range.

Thermal Conditions

The mean monthly surface and bottom temperatures in degrees C and the mean of temperatures at 1, 6, and 15 m are shown in Figure 6. Dredge-haul temperatures are shown as means for depths of 1, 6, and 15 m (Figure 7). The lake was homothermous until the end of March and by early June a strong stratification was developing. Later in June, the influx of a considerable volume of cool run-off water depressed the temperature of the hypolimnion by 1.3 degrees, but had no measurable effect on surface temperature. The run-off had no apparent effect on the temperature of bottom sediments at one meter, but was reflected in a drop of three degrees in the sediment temperature at 6 meters, and a

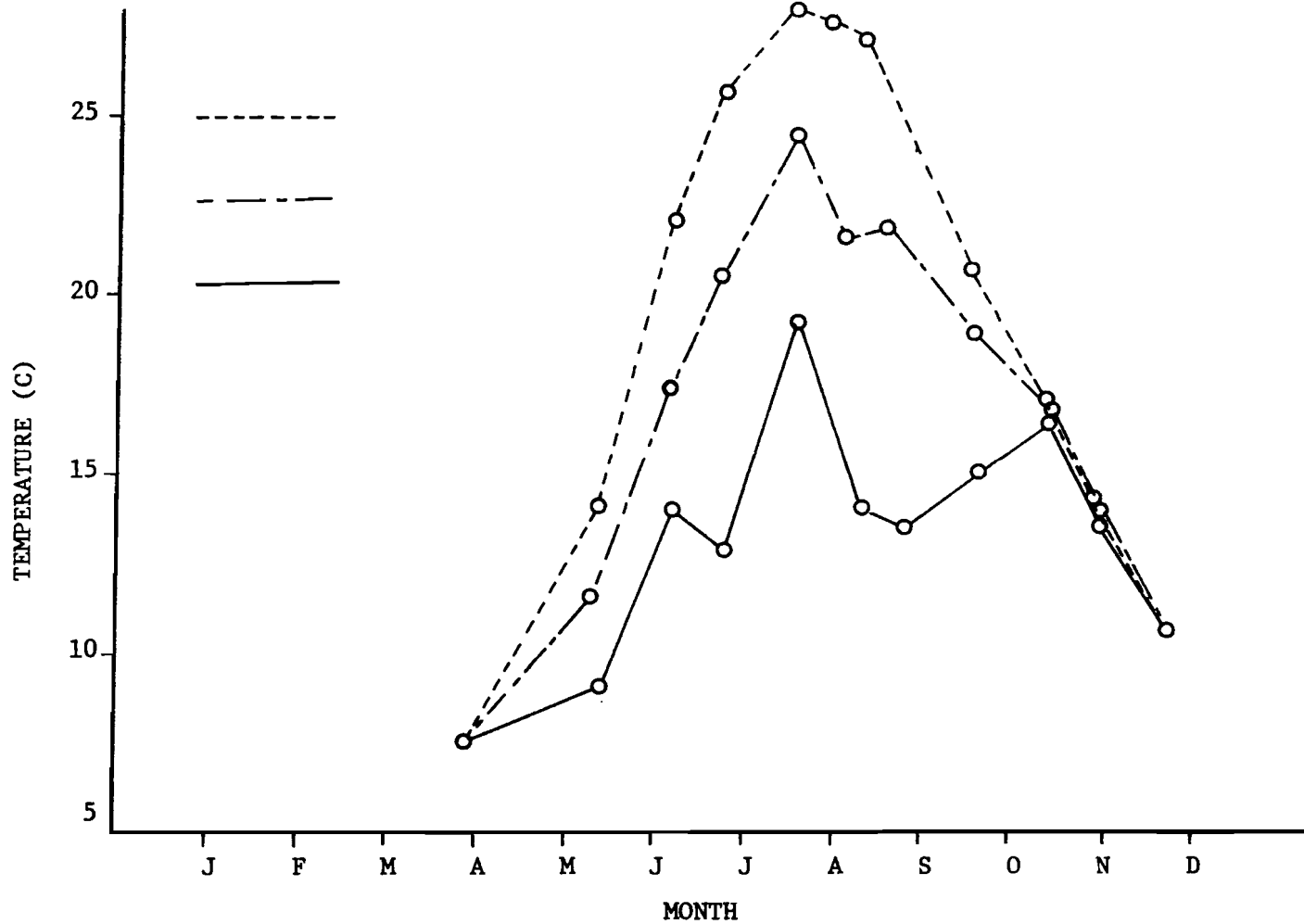


Figure 6. Mean Temperatures (Annual; One Meter; and Fifteen Meters).

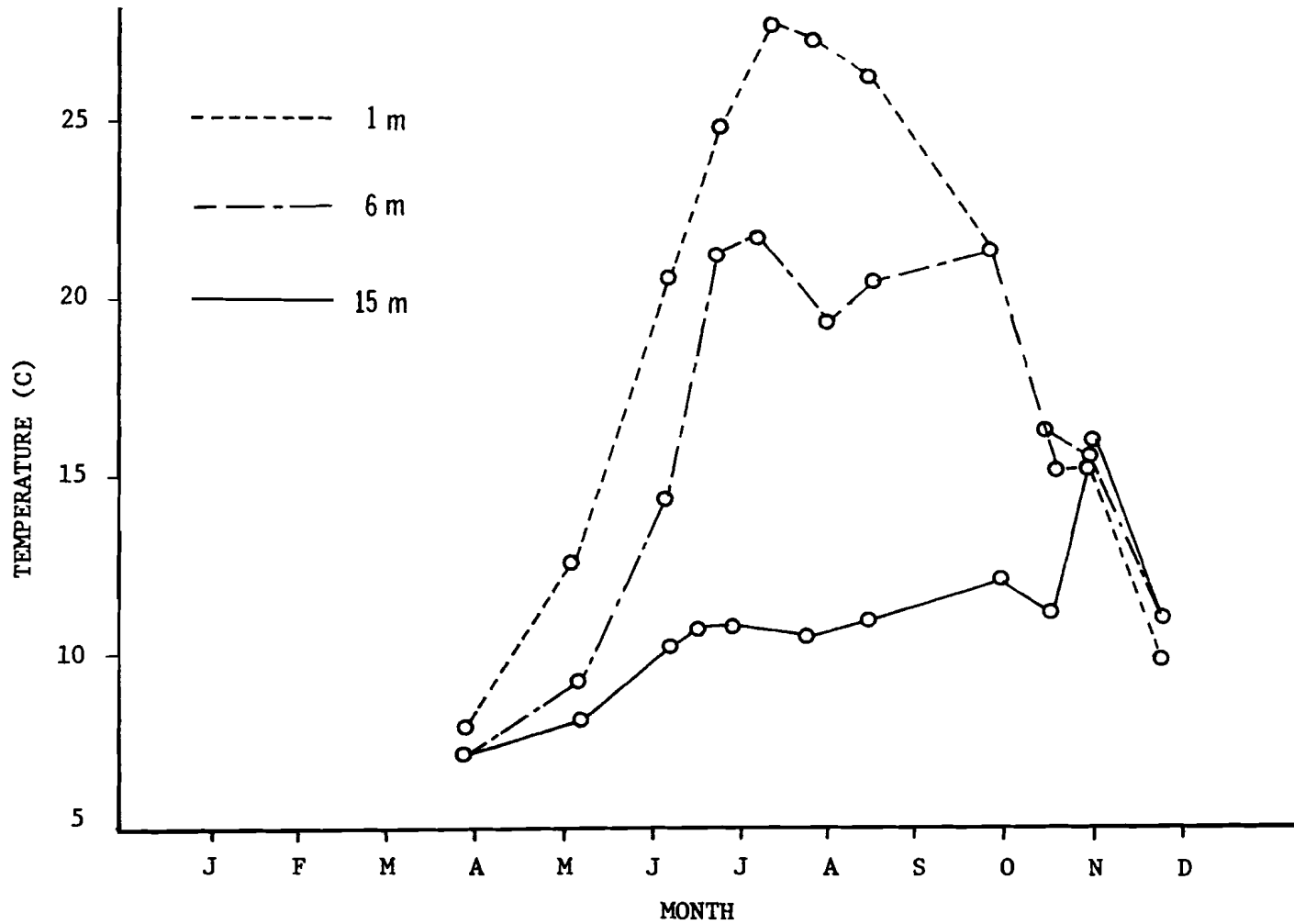


Figure 7. Mean Dredge Haul Temperatures, One, Six, and Fifteen Meters.

barely-perceptible drop at 15 meters.

High ambient temperature and strong wind over the relatively long fetch of the lake caused an erosion of the hypolimnion and decreased the intensity of the stratification during mid-July. Heavy run-off in July again depressed the temperature of the hypolimnion and strengthened the stratification but, again, was not reflected in a lowering of surface temperature. The effect of the new volume of run-off on sediment temperatures was slightly more pronounced than from the earlier occurrence. Sediment at 1 meter showed no change and that at 6 meters dropped 2.6 degrees, while the change at 15 meters was, again, barely perceptible.

Strong winds from the south, moving with the long axis of the lake, again caused an erosion of the hypolimnion. Cooling of the surface water and wind-generated currents finally brought the lake to holomixis in early October.

The effect of relatively cool run-off water in aiding the development of a thermal stratification was reported by Prophet et al. (1967) in a study done on Lyon County State Lake, Kansas. In Wyandotte County Lake, run-off water was responsible twice for reinforcing an eroding hypolimnion. It was observed in both cases that run-off water had a marked effect on the temperature of deeper water and no measurable effect on surface temperature. When considering the effect of run-off on sediment temperatures, it appeared that considerable lag in the temperature rise of the deeper sediments under normal conditions resulted in those sediments being of approximately the same temperature as the run-off water. The effect of cool run-off was considerably greater on the sediments at 6 m, since the temperature there had risen several degrees above

that of the run-off volume. This would provide a considerable temperature differential between the two masses and result in more rapid heat transfer from the warmer to the cooler mass.

Transparency

Secchi disc transparency varied from 0.53 to 2.50 m. Mean monthly secchi disc measurements are shown in Figure 8. In general, light penetration was greatest during the summer and lowest during the spring and early fall. Increased light penetration during early summer was probably due to a more direct angle of solar insolation as well as a depletion of nutrients in the euphotic zone by the spring pulse of planktonic algae. The interval of minimum transparency in the fall was probably due to a combination of circulating sediments expected with the fall holomixis, decreasing angle of solar insolation, and a moderate pulse of phytoplankton, using the increased nutrients available in the circulating sediments.

In a study done on Lyon County, Kansas, State Lake Prophet et al. (1967) developed a conversion factor for the comparison of Secchi disc readings with those obtained by Whitney Underwater Photometer. Their research indicated the compensation level or lower edge of the euphotic zone (depth at which light intensity is only 1% of surface brightness) lay at 3.5 times the depth at which the Secchi disc became invisible. On this basis, the average annual depth of the euphotic zone for Wyandotte County Lake was 4.66 m.

Dissolved Oxygen

The mean monthly dissolved oxygen concentrations at the surface and at 15 m varied inversely with water temperature (Figure 9). The surface

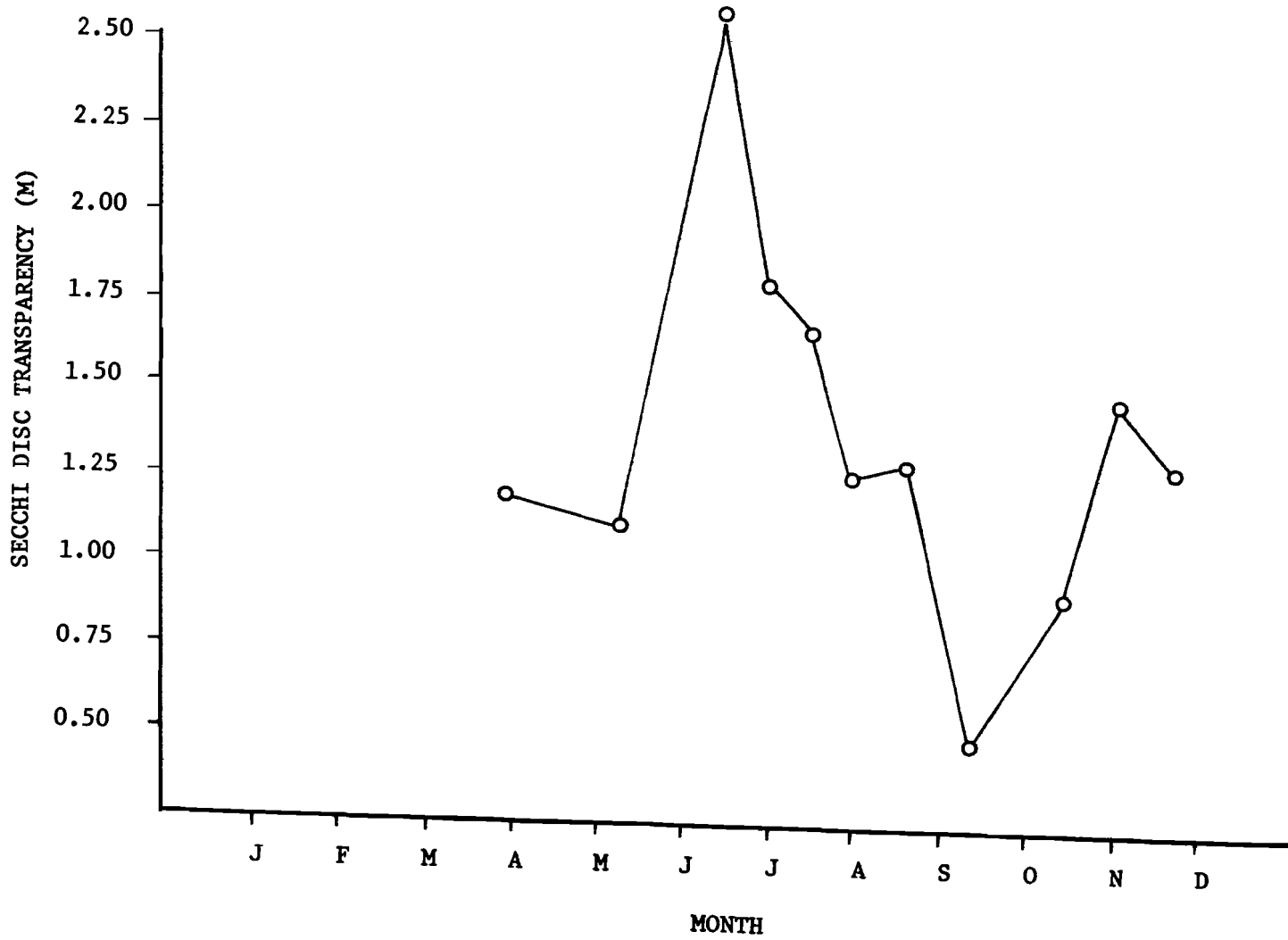


Figure 8. Mean Monthly Secchi Disc Transparency.

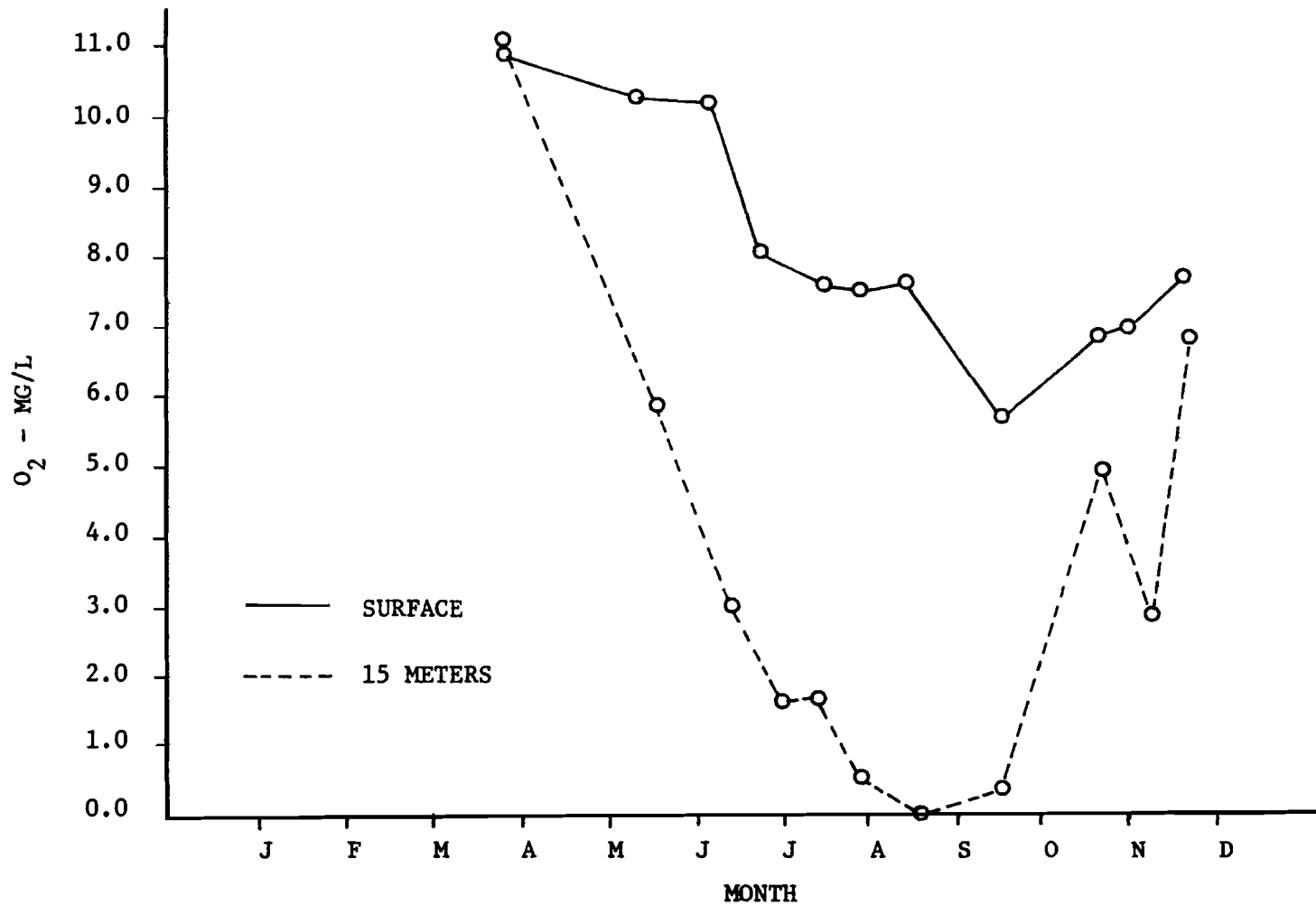


Figure 9. Monthly Mean Concentration of Dissolved Oxygen at the Surface and at Fifteen Meters.

concentrations ranged from 10.8 mg/liter in March to 5.6 mg/liter in mid-September. At 15 m oxygen ranged from 10.9 mg/liter in March to depletion by early August. After reaching these seasonal low points, oxygen became more abundant at all depths and, by mid-November the concentration at any depth was within 0.5 mg/liter of the concentration at any other depth. There was a period of at least 52 consecutive days during the study that hypolimnetic oxygen was depleted, or present in a concentration not greater than 0.5 mg/liter. Temperature of the hypolimnion over that time interval ranged from 13.5 to 19.0 C. Such a combination of environmental pressures produced sufficient stress to explain the paucity of benthic macroinvertebrates collected at 15 m during the summer. Concentrations of dissolved oxygen were compared, using the t-test at $p = .05$ level of significance. There were no significant differences between surface concentrations or between bottom concentrations. There was a significant difference between each surface and bottom concentration.

Nitrate and Phosphate

Nitrate and phosphate values, taken at depths of 1 and 6 meters, were relatively high when compared with other eastern Kansas impoundments. Differences were noted among sampling dates and depths, but were too slight to suggest definite trends (Table VIII). Using the t-test, at $p = .05$ level of significance, there were no significant differences between nitrate levels at any depth, nor between phosphate levels at any depth. Prophet et al. (1970) reported phosphate means from June through August in Council Grove Reservoir, Marion Reservoir, and John Redmond Reservoir to be 0.09, 0.18, and 0.33 mg/liter,

TABLE VIII. Monthly ortho-phosphate and nitrate nitrogen by depth.

Date	Phosphate		Nitrate	
	1 m	6 m	1 m	6 m
3/30	0.07	0.07	15.0	17.0
5/4	0.06	0.08	17.0	6.0
6/2	0.07	0.07	11.0	15.0
6/22	0.06	0.07	9.0	8.5
7/12	0.07	0.14	7.5	7.5
7/26	0.06	0.14	7.0	10.0
8/10	0.07	0.09	10.0	10.0
9/17	0.21	0.23	10.5	10.5
10/8	0.17	0.17	11.0	11.5
10/28	0.09	0.60	18.0	11.0
11/18	0.09	0.09	13.0	15.0

respectively. The three-month mean for Wyandotte County Lake was 0.08 mg/liter, almost identical to Council Grove Reservoir, but considerably less than the other two impoundments. John Redmond Reservoir was known to receive periodic effluents from feedlots. Nitrate means for the three reservoirs were 0.95, 0.37, and 0.90 mg/liter, respectively. Wyandotte County Lake had a mean reading of 9.95 mg/liter for the same time of year. The over-all phosphate mean for Wyandotte County Lake was 0.16 mg/liter. The nitrate mean was 11.4 mg/liter.

The summer mean diversity per individual (\bar{d}) of Council Grove, John Redmond, and Marion Reservoirs, based on zooplankton, was 2.86, 2.57, and 2.50, respectively. Organisms in all three reservoirs were exposed to moderate stress on the basis of the \bar{d} assessment. Based on benthic macroinvertebrates at comparable dates and depths, Wyandotte County Lake produced a \bar{d} value of 1.68. It is possible that the much higher nitrate level in Wyandotte County Lake is significant in the cause of the lower \bar{d} value, since the phosphate, sulfate, and ammonia levels are lower than the other three impoundments, and the pH and dissolved oxygen values indicate favorable conditions. As a further means of comparison, Hulen and Angino (1979) cited the FWPCA (now EPA) in 1968 as stating that the total phosphate in flowing streams should not exceed 0.30 mg/liter. The same agency set the acceptable drinking water standard regarding nitrate nitrogen at a maximum of 45 mg/liter. Wyandotte County Lake fits easily beneath these limits regarding both nutrients. From the viewpoint of the aquatic biologist, the unpolluted range for phosphate is from 0.01 to 0.03 mg/liter. High phosphate ranges from 0.03 to 0.30 mg/liter. A normal ratio between nitrate and phosphate is 10 nitrate :

1 phosphate (Ransom, 1973). Compared to these categories, the yearly mean of 0.16 mg/liter phosphate in Wyandotte County Lake is high, but not exceptionally so, and the lake ratio of 70 nitrate : 1 phosphate indicates an unusual source of nitrate. High nitrate levels in reservoirs are sometimes due to nitrogen fixation by Cyanophyta when there is no other important known source of nitrate (Prophet et al., 1970). The water color in Wyandotte County Lake sometimes suggested the presence of blue-green organisms. There is no other known explanation for the high nitrate level, with the possible exceptions of septic tank leaching, normal allochthonous organic material and, perhaps, deliberate fertilization.

Ammonia

Ammonia nitrogen was relatively low when compared to other eastern Kansas impoundments. Concentrations are shown in Table IX for depths of 1 and 6 m. The yearly mean for readings taken at depths of one and 6 meters was 0.73 mg/liter. This value is below the 1.0 mg/liter standard for unpolluted water. The yearly maximum concentration was 1.26 mg/liter, recorded from a 6 m sample in mid-November. The yearly minimum concentration was 0.18 mg/liter, recorded from surface samples in early June, late July, and early August. Ammonia concentrations tended to be highest at both the surface and at 6 m in early spring and late fall. Concentrations were lowest at those depths from May through July. No samples were taken at 15 m, but ammonia would have undoubtedly been high at that depth, especially from late July to mid-September when the oxygen concentration at that depth ranged from 0.0 to 0.5 mg/liter. Funk (1973) reported ammonia concentrations for John Redmond Reservoir

TABLE IX. Monthly sulfate and ammonia nitrogen by depth.

Date	Sulfate		Ammonia	
	1 m	6 m	1 m	6 m
3/30	22.0	21.8	1.00	1.08
5/4	21.5	20.0	0.54	0.68
6/2	18.0	16.5	0.18	0.58
6/22	21.8	17.5	0.42	0.83
7/12	18.0	16.5	0.30	0.36
7/26	15.0	12.5	0.18	0.80
8/10	0.33	0.28	0.18	1.19
9/17	15.0	16.5	0.77	0.80
10/8	12.5	12.0	0.77	0.74
10/28	20.0	20.0	1.11	1.19
11/18	20.0	19.5	1.08	1.26

by one-meter increments to a depth of 4 m. The annual mean of all depths combined was 1.37 mg/liter. Prophet et al. (1970) reported concentrations for June through August, 1968, from Council Grove, John Redmond, and Marion reservoirs as 0.70, 0.74, and 1.00 mg/liter, respectively. The mean depth of the deepest of the three reservoirs was 4.4 m. During the same time of year, Wyandotte County Lake produced a mean concentration of 0.50 mg/liter to depths including 6 m. Mean ammonia concentrations were compared by depth using the t-test at $p = .05$ level of significance. There were no significant differences in surface concentrations, bottom concentrations, or surface-to-bottom concentrations.

Sulfate

Sulfate was generally low throughout the study when compared to a normal standard of from 10 to 70 mg/liter (Table IX). Concentrations ranged from 12.0 to 22.0 mg/liter, with a combined mean from depths of one and six meters of 17.8 mg/liter. No seasonal trends were apparent. Sulfate enters a body of water with rain or through solution of sulfate compounds in the watershed. A short supply of the anion will lower primary production by inhibiting the growth of phytoplankton. Sulfate is the sulfur source for protein metabolism in producer organisms (Reid, 1961). Prophet et al. (1970) reported sulfate concentrations from 16.7 to 178.3 mg/liter for the three Neosho River impoundments and Funk (1973) reported data showing a yearly mean of 57.4 mg/liter in John Redmond Reservoir, for depths to four m. Although sulfate was relatively low in Wyandotte County Lake, it was not limiting since concentrations remained above 12.0 mg/liter throughout the study. At

depths approaching 15 m and during anoxia of the hypolimnion, sulfur bacteria were reducing sulfate to hydrogen sulfide. The characteristic odor of the gas accompanied dredge hauls lifted from those depths. Sulfate concentrations were compared using the t-test at $p = .05$ level of significance. There were no significant differences among surface concentrations, bottom concentrations, or surface-to-bottom concentrations.

Nitrite

Nitrite was slightly more abundant than the unpolluted standard of 0.001 to 0.01 mg/liter. Concentrations ranged from 0.027 to 0.024 mg/liter, with a combined mean of depths 1 and 6 m of 0.026 mg/liter. No seasonal trend was apparent, but the data suggest a tendency to be slightly lower during the summer.

Trace Metals

Two trace metals, copper and iron, were measured at the beginning and end of the study. Copper ranged from 1.09 to 1.95 mg/liter, while iron ranged from 0.06 to 0.1 mg/liter. Both are insoluble in oxidized states and in intensely reducing environments where they form sulfides. Hydrous copper sulfate has long been used as an algicide in aquatic systems. It accumulates as copper carbonate in the sediments of hard water lakes where it may be detrimental to bottom fauna (Cole, 1975).

SUMMARY

A limnological study was conducted on the 135 ha Wyandotte County Lake, located in the County Park at 91st Street and Leavenworth Road in Kansas City, Kansas. Water quality data were established by determining physicochemical parameters and sampling the benthic macroinvertebrate community from 1 June 1977 to 18 November 1977 and from 30 March 1978 to 5 May 1978. Seven stations were established over the lake at depths from 1 to 15 meters. A total of 28 taxa consisting of 11,897 individuals of benthic macroinvertebrates was collected. Eight taxa of zooplankton were collected. Individual species diversity (\bar{d}) indices for benthic macroinvertebrates were calculated for each station by depth and mean monthly variations in \bar{d} were calculated with all depths combined. Annual \bar{d} values ranged from 1.0 to 1.9, with an annual mean of 1.4, indicating moderate stress in the aquatic system. Coliform counts averaged 62/100 ml. Thermal conditions were in line with expected seasonal variations for a moderately-deep temperate lake with a spring and fall holomixis and a well-established direct stratification in mid-summer. Oxygen was present in the summer at concentrations from 2.5 to 7.7 mg/liter, and at depths from 8 to 15 meters oxygen was likely to be depleted. Secchi disc transparency varied from 0.53 to 2.50 meters. The mean indicated the lake euphotic zone averaged 4.66 meters. Nitrate was high, ranging from 6.0 to 17.0 mg/liter, with an annual mean of 11.41 mg/liter. Phosphate ranged closer to normal, with a minimum of 0.06 and a maximum of 0.23 mg/liter. Mean annual phosphate was 0.16 mg/liter. The nitrate : phosphate ratio was 70 : 1, suggesting an important outside source of nitrate. Ammonia nitrogen

showed a yearly mean of 0.73 mg/liter, within the limits for unpolluted water. Sulfate was low, ranging from 12.0 to 22.0 mg/liter, with an annual mean to 6 meters of 17.8 mg/liter. Nitrite was slightly above unpolluted standards, ranging from 0.001 to 0.26 mg/liter, with an annual mean of 0.026 mg/liter. Trace metals were measured at the beginning and end of the study. Copper ranged from 1.09 to 1.95 mg/liter. Iron ranged from 0.06 to 0.1 mg/liter. Wyandotte County Lake appeared to be a moderately enriched system.

LITERATURE CITED

LITERATURE CITED

- American Public Health Association. 1961. Standard methods for examination of water, sewage, and industrial waste. 11th ed. Amer. Public Health Assn., New York.
- Beck, W. M. 1955. Suggested method for reporting biotic data. Sew. and Ind. Wastes. 27:1193-1197.
- Cole, G. A. 1975. Textbook of Limnology. The C. V. Mosby Co., St. Louis. 283 p.
- Edmondson, W. T., Editor. 1966. Ward and Whipple fresh water biology. John Wiley and Sons, Inc., New York. 1248 p.
- Edwards, N. L. 1970. The effect of feedlot runoff on community structure in the Cottonwood River, Kansas. Unpubl. M. S. Thesis. Kansas State Teachers College. 20 p.
- Funk, F. L. 1973. Species diversity and relative abundance of benthic fauna, and related physicochemical features in John Redmond Reservoir, Kansas 1971-72. Unpubl. M. S. Thesis. Kansas State Teachers College. 35 p.
- Gaufin, A. R. and C. M. Tarzwell. 1952. Aquatic invertebrates as indicators of stream pollution. Publ. Health Rep. 67:57-67.
- Harrel, R. C. and T. C. Dorris. 1968. Stream order, morphometry, physicochemical conditions, and community structure of benthic macroinvertebrates in an intermittent stream system. Am. Mid. Nat. 80:220-251.
- Horner, C. S. 1977. Some ecology of benthic insects in Gladfelter Pond. Unpubl. M. S. Thesis. Emporia State University. 32 p.
- Hulen, P. L. and E. E. Angino. 1979. Nitrate and phosphate: time-trend concentrations in selected Kansas streams. Trans. Kansas Acad. Sci. 82(2):73-83.
- Kansas Water Resources Board. 1967. A Kansas water atlas. "701" Project No. Kansas P-43. Report No. 16-a. Topeka, Kansas. 57 p.
- Lind, O. T. 1974. Handbook of common methods in limnology. The C. V. Mosby Co. St. Louis. 154 p.
- Margalef, R. 1956. Informacion y diversidad espicfica en las cominudades de organisms. Inv. Pesq. 3:99-106.
- Mason, W. T. 1968. An introduction to the identification of chironomid larvae. Div. of Poll. Surv., Fed. Water Poll. Cont. Admin., U. S. Dept of Int. Cincinnati, Ohio. 89 p.

- Mathis, B. J. 1968. Species diversity of benthic macroinvertebrates in three mountain streams. Ill. State Acad. of Sci. 61(2):171-176.
- _____, and T. C. Dorris. 1968. Community structure of benthic macroinvertebrates in an intermittent stream receiving oil field brines. Am. Mid. Nat. 80:428-439.
- Patrick, R. 1949. A proposed biological measure of stream conditions, based on a survey of the Conestoga Basin, Lancaster County, Penna. Proc. Acad. Nat. Sci. of Phila. 101:277-341.
- Patten, B. C. 1962. Species diversity in net phytoplankton of Raritan Bay. J. Mar. Res. 20(1):57-75.
- Pennak, R. W. 1953. Fresh-water invertebrates of the United States. The Ronald Press Co., New York. 769 p.
- Prophet, C. W. 1965. Some limnological features of Lyon County State Lake during reflooding. Trans. Kansas Acad. Sci. 67:676-685.
- _____, N. Youngsteadt, and L. Schnittker. 1967. Limnology of Lyon County State Lake during reflooding, April 1964 - March 1966. Trans. Kansas Acad. Sci. 69:214-225.
- _____, J. E. Prather, and N. L. Edwards. 1970. Comparison of summer water quality features in three Grand River reservoirs, Kansas. Emporia State Research Studies. 18:4.
- Ransom, J. D. 1969. Community structure of benthic macroinvertebrates and related physicochemical conditions in Keystone Reservoir, Oklahoma. Unpubl. Ph.D. Thesis. Okla. State Univ. 59 p.
- _____, and T. C. Dorris. 1972. Analysis of benthic community structure in a reservoir by use of diversity indices. Am. Mid. Nat. 2:434-447.
- _____. 1973. Personal communication.
- _____, and C. W. Prophet. 1974. Species diversity and relative abundance of benthic macroinvertebrates in Cedar Creek basin, Kansas. Am. Mid. Nat. 92:217-222.
- Reid, G. K. 1961. Ecology of inland water and estuaries. Reinhold Pub. Corp., New York. 375 p.
- Richardson, R. E. 1928. The bottom fauna of the middle Illinois River, 1913 - 1925. Ill. St. Nat. Hist. Sur. 17:387-475.
- Shannon, C. E. and W. Weaver. 1949. The mathematical theory of communication. Univ. of Ill. Press, Urbana, Ill. 117 p.

- Tarzwel, C. M. 1965. Biological problems in water pollution. U. S. Dept. of Hlth., Ed., and Welf. PB 168 784. Cincinnati, Ohio.
- Wilhm, J. L. and T. C. Dorris. 1966. Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluents. Am. Mid. Nat. 76:427-449.
- _____. 1970. Range of diversity index in benthic macroinvertebrate populations. Journ. Water Poll. Cont. Fed. 42(5):R221-R224.