# COMMUNITY STRUCTURE OF NET ZOOPLANKTON AND RELATED PHYSICOCHEMICAL LIMNOLOGY IN KEYSTONE RESERVOIR, OKLAHOMA

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# CHAPTER I

# INTRODUCTION

Limnetic zooplankton are important organisms in lacustrine ecosystems because they occupy an intermediate trophic level between producers and higher consumers, and function in nutrient regeneration. Zooplankton are coupled via food chains to the benthos (Margalef 1967) and to fish (Brooks and Dodson 1965, Applegate and Mullan 1967a). Zooplankton have been shown to be effective agents in regeneration of micronutrients (Olsen, Chakravarti, and Olson 1967) and macronutrients important to phytoplankton (Redfield 1958, Harris 1959, Barlow and Bishop 1965, Martin 1968).

Studies of zooplankton in natural systems are usually by one of two methods. One method analyzes their production and biomass to obtain estimates of their functional status within a system. The other method evaluates community structure or the distribution of individuals among species.

Community structure usually may be expressed in terms of species frequency, numerical abundance of species, or by spatial and temporal distribution of individuals and species (Hairston 1959). Pennak (1957) characterized limnetic zooplankton of Colorado lakes according to species frequency of copepoda, cladocera, and rotifers. Pennak observed that in the species frequency distribution of limnetic zooplankton there were a few species with many individuals and many species with few individuals. A similar pattern of species frequency in zooplankton has been observed by Raymond (1937), Scheffer and Robinson (1939), Brook and Woodward (1956), Prophet (1957), and Cushing (1964). Numerical distribution of individuals were used by Applegate and Mullan (1967b) to characterize zooplankton in Beaver and Bull Shoals Reservoirs, Arkansas and Missouri, and by Cowell (1967) for zooplankton in Lewis and Clark Lake, South Dakota. Applegate and Mullan (1967b) and Cowell (1967) found that species frequency in the impoundments differed from Pennak's (1957) classification of zooplankton community structure because of importation of individuals and increased numbers of congeneric species in the reservoirs. Spatial and temporal changes in species and numbers of individuals have been used to explain zooplankton community structure by Pennak (1946, 1955), Anakru (1964), and Johnson (1964).

The usual methods of reporting community structure do not permit concise and meaningful comparisons of data. Information concerning community structure would have greater value if results could be interpreted by a brief and clear summarization of individual and species assemblages. Such analyses of community structure are provided by species diversity indices. Diversity indices are mathematical models which summarize community structure on a numerical basis. They allow summarization of large amounts of information from which meaningful comparisons of community structure can be made (Patten 1962).

Various diversity indices have been proposed to evaluate community structure. Fisher, Corbet, and Williams (1943) used a logarithmic series, and Preston (1948) used a lognormal series to describe relationships between species and individuals. Margalef (1951) used the relationship between species and the logarithm of the individuals as a measure of diversity.

Margalef (1956) proposed using diversity indices derived from information theory to analyze mixed species populations. Diversity is related to the uncertainty of obtaining a particular species of individual in a random sample of a population. The more equally distributed the species are in a sample, the greater the uncertainty. Thus, uncertainty existing within a sample is a reasonable estimate of diversity.

Brillouin's (1960) equation used to compute information per individual is,

$$H = (1/N)(\log N! - \sum_{1}^{s} \log N_i!),$$

where N is the number of individuals in s species, and $N_i$ is the number of individuals in the ith species. Shannon (1963) using Stirling's approximation to estimate the factorials in Brillouin's equation introduced the transformation,

$$H' = -\sum_{1}^{s} p_i \log_2 p_i$$

where $p_i = N_i/N$. $N_i/N$ are population values which are estimated from sample values to yield the equation,

$$\bar{d} = \sum_{1}^{s} (n_i/n) \log_2(n_i/n).$$

Reviews of Shannon's formula and its use in ecological studies have been made by Patten (1962), Lloyd and Ghelaridi (1964), Pielou (1965, 1966), Wilhm and Dorris (1966, 1968), and Wilhm (1968). Several features of Shannon's formula make it useful in evaluating community structure. The diversity index ($\bar{d}$) is dimensionless and any units of numbers can be used in the basic formula. Wilhm (1968) used biomass units rather than numbers of individuals to compute diversity of benthic macroinvertebrates. When more calorific values for species are known, diversity may be characterized in functional terms of energy units. $\bar{d}$ also estimates the relative importance of the various species since the ratio of $n_i/n$ represents the contribution of the ith species to the total estimate of species diversity in the community. Another advantage of $\bar{d}$ is independence of sample size. Usually, not every species in a system will be collected in a zooplankton sampling program. If a rare species is not included in the sample, its absence will have little effect on the estimation of community structure, so that estimates of total numbers of individuals or species in populations are not required (Wilhm and Dorris 1968). Pielou (1966) and Wilhm and Dorris (1968) have shown that when successive samples are pooled, $\bar{d}$ reaches asymptotic levels. Further sampling has little influence on $\bar{d}$ once an asymptotic is reached. $\bar{d}$ reaches an asymptote because rare species are being added at a slower rate than common species which increases the value of $\bar{d}$ and common species are added more rapidly which causes a depression in $\bar{d}$ (Pielou 1966).

Since asymptotic levels of $\bar{d}$ can be obtained from pooled samples, it should be feasible to determine the asymptote for a replicate series in a particular sampling technique. However, little is known about changes in statistical variation among replicate samples of $\bar{d}$ from various sample sizes. If the within sample variance, coefficient of variation, and error associated with particular sampling techniques of $\bar{d}$ were known, it would be shown to be more reliable in determining community structure in aquatic environments.

The objective of this study was to evaluate the usefulness of $\bar{d}$ in summarizing community structure of zooplankton populations. $\bar{d}$ was evaluated by determining the asymptotic sample size by progressively pooling samples of increasing size, and by determining the statistical variation among replicate samples of various sample sizes. Spatial and temporal changes in $\bar{d}$ and the influence of certain physicochemical conditions on the zooplankton community structure were also examined.

# CHAPTER II

# DESCRIPTION OF AREA AND PROCEDURES

## General Description of Reservoir

Keystone Reservoir was formed by damming the Arkansas River approximately 3.2 km below its confluence with the Cimarron River. It is used for flood control, navigation, power generation, and recreation. The reservoir can be divided into the central pool below the mergence of the two rivers, the Cimarron River Arm, the Arkansas River Arm, and Salt Creek (Fig. 1).

The drainage area above the dam is 1.92 x $10^5$ $km^2$ (U.S. Army Corps of Engineers 1961). The area of the conservation pool at normal levels is 76.7 $km^2$, while that of the flood control pool is 224.3 $km^2$. Maximum storage capacity is 2.3 $km^3$. The lengths of the Cimarron and Arkansas River Arms are approximately 49 and 45 km, respectively. Maximum width varies from 1.6 km at normal water level to 2.1 km during flood stage.

## Sampling Areas

Four sampling stations each were established on the Cimarron (C1 through C4) and Arkansas Arms (A1 through A4) of the reservoir and one at the dam site (Fig. 1). Table I lists yearly mean depth and distance above the dam of the stations. Stations were designated by fixed buoys in the former river channels.

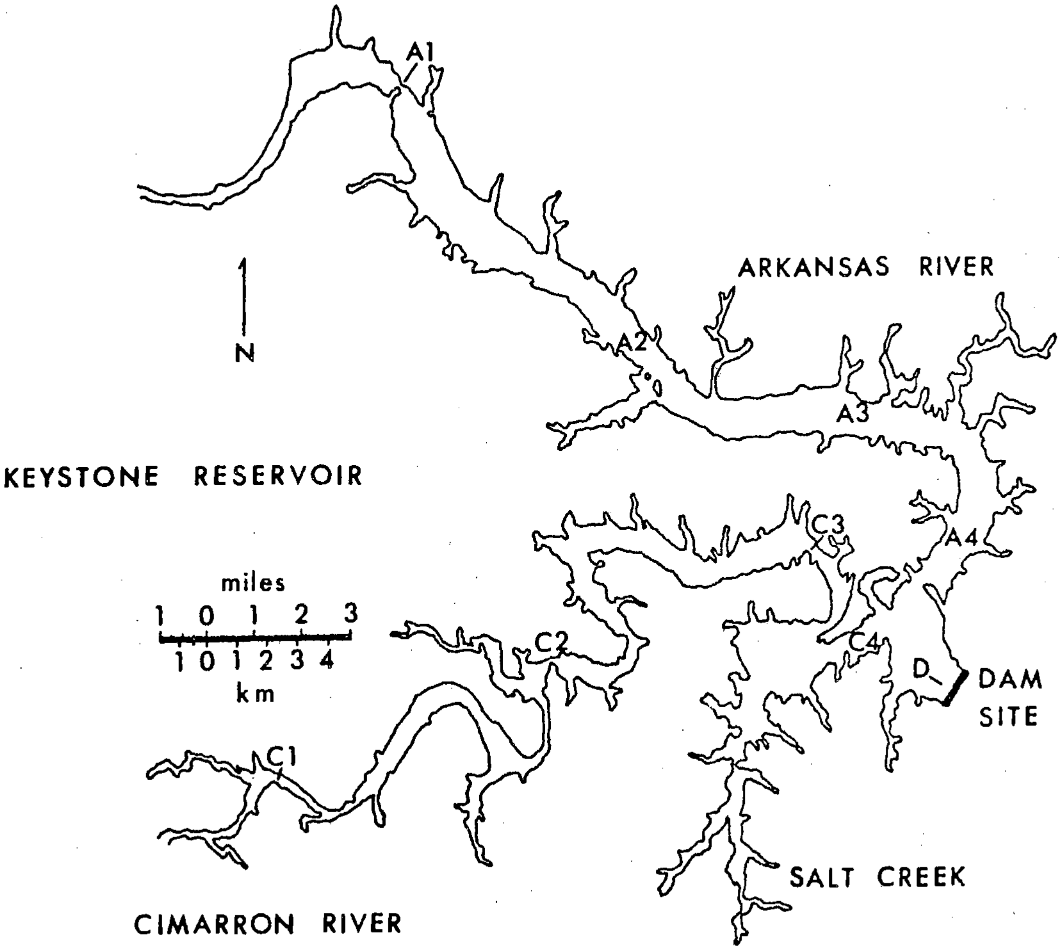

Figure 1. Keystone Reservoir, Oklahoma.

TABLE I

LIST OF STATIONS BY AREAS, MEAN ANNUAL DEPTH, AND DISTANCE ABOVE THE DAM

| | Cimarron Arm | | | | | Arkansas Arm | | | |
|---|---|---|---|---|---|---|---|---|---|
| Stations | C1 | C2 | C3 | C4 | Dam | A4 | A3 | A2 | A1 |
| $\bar{x}$ depth (m) | 1 | 8 | 14 | 18 | 18 | 16 | 11 | 9 | 7 |
| distance above dam (km) | 49 | 30 | 15 | 4 | .1 | 6 | 14 | 22 | 34 |

### Physicochemical Samples

Physicochemical measurements were taken monthly at each station. Temperature, dissolved oxygen concentration, and conductivity were determined at intervals of 1.0 m from the surface to the bottom. Turbidity, pH, total alkalinity, and inorganic ions were measured at 4.0 m depth intervals. In order to reduce variation between reservoir arms, sampling regimes were alternated monthly (i.e., sampling started at C1 one month and A1 the next).

Water temperature was determined with a Yellow Springs telethermometer. Oxygen concentration was measured with a Precision Scientific Instruments galvanic cell oxygen analyzer, calibrated against a standard Alsterberg (Azide) Modification of the Winkler method (A.P.H.A. 1960). Micromhos $cm^{-1}$ (umhos) specific conductance at 25 C were measured with an Industrial Instruments R-B solu-bridge. Hydrogen ion concentration was determined with a Hellige comparator. Turbidity was estimated with a Bausch and Lomb Spectronic 20 colorimeter, with per cent light transmission converted to "Turbidity Units," which approximate mg $liter^{-1}$. Methyl purple and phenolphthalein alkalinity were measured by titration with 0.02 N sulfuric acid (A.P.H.A. 1960). Light intensity was determined by using a Gem submarine photometer. Analysis of $Cl^-$, $Na^+$, and $SO_4^{--}$ ions was conducted by P. C. Falls, Sinclair Research Center, Tulsa, Oklahoma.

Monthly and seasonal means for all physicochemical parameters were determined for all stations. Seasons were based on water temperature conditions of all stations in the reservoir. Summer was considered to be June through September; fall, October and November; winter, December through March; and spring, April and May.

## Biological Samples

Four vertical zooplankton hauls were made monthly at each station from 24 June 1967 through 21 June 1968. A Wisconsin Plankton Net with number 20 nylon bolting cloth and a mouth aperture of 12.0 cm was used. Samples were concentrated, washed, placed in 30 ml bottles, and fixed with formalin. Two paired 6-liter zooplankton samples were taken with Kemmerer bottles for diel analysis every 4 hours from five strata at Station C4 in the Cimarron River on 9 and 10 July 1968. Treatment and preservation of the samples were the same as in monthly collections.

Three samples from each station were evaluated monthly. The fourth sample was used only when one of the three samples was accidently destroyed. The differential count method and a Sedgwick-Rafter slide (A.P.H.A. 1960) were used in enumerating zooplankton. One ml subsamples were taken from the concentrated samples, and counts were made of species frequency until 600 individuals had been counted in June, July, August, and December. Since the data collected during these 4 months revealed that little additional information was obtained after counting 400 individuals, this smaller number was counted during the remaining months.

The same method of tabulation was used for diel samples. Due to the small numbers of individuals present in some samples, it was not possible to specify a prescribed number of specimens for all samples. Therefore, three 1 ml subsamples from each paired total sample were counted so that six slides per stratum per time were evaluated.

Species diversity estimates were computed on all monthly and diel zooplankton samples using Shannon's formula. For counts of 600 individuals, $\bar{d}$ values were calculated for six sets of 100 individuals, three sets of 200 individuals, two sets of 300 individuals, and one set each of 400, 500, and 600 individuals. This design was developed to examine the change in $\bar{d}$ as the number of individuals counted increased. This same design was used for counts of 400 individuals, with $\bar{d}$ being computed over four sets of 100 individuals, two sets of 200 individuals, and one each for 300 and 400 individuals. The above procedures were applied to each of the 27 samples collected. Analysis of diel species diversity in each sample was based on the total numbers of individuals counted in three 1 ml subsamples.

Species diversity was also computed using the graphical method of Yount (1956). Species diversity was determined as the slope value of a line from cumulative increases in species versus the logarithm of cumulative individuals.

Analysis of variance and tests for equality of variance of $\bar{d}$ for different sample sizes were computed on the monthly samples. Duncan's New Multiple Range test was conducted to test for significant differences in $\bar{d}$ between stations. Statistical tests for station homogeneity were conducted on the slopes from cumulative species versus logarithm of cumulative individuals.

# CHAPTER III

# RESULTS AND DISCUSSIONS

## Physicochemical Conditions

Conductivity in Keystone Reservoir varied from 1210 to 12,000 umhos in the Cimarron Arm and from 613 to 2215 umhos in the Arkansas Arm (Table II). Conductivity in Keystone Reservoir exceeded values reported from similar riverine impoundments. Applegate and Mullan (1967b) reported conductivity values of 85 to 320 umhos in Beaver and Bull Shoals Reservoirs in Arkansas and Missouri. Cowell (1967) reported values of conductivity from 650 to 840 umhos in Lewis and Clark Lake, South Dakota. High conductivity of water in Keystone Reservoir is caused by dissolved solids carried by the Cimarron and Arkansas Rivers which flow through semiarid regions of the Great Plains. The primary source of dissolved salts in the Arkansas River is the salt plains area of northern Oklahoma. The Cimarron River presumably receives much of its dissolved load from the Grant-Pond Creek-Nash association in northcentral Oklahoma which contains large amounts of soluble salts (Gray and Galloway 1959).

Principle ions contributing to the dissolved solid concentrations in both rivers are chloride, sodium, and sulfate. The annual mean concentration of $Cl^-$, $Na^{++}$, and $SO_4^{--}$ were 551.2 mg $liter^{-1}$, 359.6, and 118.6, respectively, in the Cimarron Arm and 298.5 mg $liter^{-1}$, 235.7, and 97.3, respectively, in the Arkansas Arm. The Cimarron

## TABLE II

## MEAN MONTHLY AND ANNUAL SPECIFIC CONDUCTANCE*

| | Stations | | | | | | | | | Reservoir Arm | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C1 | C2 | C3 | C4 | Dam | A4 | A3 | A2 | A1 | Cim | Ark |
| Jun | 3150 | 2033 | 2800 | 2680 | 2572 | 1911 | 1738 | 1050 | 825 | 2640 | 1520 |
| Jul | 9000 | 3192 | 1738 | 1880 | 1156 | 1019 | 1060 | 1053 | 1233 | 2391 | 1069 |
| Aug | 12000 | 4000 | 2419 | 1360 | 1100 | 960 | 967 | 1000 | 925 | 2101 | 967 |
| Sep | 5255 | 1653 | 1438 | 1523 | 1156 | 1077 | 1094 | 1084 | 2012 | 1814 | 1213 |
| Oct | 4200 | 2400 | 1575 | 1210 | 1055 | 895 | 758 | 613 | 700 | 1829 | 783 |
| Nov | 8400 | 2090 | 1358 | 1473 | 1276 | 1100 | 888 | 823 | 1425 | 2119 | 1079 |
| Dec | 1946 | 1415 | 1495 | 1218 | 1200 | 1100 | 1033 | 1117 | 1815 | 1569 | 1181 |
| Jan | 3150 | 1680 | 1493 | 1374 | 1258 | 1298 | 1240 | 1330 | 1850 | 1770 | 1300 |
| Feb | 4700 | 1850 | 1625 | 1518 | 1536 | 1470 | 1420 | 1543 | 2215 | 1875 | 1632 |
| Mar | 2041 | 2830 | 2165 | 1636 | 1544 | 1600 | 1627 | 1703 | 900 | 2105 | 1528 |
| Apr | 3380 | 1773 | 2300 | 1822 | 1624 | 1622 | 1300 | 1337 | 1280 | 2078 | 1429 |
| May | 1890 | 2190 | 1966 | 1580 | 1466 | 1298 | 890 | 797 | 490 | 1903 | 964 |
| Jun | 1627 | 2093 | 2475 | 2046 | 1306 | 1158 | 1118 | 1037 | 740 | 2383 | 1142 |
| $\bar{x}$ | 4752 | 2309 | 1885 | 1604 | 1407 | 1245 | 1128 | 1116 | 1256 | 2044 | 1216 |

*Specific conductance measured in micromhos $cm^{-1}$

River water has a considerably greater dissolved solid concentration than the Arkansas River. The differences in specific ion concentration between the two rivers probably reflect localized geological formations with varying ion concentrations.

Conductivity generally decreased downstream in both arms of the reservoir as dilution of dissolved solids occurred in the reservoir (Table II). Mean annual conductivity of the Cimarron decreased from 4752 umhos at C1 to 1604 umhos at C4 and from 1256 umhos at A1 to 1128 umhos at A3 in the Arkansas Arm. Conductivity averaged 1407 umhos at the dam. Dilution of waters in the Arkansas Arm resulted from precipitation and from less conductive waters of tributaries. Water in the Cimarron Arm was diluted by tributaries, precipitation, and less conductive Arkansas River water. Higher conductivity at Station A4 than at A3 and A2 suggests mixing of the lower Cimarron water with the lower Arkansas waters. This supposition is supported by current measurements and ion ratios (Eley, personal communication). A distinct circular current was found between Stations A3 and C3 with the Arkansas waters flowing up the Cimarron and returning to the Arkansas Arm.

Mean monthly conductivity in the Cimarron Arm varied from 1569 umhos in December to 2640 umhos in June (Table II). Conductivity decreased steadily from June through September due to flooding in June and decreased inflow during July and August. The June flood contributed 23.39 x $10^7$ $m^3$ of water to the reservoir which diluted a majority of the water mass. Conductivity was generally higher in summer and spring than in fall and winter. Mean monthly conductivities in the Arkansas Arm varied from 783 umhos in October to 1632 umhos in

February (Table II). The June and July floods in the Arkansas watershed contributed a total inflow of 13.58 x $10^8 m^3$ of water which reduced conductivities by dilution in the arm through August. Increased inflow in October reduced conductivity but less than in June. Conductivity increased from October through February and decreased in spring due to increased precipitation. Mean monthly conductivity at the Dam Station ranged from 1055 umhos in October to 2572 umhos in June and was generally intermediate to values measured at Stations C4 and A4.

Turbidity in Keystone Reservoir varied from 4 to 275 mg $liter^{-1}$ in the Cimarron Arm and from 3 to 275 mg $liter^{-1}$ in the Arkansas Arm (Table III). Minimum and maximum values recorded in Keystone are similar to values of 0 to 280 mg $liter^{-1}$ reported for several Oklahoma impoundments (Rainwater 1962), but not as high as the 10 to 680 mg $liter^{-1}$ reported for a Missouri River reservoir (Cowell 1967).

Turbidity in the Arkansas Arm was generally higher than the Cimarron Arm (Table III). Differences in turbidity between the arms was influenced by three factors. The highly mineralized Cimarron River water produced a higher rate of precipitation of the suspended solids. Waters of high conductivity have been reported to be less turbid than water of low conductivity (Keeton 1959, Harrel and Dorris 1968). The Cimarron waters also had a longer retention time than the Arkansas waters, which would permit more settling of suspended solids in the Cimarron Arm (Eley 1970). Turbidity flows in the Cimarron Arm were generally due to greater density of the mineralized water and were observed to flow along the bottom and out the dam. Flows in the

## TABLE III

## MEAN MONTHLY AND ANNUAL TURBIDITY IN "TURBIDITY UNITS"*

| | Stations | | | | | | | | | Reservoir Arm | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C1 | C2 | C3 | C4 | Dam | A4 | A3 | A2 | A1 | Cim | Ark |
| Jun | 118 | 83 | 25 | 21 | 25 | 45 | 72 | 168 | 265 | 62 | 138 |
| Jul | 96 | 48 | 37 | 56 | 55 | 102 | 114 | 127 | 226 | 59 | 142 |
| Aug | 275 | 61 | 39 | 46 | 65 | 76 | 70 | 89 | 212 | 105 | 110 |
| Sep | 275 | 104 | 43 | 35 | 25 | 25 | 28 | 33 | 230 | 114 | 79 |
| Oct | 240 | 92 | 35 | 47 | 94 | 83 | 135 | 123 | 138 | 103 | 120 |
| Nov | 54 | 45 | 49 | 29 | 39 | 79 | 61 | 43 | 80 | 44 | 66 |
| Dec | 94 | 84 | 99 | 81 | 80 | 81 | 78 | 73 | 54 | 89 | 71 |
| Jan | 17 | 8 | 7 | 13 | 10 | 11 | 6 | 7 | 28 | 12 | 13 |
| Feb | 21 | 9 | 7 | 4 | 7 | 8 | 3 | 6 | 7 | 11 | 6 |
| Mar | 275 | 75 | 22 | 11 | 11 | 11 | 14 | 20 | 275 | 96 | 80 |
| Apr | 275 | 145 | 36 | 4 | 4 | 12 | 9 | 70 | 163 | 112 | 64 |
| May | 275 | 126 | 45 | 34 | 39 | 89 | 227 | 270 | 275 | 120 | 215 |
| Jun | 275 | 67 | 33 | 66 | 64 | 77 | 104 | 142 | 275 | 110 | 149 |
| $\bar{x}$ | 176 | 73 | 37 | 34 | 39 | 54 | 71 | 90 | 171 | 80 | 96 |

*Approximates mg liter$^{-1}$

Arkansas Arm were generally mixed throughout by wind generated currents producing higher turbidities in the Arkansas Arm compared to the Cimarron Arm.

Turbidity generally decreased downstream in both arms of the reservoir and was related to settling out of suspended material as the velocity of the water mass decreased (Table III). Mean annual turbidity in the Cimarron decreased from 171 mg liter$^{-1}$ at C1 to 34 mg liter$^{-1}$ at C4 and from 171 mg liter$^{-1}$ at A1 to 54 mg liter$^{-1}$ at A4. Mean annual turbidity at the Dam Station was intermediate between values recorded at Stations C4 and A4.

Turbidity was usually highest during spring and lowest during the winter in both reservoir arms (Table III). Exceptions to this occurred periodically during increased river discharge when the suspended load carried by the two rivers increased. However, not all flooding caused increased turbidities. Turbidity increases were probably related to the amount of runn-off waters during periods of precipitation. Presumably, large amounts of run-off carried a larger suspended load than smaller amounts of run-off. Most noticeable increases in turbidity occurred in the Arkansas Arm with the floods of June and July. The less dense Arkansas water overflowed the Cimarron water to a point midway between C3 and C4 which increased turbidities at C4 and Dam during June and July.

Temperatures in the reservoir varied from 2.5 to 30.9 C (Table IV). A mean maximum temperature of 25.9 C for the entire reservoir was recorded in July and a minimum of 3.9 C was observed in January. Temperatures in the reservoir are similar to values reported for other riverine impoundments. Cowell (1967) reported temperatures for

# TABLE IV

## MEAN MONTHLY AND ANNUAL TEMPERATURE (C)

| | Stations | | | | | | | | | Reservoir Arm | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C1 | C2 | C3 | C4 | Dam | A4 | A3 | A2 | A1 | Cim | Ark |
| Jun | 27.8 | 24.9 | 25.3 | 24.2 | 24.5 | 24.8 | 24.8 | 24.8 | 22.8 | 25.5 | 24.3 |
| Jul | 27.9 | 25.9 | 25.6 | 25.5 | 24.9 | 24.9 | 24.8 | 25.7 | 26.3 | 26.2 | 25.6 |
| Aug | 23.9 | 25.2 | 25.8 | 25.7 | 25.5 | 25.4 | 25.6 | 26.1 | 25.0 | 25.2 | 25.5 |
| Sep | 24.1 | 23.5 | 23.2 | 23.9 | 22.8 | 22.7 | 22.9 | 23.2 | 23.0 | 23.8 | 22.9 |
| Oct | 14.0 | 16.9 | 18.2 | 18.5 | 18.2 | 17.6 | 17.2 | 16.8 | 15.0 | 16.9 | 16.6 |
| Nov | 12.0 | 12.6 | 12.9 | 12.9 | 12.4 | 12.4 | 12.5 | 12.0 | 12.6 | 12.8 | 12.4 |
| Dec | 6.5 | 5.6 | 6.5 | 7.2 | 7.4 | 7.1 | 6.3 | 5.3 | 5.3 | 6.4 | 6.0 |
| Jan | 6.0 | 3.9 | 3.3 | 3.8 | 3.9 | 3.1 | 3.1 | 2.5 | 6.2 | 4.2 | 3.7 |
| Feb | 11.0 | 5.0 | 5.0 | 5.3 | 5.2 | 5.3 | 5.4 | 5.3 | 6.7 | 6.6 | 5.8 |
| Mar | 6.9 | 10.4 | 8.4 | 7.2 | 7.1 | 7.2 | 8.0 | 9.0 | 7.2 | 8.2 | 7.8 |
| Apr | 19.5 | 17.1 | 16.0 | 15.0 | 15.0 | 15.2 | 15.3 | 15.7 | 16.2 | 16.9 | 15.6 |
| May | 25.5 | 20.1 | 20.2 | 20.6 | 19.5 | 19.6 | 19.1 | 18.8 | 20.4 | 21.6 | 19.5 |
| Jun | 30.9 | 27.3 | 26.3 | 24.2 | 23.2 | 23.6 | 25.6 | 26.8 | 27.2 | 27.2 | 25.8 |
| $\bar{x}$ yr | 18.2 | 16.8 | 16.7 | 16.5 | 16.2 | 16.1 | 16.2 | 16.3 | 16.4 | 17.0 | 16.2 |

Lewis and Clark Lake from 0 to 28 C and temperatures of 4.4 to 27.3 C were converted from data reported for Tenkiller Ferry Reservoir, Oklahoma (Summers 1961).

The Arkansas Arm was generally cooler than the Cimarron Arm (Table IV). Temperature in the Arkansas Arm varied from 2.5 to 27.2 C and from 3.3 to 30.9 C in the Cimarron Arm (Table IV). Temperature differences between the arms varied from 0.3 to 2.1 C during the year. Variation was related to distinct warm and cool water masses moving through the reservoir from the respective rivers prior to sampling periods and turbidity differences. Ellis (1937) and Wallen (1951) reported generally cooler bottom waters under highly turbid conditions than when turbidity was low.

Temperature values for the reservoir generally decreased downstream as depth increased (Table IV). Mean annual temperature decreased from 18.2 C at C1 to 16.5 C at C4 and from 16.4 C at A1 to 16.1 C at A4. Mean annual temperature at the Dam Station was 16.2 C. The slightly higher temperature at the Dam Station was related to warm water contributions by the Cimarron being mixed with the generally cooler Arkansas water mass.

Thermal stratification was observed at Stations C4, Dam, and A4 during June 1967 and 1968. Thermal stratification in 1967 was destroyed by the June and July floods. Nearly uniform conditions existed from top to bottom from July 1967 to May 1968. Wind generated currents and reservoir discharge procedures at the dam were the primary factors contributing to the nearly homogeneous temperature conditions.

Mean monthly temperatures in the Cimarron Arm varied from 4.2 C in January to 27.2 C in June 1968 (Table IV). Temperatures decreased steadily from July through January due to atmospheric cooling and influences by colder waters entering from the Cimarron River. Warming from February through June was related to increased warm water discharge due to increased precipitation and overall mixing by warm winds in the spring. Effects of atmospheric conditions on temperature were most noticeable at C1. The Cimarron River above C1 is broad, shallow, and has little shading. The Arkansas Arm exhibited the same temperature trends as the Cimarron. Monthly mean temperatures in the Arkansas Arm varied from 3.7 C in January to 25.8 C in June 1968.

Mean dissolved oxygen concentrations in the reservoir varied from 2.3 to 14.7 mg liter$^{-1}$ (Table V). Oxygen concentrations in Keystone during this study did not differ greatly from concentrations of 3 to 16 mg liter$^{-1}$ observed by Eley (personal communication) in the reservoir and were comparable to mean values of 3 to 10 mg liter$^{-1}$ computed from reported values for Tenkiller Ferry Reservoir, Oklahoma (Summers 1961).

In general, higher oxygen concentrations were recorded in the Cimarron Arm throughout the study. Mean dissolved oxygen concentrations varied from 3.1 to 14.5 mg liter$^{-1}$ in the Arkansas Arm and from 2.3 to 16.4 mg liter$^{-1}$ in the Cimarron Arm (Table V). Variation between the arms was related to distinct water masses and possibly to turbidity differences between the arms. Turbidity has been shown to reduce the depth of light penetration in water, which reduces the depth at which photosynthesis could occur (Reid 1961). Turbidity

## TABLE V

## MEAN MONTHLY AND ANNUAL OXYGEN CONCENTRATIONS*

| | Stations | | | | | | | | | Reservoir Arm | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C1 | C2 | C3 | C4 | Dam | A4 | A3 | A2 | A1 | | |
| Jun | 7.6 | 2.3 | 5.8 | 4.0 | 5.9 | 5.0 | 3.7 | 5.3 | 5.5 | 4.9 | 4.9 |
| Jul | 8.2 | 6.3 | 4.3 | 4.1 | 4.2 | 5.3 | 4.8 | 4.8 | 6.0 | 5.7 | 5.2 |
| Aug | 3.6 | 6.6 | 3.8 | 4.3 | 3.9 | 5.3 | 5.9 | 6.6 | 8.8 | 4.6 | 6.6 |
| Sep | 4.6 | 6.6 | 5.5 | 5.9 | 6.0 | 6.3 | 5.4 | 7.0 | 6.7 | 5.6 | 6.4 |
| Oct | 9.0 | 9.4 | 8.9 | 9.1 | 7.4 | 8.0 | 8.0 | 7.6 | 9.0 | 9.1 | 8.2 |
| Nov | 9.4 | 11.3 | 9.7 | 8.9 | 9.5 | 8.9 | 9.2 | 9.5 | 11.0 | 9.8 | 9.6 |
| Dec | 15.8 | 10.9 | 12.4 | 11.5 | 10.9 | 11.2 | 11.0 | 11.6 | 10.9 | 12.6 | 11.2 |
| Jan | 16.4 | 13.0 | 12.4 | 12.6 | 13.0 | 12.9 | 14.0 | 14.9 | 12.5 | 13.6 | 13.6 |
| Feb | 14.0 | 14.7 | 13.3 | 13.0 | 11.7 | 11.8 | 12.5 | 12.8 | 14.5 | 13.8 | 12.9 |
| Mar | 10.6 | 6.1 | 10.3 | 11.5 | 10.9 | 10.7 | 11.9 | 11.0 | 9.0 | 9.6 | 10.6 |
| Apr | 8.4 | 6.0 | 8.2 | 7.7 | 9.3 | 6.4 | 8.3 | 7.5 | 6.2 | 7.6 | 7.1 |
| May | 6.8 | 5.6 | 7.9 | 7.2 | 6.7 | 4.7 | 4.6 | 4.2 | 6.4 | 6.9 | 5.0 |
| Jun | 7.1 | 9.0 | 4.8 | 3.0 | 4.4 | 3.1 | 6.2 | 4.6 | 5.6 | 6.0 | 4.9 |
| $\bar{x}$ | 9.3 | 8.3 | 8.2 | 7.9 | 7.9 | 7.7 | 8.1 | 8.3 | 8.6 | 8.4 | 8.2 |

*Concentrations in mg liter$^{-1}$

in the Arkansas Arm probably restricted oxygen production to surface waters causing lower oxygen concentrations at greater depth, thereby producing lower oxygen concentrations in the Arkansas Arm.

Mean annual oxygen concentrations decreased from 8.6 mg liter$^{-1}$ at Station A1 to 7.7 mg liter$^{-1}$ at A4 and from 9.3 mg liter$^{-1}$ at C1 to 7.9 mg liter$^{-1}$ at C4. Mean annual oxygen concentration at the Dam Station was 7.9 mg liter$^{-1}$ (Table V). Longitudinal oxygen reduction in both arms was related to increased depth and decreased oxygen concentrations at lower depths presumably due to increased oxidation of allochthonous and autochthonus organic material.

Lowest oxygen concentrations were observed during spring and summer and were related to oxygen depletion in bottom waters, high temperatures, and flooding. The latter produced increased oxygen demands caused by increased turbidity, lower photosynthetic oxygen production, and increases in respiration. Highest oxygen concentrations occurred throughout the reservoir during fall and winter. Increased oxygen concentrations were related to increased solubility of oxygen in colder waters (Hutchinson 1957) and presumably lower rates of organic decomposition at colder temperatures.

Mean monthly oxygen concentrations in the Cimarron Arm varied from 4.6 mg liter$^{-1}$ in August to 13.8 mg liter$^{-1}$ in February (Table V). Low monthly oxygen concentrations from June through September were attributed to increased water temperatures, generally high turbidity values, and variation in oxygen concentration of water masses moving through the reservoir. Colder water temperature, low turbidity, and variation in oxygen concentrations of water mass were related to the highest values being recorded from December through March (Table V).

Mean monthly oxygen concentration in the Arkansas Arm varied from 4.9 mg liter$^{-1}$ in both June sampling periods to 13.5 mg liter$^{-1}$ in January (Table V). Monthly variations in oxygen concentrations were related to the same physical factors influencing oxygen concentrations in the Cimarron Arm.

Mean bicarbonate alkalinity in Keystone varied from 75.7 to 219.0 mg liter$^{-1}$ (Table VI). Variation in bicarbonate alkalinity in the reservoir was greater than the values of 140 to 180 mg liter$^{-1}$ reported for bicarbonate alkalinity in Lewis and Clark Lake (Cowell 1967). Keystone Reservoir can be considered a medium-hard water lake according to the classification of Reid (1961). When pH was 8.1 to 8.6, carbonates varied from 8 to 32 mg liter$^{-1}$ and bicarbonates ranged from 76 to 172 mg liter$^{-1}$. When pH was 7.2 to 8.0, carbonates ranged from 0 to 4 mg liter$^{-1}$ and bicarbonates 103 to 219 mg liter$^{-1}$.

The Arkansas Arm exhibited slightly higher alkalinity during the year than did the Cimarron Arm (Table VI). Mean bicarbonate alkalinity varied from 87.3 to 183.6 mg liter$^{-1}$ in the Arkansas Arm and from 75.7 to 219.0 mg liter$^{-1}$ in the Cimarron Arm. Variation in bicarbonate alkalinity between the arms presumably resulted from varying contributions of ground waters encountering calcareous rock formations and carbon dioxide concentrations from decomposition.

Mean total alkalinity generally decreased from upper reservoir stations to the Dam Station (Table VI). Annual mean bicarbonate alkalinity varied from 131.7 mg liter$^{-1}$ at A1 to 126.3 at A4 and from 142.8 mg liter$^{-1}$ at Station C1 to 121.0 at C4. Annual mean bicarbonate alkalinity was 120.8 mg liter$^{-1}$ at the Dam Station. Longitudinal

## TABLE VI

## MEAN MONTHLY AND ANNUAL TOTAL ALKALINITY*

| | Stations | | | | | | | | | Reservoir Arm | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C1 | C2 | C3 | C4 | Dam | A4 | A3 | A2 | A1 | Cim | Ark |
| Jun | 140.0 | 111.3 | 120.9 | 142.4 | 144.2 | 138.8 | 130.0 | 102.7 | 87.3 | 128.6 | 114.7 |
| Jul | 98.0 | 75.7 | 99.2 | 96.6 | 93.2 | 92.8 | 100.3 | 95.7 | 91.3 | 92.4 | 95.0 |
| Aug | 86.0 | 83.3 | 89.3 | 98.2 | 100.4 | 99.2 | 99.7 | 110.0 | 109.0 | 89.2 | 104.5 |
| Sep | 110.0 | 110.5 | 104.0 | 112.8 | 102.0 | 113.3 | 119.0 | 118.0 | 123.0 | 109.3 | 118.3 |
| Oct | 154.0 | 112.0 | 100.4 | 109.6 | 107.2 | 110.4 | 109.7 | 96.3 | 126.0 | 119.0 | 110.6 |
| Nov | 219.0 | 112.7 | 107.5 | 111.2 | 113.4 | 125.6 | 125.8 | 119.3 | 141.0 | 137.6 | 127.9 |
| Dec | 209.0 | 118.3 | 109.8 | 123.0 | 122.0 | 132.2 | 141.7 | 152.0 | 213.0 | 140.0 | 159.7 |
| Jan | 152.0 | 91.7 | 113.8 | 123.0 | 125.4 | 143.2 | 146.0 | 154.7 | 187.5 | 120.1 | 157.8 |
| Feb | 120.0 | 110.6 | 108.5 | 134.0 | 142.4 | 159.0 | 171.3 | 172.3 | 183.6 | 118.2 | 171.5 |
| Mar | 210.0 | 106.3 | 118.2 | 141.8 | 143.2 | 158.0 | 163.0 | 174.0 | 125.0 | 144.1 | 155.0 |
| Apr | 118.0 | 103.3 | 108.0 | 122.6 | 122.0 | 122.8 | 109.6 | 115.3 | 104.5 | 112.9 | 113.0 |
| May | 110.0 | 110.0 | 114.3 | 138.8 | 130.8 | 126.0 | 113.3 | 103.3 | 107.5 | 118.3 | 112.5 |
| Jun | 130.0 | 117.7 | 123.5 | 119.0 | 124.4 | 120.2 | 115.3 | 117.0 | 113.5 | 122.6 | 116.5 |
| $\bar{x}$ | 142.8 | 104.8 | 101.3 | 121.0 | 120.8 | 126.3 | 126.5 | 125.4 | 131.7 | 117.5 | 127.5 |

*Measured in mg liter$^{-1}$

variation in alkalinity was related to increases in lower waters of free carbon dioxide and associated decreased in pH.

Mean monthly alkalinity in the Cimarron Arm varied from 89.2 mg liter$^{-1}$ in August to 144.1 mg liter$^{-1}$ in March (Table VI). Alkalinity was generally lowest in the spring and summer and highest from November through March. Low values in spring and summer were related to increased river discharge and increased decomposition producing higher free carbon dioxide concentrations in deeper waters. High alkalinity was presumably related to decreased temperatures and associated decreases in decomposition of organic material in the reservoir.

Mean monthly alkalinity in the Arkansas Arm varied from 95.0 mg liter$^{-1}$ in August to 159.7 in December (Table VI). Lowest alkalinities were observed during July and August while highest values were usually recorded during colder months. Monthly variations in the Arkansas Arm were related to the same changes in free carbon dioxide and changes in metabolic demands as in the Arkansas Arm.

## Reservoir Community Structure of Net Zooplankton

A total of 46 taxa were collected from net zooplankton samples (Table VII). Rotifers accounted for 23 taxa, cladocera 12, and copepoda 11. Numbers and kinds of species taken in Keystone Reservoir compared favorably with other studies. Beach (1956) reported finding 34 species of rotifers in a lake-stream system. Applegate and Mullan (1967b) studying Beaver and Bull Shoals reservoirs recorded 18 species of cladocerans, 8 of which occurred in Keystone. Cowell (1967)

TABLE VII

MEAN MONTHLY NUMBERS OF INDIVIDUALS LITER$^{-1}$ OF ALL SPECIES COLLECTED FOR THE ENTIRE RESERVOIR

| | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun |
| ROTIFERA | | | | | | | | | | | | | |
| *Asplanchna* sp. | 5.7 | 0.3 | 2.1 | 0.2 | 0.1 | 1.2 | 61.4 | 113.1 | 5.2 | 18.9 | 22.7 | 1.9 | 10.3 |
| *Brachionus angularis* | - | - | - | - | - | - | - | - | - | - | - | 1.4 | - |
| *B. calyciflorus* | 118.0 | 3.9 | 8.6 | 15.1 | 3.3 | 8.7 | 89.8 | 606.9 | 1220.9 | 3706.2 | 93.9 | 144.3 | 180.0 |
| *B. caudatus* | 14.8 | 8.2 | 20.2 | 6.5 | 7.1 | 0.1 | 0.1 | - | - | 3.2 | 1.8 | 18.9 | 70.1 |
| *B. bavanaensis* | - | - | - | - | - | - | - | - | - | - | - | 0.7 | 1.1 |
| *B. plicatilis* | 100.7 | 18.9 | 24.6 | 35.8 | 1.4 | 0.2 | 22.8 | - | - | - | 4.0 | 137.8 | 48.3 |
| *B. quadridentata* | - | 0.6 | 1.3 | 1.8 | 0.6 | 0.7 | - | 28.0 | 113.2 | 732.3 | 139.4 | 51.6 | 22.7 |
| *Brachious* sp. | 5.5 | 0.9 | - | - | - | - | 0.2 | - | - | - | - | - | - |
| *Filinia longiseta* | 5.5 | 1.1 | 0.3 | - | 0.2 | 0.1 | - | 0.4 | 2.1 | 96.1 | 21.7 | 6.7 | 11.2 |
| *Hexarthra* sp. | 99.4 | 11.2 | 58.8 | 8.8 | 14.2 | 1.4 | - | 2.9 | 2.1 | 0.5 | - | 109.4 | 65.3 |
| *Kellicottia longispina* | - | - | - | - | - | - | - | - | 0.1 | 2.8 | 4.7 | 0.4 | - |
| *Keratella cochlearis* | 0.4 | 2.1 | 6.4 | 0.1 | 0.3 | 0.2 | 0.3 | 1.0 | 1.5 | 24.8 | 2.3 | 3.6 | 5.7 |
| *K. quadrata* | 0.7 | - | - | - | - | - | 0.3 | - | - | - | 193.2 | 31.9 | 0.1 |
| *K. vulga* | 11.4 | 8.4 | 6.0 | 33.3 | 129.2 | 36.4 | 10.0 | 1.6 | 0.1 | 28.1 | 18.9 | 10.4 | 8.9 |
| *Lecane luna* | - | 0.1 | - | - | 0.1 | - | - | 0.1 | - | 11.0 | 0.4 | 0.5 | 0.6 |
| *Monostyla* sp. | - | - | - | - | 0.1 | - | - | 0.1 | 0.1 | - | - | 0.1 | - |
| *Notholca acuminata* | - | - | - | - | - | - | 0.1 | 1.6 | 4.3 | 60.7 | - | - | - |
| *Platyias patulus* | 1.7 | 1.0 | 2.8 | 0.8 | 2.1 | - | - | - | - | - | - | 0.1 | 0.2 |
| *P. quadricornis* | - | 0.1 | - | - | - | 0.1 | - | 0.6 | - | 20.2 | - | - | - |
| *Polyarthra* sp. | 20.6 | 3.9 | 2.4 | 0.7 | 1.6 | 1.6 | 4.5 | 43.7 | 218.6 | 290.7 | 0.9 | 5.3 | 5.4 |
| *Trichocerca* sp. | 0.3 | 0.1 | - | - | - | - | 0.1 | - | - | - | - | 0.5 | 0.7 |
| *Rotifer* sp. 1 | 7.8 | 6.4 | 0.4 | 0.1 | - | 0.1 | 0.1 | - | - | - | - | 1.9 | 22.6 |
| *Rotifer* sp. 2 | 0.1 | - | 19.1 | 0.1 | 0.5 | 2.1 | - | 0.2 | - | - | - | - | - |
| CLADOCERA | | | | | | | | | | | | | |
| *Alona affinis* | 0.1 | - | 0.1 | - | - | 0.1 | - | - | 0.1 | 0.9 | 0.2 | 0.2 | - |
| *Bosmina coregoni* | - | 0.1 | - | - | - | - | 0.1 | - | - | - | - | - | 0.4 |
| *B. longirostris* | 2.5 | 0.3 | 0.2 | 0.1 | 1.9 | 3.7 | 15.0 | 12.8 | 8.3 | 49.6 | 24.5 | 25.6 | 13.0 |
| *Ceriodaphnia reticulata* | 22.2 | 0.9 | 2.9 | 0.6 | 4.6 | 2.9 | 1.2 | 0.3 | - | 0.5 | - | 1.9 | 4.6 |
| *Chydorus sphaericus* | - | - | - | - | - | - | - | 0.3 | 7.7 | 46.5 | 0.2 | 0.5 | - |
| *Daphnia ambigua* | 8.0 | 0.4 | 0.5 | 0.1 | 0.5 | 0.3 | 0.1 | - | - | - | 7.8 | 9.8 | 2.4 |
| *D. lavilis* | 17.4 | 0.5 | 1.1 | - | - | - | 7.6 | - | - | - | 0.9 | 0.2 | 2.1 |
| *D. parvula* | 8.4 | 14.8 | 30.5 | 12.1 | 19.9 | 28.7 | 41.3 | 33.2 | 15.7 | 9.7 | 150.5 | 62.2 | 50.3 |
| *Diaphanosoma leuchtenbergianum* | 29.5 | 9.0 | 95.9 | 13.3 | 9.9 | 1.4 | 0.5 | - | - | - | - | 0.5 | 96.7 |
| *Leydigia acanthocercoides* | - | - | - | - | - | - | 0.1 | - | - | - | - | - | - |
| *Moina affinis* | 4.8 | 1.9 | 3.9 | 1.1 | 0.1 | - | 0.1 | - | - | - | 5.6 | 3.4 | 13.8 |
| Imm. cladocera | 10.6 | 4.8 | 15.0 | 8.1 | 5.3 | 9.9 | 5.6 | 4.2 | 2.9 | 1.4 | 11.4 | 5.7 | 15.3 |
| COPEPODA | | | | | | | | | | | | | |
| *Diaptomus* sp. | 19.9 | 6.3 | 38.3 | 44.3 | 22.4 | 35.4 | 47.7 | 35.8 | 29.2 | 73.1 | 105.1 | 41.8 | 37.0 |
| *D. clavipes* | 0.7 | 0.5 | 5.2 | 0.5 | 0.1 | - | 11.5 | 0.1 | - | 0.5 | - | - | 0.4 |
| *D. dorsalis* | 5.5 | 2.6 | 16.4 | 33.3 | 13.9 | 6.4 | 4.4 | 1.6 | 0.8 | 2.8 | 2.0 | 7.0 | 8.2 |
| *Eurytemora affinis* | 7.3 | 1.1 | 1.2 | 2.5 | 3.0 | 20.7 | 5.9 | 28.0 | 5.5 | 18.9 | 36.5 | 12.6 | 16.6 |
| *Cyclops* sp. | 22.2 | 10.2 | 10.7 | 8.2 | 15.1 | 6.0 | 5.2 | 3.3 | 3.5 | 4.1 | 21.5 | 56.2 | 85.2 |
| *C. bicuspidatus* | - | 4.9 | 7.6 | 3.9 | 6.9 | 4.5 | 0.1 | 1.3 | 1.5 | 3.2 | 5.0 | 16.9 | 21.2 |
| *C. vernalis* | 3.5 | 0.8 | 1.4 | 0.9 | 1.3 | 0.4 | 0.9 | 0.2 | 0.5 | 2.8 | 0.9 | 3.4 | 13.0 |
| *Mesocylops edax* | 2.0 | 0.7 | 1.1 | 1.0 | 1.0 | 1.0 | 0.9 | - | - | - | - | - | 2.1 |
| *Canthocamptus* sp. | - | - | - | - | - | - | - | - | - | 5.5 | 0.3 | - | - |
| *Ergasilus versicolor* | 0.2 | 0.2 | 0.9 | 1.7 | 2.9 | 1.0 | 0.4 | - | 0.5 | - | 0.1 | 1.2 | 1.2 |
| All Nauplii | 236.1 | 65.0 | 223.9 | 151.5 | 125.6 | 107.8 | 129.4 | 167.6 | 191.2 | 304.1 | 299.1 | 292.2 | 362.8 |

- No individuals collected

collected 10 species of copepoda from Lewis and Clark Lake, 4 of which were collected in Keystone.

Four taxa were not observed in the Cimarron Arm. They were the rotifers *Lecane luna*, *Monostyla* sp., and *Platyias quadricornis*, and the cladoceran, *Leydigia acanthocercoides*. Their complete absence from the Cimarron collections suggests that they were either rare or that high conductivity in the Cimarron may have been limiting to these species. The same species were rare in the Arkansas Arm, but generally collected from all stations. These species are typically littoral inhabitants and their presence in the limnetic areas was probably caused by high waters which imported them into the Arkansas Arm. Species of zooplankton absent from collections from one to three stations in each arm, but present in both arms, were the rotifers *Brachionas angularis*, *B. havanaensis*, *Trichocerca* sp., *Kellocotta longispina*, and the harpacticoid *Canthocamptus* sp. In general, these species were rare and were collected only occasionally from upper reservoir stations. These species were observed during the spring and early summer (Table VII).

Annual mean frequency distributions of rotifers, cladocera, and copepoda for all stations are given in Figure 2. Rotifers were the most common zooplankters in the reservoir and were most frequent in the upper reaches. Cladocera and copepoda were most numerous at the lower reservoir stations where turbulence was less than in the upper reservoir areas.

Monthly variation in taxa throughout the reservoir can be seen in Table VII. Rotifers exhibiting monocyclic periodicity, one generation per year, were *Asplanchna* sp., *B. caudatus*, *B. quadridentata*, *Filinia*

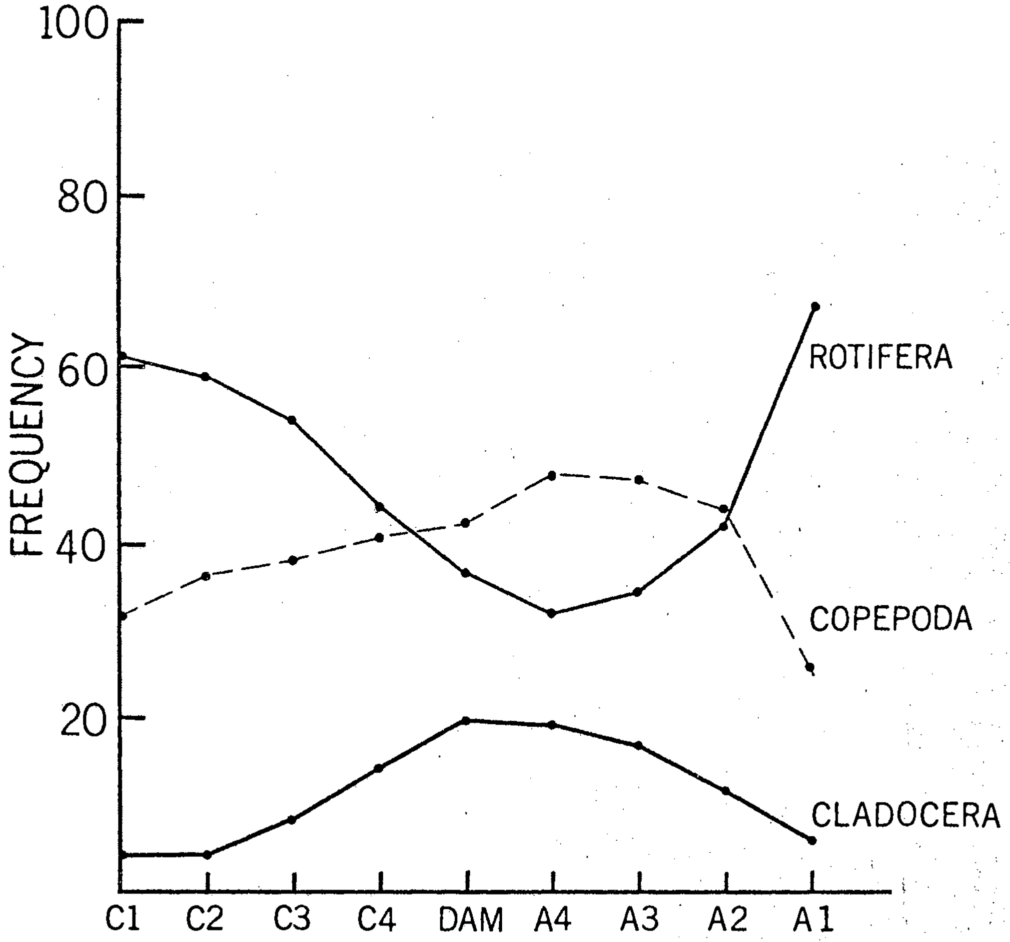

Figure 2. Mean Annual Frequency of Rotifera, Cladocera, and Copepoda in Samples at Each Station.

*longiseta*, and *Keratella quadrata*. Dicyclic periodicity was exhibited by *Polyarthra* sp. and *B. calyciflorus*. Tricyclic periodicity was observed in *B. plicatilis* and *K. vulga*. *Daphnia lavilis* and *D. parvula* exhibited two cyclic population pulses while the remaining species of cladocera were considered to have only one density peak during the study. Nearly all copepoda taxa exhibited monocyclic cyclic population pulses during the study.

Mean annual density of net zooplankton in Keystone Reservoir was 133.9 individuals liter$^{-1}$ (Table VIII). Zooplankton densities were 2.6 and 2.3 times greater than the mean annual value for Beaver and Bull Shoals Reservoirs, respectively (Applegate and Mullan 1967b). The annual zooplankton density was less than values of 247 to 1476 individuals liter$^{-1}$ reported for six Colorado lakes by Pennak (1946). Cowell (1967) reported an annual mean of 12.6 individuals liter$^{-1}$ for entomostrocans, while the Keystone Reservoir annual entomostrocan density was 69.9 individuals liter$^{-1}$.

Mean zooplankton density in the Arkansas Arm varied from 3.3 to 2030.0 individuals liter$^{-1}$ and from 0.0 to 632.5 individuals liter$^{-1}$ in the Cimarron Arm (Table VIII). Although the Arkansas Arm had a slightly greater mean annual density than the Cimarron Arm, the Cimarron Arm had a greater density for 10 months of the year. The large numbers of zooplankton collected in March in the Arkansas Arm caused the annual mean to be higher. The low standing crop of zooplankton for most of the year in the Arkansas Arm was related to turbidity, discharge rates, and retention time. Claffey (1955) found that high levels of turbidity resulted in low volumes of plankton in ponds and reservoirs in Oklahoma. Annual discharge in the Arkansas

# TABLE VIII

## MEAN MONTHLY AND ANNUAL VALUES OF INDIVIDUALS LITER$^{-1}$

| | Stations | | | | | | | | | Reservoir Location | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C1 | C2 | C3 | C4 | Dam | A4 | A3 | A2 | A1 | Cim | Ark | Total |
| Jun | 446.8 | 27.7 | 62.9 | 49.6 | 46.8 | 62.1 | 47.9 | 39.8 | 17.1 | 146.4 | 41.7 | 88.9 |
| Jul | 9.1 | 49.7 | 32.9 | 4.9 | 6.4 | 3.3 | 4.4 | 9.4 | 5.9 | 24.2 | 5.8 | 14.0 |
| Aug | - | 174.7 | 110.2 | 46.0 | 34.9 | 37.9 | 57.1 | 167.0 | 62.1 | 113.2 | 118.8 | 76.6 |
| Sep | 19.0 | 100.2 | 38.2 | 29.0 | 36.5 | 33.6 | 41.8 | 76.0 | 12.8 | 46.7 | 41.0 | 43.0 |
| Oct | - | 121.4 | 57.1 | 64.0 | 39.7 | 32.8 | 66.5 | 61.9 | 6.3 | 60.6 | 41.9 | 49.9 |
| Nov | 18.5 | 60.2 | 45.8 | 33.4 | 27.4 | 25.7 | 29.0 | 48.0 | 7.6 | 39.5 | 25.2 | 32.9 |
| Dec | 3.6 | 225.5 | 58.8 | 16.7 | 12.5 | 12.6 | 50.5 | 76.4 | 10.0 | 76.2 | 37.4 | 51.8 |
| Jan | 2.3 | 414.0 | 134.6 | 54.9 | 32.1 | 64.5 | 171.8 | 264.7 | 37.5 | 151.4 | 134.6 | 130.7 |
| Feb | 8.7 | 297.9 | 87.7 | 111.6 | 136.5 | 178.0 | 533.3 | 469.3 | 12.5 | 126.5 | 298.2 | 203.9 |
| Mar | 106.4 | 179.8 | 700.0 | 518.5 | 632.5 | 518.5 | 883.6 | 2030.0 | 21.1 | 376.2 | 863.3 | 621.1 |
| Apr | 174.7 | 161.7 | 238.8 | 110.8 | 144.7 | 102.6 | 109.8 | 103.4 | 39.0 | 171.5 | 88.7 | 131.7 |
| May | 196.4 | 37.5 | 170.9 | 112.9 | 149.9 | 205.1 | 80.5 | 54.2 | 24.4 | 129.4 | 91.1 | 114.6 |
| Jun | 112.7 | 137.1 | 555.6 | 106.9 | 85.6 | 64.9 | 71.4 | 65.6 | 41.4 | 228.1 | 60.7 | 137.9 |
| $\bar{x}$ | 99.9 | 152.9 | 191.1 | 96.8 | 106.6 | 103.2 | 165.2 | 266.6 | 22.9 | 130.0 | 142.2 | 133.9 |

- No individuals collected

River was 4.9 times greater than in the Cimarron River. Higher rates of discharge and associated increases in turbulence would tend to reduce numbers of zooplankton. Retention time was greater for most of the Cimarron water mass than for the Arkansas water mass. Low retention time has been related to low plankton production (Brook and Woodward 1956, Johnson 1964).

Longitudinal differences in densities of zooplankton can be seen in Table VIII. Annual mean densities were lower at Stations C1 and A1, with highest values at Stations C3 and A2. Although the mean annual zooplankton was higher at C3 than C2, Station C2 showed greater densities than C3 for 8 months of the year. Density of individuals decreased in both arms below Stations C3 and A2 (Table IX). Similar patterns of low densities at upper and lower stations of an impoundment have been recorded by Applegate and Mullan (1967b) and Eddy (1932). Reasons for this pattern are unclear, but low food supply, turbulence, and variable physicochemical conditions would influence low densities in upper stations. When these factors become favorable, densities would increase. Reinhard (1931) found current to be the controlling influence in plankton populations in the Mississippi River. Possible limiting factors on zooplankton at lower reservoir stations may have been dam discharge procedures, and current patterns in the fetch areas.

Monthly values of individuals liter$^{-1}$ were extremely variable between stations (Table VIII). Variations were attributed in part to plankton patchiness and seasonal periodicity of reproduction.

Physicochemical conditions during the June and July floods radically reduced the density of zooplankton at all stations except

C2 and C3. High water and increased turbulence were shown to be the primary cause for rapid declines of zooplankton by Pennak (1957). High conductivity (12,000 umhos) was suspected as the cause for no organisms being collected at Station C1 during August, while high conductivity and low flow may have produced the same condition in October. During August when less variable physicochemical conditions were observed after flooding the population densities at all stations excluding C1 exhibited density increases.

From August through November densities generally decreased at most stations (Table VIII). A winter zooplankton bloom started in December and peak densities occurred in both arms in March. Decline in densities during April and May were related to flooding and turbidity. During June 1968, increased densities were observed in the Cimarron Arm while decreased densities were recorded for the Arkansas Arm. Decreased values in the Arkansas were related to increased turbidity values.

## Reservoir Species Diversity

The number of individuals needed to describe precisely community structure with $\bar{d}$ was determined from 108 zooplankton samples collected during June, July, August, and December. The method of counting and pooling sets of 100 individuals within each sample allowed computation of $\bar{d}$ on 6 sets of 100 individuals and one $\bar{d}$ value for 400, 500, and 600 individuals. Total $\bar{d}$ values computed were 642, 318, and 210 for sample sizes 100, 200, and 300, respectively. For sample sizes 400, 500, and 600 individuals, 102 $\bar{d}$ values each were determined.

Figure 3 shows plots of $\bar{d}$ values at various sample sizes. Since a sample size of 100 consistently underestimated $\bar{d}$ values, it was of little value for determining asymptotic levels of $\bar{d}$. Values of $\bar{d}$ steadily increased through sample sizes 200, 300, and 400 individuals with little or no change above the asymptotic sample size of 400.

Values of $\bar{d}$ from all sample sizes for a given month for each station were evaluated with an analysis of variance (Table IX). Sample size 100 always exhibited a greater range of within station variance (R.var.) of mean $\bar{d}$, within station error, and coefficient of variation of mean $\bar{d}$ than other sample sizes. All variance components decreased as sample sizes were increased to 400 individuals (Table IX). The variance values indicated only a slight gain in precision by increasing the sample size above 400 individuals.

Examination of the graphical representation of $\bar{d}$ and of the statistical analysis indicated that sample size 400 provided the most economical estimates of zooplankton community structure for all samples tested and was chosen as the sample size for computing $\bar{d}$ from all remaining monthly zooplankton samples.

Mean $\bar{d}$ values for the entire reservoir varied from 1.48 to 3.13 with a mean annual value of 2.48 (Table X). The mean annual $\bar{d}$ for zooplankton is in the category of "moderate pollution" according to the classification of Wilhm and Dorris for benthic macroinvertebrates. They reported $\bar{d}$ values (using Shannon's formula) in polluted waters from 0.84 to 1.59 and in clean water areas from 1.59 to 3.80. Ransom (1969), working with benthic fauna in Keystone Reservoir, reported a -.93 correlation between conductivity and $\bar{d}$. Values of $\bar{d}$ varied from 0.55 to 3.01 where mean conductivity was 4200 and 2200 umhos,

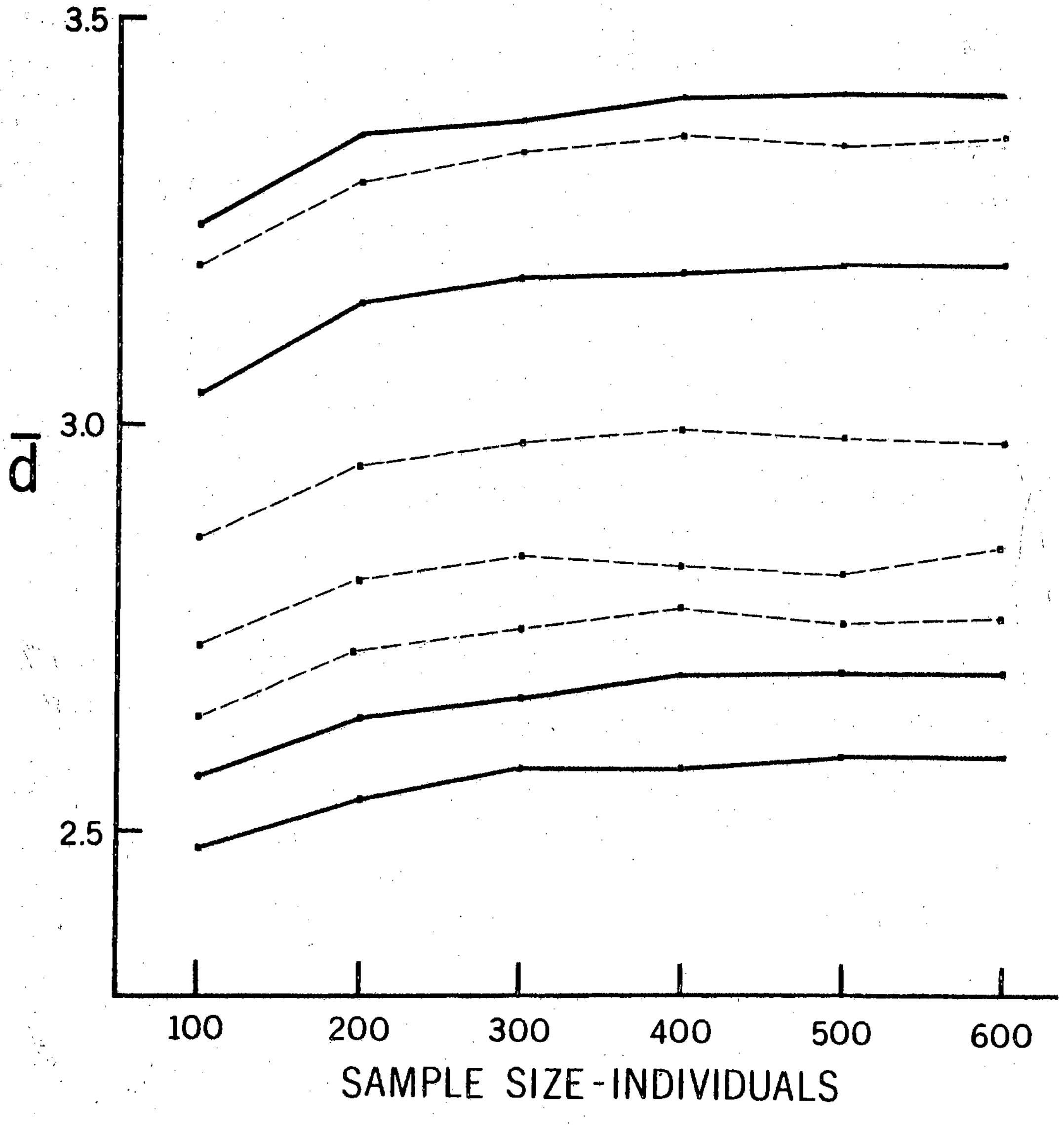

Figure 3. Graph of $\bar{d}$ at Various Sample Sizes. Asymptotic Levels Were Reached at Sample Size 400.

## TABLE IX

## RANGE OF WITHIN STATION VARIANCE (R.var.) OF MEAN $\bar{d}$, WITHIN STATION ERROR (S.E.), AND COEFFICIENT OF VARIATION (C.V.) OF MEAN $\bar{d}$ VALUES FROM SIX SAMPLE SIZES DURING JUNE, JULY, AUGUST, AND DECEMBER 1967

| | Sample Size | | | | | |
|---|---|---|---|---|---|---|
| Month | 100 | 200 | 300 | 400 | 500 | 600 |
| Jun | | | | | | |
| R.var. $\bar{x}$ | 0.1122 | 0.0499 | 0.0219 | 0.0185 | 0.0196 | 0.0107 |
| S.E. | 0.0288 | 0.0162 | 0.0128 | 0.0074 | 0.0081 | 0.0062 |
| C.V. | 6.09 | 6.76 | 3.85 | 2.97 | 3.12 | 2.60 |
| Jul | | | | | | |
| R.var. $\bar{x}$ | 0.0119 | 0.0636 | 0.0453 | 0.0217 | 0.0188 | 0.0112 |
| S.E. | 0.0231 | 0.0115 | 0.0105 | 0.0073 | 0.0063 | 0.0088 |
| C.V. | 5.02 | 3.46 | 3.25 | 2.71 | 2.52 | 2.99 |
| Aug | | | | | | |
| R.var. $\bar{x}$ | 0.0523 | 0.0261 | 0.0156 | 0.0097 | 0.0071 | 0.0076 |
| S.E. | 0.0169 | 0.0080 | 0.0057 | 0.0042 | 0.0035 | 0.0037 |
| C.V. | 4.71 | 3.16 | 2.64 | 2.27 | 2.05 | 2.36 |
| Dec | | | | | | |
| R.var. $\bar{x}$ | 0.0906 | 0.0193 | 0.0102 | 0.0066 | 0.0111 | 0.0060 |
| S.E. | 0.0264 | 0.0113 | 0.0142 | 0.0045 | 0.0056 | 0.0031 |
| C.V. | 6.81 | 4.36 | 4.86 | 2.74 | 3.02 | 2.28 |

## TABLE X

## MEAN MONTHLY AND ANNUAL $\bar{d}$ VALUES FOR ALL STATIONS

| | Stations | | | | | | | | | Reservoir Location | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C1 | C2 | C3 | C4 | Dam | A4 | A3 | A2 | A1 | Cim | Ark | Total |
| Jun | 1.73 | 3.26 | 2.83 | 3.19 | 3.16 | 2.71 | 2.56 | 3.41 | 3.16 | 2.75 | 2.96 | 2.89 |
| Jul | 2.92 | 2.83 | 2.78 | 2.76 | 3.17 | 2.99 | 3.36 | 3.58 | 3.80 | 2.82 | 3.43 | 3.13 |
| Aug | - | 2.84 | 2.86 | 2.94 | 2.99 | 2.77 | 2.66 | 2.35 | 3.39 | 2.88 | 2.79 | 2.85 |
| Sep | 2.66[3] | 2.62 | 2.84 | 2.39 | 2.38 | 2.39 | 2.66 | 2.88 | 1.58 | 2.63 | 2.38 | 2.49 |
| Oct | - | 2.94 | 2.86 | 2.35 | 2.93 | 2.65 | 2.68 | 2.85 | 2.37 | 2.72 | 2.64 | 2.70 |
| Nov | 1.97[3] | 2.40 | 2.63 | 2.46 | 2.45 | 2.62 | 2.84 | 3.07 | 1.81 | 2.36 | 2.58 | 2.47 |
| Dec | - | 1.43 | 2.68 | 3.03 | 3.16 | 3.08 | 2.44 | 2.21 | 1.73 | 2.38 | 2.36 | 2.47 |
| Jan | 0.59[2] | 1.56 | 1.69 | 2.08 | 2.05 | 1.93 | 1.74 | 1.82 | 2.44 | 1.48 | 1.98 | 1.77 |
| Feb | - | 1.45 | 1.33 | 1.32 | 1.31 | 1.60 | 1.36 | 1.61 | 1.85 | 1.37 | 1.60 | 1.48 |
| Mar | 2.37 | 1.49 | 1.28 | 1.16 | 1.19 | 1.25 | 1.59 | 1.05 | 2.72 | 1.58 | 1.65 | 1.57 |
| Apr | 2.45 | 2.34 | 1.58 | 2.42 | 2.90 | 2.95 | 2.61 | 2.16 | 2.98 | 2.19 | 2.68 | 2.49 |
| May | 3.16 | 3.47 | 2.90 | 2.86 | 2.85 | 3.09 | 2.93 | 2.73 | 3.13 | 3.10 | 2.97 | 3.01 |
| Jun | 3.71 | 3.49 | 2.35 | 3.11 | 2.41 | 2.72 | 2.48 | 3.36 | 3.02 | 3.16 | 2.89 | 2.96 |
| $\bar{x}$ | 2.39 | 2.47 | 2.35 | 2.47 | 2.53 | 2.52 | 2.45 | 2.54 | 2.61 | 2.42 | 2.53 | 2.48 |

- Insufficient numbers to compute $\bar{d}$

[2] Sample size 200

[3] Sample size 300

respectively. Margalef (1962) reported zooplankton diversity from 0.8 to 4.0 in Lake Maggiore. Margalef's findings are close to the range of 0.59 to 3.80 obtained during the present study.

Mean $\bar{d}$ varied from 1.60 to 3.43 in the Arkansas Arm and from 1.37 to 3.16 in the Cimarron Arm (Table X). There was no significant difference in the mean annual $\bar{d}$ at the 0.05 level between the arms and the Dam Station. Mean annual values of $\bar{d}$ being similar over time suggests little effect by measured physicochemical conditions such as conductivity and turbidity which differed considerably within and between reservoir arms. Mean annual conductivity of the Cimarron Arm was 2044 umhos and 1216 umhos for the Arkansas Arm. Mean annual turbidity was 80 mg liter$^{-1}$ in the Cimarron Arm and 96 mg liter$^{-1}$ in the Arkansas Arm.

A correlation of 0.38 and -0.57 between conductivity and $\bar{d}$ was observed in the Cimarron and Arkansas Arms, respectively. The correlation coefficient 0.38 is not significantly different from zero at the 0.05 level but -0.57 is significantly different from zero. A correlation of 0.75 was observed between $\bar{d}$ and turbidity in the Cimarron Arm and 0.76 in the Arkansas Arm. Both correlations were significant at the 0.01 level. The close similarity between the two arms in $\bar{d}$, but not in turbidity suggests that at times turbidity may influence a more even distribution of individuals among the species. This speculation is supported by Cushing (1964).

Highest correlation values were between $\bar{d}$ and temperature. The correlation coefficients of 0.86 and 0.81 in the Cimarron and Arkansas Arms, respectively, were both significant at the 0.001 level.

It is conceivable that warmer temperatures may have provided a more suitable environment which allowed more species to be present in reservoir than did colder temperatures (Table VII).

The difference in mean annual $\bar{d}$ values between the highest and lowest station values was 0.26 (Table X). Duncan's multiple range test on the mean annual $\bar{d}$ values showed no significant difference among stations throughout the reservoir at the 0.05 level, despite annual differences in ambient physicochemical conditions and taxa composition.

Mean monthly $\bar{d}$ values in the Cimarron Arm were above 2.0 in all months except January, February, and March (Table X). $\bar{d}$ exceeded 3.0 in May and June. Highest values occurred after flooding and lowest values when large numbers of rotifers were collected in the winter. Warmer waters, probable influxes of species from cove areas, and presumed increases in food supply brought about a rise in $\bar{d}$ from March through June. Mean monthly $\bar{d}$ values in the Arkansas Arm were also above 2.0 in all months except January, February, and March and was 3.43 in July (Table X). In general, the Arkansas Arm followed the same monthly trends in $\bar{d}$ as observed in the Cimarron Arm. Monthly differences in $\bar{d}$ values between the arms ranged from 0.02 to 0.61 $\bar{d}$ units. The variation between the arms was attributed to differences in monthly physicochemical conditions and temporal changes in the population dynamics of the zooplankton species.

Monthly longitudinal differences in $\bar{d}$ within and between stations as tested by Duncan's multiple range test at the 0.05 level can be seen in Table XI. In general, the Arkansas stations were significantly different from each other more often than stations in the Cimmaron Arm.

## TABLE XI

## DUNCAN'S MULTIPLE RANGE TEST (p = 0.05)* APPLIED TO MEAN MONTHLY $\bar{d}$ VALUES** AT ALL STATIONS

| | Rank of Means - Lowest to Highest | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Jun | C1 | A3 | A4 | C3 | Dam | A1 | C4 | C2 | A2 |
| Jul | C4 | C3 | C2 | C1 | A4 | Dam | A3 | A2 | A1 |
| Aug | A1 | A2 | A3 | C2 | C3 | C4 | A4 | Dam | - |
| Sep | A1 | Dam | C4 | A4 | C2 | A3 | C1 | C3 | A2 |
| Oct | C4 | A2 | A4 | A1 | A3 | C3 | Dam | C2 | - |
| Nov | A1 | C1 | C2 | Dam | C4 | A4 | C3 | A3 | A2 |
| Dec | C2 | A1 | A2 | A3 | C3 | C4 | A4 | Dam | - |
| Jan | C1 | C2 | C3 | A3 | A2 | A4 | Dam | C4 | A1 |
| Feb | Dam | C4 | C3 | A3 | C2 | A4 | A2 | A1 | - |
| Mar | A2 | C4 | Dam | A4 | C3 | C2 | A3 | C1 | A1 |
| Apr | C3 | A2 | C2 | C4 | C1 | A3 | Dam | A4 | A1 |
| May | A2 | Dam | C4 | C3 | A3 | A4 | A1 | C1 | C2 |
| Jun | C3 | Dam | A3 | A4 | A1 | C4 | A2 | C2 | C1 |

*Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different.

**Monthly mean $\bar{d}$ values for all stations are listed in Table XI.

Variation among Arkansas stations were probably caused by differences in turbidity and more turbulence than in the Cimarron Arm. Stations C4, Dam, and A4, when considered together, were significantly different 10 months of the year and not significantly different during September, November, and March. Stations C4 and A4 were not significantly different from the Dam Station during 7 and 6 months of the study, respectively. This implies that the lower reservoir arm stations were more similar to each other than upper reservoir stations in their respective arms because of less severe fluctuations in physicochemical conditions.

Shannon's formula provided several important advantages during this study. The numerical expression of diversity as expressed by $\bar{d}$ was a concise summation of large amounts of information without the need for cumbersome species lists. The determination of a sample size sufficient to obtain asymptotic levels of $\bar{d}$ was most important so that the best estimate of diversity was obtained from all but 12 samples from Station C1. Equal sample sizes allowed statistical analysis to be made on values of $\bar{d}$ for the comparison of stations within and between reservoir arms. Monthly changes within reservoir locations as well as annual values could be compared to determine if there were distinct differences between reservoir stations.

The method of Yount (1956) using cumulative species versus logarithm of cumulative individuals was applied to the data to determine if additional information was gained concerning diversity and determine the correlation between slope values generated by this method and $\bar{d}$. Figure 4 shows a typical graph of such data. Each line represents a plot of one sample within a station. Diversity of each

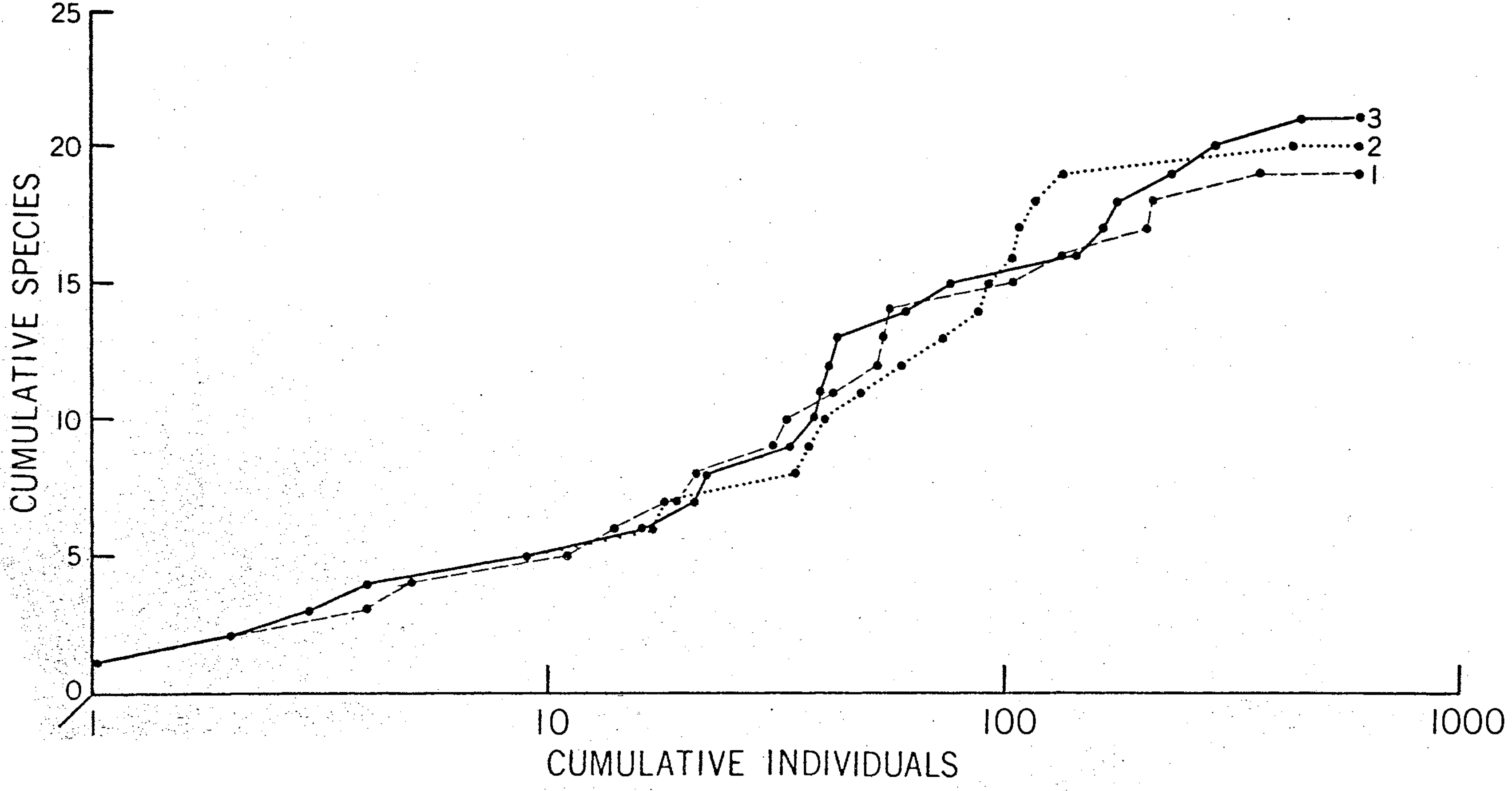

Figure 4. Graphic Plot of Cumulative Species Versus Logarithm Cumulative Individuals.

sample was equivalent to the slope of each line (Table XII). None of the 113 data sets of three samples each, showed significant differences in the homogeneity of the slopes within a data set at the 0.05 level. Calculated F values varied from 0.00 to 5.92 which were always less than the tabular values of 9.45 and 9.48. Multiple correlations of the data to a straight line for all samples varied from 0.93 to 0.99 indicating a significant linear relationship between cumulative species and the logarithm of cumulative individuals.

Mean monthly slope values (b) in the Cimarron Arm were above 5.0 in all months except January, February, March, and April (Table XII). Slope values exceeded 8.0 during May and June. Monthly slope values for zooplankton in the Cimarron followed the same trends as did computed $\bar{d}$ values (Table X). Slope values in the Arkansas Arm were above 5.0 in all months except December through March. The highest slope of 10.09 was recorded in July (Table XII). Monthly trends between slope values and $\bar{d}$ were similar in the Arkansas Arm.

Mean annual logitudinal slope values for all stations varied from 6.04 to 6.64 with a range of 0.60 (Table XII) compared to the range of 0.26 for longitudinal $\bar{d}$ values (Table X). A correlation coefficient of 0.99 (significant at the 0.001 level) was found between the mean $\bar{d}$ values and the computed average slope values. The ratio $(b/\bar{d})$ of the line slope (b) to mean $\bar{d}$ of all monthly samples varied from 2.48 to 2.79. The mean ratio of all $(b/\bar{d})$ values was 2.56±0.26, which implies that both techniques used to express community structures were in close agreement. However, some discrepancies were observed between the monthly values. At times, slope values differed from computed $\bar{d}$ values. This probably was caused by the varied distribution of

## TABLE XII

## COMPUTED COMMON SLOPE VALUES OF CUMULATIVE SPECIES VERSUS LOGARITHM CUMULATIVE INDIVIDUALS FROM THREE REPLICATE SAMPLES AT EACH STATION

| | Stations | | | | | | | | | Reservoir Location | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C1 | C2 | C3 | C4 | Dam | A4 | A3 | A2 | A1 | Cim | Ark |
| Jun | 3.69 | 9.63 | 8.16 | 10.48 | 9.41 | 8.76 | 8.65 | 10.80 | 8.32 | 7.99 | 9.13 |
| Jul | 4.81 | 7.15 | 8.03 | 8.41 | 7.58 | 10.12 | 9.52 | 10.42 | 10.31 | 7.03 | 10.09 |
| Aug | - | 7.58 | 7.39 | 8.61 | 7.48 | 7.31 | 6.51 | 5.73 | 10.21 | 7.86 | 7.39 |
| Sep | 7.16 | 6.82 | 7.02 | 6.95 | 4.76 | 4.81 | 5.94 | 7.12 | 8.64 | 6.98 | 6.60 |
| Oct | - | 7.43 | 7.47 | 6.35 | 6.54 | 6.26 | 7.09 | 6.94 | 3.32 | 7.08 | 5.90 |
| Nov | 4.64 | 6.63 | 5.47 | 6.28 | 7.08 | 6.65 | 7.26 | 6.56 | 3.76 | 5.75 | 6.05 |
| Dec | - | 4.65 | 5.90 | 8.05 | 8.65 | 6.70 | 4.66 | 5.00 | 3.03 | 6.02 | 4.85 |
| Jan | - | 2.53 | 4.12 | 4.89 | 4.52 | 3.39 | 4.69 | 3.35 | 5.21 | 3.84 | 4.16 |
| Feb | - | 3.17 | 3.23 | 4.08 | 4.27 | 5.27 | 3.15 | 2.45 | 2.22 | 3.49 | 3.27 |
| Mar | 5.70 | 4.73 | 3.74 | 2.67 | 2.97 | 3.37 | 3.82 | 3.95 | 3.34 | 4.46 | 3.62 |
| Apr | 6.52 | 5.37 | 3.14 | 4.43 | 5.75 | 5.85 | 5.89 | 4.59 | 8.40 | 4.86 | 6.18 |
| May | 9.57 | 9.48 | 6.82 | 6.12 | 6.96 | 7.67 | 7.41 | 7.23 | 9.87 | 8.01 | 8.04 |
| Jun | 10.90 | 7.49 | 7.06 | 9.09 | 7.85 | 7.11 | 7.12 | 9.60 | 7.83 | 8.63 | 7.92 |
| $\bar{x}$ | 6.62 | 6.36 | 6.04 | 6.64 | 6.45 | 6.40 | 6.28 | 6.44 | 6.24 | 6.31 | 6.40 |

- Insufficient numbers to run multiple linear regression analysis species on the slides which produced an increase or decrease in the slope per number of individuals counted. The differences in slope values compared to $\bar{d}$ values may have caused some stations to be interpreted as having a lower or higher diversity than actually existed if only the graphical method was utilized to express community structure. The overall agreement among samples using both $\bar{d}$ and graphical methods implies that a satisfactory method was used in enumerating zooplankton and that ratios of $n_i/n$ provided the best estimate of community structure and that the graphical method provided no additional information in ascertaining the community structure.

## Diel Physicochemical Conditions of 9 and 10 July 1968

Conductivity was relatively uniform from 0.5 to 8.0 m and increased sharply below 8.0 m (Table XIII). The higher saline waters at lower depths are characteristic of Cimarron River water. The high conductivity at lower depths could act as a barrier to species that could not osmoregulate, since this would approximate 934 mg liter$^{-1}$ as $Cl^-$ at 12.0 m and 1963 mg liter$^{-1}$ at 16.0 m.

TABLE XIII

MEAN PHYSICOCHEMICAL CONDITIONS DURING 24 HOUR SAMPLING PERIOD AT STATION C4 ON 9 AND 10 JULY 1968

| Depth m | Conductivity umhos cm$^{-1}$ | $O_2$ mg liter$^{-1}$ | Temperature C | Turbidity mg liter$^{-1}$ | Current m min$^{-1}$ |
|---|---|---|---|---|---|
| 0.5 | 1391 | 16.0 | 28.9 | 14 | 1.6 |
| 4.0 | 1398 | 5.0 | 25.4 | 23 | 0.9 |
| 8.0 | 1544 | 3.8 | 25.2 | 23 | 0.6 |
| 12.0 | 2970 | 2.1 | 25.8 | 15 | 1.5 |
| 16.0 | 4799 | 0.5 | 25.8 | 24 | 2.6 |

Oxygen concentration was high at 0.5 m, with a mean value of 16.0 mg liter$^{-1}$. Oxygen saturation was 218 per cent at 0.5 m and was less than 64 per cent at remaining depths. The rapid decline in oxygen concentration with depth was influenced by diminution of photosynthesis.

Temperatures decreased rapidly between 0.5 and 4.0 m and was relatively constant from 4.0 to 16.0 m. Slightly higher temperatures at the two lower depths than at 4.0 and 8.0 m were attributed to the denser, Cimarron River water flowing through the reservoir.

Light intensity at 0.5 m was 85 per cent of the surface value. Light intensity was 1 per cent of the incident radiation at 3.6 m. Thus, all sampling depths were below the euphotic zone except the 0.5 m depth.

Turbidity values were greater at 4.0 and 8.0 m than at 0.5 and 12.0 m. The maximum turbidity value was recorded at 16.0 m, presumably caused by large amounts of suspended detritus and silt particles carried by the moving water mass.

Wind activity was greatest at 1600 hours and calm by 2100 hours. Current flow at 4.0 m was upstream, while at 8.0 m movement was circular. Current velocity was greater at 12.0 and 16.0 m as water was moving into the main reservoir to replace that lost by power generation. Outflow at the dam was reported to be approximately 20,000 c.f.s. with the peak flow at 1200 hours which produced a current of 2.7 m/min$^{-1}$ at 16.0 m. The 1.6 m/min$^{-1}$ value at the o.5 m level was caused by slight winds from variable directions.

## Diel Community Structure of Net Zooplankton of 9 and 10 July 1968

A total of 20 species of zooplankton were collected during the sampling period. Seven species of rotifers, 4 cladocera, 8 copepoda, and 1 dipteran were counted. Numerical abundance of pooled day and pooled night samples is given in Table XIV.

Rotifers comprised 63 per cent of the total numbers of individuals collected. Brachionus caudatus and Trichocera sp. were found at all depths and constituted 89 per cent of the rotifers counted. Both species exhibited vertical stratification and were most numerous at 0.5 m during both day and night. Most rotifers were generally more abundant in the upper 8.0 m of water and were relatively rare in the lower depths at night. Over 23 per cent of the total numbers of rotifers collected during the day were at 12.0 and 16.0 m, while only 5 per cent were taken from the same strata at night.

Cladocera represented less than 1 per cent of the total number of individuals collected. Daphnia parvula were collected from all depths and dominated the cladocera. Cladocera were generally absent in the 0.5 samples during the day. The percentage of cladocera in the surface sample increased from 7 during the day to 22 at night. These crustacea were most abundant between 4.0 and 8.0 m throughout the sampling period.

Copepods were numerous in all samples and constituted 32 per cent of the total number of individuals collected. Nauplii of adult forms were common and were considered one species during the study because of taxonomic difficulties. Cyclops vernalis comprised 66 per cent of

# TABLE XIV

## SPECIES FREQUENCY OF POOLED DAY AND NIGHT SAMPLES

| Species | Day | | | | | | Night | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.5 | 4.0 | 8.0 | 12.0 | 16.0 | Total | 0.5 | 4.0 | 8.0 | 12.0 | 16.0 | Total |
| <u>Brachionus</u> <u>calyciflorus</u> | 55 | 8 | 7 | | 1 | 71 | 74 | 19 | 8 | | 1 | 102 |
| <u>B.</u> <u>caudatus</u> | 1844 | 390 | 274 | 48 | 46 | 2602 | 1499 | 357 | 235 | 55 | 16 | 2162 |
| <u>B.</u> <u>phcatilis</u> | 19 | | 3 | 18 | 29 | 69 | 51 | 7 | 1 | 2 | | 61 |
| <u>Hexarthra</u> sp. | 3 | 2 | | | | 5 | 11 | 40 | 9 | | | 60 |
| <u>Keratella</u> <u>cochlearis</u> | 25 | 30 | 23 | 8 | 3 | 89 | 24 | 109 | 44 | 1 | 8 | 186 |
| <u>Polyarthra</u> sp. | 143 | 23 | 18 | 5 | 7 | 186 | 48 | 12 | 16 | | 3 | 79 |
| <u>Trichocerca</u> sp. | 669 | 377 | 352 | 640 | 448 | 2486 | 213 | 110 | 52 | 53 | 50 | 478 |
| <u>Bosmina</u> <u>longirostris</u> | | 5 | 1 | | | 6 | 3 | 1 | | | | 4 |
| <u>Ceriodaphnia</u> <u>reticulata</u> | | 14 | 8 | 11 | | 33 | | 7 | 7 | 9 | | 23 |
| <u>Diaphanosoma</u> <u>leuchtenbergiaum</u> | 1 | 30 | 20 | 10 | | 61 | 85 | 91 | 32 | 6 | | 214 |
| <u>Daphina</u> <u>parvula</u> | 19 | 63 | 47 | 29 | 21 | 179 | 1 | 83 | 26 | 39 | 5 | 154 |
| <u>Cyclops</u> <u>vernalis</u> | 2 | 196 | 50 | 131 | 141 | 520 | 39 | 95 | 40 | 39 | 18 | 228 |
| <u>Diaptomus</u> <u>clavipes</u> | | | 6 | 4 | | 10 | | 2 | | | | 2 |
| <u>D.</u> <u>dorsalis</u> | | 32 | 26 | 29 | 16 | 103 | 13 | 36 | 33 | 30 | 1 | 113 |
| <u>Ergasilis</u> <u>versicolor</u> | | 3 | 11 | | | 14 | 1 | 5 | | | | 6 |
| Nauplii | 38 | 271 | 236 | 211 | 1061 | 1817 | 247 | 365 | 199 | 303 | 245 | 1359 |
| <u>Eurytemora</u> <u>affinis</u> | | 5 | 10 | 12 | 4 | 31 | 8 | 25 | 4 | 5 | 2 | 44 |
| <u>Mesocyclops</u> <u>edax</u> | | 10 | 3 | 2 | 10 | 25 | 1 | 12 | 5 | 2 | 2 | 22 |
| <u>Mesocyclops</u> sp. | | | | | | | 8 | | | | | 8 |
| <u>Chaoborus</u> <u>punctipennis</u> | | | | | | | | 1 | | | | 1 |

the adult copepods counted and were rare in surface samples during the day. Most copepods were generally found below 0.5 m during the day. Only 40 individuals of one species and nauplii were collected from the surface during the day, while 317 individuals distributed among 6 species and nauplii were taken from the surface during the night.

Chaoborus punctipennis, the phantom midge, was taken only once during the study, 4.0 m at 2000 hours.

## Diel Species Diversity of 9 and 10 July 1968

Figure 5 shows a phase space diagram of spatial and temporal changes in $\bar{d}$. The range of spatial variation in $\bar{d}$ exceeded 1.20 at all time periods and the mean range of all time periods was 1.36. $\bar{d}$ varied from 1.03 at 16.0 m to 3.19 at 4.0 m. Spatial variation was related to physicochemical conditions. Highest $\bar{d}$ values were either at 4.0 or 8.0 m during all time periods. Low $\bar{d}$ values at the surface and bottom strata were associated with relatively harsh physicochemical conditions. High light intensity (Reid 1961) and temperature (Brown 1929) probably interacted in such a way as to make the upper strata intolerable to certain species, especially cladocera and copepoda. Low $\bar{d}$ values at 16.0 m may be related to low oxygen and high conductivity.

Despite vertical migration of certain species, variations in numbers of individuals between day and night samples, and the patchiness of species that has been reported (Wiebe and Holland 1968), temporal variation at a particular depth was less variable than spatial variation at a particular time. The range of temporal

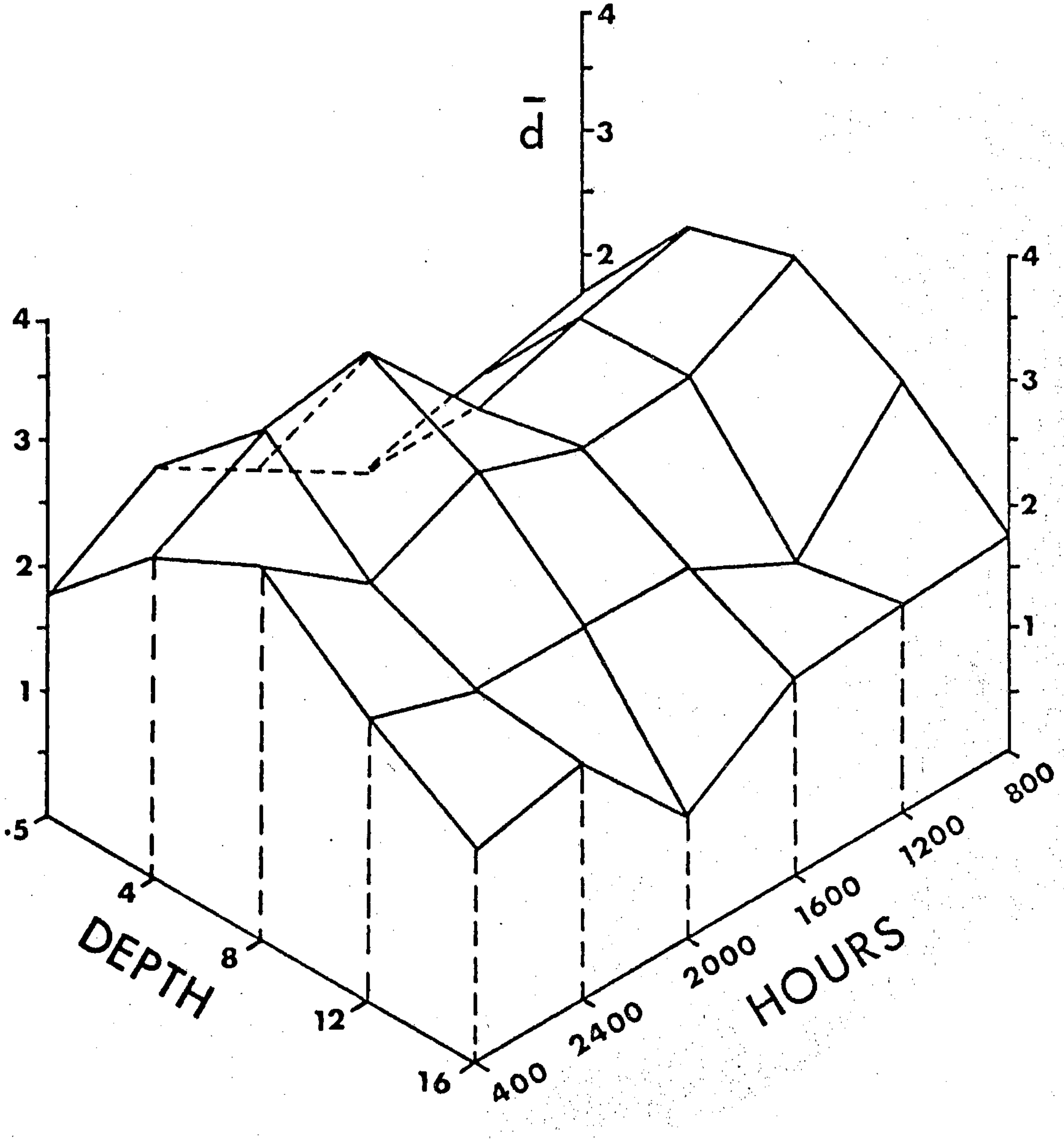

Figure 5. Phase-Space Diagram of $\bar{d}$ from Diel Sampling Period.

variation in $\bar{d}$ was less than 1 at all depths and the mean range of all depths was 0.85. $\bar{d}$ is related not only to the numbers of species in a community, but also to the relative abundance of the different species. A dispersal of a large number of individuals into an area may result in little variation in $\bar{d}$ if the ratios, $n_i/n$, are relatively unchanged. An immigration of new species may not significantly alter $\bar{d}$ if they are rare. Wilhm (1968) showed that the maximum contribution to $\bar{d}$ is made by a species that contributes 37 per cent of the sample and that the contribution made by rare species is small. In the present study, reporting numbers of species or numbers of individuals would have suggested considerable variation in community structure. However, $\bar{d}$ demonstrated that the pattern of numerical abundance was relatively unchanged in a particular stratum over time. The maintenance of similar patterns at a specific depth despite changes in numbers of species and individuals merits further study.

# CHAPTER IV

## SUMMARY

1. Four sampling stations each were established on the Cimarron and Arkansas Arms and one at the Dam site of Keystone Reservoir, Oklahoma. Each station was sampled monthly from 24 June 1967 to 21 June 1968. Net zooplankton community structure was estimated using conventional methods as well as species diversity analyses employing Shannon's formula and Yount's graphical method. Changes in net zooplankton community structure as related to changing physicochemical conditions were investigated.

2. A total of 46 taxa were collected from net zooplankton samples during the year. Rotifera species comprised 50 per cent of the total with the rotifer genera *Brachionus* dominating the zooplankton of the reservoir. *Brachionus calyciflorus* was the most common zooplankter collected. The most abundant cladoceran was *Daphnia parvula*, while the most common copepod was *Diaptomus* sp. Rotifers dominated upper reservoir locations while copepoda and cladocera exhibited greatest densities at lower reservoir locations.

3. Species diversity ($\bar{d}$) computed from triplicate samples by pooling six sets of 100 individuals within each sample allowed determination of a standard sample size based on observed asymptotic levels and statistical analysis. A $\bar{d}$ asymptote was reached by sample size 400. All variance components decreased as the sample size increased.

The coefficient of variation varied from 2.05 to 3.12 for sample sizes of 400 to 600 individuals. The range of within station variance varied from 0.0066 to 0.0217 for the same sample sizes of 400 to 600 individuals. The standard error of mean $\bar{d}$ varied from 0.0005 to 0.0015 over the same sample sizes. Slight differences in the standard error above 400 individuals was related to inherent variability of the samples and was considered to have little influence on computed $\bar{d}$ values.

4. Mean $\bar{d}$ values for the entire reservoir varied from 1.48 to 3.13 with a mean annual value of 2.48. Mean monthly $\bar{d}$ values in the Cimarron Arm were above 2.0 in all months except January, February, and March. $\bar{d}$ values greater than 3.0 were observed in May and June in the Cimarron Arm. Mean monthly $\bar{d}$ values in the Arkansas Arm were above 2.0 in all months except January, February, and March with a $\bar{d}$ of 3.43 being observed in July. Lowest $\bar{d}$ values were recorded during the winter when increased densities of rotifers were encountered.

5. Correlation coefficients of 0.38 and -0.57 between conductivity and $\bar{d}$ were observed in the Cimarron and Arkansas Arms, respectively. The value -0.57 was found to be significantly different from 0.0. Conductivity appears to have influenced community structure in the Arkansas Arm more than in the Cimarron Arm even though water in the Cimarron Arm was more conductive than the water of the Arkansas Arm.

6. Correlation coefficients of 0.75 and 0.76 were computed between turbidity and $\bar{d}$ in the Cimarron and Arkansas Arms, respectively. Both coefficients were significantly different from 0.0 at the 0.01 level. Mean annual turbidity in the Cimarron Arm was

80 mg liter$^{-1}$ and 96 mg liter$^{-1}$ in the Arkansas Arm. The close similarity between the two arms in $\bar{d}$ but not in turbidity suggests that turbidity may influence a more even distribution of individuals.

7. Computed correlation coefficients between temperature and $\bar{d}$ were 0.86 for the Cimarron Arm and 0.81 for the Arkansas Arm. Both values were significant at the 0.01 level. This implies that warmer water temperatures may have provided a more suitable environment for a greater variety of species than did colder waters of winter.

8. The difference in the mean annual $\bar{d}$ values among all stations was 0.26 units. Duncan's Multiple Range Test showed there was no significant difference ($p = 0.05$) between any stations throughout the reservoir in terms of $\bar{d}$, despite annual differences in ambient physicochemical conditions and taxa composition.

9. A comparison of $\bar{d}$ and slope (b) values computed from the graphical method indicated close agreement between both methods of estimating community structure. A correlation coefficient of 0.99 was computed for $\bar{d}$ and b values. The mean ratio of all $b/\bar{d}$ values was $2.56 \pm 0.26$. The graphical method was found to provide no additional information in ascertaining community structure. The ratios of $n_i/n$ provided the best estimates of zooplankton diversity.

10. Diel changes in community structure as estimated by $\bar{d}$ showed that spatial variation was related to physicochemical conditions. Highest $\bar{d}$ values were either at 4.0 or 8.0 m during all periods. Low $\bar{d}$ values at the surface were related to increased light intensity and high temperatures. Low $\bar{d}$ values at 12.0 and 16.0 m was thought to be related to increased conductivity and low oxygen concentrations.

Temporal variation at a particular depth was less variable than spatial variation at a particular time. Temporal variation was less than 1.0 at all depths compared to 1.36 for spatial variation.

11. $\bar{d}$ was shown to be a valuable tool in ascertaining community structure of net zooplankton. $\bar{d}$ also allowed meaningful statistical comparisons to be made within and between reservoir locations. Furthermore, concomitant analysis of physicochemical conditions and $\bar{d}$ enabled a more valid characterization of the reservoir than by considering only physicochemical parameters.

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## VITA

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