A COMPARISON OF ZOOPLANKTON SPECIES DIVERSITY IN JOHN REDMOND, MARION, AND COUNCIL GROVE RESERVOIRS, KANSAS, SUMMER 1968

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INTRODUCTION

In general, studies conducted at the community level are concerned with accumulation of data which characterize the general ecological condition of the community in question and which enable ecologists to compare its structure and relative maturity with that of other communities. Community structure refers to the complex of individuals of different species comprising a community. Classically, the ecologist has relied on voluminous verbal descriptions and species lists, such as those by Patrick, Cairns, and Roback (1967) and Gaufin and Tarzwell (1956) to characterize communities; but comparisons based on such information are often difficult to interpret.

Community structure and relative stability can be quantitatively defined by the use of species diversity indices based on methods derived from information theory (Margalef, 1958). This approach equates diversity with the uncertainty that a randomly selected individual in a community will belong to a given species. In a community consisting of many species of nearly equal abundance, the uncertainty is great and therefore species diversity is large. This is true in a stable (mature) community (Odum, 1962). Seral communities and other communities undergoing ecological stress (pollution) tend to have fewer species but great numbers of individuals of some species. In these cases, uncertainty is less and species diversity is low (Wilhm and Dorris, 1968).

Recent studies have demonstrated the characterization of water quality by use of species diversity indices. Patten (1962) used diversity and redundancy as ecological variables to describe changes in community composition and to denote precisely the successional status of a community. Patten's study, based on annual net phytoplankton in Rariton Bay, New York, demonstrated a direct correlation between the general circulation pattern of the bay and mean diversity per station. Diversity levels were high in the lower estuary but progressively diminished upbay, reflecting gross pollution occurring at the head of the estuary.

Wilhm and Dorris (1968) drew attention to the use of species diversity indices to characterize water quality of streams. They reported that diversity indices based on benthic macroinvertebrates tended to be less than 1 in grossly polluted streams, 1 to 3 in moderately polluted communities, and greater than 3 in clean water communities. Ransom (1969) found a positive correlation between species diversity of benthic macroinvertebrates and conductivity in Keystone Reservoir, Oklahoma. This demonstrated the application of diversity indices based on benthic macroinvertebrates to characterize water quality conditions in a reservoir.

A preliminary survey of water quality in three U.S. Army Corps of Engineers reservoirs on the Upper Grand (Neosho) River in east-central Kansas was made by members of the Limnology Laboratory at Kansas State Teachers College during the 1967 summer. Results revealed significant differences in physicochemical factors between reservoirs; but no attempt was made to assess their possible ecological significance. During the 1968 summer, a comparative study was made of the zooplankton in these reservoirs. The primary objectives of this study were: 1. to determine the summer species composition of the Cladocera, Copepoda, and Rotifera; 2. to characterize and compare summer community structure of zooplankters using species diversity indices; and 3. to relate species diversity indices to water quality conditions in the reservoirs.

MATERIALS AND METHODS

The general geographical location and morphometry of John Redmond, Council Grove, and Marion Reservoirs were described by Prophet (1969). Five sampling sites were selected in each reservoir, with one station located near the outlet and another near the upstream boundary of each reservoir. The remaining stations were located within the basin to represent variation in depth and other morphometric features (Figs. 1, 2, and 3).

From June 10 to September 6, 1968, townet samples were taken during the same week at monthly intervals in the three reservoirs. To insure adequate sampling, four vertical hauls were made at each station with a 24 cm diameter plankton tow-net (Fig. 4). One haul was made on either side at bow and stern of the boat by sinking the plankton net to the bottom and slowly drawing it to the surface. The depth of each tow was recorded for later use in determining the volume of water strained. Samples were preserved in ten per cent formalin and returned to the laboratory for examination.

In the laboratory, one of the four samples from each station was selected at random for examination. Only one sample was used since there was no significant difference between estimates of the number of species and individuals per species at each station based on a single vertical tow and estimates based on all four tows (Fig. 5). Figure 5 is representative of the relationship between diversity per individual ($\overline{d}$) and the number

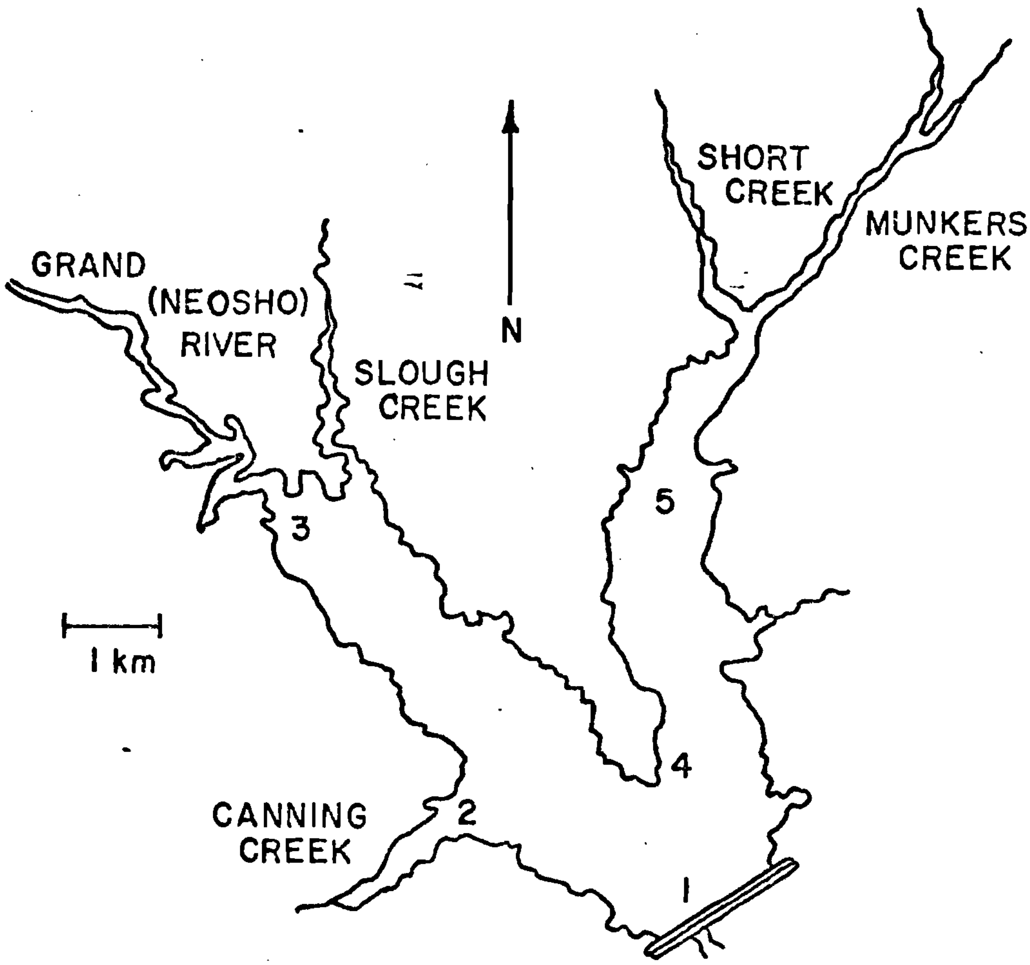

Figure 1. Location of sampling stations in Council Grove Reservoir.

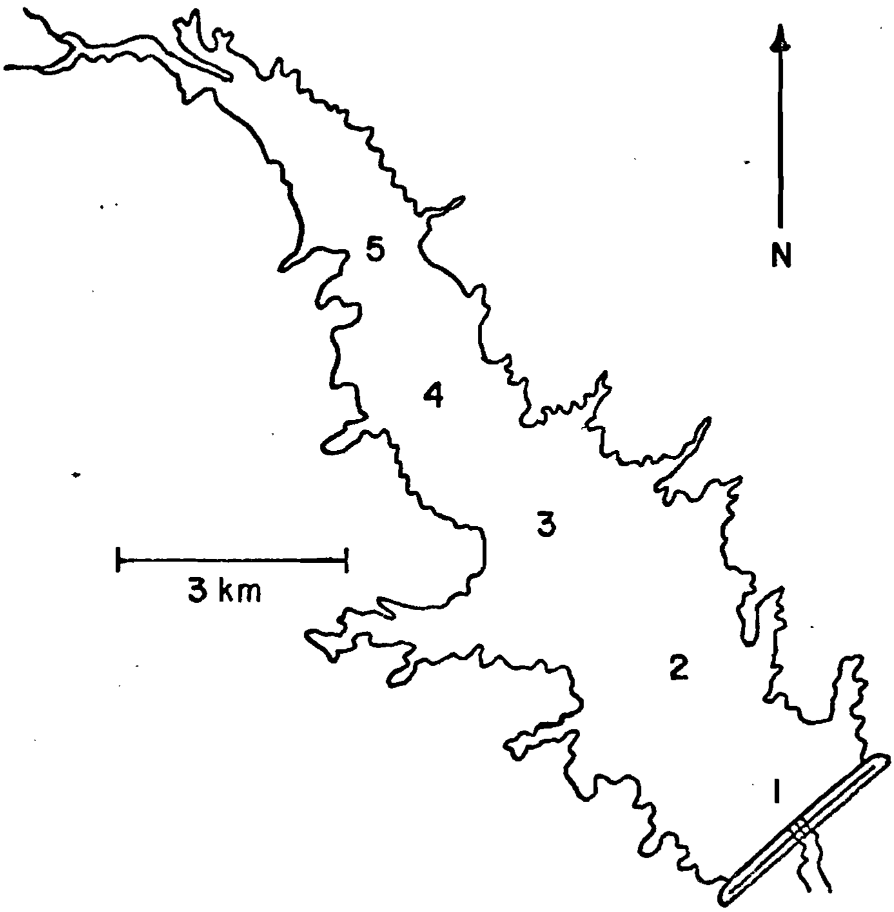

Figure 2. Location of sampling stations in Marion Reservoir.

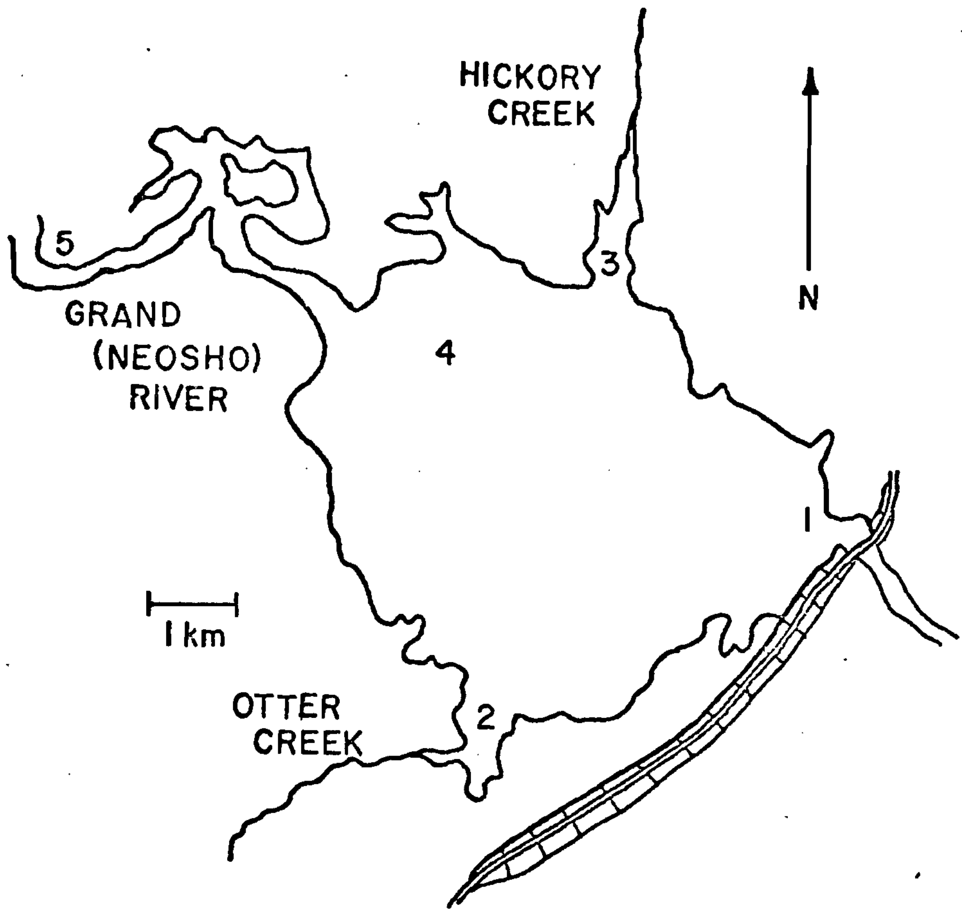

Figure 3. Location of sampling stations in Redmond Reservoir.

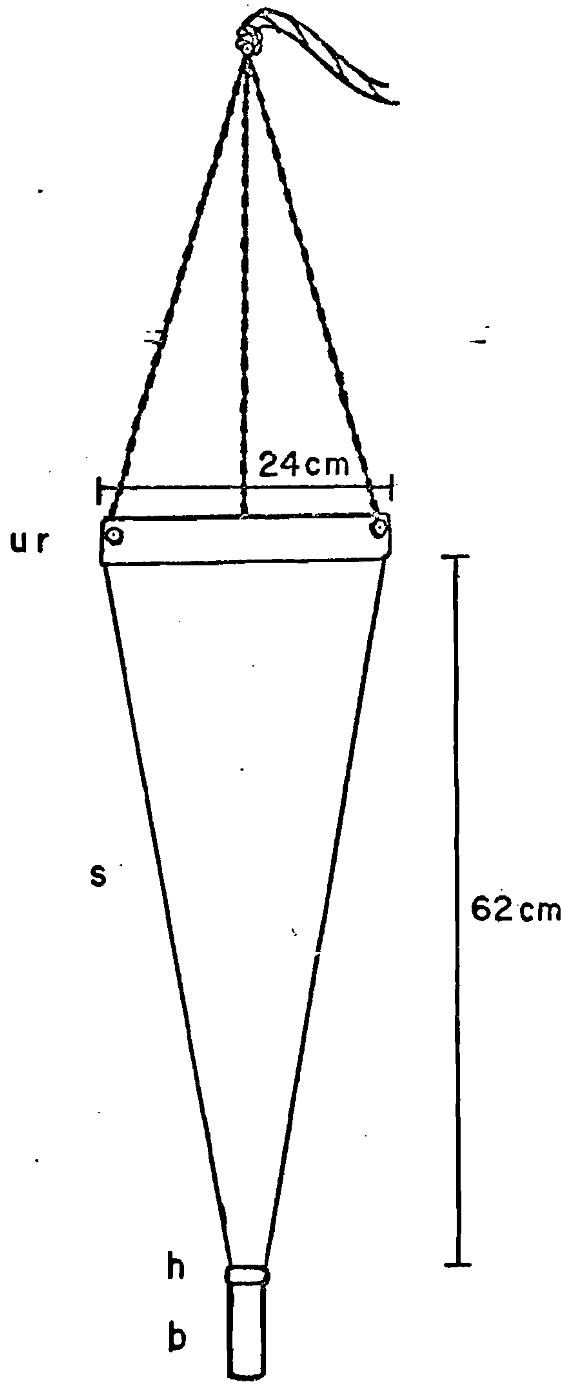

Figure 4. Plankton townet, constructed of silk no. 20 bolting (173 meshes/inch or .176 mm), with a mouth diameter of 24 cm and a sleeve length of 62 cm. ur = upper ring, s = sleeve, h = headpiece, and b = sample bottle.

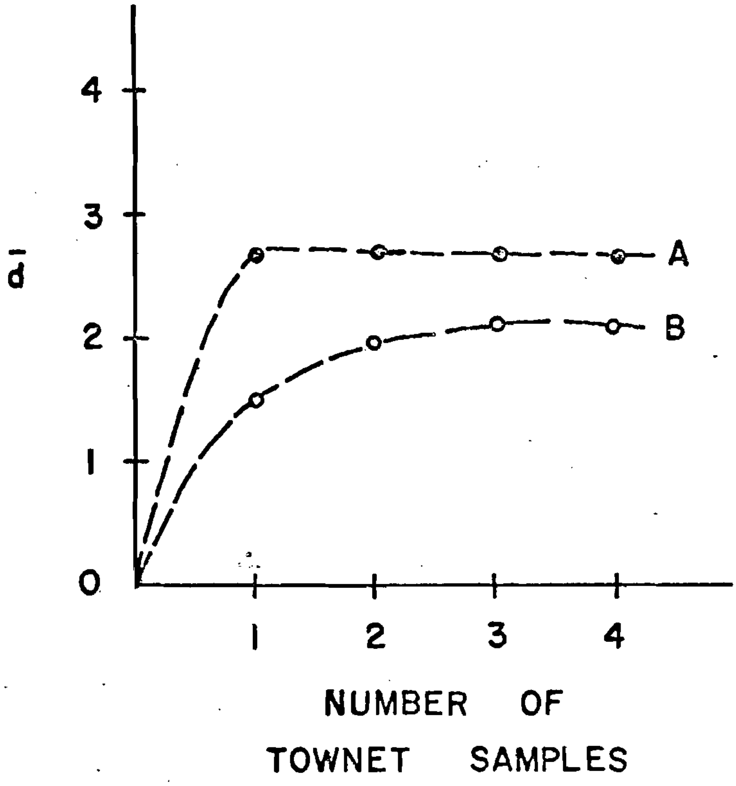

Figure 5. Variation in estimates of diversity per individual ($\bar{d}$) and the number of townet samples analyzed. B = Redmond Station 5, and A = all other stations.

of pooled townet samples. The asymptotic diversity value was almost reached using one sample in nearly all instances. The only exception was Station 5 in Redmond (Fig. 5B), where all four samples were examined.

Copepoda and Cladocera were identified to species and the Rotifera to genus. Taxonomic keys utilized in identifying specimens were The Systematics of North American Daphnia (Brooks, 1957), The systematics and evolution of the Moinidae (Goulden, 1968), Fresh-Water Invertebrates of the United States (Pennak, 1953), and Fresh-Water Biology (Ward and Whipple, 1959). Identifications of Moinidae were verified by Dr. Clyde E. Goulden, Associate Curator of Limnology at the Academy of Natural Sciences of Philadelphia. Identifications of the Diaptomidae were verified by Mildred S. Wilson, Arctic Health Research Center, U.S. Public Health Service, Anchorage, Alaska.

Estimates of population densities were obtained in the following manner. The volume of a townet sample was first made to 60 ml. The sample was then shaken gently and a 1 ml subsample was withdrawn with an automatic pipette before the plankters had settled to the bottom of the container. The subsample was then placed in a Sedgwick-Rafter counting cell and plankters identified and enumerated at magnifications of x7 to x440. Population densities of the cladocerans, copepods, and rotifers in three separate subsamples were recorded and used to estimate relative abundance of individuals.

The number of subsamples that needed to be examined to provide an adequate representation of each townet sample was determined by comparing estimates of diversity per individual ($\bar{d}$) based on one through six subsamples (Fig. 6). As can be seen, estimates leveled off between two and three subsamples. It was therefore concluded that three 1 ml subsamples provided an adequate representation of $\bar{d}$ for a sample.

Relative abundance of zooplankton species per townet sample was estimated by the following equation:

$$N = \frac{n\ v}{T}$$

where N is the number of individuals of a species per liter, n is the mean number of individuals per ml of townet sample, v is the volume of the concentrated sample in ml's, and T is the total volume of water strained.

Species diversity indices were calculated using equations from Patten (1962), as later modified by Wilhm and Dorris (1968) and by Ransom (1969). The manner in which individuals are distributed among species in a community is reflected by species diversity (d), which was calculated using the equation:

$$d = \sum_{i=1}^{s} n_i \log_2 \frac{n_i}{n}$$

where n is the total number of individuals, n_i is the number of individuals of species i, and s is the number of species per

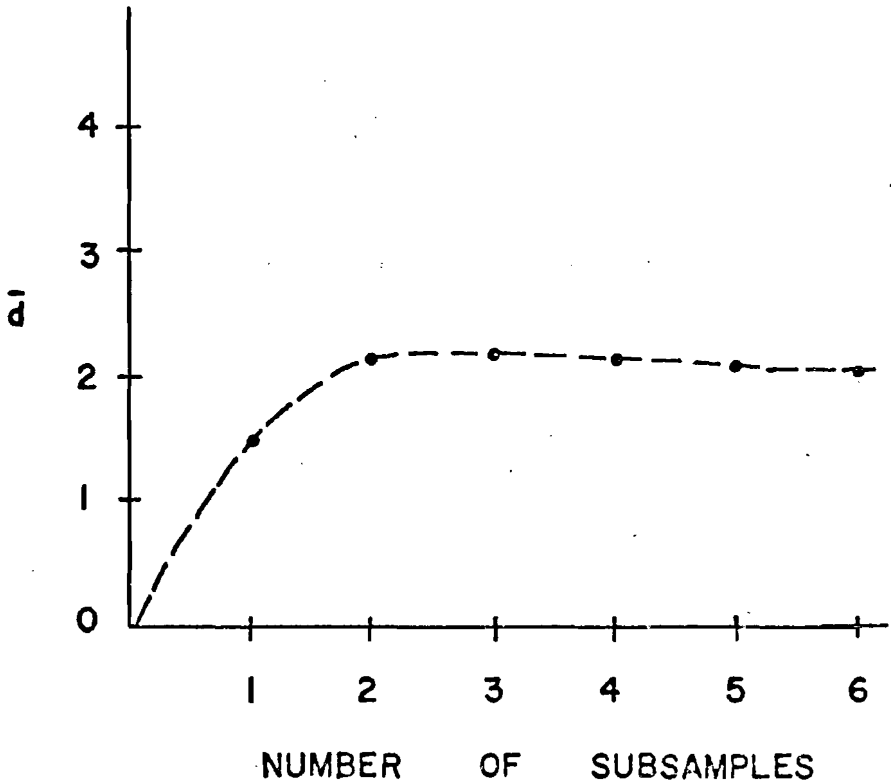

Figure 6. Variations in estimates of $\overline{d}$ based on one to six subsamples.

unit area. Species diversity (d) values lie between a theoretical maximum diversity (d_{max}) and minimum diversity (d_{min}). Minimum diversity occurs if all individuals in a sample or community are of one species, and maximum diversity occurs if each individual belongs to a different species. Maximum diversity was determined from the equation:

$$d_{max} = \log_2 n! - s \log_2 \left(\frac{n}{s} \right)!$$

Minimum diversity was calculated from the equation:

$$d_{min} = \log_2 n! - \log_2 \left[n - (s - 1) \right] !$$

Diversity per individual ($\bar{d}$) is the ratio of the number of individuals of each species to the total number of individuals in the sample. Calculation of $\bar{d}$ is demonstrated in the equation:

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

Redundancy (R) is an expression of the dominance of one or more species, and is inversely proportional to the wealth of species (Wilhm and Dorris, 1968). Redundancy is calculated by the equation:

$$R = \frac{d_{max} - d}{d_{max} - d_{min}}$$

Data were analyzed by the Kansas State Teachers College Data Processing Center, using the above equations. Diversity indices were compared by the F Test at the .05 level. If significant differences were found, Duncan's Multiple Range Test at the .05 level was used to determine which values were significantly different.

RESULTS AND DISCUSSION

Species Composition of Summer Zooplankton

Twenty species of Cladocera and Copepoda and eight genera of Rotifera occurred in townet samples collected from the three reservoirs during the 1968 summer (Table I). There was little difference in the number of taxa collected from each reservoir, with 23 taxa present in Redmond, 20 in Council Grove, and 23 in Marion. However, there was less similarity between reservoirs with regard to dominant forms. The dominants in Redmond in order of decreasing abundance were; *Bosmina longirostris*, *Diaptomus siciloides*, *Diaphanosoma brachyurum*, *Polyarthra*, *Cyclops vernalis*, *Moina minuta*, *Keratella*, *Diaptomus pallidus*, and *Daphnia parvula*. Dominant plankters in Marion were; *Diaptomus sicloides*, *Keratella*, *Bosmina coregoni*, *Daphnia pulex*, *Cyclops vernalis*, *Moina wierzejskii*, and *Diaptomus clavipes*. Those organisms dominant in Council Grove were; *Keratella*, *Polyarthra*, *Daphnia parvula*, *Bosmina longirostris*, *Diaphanosoma brachyurum*, *Cyclops vernalis*, *Diaptomus pallidus*, and *Ceriodaphnia reticulata*.

Most of the species of Cladocera and Copepoda identified appear to be common in other Kansas impoundments (Prophet, Andrews, and Goulden, 1959; Tash and Armitage, 1960; and Prophet, 1964). However, the occurrence of males and sexual females of *Moina minuta* in the September samples from Redmond

Table I. Species list and per cent composition of zooplankton in Redmond, Marion, and Council Grove Reservoirs, summer, 1968.

Species	Redmond	Marion	Council Grove
Diaphanosoma brachyurum	9.8	3.8	8.1
Daphnia parvula	5.1		12.8
Daphnia pulex		8.0	
Daphnia ambigua	1.3		1.2
Daphnia galeata mendotae		0.8	
Ceriodaphnia reticulata	0.4	2.8	5.6
Ceriodaphnia lacustris	*	0.5	3.4
Simocephalus serrulatus		0.1	
Moina wierzejskii	*	6.7	
Moina micrura	0.1	1.2	*
Moina minuta	6.3		
Bosmina coregoni		13.0	
Bosmina longirostris	19.5		10.9
Leydigia quadrangularis	*	*	0.1
Chydorus sphaericus	*	0.6	0.1
Diaptomus siciloides	16.5	25.1	4.6
Diaptomus pallidus	5.7	4.7	7.5
Diaptomus clavipes	0.7	5.9	0.2
Cyclops vernalis	6.4	7.8	7.7
Mesocyclops edax	1.0	*	3.2
Brachionus sp.	3.9	0.5	0.7
Keratella sp.	5.9	17.2	14.3
Hexarthra sp.	*	*	
Trichocerca sp.		*	
Asplanchna sp.	2.1	0.8	2.3
Polyarthra sp.	8.3	0.3	14.0
Filinia sp.	4.6	*	0.4
Pedalia sp.	1.9		2.9

The * denotes the presence of a species which contributed less than 0.1 per cent to the total density.

Reservoir is a new record for North America (Goulden, 1968). Marion was in the initial stages of flooding during this study, which may account for the occurrence of Bosmina coregoni rather than Bosmina longirostris. Apparently, B. coregoni occurs during the early history of some natural lakes and is eventually replaced by B. longirostris (Goulden and Frey, 1963). Applegate and Mullan (1967) reported that B. longirostris was more abundant in the older of two Arkansas-Missouri Ozarks reservoirs on the White River. Diaphanosoma brachyurum and Cyclops vernalis occur primarily in summer (Prophet, 1964; Andrews, 1953).

Zooplankters were most abundant in Marion and least abundant in Redmond as exemplified by the average summer density. Zooplankton averaged 63 individuals per liter in Marion compared to 20 per liter in Redmond and 28 per liter in Council Grove. Individual contribution of copepods, cladocerans, and rotifers to total density of these zooplankters in each reservoir is given in Table II. Cladocerans constituted the greatest portion of the zooplankton in Redmond and Council Grove, while copepods were dominant in Marion. Relative to the other zooplankters, rotifers were most abundant in Council Grove and least numerous in Marion. Redmond and Council Grove appeared to have the most similar associated organisms, as 88 per cent of the taxa identified in the samples from these two reservoirs were present in both. There was less similarity in species composition between Redmond and Marion, and between Marion and Council Grove (Fig. 7).

Table II. Per cent contribution of Copepoda, Cladocera, and Rotifera to total density of the zooplankton community in Redmond, Marion, and Council Grove Reservoirs, summer, 1968.

Taxonomic group	Redmond	Marion	Council Grove
Copepoda	30.3	43.5	23.2
Cladocera	42.5	37.5	42.2
Rotifera	26.7	18.8	34.6

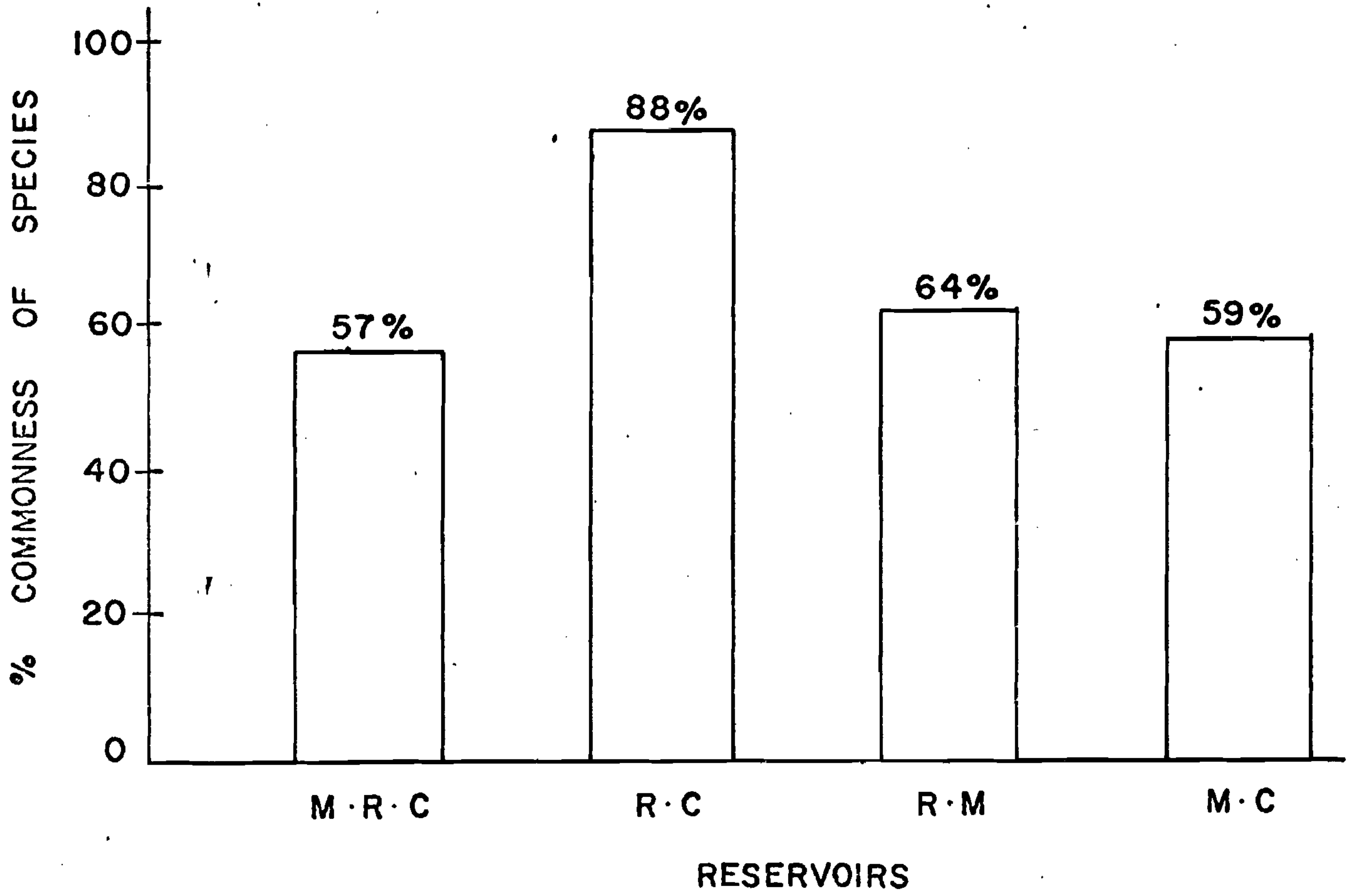

Figure 7. The per cent commonness of zooplankton species among reservoirs during the 1968 summer. R = Redmond, M = Marion, and C = Council Grove Reservoirs.

Based on these comparisons, it appeared that the summer zooplankton communities of Redmond and Council Grove were not significantly different while the zooplankton community in Marion was less similar to that of either Redmond or Council Grove. In this respect, relationships between the 1968 summer zooplankton communities appeared to agree with the trends reported for the physicochemical conditions (Prophet, 1969).

Variations in Diversity per Individual Within Reservoirs

There was no significant difference in $\bar{d}$ among stations in either Redmond or Council Grove. However, there were significant differences among some stations in Marion (Table III). Diversity per individual based on copepods and cladocerans at Station 5 was significantly different from $\bar{d}$ at Station 4, but the differences between Station 5 and the remaining stations were not significant. When $\bar{d}$ was based on all three taxonomic groups, relationships changed slightly. In this instance, $\bar{d}$ at Station 5 was significantly different from that of Station 1 as well as Station 4. Thirty-eight per cent of all zooplankters collected in Marion were collected at Station 1, while Stations 4 and 5 contributed only 17 and 7 per cent, respectively, of the total zooplankton. There were 16 species present at Station 1, 17 at Station 4, and 18 at Station 5. A lower $\bar{d}$ was expected at Station 1, as it contributed the largest number of individuals and the smallest number of species of the three stations. Since Station 5

Table III. Comparison of mean $\bar{d}$ values among stations within each reservoir, summer, 1968.

Based on Copepoda and Cladocera					Based on Copepoda, Cladocera, and Rotifera				
Redmond Reservoir station no.									
1	2	3	4	5	1	2	3	4	5
1.83	2.04	2.18	1.85	2.04	2.55	2.68	2.70	2.44	2.48
Marion Reservoir station no.									
4	1	2	3	5	1	4	2	3	5
2.15	2.29	2.32	2.46	2.66	2.19	2.30	2.45	2.57	3.02
Council Grove Reservoir station no.									
1	2	3	4	5	1	2	3	4	5
2.44	2.38	2.28	2.54	2.29	2.66	2.84	2.94	3.06	2.79

The numbers 1 through 5 indicate the station number, and the $\bar{d}$ value for that station is given directly below the station number. There is no significant difference between underlined values.

contributed only 7 per cent of the total zooplankters but the largest representation of species, it was expected to have a higher $\bar{d}$ than the other stations.

Comparison of Diversity per Individual and Redundancy Among Reservoirs

Diversity per individual and redundancy values were used to compare community structure and relative maturity of the reservoirs (Table IV). In Redmond, diversity per individual based on copepods and cladocerans was significantly different from values for both Council Grove and Marion; but when the rotifers were included relationships changed so that $\bar{d}$ in Marion as well as Redmond was significantly different from that in Council Grove.

Significant differences in physicochemical factors were the opposite of those for $\bar{d}$. Physicochemical factors in Marion during the 1968 summer were significantly different from those in both Council Grove and Redmond (Prophet, 1969), but there were few significant differences among the physicochemical factors in Council Grove and Redmond. According to $\bar{d}$ values, Council Grove and Redmond were significantly different from each other, and Marion was intermediate. Several variables may have been responsible for this disagreement. In the absence of induced environmental stresses, the structure of a community undergoes a directional change through time. The more mature (closer to the climax state) the community, the

Table IV. Comparison of mean $\bar{d}$ and R values for Redmond, Marion, and Council Grove Reservoirs, summer, 1968.

Based on Copepoda and Cladocera				Based on Copepoda, Cladocera, and Rotifera		
JR	M	CG		JR	M	CG
1.99	2.38	2.39	$\bar{d}$	2.57	2.50	2.86
.27	.26	.16	R	.25	.27	.17

The letters JR = John Redmond, M = Marion, CG = Council Grove Reservoirs, $\bar{d}$ = diversity per individual, and R = redundancy. There is no significant difference between underlined values.

greater the diversity in that community. Environmental stresses of either pollution or pioneer stages of succession lower diversity values. Although the relationships between $\bar{d}$ values varied depending upon the number of zooplankter groups considered, the lower values obtained for Redmond and Marion probably indicate that both were being subjected to some form of environmental stress. Marion was being flooded at the time of this study, while both Council Grove and Redmond were impounded four years earlier. Because of its recent impoundment, community structure in Marion was considered less mature than that of either Redmond or Council Grove and therefore was expected to yield a relatively low $\bar{d}$. The low $\bar{d}$ for Redmond was not totally unexpected, since this reservoir is known to be polluted by runoff from commerical feedlots (Prophet, 1969).

This disagreement between apparent relationships among the reservoirs based on physicochemical measurements and species diversity indices demonstrates the danger of characterizing ecological conditions solely by physicochemical data. Characterization of community relationships by merely comparing species lists is also likely to be misleading, especially if relative abundance of species is not taken into consideration.

Physicochemical conditions at all stations within a given reservoir were fairly uniform and values used to compare the reservoirs were based on data recorded at the outlet stations only (Prophet, 1969). To determine if the disagreement between interpretations based on physicochemical data and those based on $\bar{d}$ values was due to differences in community structure among stations, a station by station comparison was made. There was no significant difference among $\bar{d}$ values for Station 1. The only significant difference occurred at Station 4 (Table V), and the trend there was essentially the same as that reported for overall $\bar{d}$ values in Table IV.

Estimations of diversity per individual and redundancy did not support assumptions concerning similarity of reservoirs based on physicochemical conditions during the 1968 summer. On the contrary, while physicochemical data indicated that Redmond and Council Grove were similar, their $\bar{d}$ values were significantly different. An increased number of zooplankton groups changed the relationship between $\bar{d}$'s of the reservoirs indicating perhaps that $\bar{d}$ based on Copepoda, Cladocera, and Rotifera was more reliable than that based on only Copepoda and Cladocera. A future study should be made to determine the number of plankton groups on which $\bar{d}$ must be based to provide an adequate description of community structure. A year-round diversity study might also yield a more characteristic index, as seasonal occurrence of species may cause summer $\bar{d}$ values to be different from annual values. Also, a diversity study of zooplankton as compared to benthic macro-invertebrates within the same reservoir would more readily demonstrate the validity of $\bar{d}$ based on zooplankton species.

Table V. A station by station comparison of mean $\bar{d}$ values between Redmond, Marion, and Council Grove Reservoirs, summer, 1968.

	Based on Copepoda and Cladocera			Based on Copepoda, Cladocera, and Rotifera		
Station	R	M	CG	R	M	CG
1	1.83	2.29	2.44	2.55	2.19	2.66
2	2.04	2.32	2.38	2.65	2.45	2.84
3	2.18	2.46	2.28	2.70	2.58	2.94
4	1.85	2.15	2.54	2.44	2.30	3.06
5	2.04	2.66	2.29	2.48	3.06	2.79

The letters R = Redmond, M = Marion, and CG = Council Grove Reservoirs. There is no significant difference between underlined values.

SUMMARY

Zooplankters were collected at John Redmond, Marion, and Council Grove Reservoirs, from June 10 through September 6, 1968. Organisms identified and enumerated in these collections were the Copepoda, Cladocera, and Rotifera. On the basis of species lists, Redmond and Council Grove appeared to be similar in community structure, while both differed from Marion. But, Redmond and Council Grove were significantly different and Marion intermediate when community structure of zooplankton was described by species diversity indices.

Estimations of diversity per individual and redundancy did not support assumptions concerning similarity of reservoirs based on physicochemical conditions. While physicochemical data indicated that Redmond and Council Grove were similar, their $\bar{d}$ values were significantly different. Several variables contributed to this disagreement. Both Marion and Redmond had a lower $\bar{d}$ than that of Council Grove, each for a different reason. Marion Reservoir was only recently impounded and therefore an immature community, while Redmond received pollution in the form of commerical feedlot runoff.

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LITERATURE CITED

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APPENDIX

DIVERSITY PER INDIVIDUAL*

Reservoir	Date	Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5
R**	610	1.36	2.36	2.14	1.85	2.03
R	701	2.66	1.73	2.52	1.66	0.98
R	802	2.21	2.47	1.79	2.25	2.89
R	903	1.10	1.59	2.27	1.63	2.27
M	614	2.33	2.19	2.45	1.76	2.74
M	708	2.79	3.05	2.91	2.34	2.72
M	801	2.32	2.10	2.33	2.35	2.69
M	906	1.72	1.94	2.15	2.14	2.50
CG	612	2.12	2.16	1.71	1.91	1.91
CG	701	2.81	2.18	2.18	2.83	2.55
CG	805	2.13	2.65	2.69	2.71	2.23
CG	903	2.70	2.52	2.54	2.70	2.49
R	610	2.23	2.80	2.80	2.18	2.42
R	701	3.06	2.49	2.90	2.33	1.85
R	802	2.64	2.79	2.54	3.19	3.07
R	903	2.28	2.53	2.57	2.05	2.56
M	614	2.33	2.53	2.73	2.01	3.30
M	708	2.30	3.24	3.09	2.70	2.98
M	801	2.36	2.10	2.33	2.35	2.99
M	906	1.79	1.94	2.15	2.15	2.79
CG	612	2.65	2.79	2.75	2.57	2.39
CG	701	3.08	2.73	2.60	3.13	2.77
CG	805	2.12	3.06	3.22	3.30	2.83
CG	903	2.80	2.76	3.19	3.23	3.18

*The first half of the above table refers to values obtained for Copepoda and Cladocera, while the last half refers to values obtained for Copepoda, Cladocera, and Rotifera.
**R = Redmond, M = Marion, and CG = Council Grove Reservoirs.

REDUNDANCY*

Reservoir	Date	Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5
R**	610	0.00	0.21	0.28	0.21	0.27
R	701	0.00	0.39	0.21	0.45	0.68
R	802	0.35	0.17	0.40	0.25	0.12
R	903	0.49	0.31	0.24	0.42	0.19
M	614	0.26	0.22	0.29	0.41	0.09
M	708	0.19	0.18	0.19	0.26	0.14
M	801	0.27	0.34	0.22	0.22	0.19
M	906	0.43	0.39	0.32	0.36	0.21
CG	612	0.33	0.29	0.13	0.32	0.25
CG	701	0.13	0.15	0.20	0.05	0.05
CG	805	0.28	0.11	0.08	0.04	0.13
CG	903	0.14	0.15	0.08	0.14	0.15
R	610	0.26	0.22	0.22	0.28	0.27
R	701	0.11	0.28	0.17	0.35	0.47
R	802	0.36	0.25	0.33	0.16	0.16
R	903	0.21	0.16	0.30	0.43	0.26
M	614	0.26	0.20	0.28	0.42	0.08
M	708	0.39	0.17	0.19	0.22	0.14
M	801	0.29	0.34	0.22	0.22	0.15
M	906	0.46	0.39	0.32	0.38	0.24
CG	612	0.30	0.19	0.12	0.23	0.31
CG	701	0.19	0.14	0.17	0.09	0.11
CG	805	0.33	0.11	0.06	0.07	0.21
CG	903	0.21	0.16	0.09	0.12	0.13

* The first half of the above table refers to values obtained for Copepoda and Cladocera, while the last half refers to values obtained for Copepoda, Cladocera, and Rotifera.
**R = Redmond, M = Marion, and CG = Council Grove Reservoirs.