INFLUENCE OF SPATIAL HETEROGENEITY ON ESTIMATES OF CONCENTRATION AND SPECIES DIVERSITY OF PELAGIC NET ZOOPLANKTON

By

LARRY GARNER BOWLES

Bachelor of Science

University of Tulsa

Tulsa, Oklahoma

1963

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1973

INFLUENCE OF SPATIAL HETEROGENEITY ON ESTIMATES

OF CONCENTRATION AND SPECIES DIVERSITY

OF PELAGIC NET ZOOPLANKTON

Thesis Approved:

Jerry Wilhm
Thesis Adviser

Robert Summerfelt

Troy C. Dorris

N N Durham
Dean of the Graduate College

PREFACE

The objective of this study was to determine if traditional sampling procedures adequately result in estimates of species diversity and concentration of pelagic net zooplankton. A mathematical model derived from information theory was used to estimate species diversity and an analysis of variance was done using the F statistic at the .05 level.

I thank my major adviser, Dr. Jerry Wilhm, and Drs. Robert C. Summerfelt and Troy C. Dorris, members of my advisory committee, for their advice and criticisms.

My gratitude is expressed to Mr. Bruce Hysmith for assistance with sampling, Ms. Karla Cooper for assisting with typing and preparation of the drafts, and Mrs. Dixie Jennings for final copy of this report.

Funds for support of the field work were furnished through the Oklahoma Cooperative Fishery Unit and my personal support was through an Oklahoma Fish and Game Council Fellowship under the sponsorship of the U. S. Army, Corps of Engineers, Tulsa District. Mr. Lowell Leach of the Robert S. Kerr Laboratory, Office of Water Programs, EPA, furnished the original of my Figure 1.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Investigators of spatial variations of zooplankton population parameters in lakes typically collect single or replicate samples from a single site at each station. Applegate and Mullan (1967) used oblique tows of a plankton net and a pump to determine zooplankton populations in Beaver and Bull Shoals lakes on the White River in Arkansas. They used a single site at each of their 14 stations. Zooplankton of Lewis and Clarke Lake on the Missouri River at the border of Nebraska and South Dakota were collected with oblique and horizontal hauls of plankton nets at single sites at each of ten stations (Cowell, 1970). Hammer and Sawchyn (1968) in a study of *Diaptomus* spp. in ponds in Canada sampled a single site and one depth in each of the ponds studied. Horizontal zooplankton distribution was studied in Finger Lakes of New York using plankton net hauls at single sites in the deeper part of the lakes (Hall and Waterman, 1967). Peterka (1970) studied relationships between water quality and plankton in Ashtabula Lake, North Dakota, using single site, single replicate samples for quantitative estimates of zooplankton. In all of these examples, it was assumed that the samples were representative of the aquatic environment at the station and the station represented the environment in the area.

Nonrandom spatial distribution or patchiness of zooplankton may bias estimates of population parameters (Wiebe, 1971; Wiebe, 1970; Wiebe and

Holland, 1968; Barnes and Marshall, 1951). Wiebe and Holland (1968) used a computer model to study the effect of changes in the size of patches, the distribution of the centers of patches, and net size on estimates of the mean number of individuals and variability about the mean. They found that size of patches affects both accuracy and precision of the estimates. Significant patchiness existed among marine zooplankton (Wiebe, 1970). Significant changes in coefficients of variability can occur as a function of patchiness size and distribution (Wiebe, 1971). Barnes and Marshall (1951) found variations in the type of dispersion among nauplii of marine copepods from underdispersed to overdispersed.

Species diversity indices have been used in recent years to characterize community structure. Patten (1962) used the following formula derived from information theory (Shannon and Weaver, 1963) to characterize plankton in Raritan Bay:

$$\bar{d} = \sum_{1}^{s} \left(\frac{n_i}{n}\right) \log_2 \left(\frac{n_i}{n}\right) \quad ,$$

where s is the number of species, n_i is the number of individuals in the ith species, and n the total number of individuals. Since Patten's work, numerous studies of aquatic communities have included estimates of species diversity using the above formula (Wilhm, 1968; Kochsiek and Wilhm, 1970; Kochsiek, et al., 1971; Prather and Prophet, 1969; Cooper, 1972, and Staub, et al., 1970). This equation is dimensionless, independent of sample size, and expresses the relative importance of each species (Wilhm and Dorris, 1968).

Patchiness may result in considerable variation in total number of organisms, numbers within each species, and numbers of species. Since numbers of organisms and species are basic data in species diversity indices, indices calculated from data taken from a single site may not be representative of the entire area. The objective of this study was to determine if spatial variation in species diversity and abundance of pelagic net zooplankton among samples at a particular sampling station caused statistically biased results.

The area selected for study was Eufaula Lake, part of the Arkansas River Basin Development Plan. The purposes of the lake and dam are flood control, power generation, and storage of water for conservation and silt deposition (Table I). The earth-filled dam is located on the Canadian River in McIntosh and Haskell counties, Oklahoma (Figure 1) at 35° 18' 20" N - 95° 21' 36" W. Shore line length is 965.61 km at power pool level with a mean depth of 7.07 m and shore development of 13.4. Final closure occurred in February, 1964.

TABLE I

EUFAULA LAKE DATA

Feature	Elevation (m, sea level)	Area (Hectares)	Capacity ($m^3 \times 10^4$)
Top of dam	186.54	----	----
Top of gates	181.97	57,870.67	474,650.80
Top of power pool	178.31	41,480.72	293,326.30
Spillway crest	172.21	19,425.12	11,064.50
Stream bed at dam	152.40	----	----

Calculated using data from U. S. Army, Corps of Engineers.

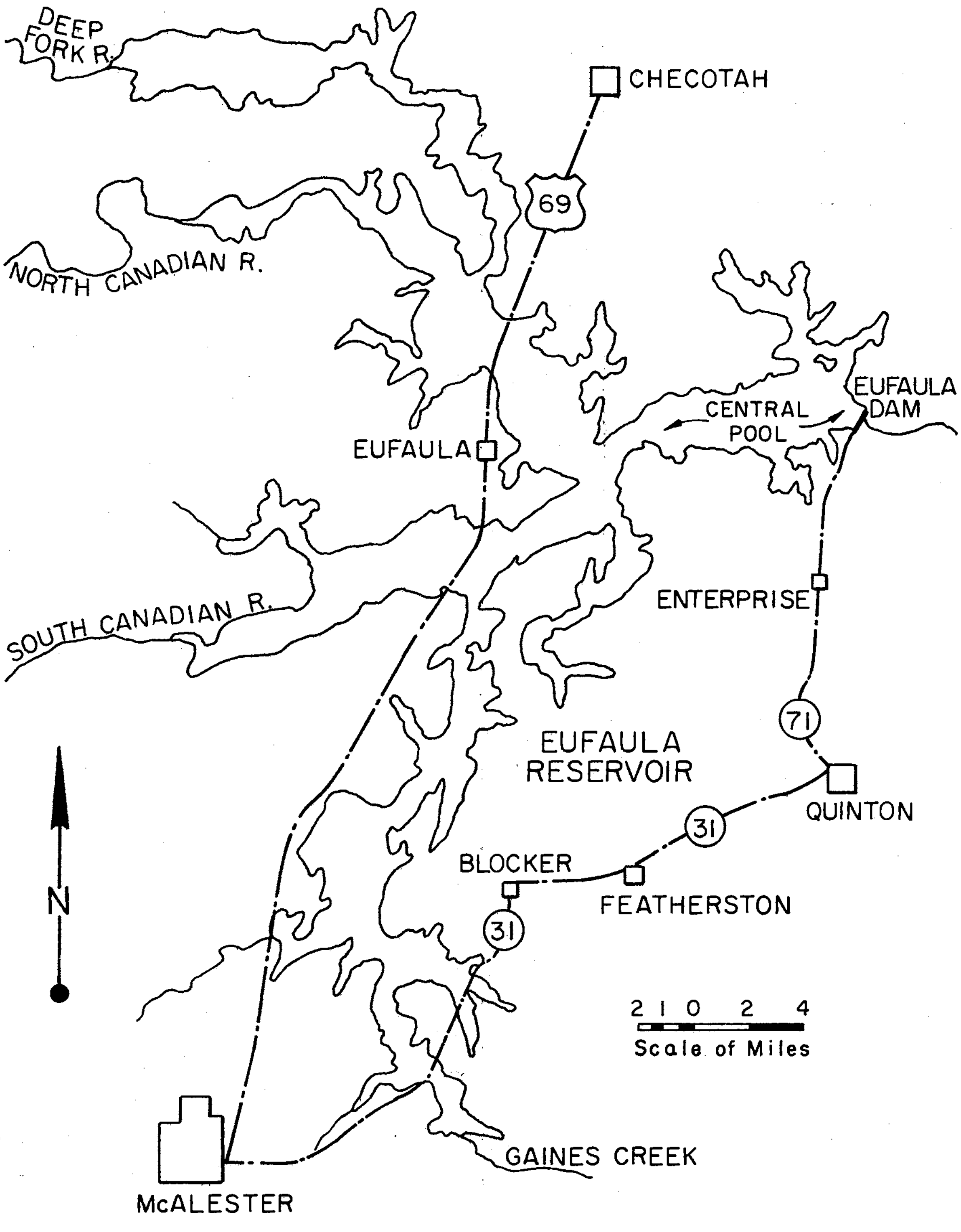

Figure 1. Area Location Map of Eufaula Lake, Oklahoma

CHAPTER II

METHODS

Four stations were established approximately 2 km apart in the central pool of Eufaula Lake (Figure 2), 4 - 6 August, 1969. All samples were taken between the hours of 1000 and 1500. At each station nine sites were specified in three rows and three columns (Figure 3). The center site was marked by a carboy bottle buoy. The other eight sites were located from the center site by using a magnetic compass and measured nylon line. Four vertical hauls were taken from the bottom to the surface at each site with a Wisconsin plankton sampler fitted with a size 20 net. Thus, a total of 36 samples were obtained from each station. The volume of water sampled was calculated by multiplying the depth of the water sampled by the area of the mouth of the net.

Three samples from each site were analyzed with the fourth held in reserve to be used if a sample were accidentally destroyed. Samples were diluted or concentrated to a specified volume and subsamples removed and analyzed in a counting chamber under a wide-field dissecting microscope (Ward, 1955; Cowell, 1967).

It has been shown that as samples are pooled, $\bar{d}$ increases rapidly at first and then approaches an asymptote (Pielou, 1966; Wilhm and Dorris, 1968; and Kochsiek, et al., 1971). Kochsiek (1971) successively pooled counts of 100 zooplankters and found that for pelagic zooplankton, a sample size of 400 provided adequate precision in estimating $\bar{d}$ with

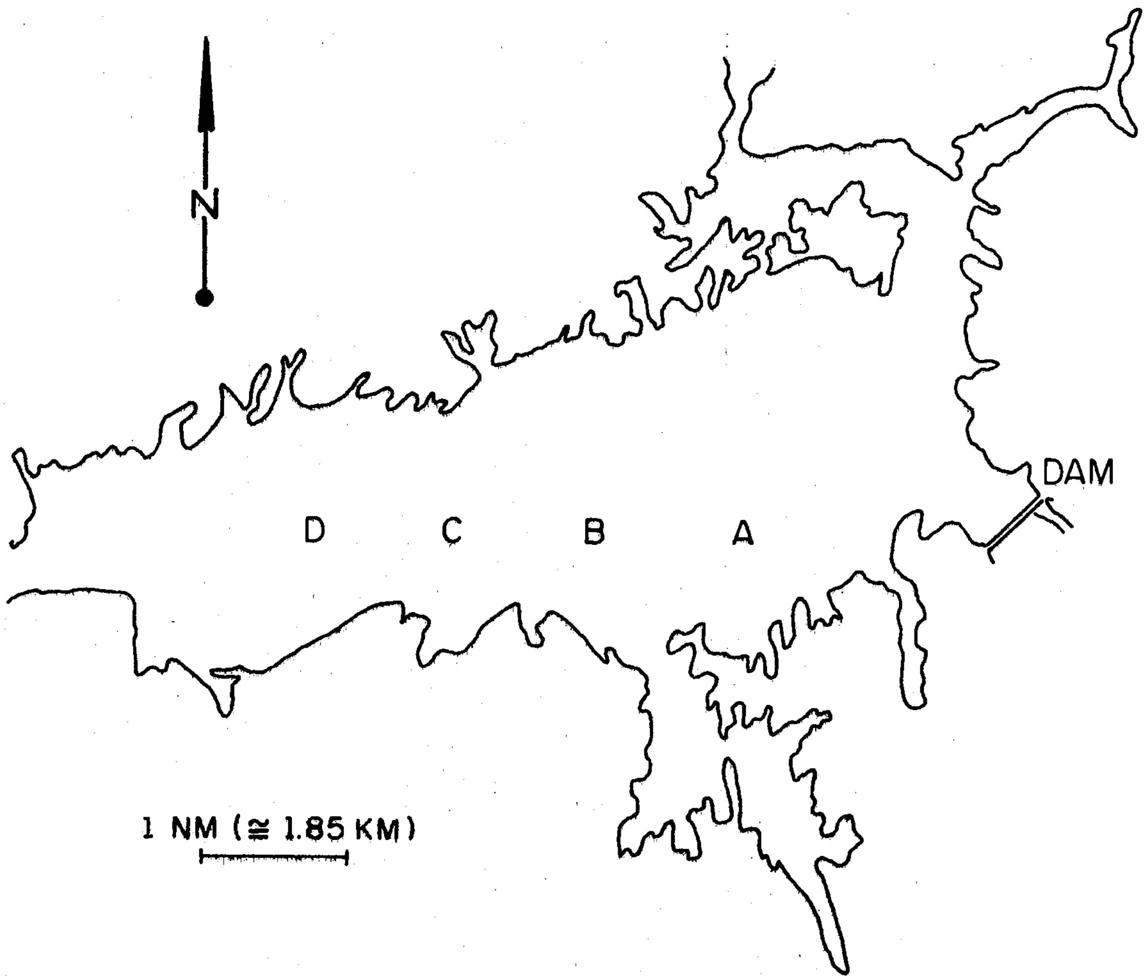

Figure 2. Shoreline Map of the Main Pool of Eufaula Lake Showing Location of Sampling Stations

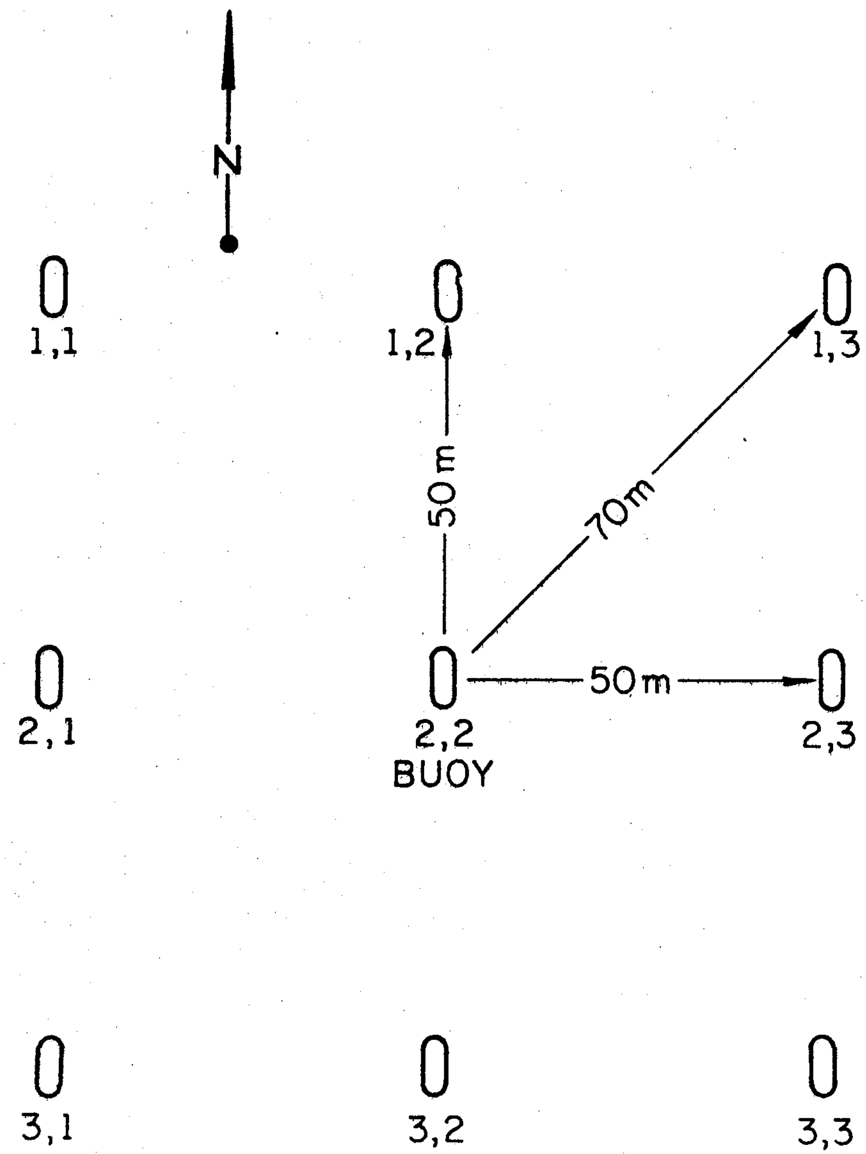

Figure 3. Diagram Showing Arrangement of Sites at Each Sampling Station

insignificant gains above 400. Cooper (1972) pooled counts of 100 to a total of 1000 and found 100 to be adequate for estimating periphyton diversity in a stream. Prather and Prophet (1968) obtained similar results on the basis of pooling 1 ml subsamples and found one subsample sufficient to estimate $\bar{d}$. In the present study, 400 zooplankters were identified to species and analyses made of number of species, number of individuals per species, and total number of individuals. Appropriate calculations were made to determine concentration and the equation derived from information theory was used to calculate species diversity.

Variation within stations was analyzed using the analysis of variance (Steel and Torrie, 1960). The F statistic was used to test the null hypothesis that $\bar{d}$ and concentration estimates are not affected by spatial heterogeneity (patchiness) of pelagic net zooplankton. The alternative was that significant variations would occur, indicating patchiness affects.

CHAPTER III

RESULTS

A total of 23 species of zooplankton were found (Table II). Occurrence of species indicates numerical dominance shared by only a few species. Nine species and immature copepoda composed approximately 99%, and five species and immature copepoda composed approximately 80%, of the total number of individuals counted. Pennak (1946) concluded, after examining data from 24 Colorado lakes and 22 lakes from other parts of the world, that most limnetic zooplankton communities are characterized at any one time by one numerically dominant species of Cladocera, Copepoda, and Rotifera.

Mean concentration estimates (Table III) of the nine most numerous species and immature copepoda ranged from less than 0.1 liter^{-1} for *Asplanchna* sp. at station B to 11.3 for immature copepoda at station A. The most abundant species were *Ceriodaphnia lacustris* with a concentration of 7.5 liter^{-1} at station D. *C. lacustris* and *Keratella valga* increased and *Polyarthra vulgaris* decreased slightly in abundance from east to west. Other speices showed less or no longitudinal variation.

Mean zooplankton concentrations in Keystone Lake in August were two to four times greater than obtained in this study (Kochsiek, 1971). Rotifers were more abundant in Keystone than in Eufaula, perhaps attributable to more stream-like conditions existing in eight of the nine stations in Keystone Lake as compared to the expansive open water

TABLE II

SPECIES LIST AND FREQUENCY OF OCCURRENCE IN THE 108 SAMPLES OF PELAGIC NET ZOOPLANKTON, MAIN POOL, EUFAULA LAKE, AUGUST, 1969

	Occurrence (max. = 108)
Cladocera	
Daphnia ambigua	1
Daphnia galeata	29
Daphnia parvula	30
Daphnia pulex	8
Diaphanasoma leuchtenbergianum	108
Ceriodaphnia lacustris	108
Bosmina longirostris	108
Copepoda	
Immature copepoda	108
Calanoida	
Diaptomus clavipes	108
Cyclopoida	
Mesocyclops edax	108
Ectocyclops phaleratus	1
Rotifera	
Keratella valga	108
Keratella longispina	1
Filinia longiseta	9
Trichocerca multicrinus	1
Trichocerca similis	24
Trichocerca longiseta	1
Hexarthra sp.	108
Asplanchna sp.	108
Platyias patulus	9
Polyarthra vulgaris	108
Kurzia latissima	1
Monostyla quadridentata	1
Coelenterata	
Craspedacusta sowerbyi	1

TABLE III

MEAN CONCENTRATIONS IN NUMBER LITER^{-1} OF PELAGIC NET ZOOPLANKTON, MAIN POOL, EUFAULA LAKE, AUGUST, 1969

	Station			
	A	B	C	D
Diaphanasoma leuchtenbergianum	2.8	2.4	3.3	2.6
Ceriodaphnia lacustris	2.8	4.7	6.0	7.5
Bosmina longirostris	0.4	0.5	0.6	0.4
Immature copepoda	11.3	6.1	11.0	10.4
Diaptomus clavipes	5.3	3.7	3.5	4.2
Mesocyclops edax	1.1	0.9	1.5	1.3
Keratella valga	0.7	0.1	2.0	2.1
Hexarthra sp.	0.2	0.1	0.3	0.4
Asplanchna sp.	0.3	< 0.1	0.3	0.2
Polyarthra vulgaris	2.6	0.5	0.5	0.2
Others	0.1	> 0.6	1.2	0.2

environment existing in the main pool of Eufaula Lake.

Estimates of $\bar{d}$ ranged from 2.16 to 2.96, within station D. Kochsiek, et al. (1971) found $\bar{d}$ values around 2.9 for zooplankton in August, 1967, in Keystone Lake, and Prather and Prophet (1969) obtained values ranging from 1.83 to 3.06 for zooplankton found during the summer of 1968 in three small lakes in Kansas (Table IV).

Variation among stations of concentration was apparent, but little variation existed among stations in $\bar{d}$ and number of species. Mean concentration ranged from 19.7 at station B to 30.2 at station C, while mean number of species ranged from 10.6 at stations A, B, and D to 11.1 at station C. Mean $\bar{d}$ ranged from 2.50 at station A to 2.54 at stations B and D. Variation of concentration within a station was greatest at station C and least at station B.

Significant variation existed at station A for $\bar{d}$ and station B for concentration (Table V). The coefficient of variation (CV) of concentration estimates ranged from 13.55% at station D to 33.54% at station A. CV for $\bar{d}$ ranged from 3.47% at station B to 11.10% at station D. The greater CV at D may have been caused by emergent tree areas. Changes in abundance of the most common species have an effect on $\bar{d}$ estimates and lowest $\bar{d}$ occurred within station D. Where variance may vary in proportion to the mean, as with plankton data, logarithmic transformations have a stabilizing influence on the variance (Cassie, 1963). The logarithmic transformation used in the equation to calculate $\bar{d}$ probably lowers the CV.

By comparing the CV for $\bar{d}$ to those of concentration it appears that more confidence may be placed on the $\bar{d}$ estimates derived from traditional sampling programs than from total concentration estimates. However,

TABLE IV

NUMBER OF SPECIES (s), TOTAL CONCENTRATION IN NUMBER LITER^{-1} (c), AND $\bar{d}$ (N = 400) AND STANDARD DEVIATIONS OF PELAGIC NET ZOOPLANKTON IN MAIN POOL OF EUFAULA LAKE, AUGUST, 1969

Station A				Station B			
Site	s	c	$\bar{d}$	Site	s	c	$\bar{d}$
1,1	11.0	28.6	2.53	1,1	10.6	24.0	2.47
1,2	10.0	35.1	2.31	1,2	11.3	21.5	2.55
1,3	9.7	22.0	2.41	1,3	11.0	15.3	2.51
2,1	11.0	20.4	2.48	2,1	10.3	25.5	2.60
2,2	11.0	24.8	2.68	2,2	10.3	20.1	2.48
2,3	11.3	28.9	2.58	2,3	10.0	17.2	2.57
3,1	10.3	29.1	2.54	3,1	10.6	18.1	2.57
3,2	10.3	36.0	2.53	3,2	11.3	18.2	2.51
3,3	11.3	24.0	2.43	3,3	10.6	17.3	2.66
$\bar{X}$	10.6	27.6	2.50	$\bar{X}$	10.6	19.7	2.54
s		9.3	0.10	s		3.0	0.09

Station C				Station D			
Site	s	c	$\bar{d}$	Site	s	c	$\bar{d}$
1,1	10.6	22.1	2.60	1,1	10.7	27.5	2.91
1,2	10.6	24.5	2.45	1,2	11.3	25.3	2.96
1,3	11.7	31.2	2.65	1,3	11.3	33.8	2.71
2,1	12.0	27.1	2.52	2,1	10.7	31.7	2.42
2,2	11.0	37.7	2.47	2,2	10.7	27.1	2.16
2,3	11.3	32.8	2.57	2,3	10.0	29.1	2.47
3,1	11.0	29.8	2.48	3,1	10.0	31.2	2.43
3,2	11.3	33.4	2.50	3,2	10.3	32.3	2.39
3,3	10.6	33.4	2.52	3,3	10.6	27.7	2.49
$\bar{X}$	11.1	30.2	2.52	$\bar{X}$	10.6	29.5	2.54
s		6.9	0.01	s		4.0	0.28

TABLE V

ANALYSIS OF VARIANCE OF $\bar{d}$ AND CONCENTRATION (c) ESTIMATES OF PELAGIC NET ZOOPLANKTON, MAIN POOL, EUFAULA LAKE, AUGUST, 1969
(α = .05)

Source of Variation	Degrees of Freedom	F_{tab}		F_{cal}			
				Station A	Station B	Station C	Station D
Total	26						
Treatments	8	2.51	$\bar{d}$	2.52	1.42	0.95	1.79
			c	1.03	2.60	1.53	1.54
Rows	2	3.55	$\bar{d}$	4.24	1.28	2.00	3.27
			c	0.72	1.78	2.65	0.36
Columns	2	3.55	$\bar{d}$	0.33	1.33	0.92	2.68
			c	1.48	6.04*	2.18	0.69
Rows x Columns	4	2.93	$\bar{d}$	2.76	1.54	0.48	0.61
			c	0.95	1.30	0.64	2.54
Error	18	CV	$\bar{d}$	4.63%	3.47%	4.61%	11.10%
			c	33.54%	18.51%	22.77%	13.55%
		SE	$\bar{d}$	.01	.02	.01	.05
			c	1.78	.71	1.32	.77

*F_{tab} (α = .01) = 6.01.

total concentration estimates seem to be derived adequately from traditional sampling programs.

Concentration of zooplankton estimates indicate fish food potential and lower trophic level abundance and $\bar{d}$ indicating the stability and relationship to perturbations within the aquatic system. Margalef (1968) relates stability in ecosystems to diversity of species, with an increase in diversity generally accompanying succession toward a more stable, climax community. After analyzing populations on benthic invertebrates it was concluded that $\bar{d}$ values of less than 1 are usually obtained in areas of heavy pollution, values of 1 to 3 in moderate pollution areas, and values exceeding 3 in clean water areas (Wilhm and Dorris, 1968). Staub, et al. (1970) results with plankton agreed with Wilhm and Dorris except they made an added division where $\bar{d}$ values between one and two were found in areas of moderate pollution and 2 to 3 in areas of light pollution. Values of $\bar{d}$ in this study ranged from 2.16 to 2.91 with a mean of 2.53.

CHAPTER IV

CONCLUSIONS

The null hypothesis, that $\bar{d}$ and concentration estimates are not affected by spatial heterogeneity (patchiness) of pelagic net zooplankton was not rejected in three of the four tests. This means that traditional sampling programs where a single site represents a station and the water mass in that area are adequate when estimating $\bar{d}$ and concentration of pelagic net zooplankton using the sampling procedures used in this study.

LITERATURE CITED

Applegate, Richard L. and James W. Mullan. 1967. Zooplankton standing crops in a new and an old Ozark reservoir. Limnol. Oceanog. 12:592-599.

Barnes, H. and S. M. Marshall. 1951. On the variability of replicate plankton samples and some application of "contagious" series to the statistical distribution of catches over restricted periods. J. Marine Biol. Assoc. U.K. 30:233-263.

Cassie, R. M. 1962. Frequency distribution models in the ecology of plankton and other organisms. Jour. Anim. Ecol. 31:65-92.

Cooper, Mickey J. 1972. Spatial and temporal variation in productivity, species diversity, and pigment diversity of periphyton in a stream receiving domestic and oil refinery effluents. Ph.D. Thesis, Okla. State Univ.

Cowell, Bruce C. 1967. The Copepoda and Cladocera of a Missouri River reservoir: a comparison of sampling in the reservoir and the discharge. Limnol. Oceanog. 12:125-136.

Cowell, Bruce C. 1970. The influence of plankton discharges from an upstream reservoir on standing crops in a Missouri River reservoir. Limnol. Oceanog. 15:427-441.

Edmondson, W. T. 1959. Methods and equipment, p. 1194-1202. In W. T. Edmondson /ed./. Freshwater biology, 2nd Ed. John Wiley and Sons, New York.

Hall, Donald J. and George G. Waterman. 1967. Zooplankton of the Finger Lakes. Limnol. Oceanog. 12:542-544.

Hammer, Theodore U. and William W. Sawchyn. 1968. Seasonal succession and congeneric associations of *Diaptomus* spp. (Copepoda) in some Saskatchewan ponds. Limnol. Oceanog. 13:476-484.

Kochsiek, Kenneth A. and Jerry L. Wilhm. 1970. Use of Shannons formula in describing spatial and temporal variation in a zooplankton community in Keystone Reservoir, Oklahoma. Proc. Okla. Acad. Sci. 49:35-42.

Kochsiek, Kenneth A., Jerry L. Wilhm, and Robert Morrison. 1971. Species diversity of net zooplankton and physiochemical conditions in Keystone Reservoir, Oklahoma. Ecology 52:1119-1125.

Margalef, R. 1956. Informacion y diveridad espicfica en las cominudades de organismos. Inv. Pesq. 3:99-106.

Margalef, R. 1968. Perspectives in ecological theory. Univ. Chicago Press.

Patton, Bernard C. 1962. Species diversity in net phytonplankton of Raritan Bay. Jour. Mar. Res. 20:57-75.

Peterka, John J. 1970. Productivity of phytoplankton and quantities of zooplankton and bottom fauna in relation to water quality of Lake Ashtabula reservoir, North Dakota. Research Project Technical Completion Report. Water Resources Research Institute, Fargo, North Dakota.

Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. Jour. Theoret. Biol. 13:131-144.

Prather, Joy E. and Carl W. Prophet. 1969. Zooplankton species diversity in John Redmond, Marion, and Council Grove Reservoirs, Kansas, summer 1968. The Emporia State Research Studies. 18:5-16.

Shannon, C. E. and W. Weaver. 1963. The mathematical theory of communication. Univ. of Illinois, Urbana.

Staub, R., J. W. Appling, A. M. Hofstetter and I. J. Haas. 1970. The effect of industrial waste of Memphis and Shelby County on primary plankton producers. Bioscience. 20:905-912.

Steel, Roger G. D. and James H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc., New York.

U. S. Army, Corps of Engineers. No date. Eufaula Lake Information Pamphlet. U. S. Army, Corps of Engineers, Tulsa District.

Ward, J. 1955. A description of a new zooplankton counter. Quart. Jour. Microscop. Sci. 96:371-373.

Wiebe, Peter H. 1970. Small scale spatial distribution in oceanic zooplankton. Limnol. Oceanog. 15:205-217.

Wiebe, Peter H. 1971. A computer model study of zooplankton patchiness and its effects on sampling error. Limnol. Oceanog. 16:29-38.

Wiebe, Peter H. and Wilham R. Holland. 1968. Plankton patchiness: effect on repeated net tows. Limnol. Oceanog. 13:315-321.

Wilhm, J. L. and T. C. Dorris. 1968. Biological parameters for water quality. Bioscience. 18:477-481.

VITA

Larry Garner Bowles

Candidate for the Degree of

Master of Science

Thesis: INFLUENCE OF SPATIAL HETEROGENEITY ON ESTIMATES OF CONCENTRATION AND SPECIES DIVERSITY OF PELAGIC NET ZOOPLANKTON

Major Field: Zoology

Biographical:

Personal Data: Born in Jay, Oklahoma, September 19, 1940, the son of Mr. and Ms. G. W. Bowles.

Education: Graduated from Webster High School, Tulsa, Oklahoma, in May, 1959; received Bachelors of Arts and Science degrees in Life-Science Education and Botany from University of Tulsa, in 1963.

Professional Experience: Fish and Game Council Fellow, 1968-70; graduate teaching assistant, Department of Zoology, Oklahoma State University, 1971; Environmental Protection Agency Trainee, 1972.