COMMUNITY STRUCTURE OF BENTHIC MACROINVERTEBRATES

AS RELATED TO TURBIDITY IN FARM PONDS

By

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PREFACE

The objectives of this study were: (1) to evaluate turbidity caused by suspended inorganic soil particles as a pollutant by analyzing the community structure of benthic macroinvertebrates using species diversity indices as well as traditional qualitative methods and (2) to establish causal relationships for the different community structures as indicated by physicochemical features, organic content of the sediments, and primary productivity estimates.

Dr. Rudolph J. Miller served as major adviser. Dr. Dale Toetz directed the research and criticized the manuscript. Dr. Calvin G. Beames, Dr. William A. Drew, and Dr. Troy C. Dorris served on the advisory committee and criticized the manuscript. Dr. Jerry L. Wilhm assisted with data recording and Nancy Norton wrote the computer program for species diversity calculations. Wayne E. Epperson, Greg Keeler, John H. Carroll, Jr. and other personnel at the Aquatic Biology Laboratory helped make field collections. The assistance of all these people is appreciated.

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CHAPTER I

INTRODUCTION

Water pollution may be defined as any alteration of water quality
which has an adverse effect upon beneficial use of water without neces-
sarily creating a public health hazard (Stroud, 1967). Polluted waters
are often detected by chemical assays, but biological methods, such as
analysis of the community structure of the benthic fauna, should also be
employed because a principal concern of many water pollution scientists
is the maintenance of diverse aquatic communities. Natural biotic com-
munities typically are characterized by the presence of a few species
with many individuals and many species with a few individuals of each
(Odum et al., 1960). Polluted environments, however, are characterized
by fewer species and often greater numbers of individuals, especially
in organically enriched environments (Gaufin and Tarzwell, 1956).

Numerous investigators have sought to associate aquatic populations
with various levels of pollutants, but their investigations have been
primarily concerned with organic pollution. Suspensions of inorganic
particulate matter are also recognized as pollutants, but information
is lacking on the direct and indirect effects of such suspensions. Tur-
bidity, which is an expression of the optical property of water, may be
caused by a variety of suspended particulate matter. The turbidity in
central Oklahoma surface waters is due primarily to suspended inorganic

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soil particles of a montmorillonite clay type (Irwin and Stevenson, 1951). These suspended particles cause light rays to be scattered and absorbed rather than transmitted in a straight line and may exert an indirect effect on the aquatic environment through light exclusion (Bartsch, 1960).

Macroinvertebrates serve as a useful tool in detection of pollution and retain their sensitivity down to levels at which other methods of evaluation cease to be useful (Hynes, 1963). Benthic macroinvertebrates are relatively immobile, have aquatic stages lasting long enough to develop complex faunal associations, and serve as natural monitors of environmental conditions. The use of these organisms as indicators of pollution has led to considerable confusion because of the limited range of certain species, because different types of pollutants may have varied effects on the same species (Gaufin, 1958), and because some organisms found in abundance in polluted water may also be found in reduced numbers in unpolluted water (Gaufin and Tarzwell, 1952).

The total assemblage or community structure of benthic macroinvertebrates provides a more reliable evaluation method of environmental conditions than mere occurrence of specific species. Community structure has been analyzed in terms of species frequency, spatial distribution of individuals, numerical abundance of species and diversity indices (Hairston, 1959). Diversity indices are mathematical expressions which describe a ratio between the number of species and numbers of individuals or biomass within a biotic community. Analyzing community structure by species diversity indices eliminates awkward, detailed lists of species or associations of species and summarizes large amounts of data on the abundance of the taxa represented in the

community. The indices are also valid indicators of changes and differences in community structure (Patten, 1962; Mathis, 1965; Wilhm and Dorris, 1966; Harrel, 1966; Ransom, 1969).

Theoretically, diversity of species in a natural environment lies between two extremes. A maximum diversity exists when all individuals belong to separate species and a minimum diversity exists when all individuals belong to the same species. Margalef (1956) derived an index of species diversity from information theory. Information theory does not attempt to explain observed phenomena but provides the amount of information required to explain them (Hairston, 1959). Diversity and uncertainty are equated regarding individuals and species selected at random from a community (Margalef, 1961). For example, a community with relatively equal numbers of individuals belonging to different species has a greater uncertainty, i.e., a greater diversity. A community with unequal abundance among species reflects less uncertainty, i.e., less diversity.

Wilhm and Dorris (1968) stressed that certain requisites should be met when selecting an index. The index must be independent of sample size, since with increasing sample size, the number of individuals increases considerably faster than the number of species; it must express the relative importance of different species because the compositional wealth of the same species in different areas may be heterogeneous; and it must be dimensionless when using biomass units instead of numbers of individuals. If the latter condition is not met, the values generated will depend upon the arbitrary choice of weight units.

Wilhm (personal communication) concluded that Patten's (1962) equations met the criteria of Wilhm and Dorris (1968) better than other

commonly used diversity equations and were effective indices. Community diversity, diversity per individual and redundancy can be calculated using Patten's equations. Diversity per individual reflects the compositional richness of mixed species aggregations of organisms, while redundancy expresses the dominance of one or more species. The latter is inversely proportional to the wealth of the species within a community.

The present study evaluates turbidity as a pollutant by analyzing the community structure of benthic macroinvertebrates in four farm ponds with different levels of turbidity. Community structure was subjected to traditional qualitative methods and summarized by species diversity indices of Patten, which were derived from information theory. It will be shown that the primary consequence of pollution by suspended inorganic soil particles was the elimination of aquatic plants and secondarily, the reduction of the benthic fauna diversity.

CHAPTER II

PROCEDURES

Physicochemical

Physicochemical data were obtained for the surface waters of the

ponds studied from June, 1966 through May, 1967. (See Chapter III for

a description of the ponds.) The water level of each pond, relative to

the spillway level, was measured with a permanet guage. Precipitation

data were obtained from records of the U. S. Weather Station at

Stillwater, Oklahoma. Conductivity was measured with a Hellige compa-

rator. Phenolphthalein and methyl orange alkalinity of the pond water

were ascertained by standard methods (APHA, 1960). In February, 1968,

five randomly selected sediment samples were collected from each pond,

using an ooze sucker designed by Moore (1939), and the organic content

was determined by the Oklahoma State University Agricultural Extension

Service, using a chromic acid oxidation technique.

Dissolved oxygen concentration of the ponds was determined at three

hour intervals for a period of 24 hours on August 17 and 18, 1966, and

June 30 and July 1, 1967, with a Galvanic Cell Oxygen Analyzer and at-

tached thermistor (Precision Instruments Company). Photosynthetic pro-

ductivity, community respiration and diffusion rates were then calcu-

lated by construction of 24 hour rate-of-change curves (Odum and Hoskin,

1958; Copeland, 1961).

Turbidity was the main criterion in selection of the ponds. Al-
though they were in the same vicinity, the ponds displayed different
but relatively constant transparency levels prior to the study. While
turbidity is often expressed gravimetrically (ppm), it is not truly a
measure of the suspended matter, but rather an expression of the optical
property of the water (Bartsch, 1960). Therefore, turbidity was measured
with a Bausch and Lomb Spectronic 20 colorimeter and was expressed as
per cent transmission at 450 mμ. The volume and surface area of each
pond were calculated monthly. The area of the drainage basin of each
pond was estimated from aerial photographs and field observations.

Biological

Benthic samples were taken approximately every two weeks from June
through October, 1966. Monthly samples were obtained from the latter
date through May, 1967. Samples were not taken during December, 1966,
because of extensive ice cover. Gridded maps of each pond were used to
randomly choose eight benthic sample stations before going to the field.
Two Ekman dredge samples were obtained from each of the eight selected
areas. Samples were seived (0.42 mm openings) in the field, and remain-
ing debris and organisms were preserved in 10% formalin. Additional
washing and sorting by hand were accomplished in the laboratory, and
the organisms were preserved in 80% isopropyl alcohol.

Mean ash-free weights were determined for all species. Organisms
such as Odonata, which varied considerably in size, were weighed on a
monthly basis for each pond. Mean seasonal weights were determined for
such organisms with less size variation, and annual mean weights were
calculated for organisms of sparse abundance (e.g., most dipterans).

Known quantities of each species were dried at 90 C for 24 hours in tared crucibles and then weighed again to determine the dry weight. The dried organisms were burned in a muffle furnace at 600 C for two hours. After cooling in a dessicator, the crucibles were reweighed to obtain the ash weight. The ash-free weight (organic content) has been expressed as mean annual biomass per meter square for each species collected (Table IV).

Species Diversity

The species diversity models employed (Patten, 1962) estimate community structure in terms of species diversity (d), diversity per individual ($\bar{d}$), a theoretical maximum diversity ($\bar{d}_{max}$), a theoretical minimum diversity ($\bar{d}_{min}$), and redundancy (r) where n is the total number of individuals in the sample, n_i is the number of individuals of species i, and s is the number of species. When applying the indices to biomass, n is replaced by w (the sample weight), and w_i becomes the sample weight of the ith species. The equations used to make the calculations are set out below.

$$d = -\sum n_i \log_2 n_i / n$$

$$\bar{d} = -\sum (n_i/n) \log_2 (n_i/n)$$

$$\bar{d}_{max} = (1/n) \left[\log_2 n! - s \log_2 (n/s)! \right]$$

$$\bar{d}_{min} = (1/n) \left\{ \log_2 n! - \log_2 \left[n-(-1) \right]! \right\}$$

$$r = \frac{\bar{d}_{max} - \bar{d}}{\bar{d}_{max} - \bar{d}_{min}}$$

CHAPTER III

TURBIDITY AS A POLLUTANT

Morphoedaphic Features and Range Practice

The four ponds investigated are located in Payne County, Oklahoma,

approximately eight miles north of Stillwater. The ponds are referred

to as Ponds A, B, C, and D and are all located in Range 2E, Township

20N, with A in Section 5, B in Section 7, C in Section 8, and D in Sec-

tion 4. The greatest distance between any two ponds is 3.5 kilometers.

The turbidity levels of the four ponds may have been governed by

several factors. All of the following factors probably influenced the

water transparency: rainfall and runoff rate, condition of the vege-

tation in the watershed, drainage basin size, ionic concentration, ex-

tent of aquatic macrophyte abundance, wave action, and roiling by live-

stock.

Buck (1956) arbitrarily grouped turbid waters into three categories.

Those with less than 25 ppm particulate solids were "clear," those with

25-100 ppm were "intermediate," and those greater than 100 ppm were

"muddy." Using this classification and calibrating per cent transmis-

sion against a Jackson turbidimeter, Pond A with an annual mean trans-

mission of 90% (13 ppm) would be "clear" (Fig. 1, Table I). Ponds C

and D were continually "muddy," with annual values of 11% and 0% trans-

mission (261 ppm and > 310 ppm) recorded. Pond C values ranged from 0%

to 18% but were relatively steady from September to March. Pond D was

TABLE I

OBSERVED VALUES OF PER CENT LIGHT TRANSMISSION OF SURFACE WATERS OF FOUR FARM PONDS
AND THE MORPHOMETRY AND WATERSHEDS OF RESPECTIVE PONDS

Pond	A	B	C	D
Per Cent Transmission				
Mean	90	34	11	0
Range	72-98	2-56	0-18	none
Surface Area (ha)				
Mean	0.225	0.209	0.406	0.405
Range	0.195-0.310	0.152-0.351	0.308-0.697	0.303-0.608
Volume (m^3)				
Mean	3096	2698	8862	3370
Range	2650-4461	1800-4691	2706-4765	2162-5974
Depth (m)				
Maximum	3.53	3.68	3.23	2.26
Mean	1.38	1.29	1.17	0.83
Drainage Area (ha)	0.9	4.0	17.0	1.9
Drainage Area/Spillway Volume				
Ratio	2.02	8.53	19.02	3.18
Axis Direction	NE-SW	NNE-SSW	NNW-SSE	N-S
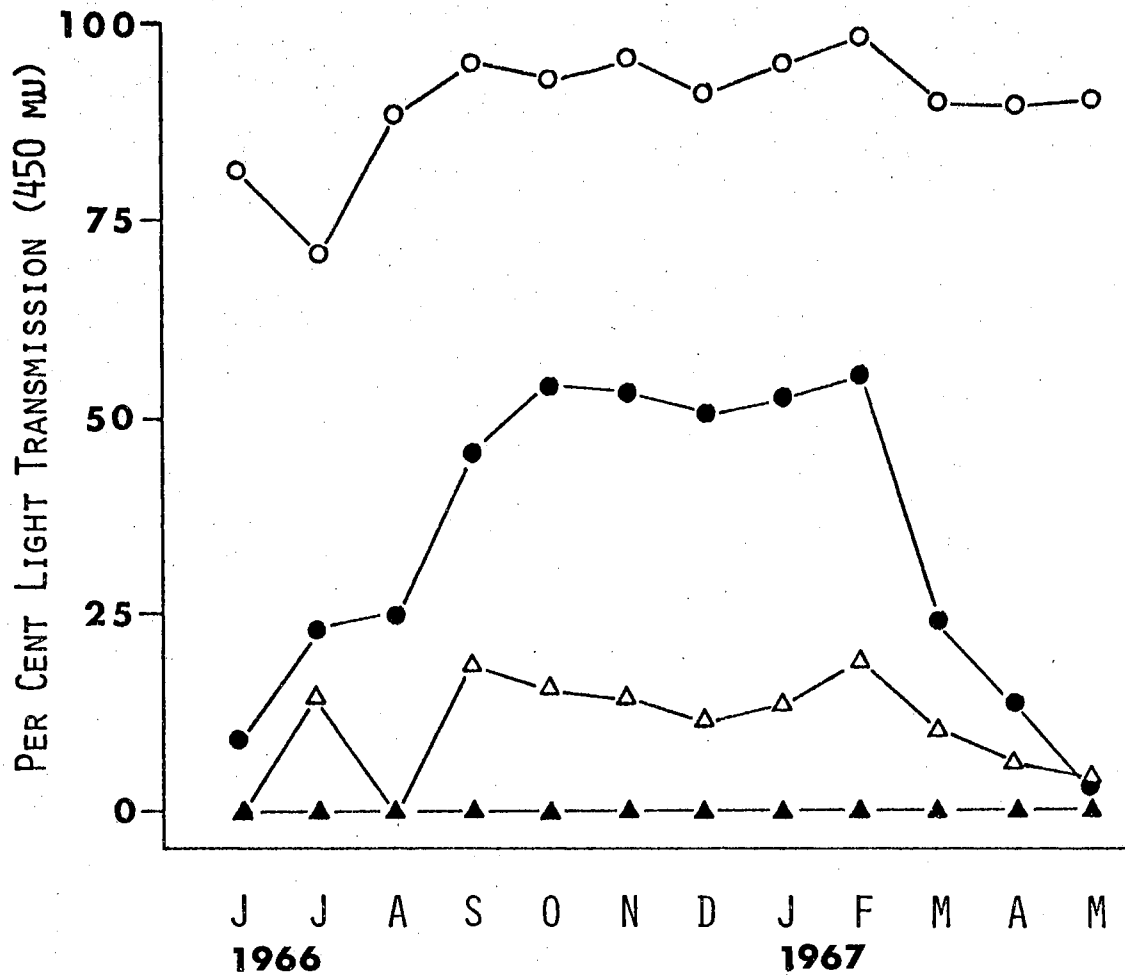
Figure 1. Monthly Variation of Per Cent Light Transmission. Pond
A-open circle; Pond B-closed circle; Pond C-open tri-
angle; Pond D-closed triangle.

never greater than 0% light transmission for the entire study period.

Turbidity of Pond B was "intermediate" during the period from October

to February, but the annual mean turbidity was considered "muddy" for

the entire study period.

Over one-half of the annual rainfall, 78.99 cm, fell during June

and July, 1966, and in May, 1967 (Fig. 2). Less than one cm fell in

November and February. Water levels of the ponds responded to the

Figure 2. Monthly Variation of Volume and Surface
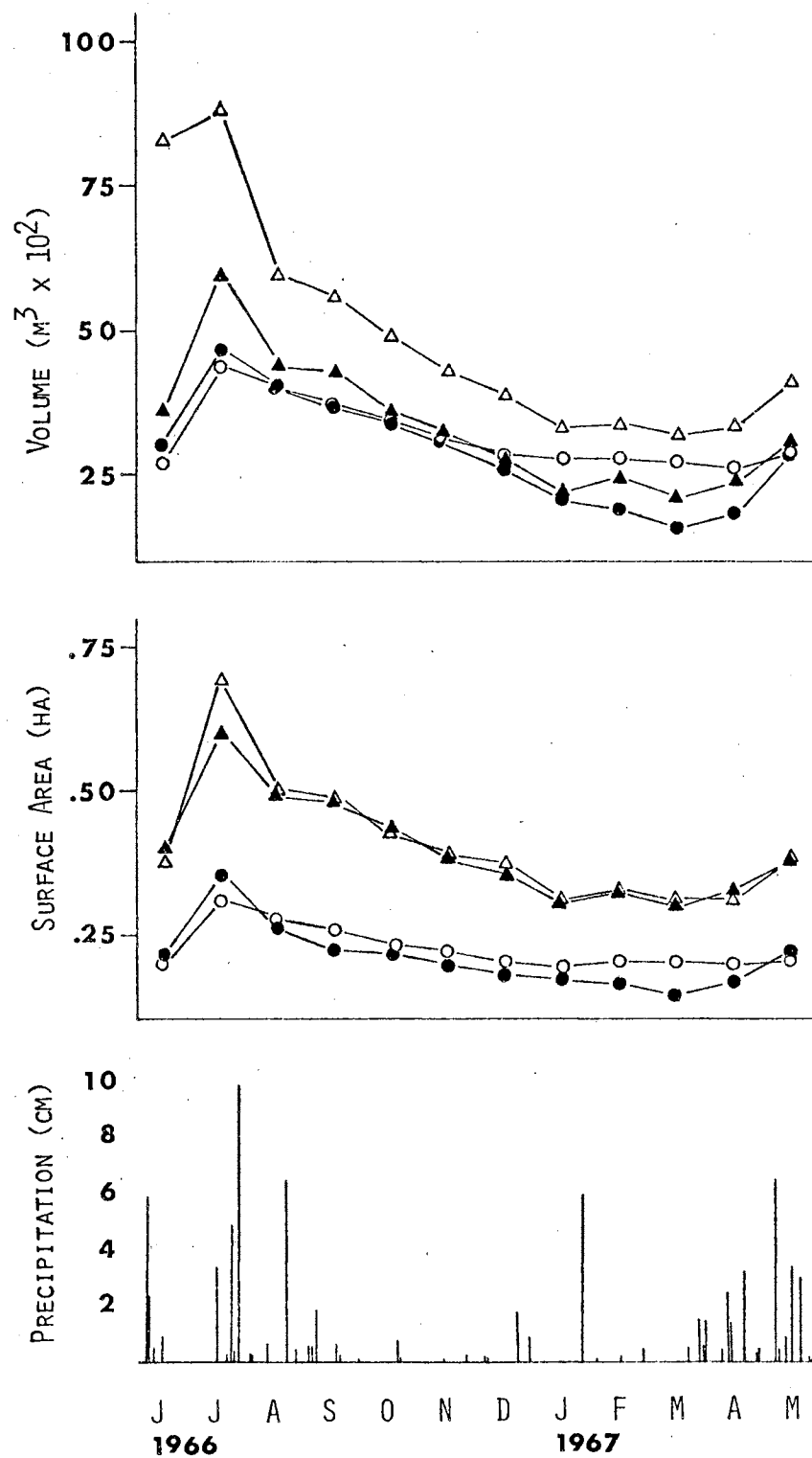Area and Daily Precipitation. Pond A-
open circle; Pond B-closed circle; Pond
C-open triangle; Pond D-closed triangle.

amount of precipitation and evaporation. During July, Ponds A, B, and D reached the spillway level, and Pond C contained its maximum volume. Water levels in all ponds receded during late summer, fall and winter but increased with the abundant rainfall of spring. Pond B exhibited the greatest reduction in volume during the period between August and March because the landowner intermittently pumped water from the pond.

Cattle had access to all pasture land in the watersheds of all ponds. The extent of grazing was reflected in the condition of vegetation, which in turn appeared to reflect some relation to turbidity. The principal grasses of the watersheds of Ponds A, B, and C were Andropogon gerardi and A. scoparius. The condition of the vegetation in these pastures was variable. Only best plants were grazed in the basin of Pond A ("light"). Grazing in the drainage basins of Ponds B and C was "close" (completely covered, with some repetition of grazing and some use of low-value plants). The principal grasses in the watershed of Pond D included Cynodon dactylon, Andropogon saccharoides, Aristida oligantha, and Buchloe dactyloides. The presence of the latter two grasses indicated overgrazing. The general condition of the vegetation in the basin was "severe" (hedged appearance and trampling damage with primary forage plants almost completely used and low-value plants carrying the grazing load). Pond D also received some drainage from a cultivated field, and Pond C drainage area included an unpaved road. Esmey et al., (1955) found that ponds in well-grazed watersheds were more turbid than those in cultivated or pastured areas, but Irwin (1945) reported that turbid conditions existed when overgrazed and/or cultivated fields were included in the drainage basin. Turbidity of the ponds, as related to condition of the watershed in this study, appear

to be in agreement with the findings of Irwin.

The size of the drainage basin did not appear to influence turbidity, Ponds A and D had small drainage areas (0.9 and 1.9 ha, respectively) but represented the two extremes in transparency (90% and 0%) (Table I). Willrich (1961) suggested that the ratio of watershed area to pond storage capacity affected turbidity, i.e., the smaller the ratio, the lower the turbidity. The same conclusion cannot be drawn for the ponds investigated. The watershed-spillway capacity ratio of Pond D was only slightly larger than A and considerably smaller than B and C, yet Pond D had the highest levels of turbidity (Table I).

The axes of all ponds approximated a north-south orientation; hence, wind direction would not tend to favor any one pond. Turbulence caused by wind tends to keep the soil particles in suspension, especially when the bottom sediments are disturbed by wave action. Pond A was located in a ravine which protected it from the wind on two sides, but other ponds were unprotected. Pond D probably was affected most by wave disturbance because of its shallowness.

Livestock access to the ponds inevitably affected the turbidity. Hall (1959) stated that many potentially clear ponds have been made turbid by cattle usage. The extent to which the cattle influenced turbidity is unknown since all the ponds were used by cattle. However, since the volume of water in Pond B was reduced considerably because water was pumped from it, excessive roiling may have occurred and may have influenced transparency to a greater degree in comparison to other ponds.

Conductivity

Generally, conductivity was directly related to light transmission of the surface waters (Figs. 1 and 3). Addition of various ions to turbid waters has been known to aid in flocculation of clay particles (Esmey et al., 1955; Keeton, 1959; Mathis, 1965; Harrel, 1966). Pond A had a mean annual concentration of 481 micromhos/cm with lesser concentrations in the other ponds. Pond B was intermediate between Ponds A and C (259 micromhos/cm). Conductivity in Ponds C and D was similar with annual means of 146 and 136 micromhos/cm, respectively. Concentration of ions due to evaporation and reduced dilution by runoff water may have been important in settling clay particles and may explain the increased transparencies between August and March (Fig. 3).

Probable Clearing Mechanisms

The growth of aquatic macrophytes is governed largely by the depth of effective light penetration and extent of fluctuation of the water levels (Welch, 1952). Aquatic macrophytes were abundant in Pond A throughout the study period and included Potamogeton sp., Najas guadalupensis, and Ceratophyllum demersium. Although a sparse population of Potamogeton sp. was present in Pond B prior to the investigation, it disappeared after the rise in water level during July. Ponds C and D contained no rooted aquatic plants.

Macrophytes may serve indirectly to aid in settling out soil particles in suspension. Irwin (1945) observed that if aquatic vegetation developed in a new impoundment, the water remained clear. Macrophytes may act as natural clay precipitating agents through photosynthetic activity which is reflected in forms of alkalinity and hydrogen ion
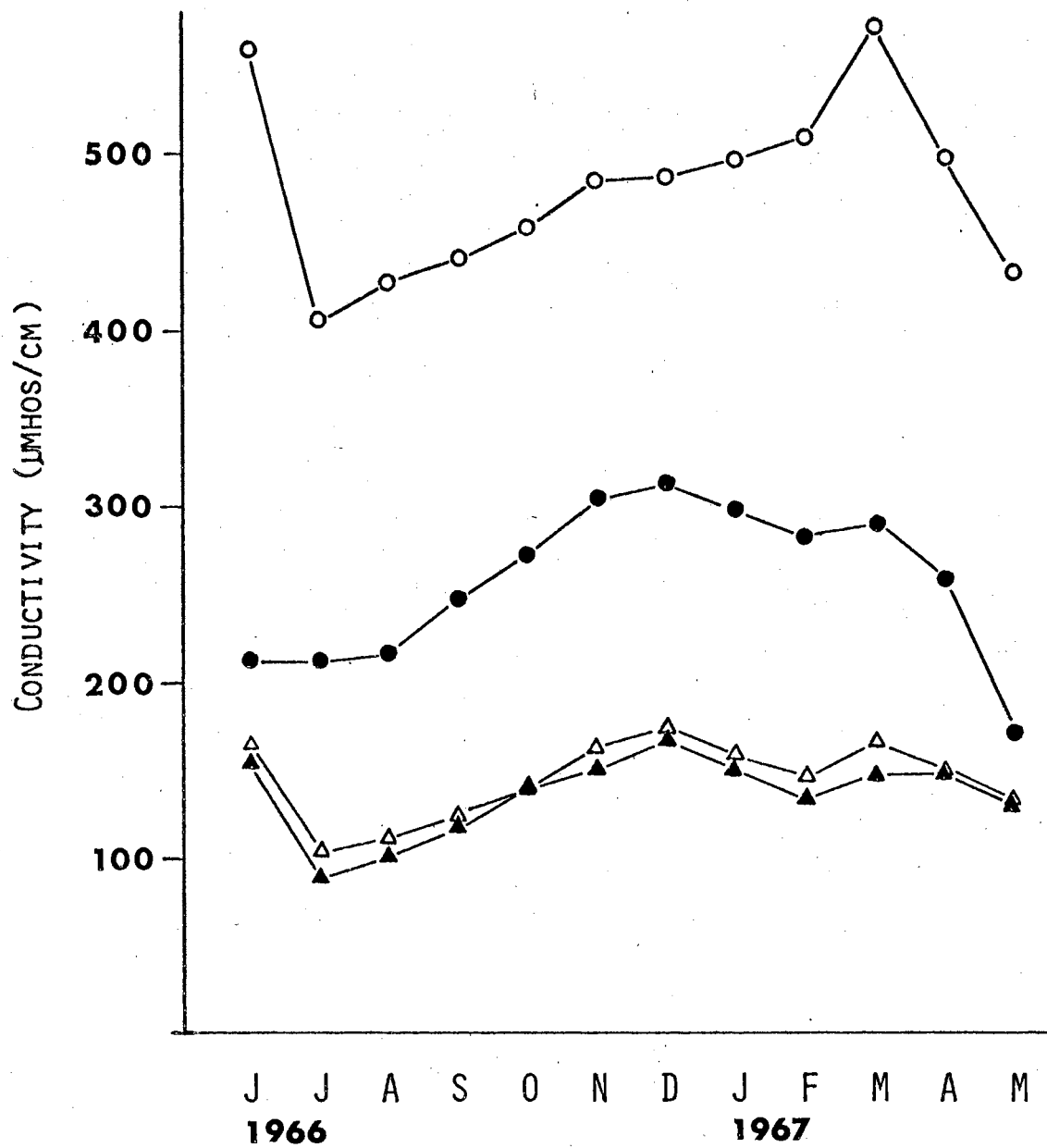
Figure 3. Monthly Variation of Conductivity. Pond A-open circle; Pond B-closed circle; Pond C-open triangle; Pond D-closed triangle.

concentration. An irregular and high pH was observed in Pond A, which also had an abundance of aquatic vegetation (Fig. 4). The relatively high pH values in Pond A during the fall coincided with a relative reduction of bicarbonates and an increase of carbonates. Aquatic plants can use bicarbonates as a carbon source for photosynthesis when carbon dioxide is limiting (Ruttner, 1965). The persistence of carbonates in the pond also indicated the absence of free carbon dioxide; hence, the bicarbonates were probably used as a carbon source for photosynthesis in Pond A. Increased hydroxyl ions may combine with multivalent cations to form a hydroxide which neutralizes the charge on such negative colloids as turbidity particles, causing them to agglomerate (V. Knudson, personal communication). Although the mechanism responsible for the flocculation of soil particles is not clearly understood, the effects of high pH and hydroxide may be instrumental in precipitating suspended particles. Thus, aquatic macrophytes may have acted indirectly as a natural clearing system.

Fluctuation of the water level was greater in the more turbid ponds (Fig. 2) which had little or no aquatic vegetation. The latter factor may have accounted for lower variability of bicarbonates and pH. The lack of carbonates in these ponds was also reflected in the lower pH values; therefore, the natural clearing agent found in Pond A appeared to be lacking in the more turbid ponds.

Turbidity levels appeared to be determined by the amount of clay entering the ponds by runoff, the extent of roiling by cattle, and the amount of wave action. Flocculation of the clay particles in suspension appeared to depend upon the amount of available cations and hydroxyl ions, the latter of which was absent in Ponds B, C, and D.
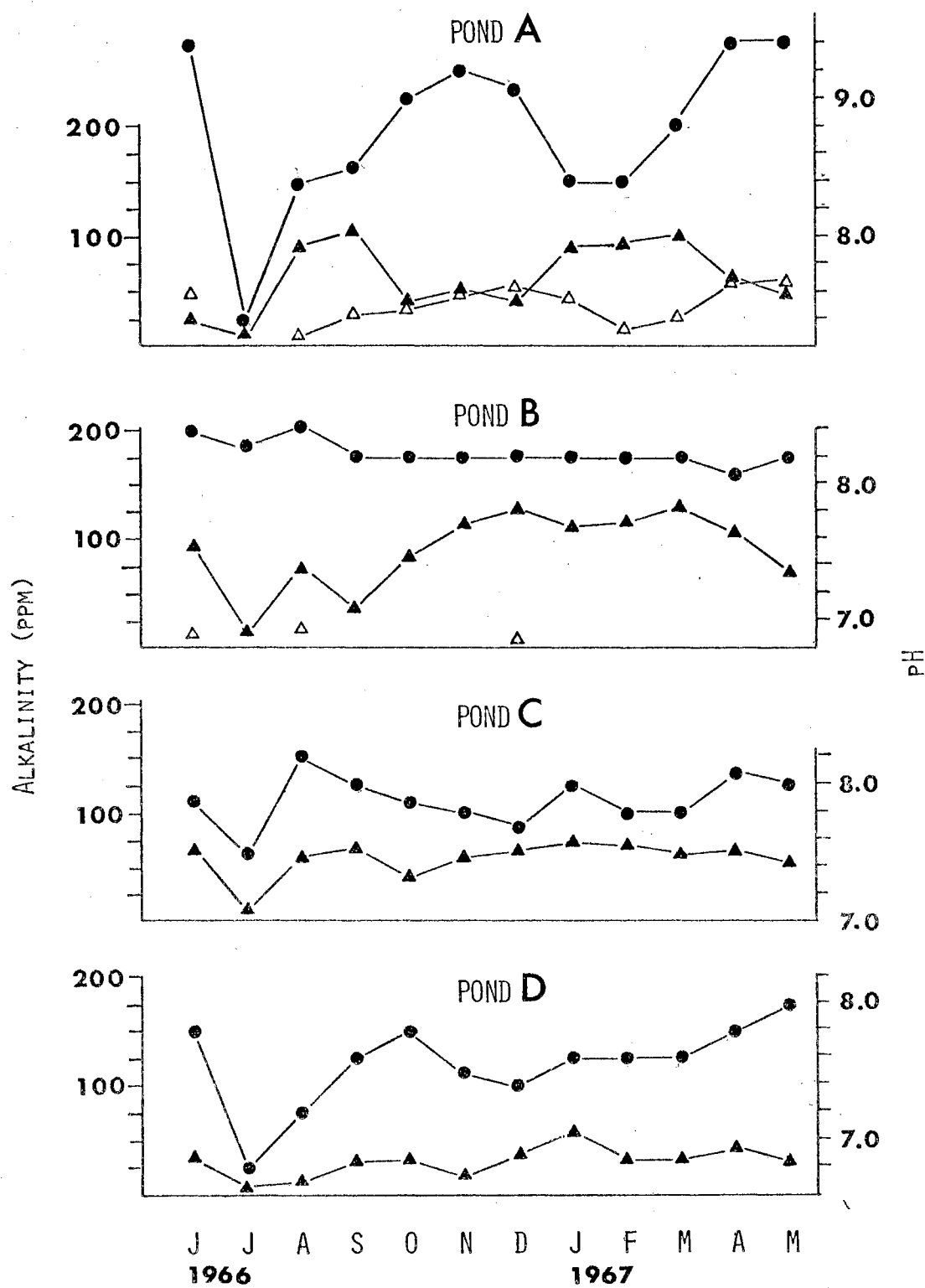
Figure 4. Monthly Variation of pH, Bicarbonates, and Carbonates.
pH-closed circles; bicarbonates-closed triangles;
carbonates-open triangles.

Sources of Environmental Stress in the Ponds

Odum (1956) classified communities into autotrophic and hetero-
trophic types. An autotrophic community yields a P/R ratio greater than
one (i.e., productivity exceeds respiration), while a heterotrophic com-
munity exhibits a P/R ratio less than one (i.e., respiration exceeds
productivity). Ponds with continuous organic enrichment have a photo-
synthetic rate often exceeding 20 g O_2/m^2/day (Bartsch and Allum, 1957;
Copeland, 1963), but respiration is also usually high and the P/R ratio
is low, especially during spring and summer (Copeland and Dorris, 1962).

The photosynthetic rates and P/R ratios in the ponds investigated
were directly related to the transparency of the water (Table II).
Oxygen production ranged from 2.10 to 4.46 g O_2/m^2/day in Ponds B, C,
and D, which were turbid, and 3.28 to 7.11 g O_2/m^2/day in Pond A, which
was clear. Butler (1964) reported similar values of 0.3 to 4.9
g O_2/m^2/day in turbid farm ponds and 5.1 to 16.1 g O_2/m^2/day in clear
ponds. The higher P/R ratio in Pond A (1.12 and 1.20) indicates that
Pond A is an autotrophic community while the other ponds with P/R < 1
are heterotrophic. The P/R ratios in heterotrophic ponds were a result
of decreased euphotic zone for photosynthesis rather than excessively
high respiration rates, which are typical of organically enriched en-
vironments.

Concentrations of organic matter in the sediment were inversely re-
lated to turbidity. The greatest mean organic content was found in
Pond D (2.69%) with 1.99, 1.84, and 1.78% of dry sediment recorded for
C, B, and A, respectively. The organic content of the bottom sediments
of the four ponds were within the average range of values reported in
Midwestern reservoirs in which chromic acid oxidation procedures were

TABLE II

COMMUNITY METABOLISM AND LIGHT TRANSMISSION IN FOUR FARM PONDS

Pond	Gross Productivity $g\ O_2/m^2/day$	Community Respiration $g\ O_2/m^2/day$	P/R Ratio	Per Cent Transmission $(450\ m\mu)$
		August 17-18, 1966		
A	7.11	6.34	1.12	92
B	2.81	2.93	0.96	25
C	2.48	3.05	0.82	0
D	4.46	5.06	0.88	0
		June 30 - July 1, 1967		
A	3.28	2.73	1.20	90
B	3.92	15.79	0.25	2
C	2.65	6.56	0.40	4
D	2.10	9.06	0.23	0

employed (Larson et al., 1951; Larson et al., 1951; Stall et al., 1951, 1952, 1953, 1954; Stall and Melsted, 1951; Norton, 1968). The mean organic content found by these investigators was 0.79 to 3.05% of the dry sediment. Although the observed concentrations of organic matter of the sediments in the ponds may not be indicative of the true mean annual content because samples were secured only in February, 1968, no pond appeared to exhibit excessive organic enrichment.

Analyses of the productivity, sediment organic content, and physicochemical conditions indicated that the primary variable causing stress in the ponds was suspended soil particles. The effect of this pollutant on the bottom fauna was indirect, and a description of its magnitude is given below.

CHAPTER IV

COMMUNITY STRUCTURE OF BENTHIC MACROINVERTEBRATES

AS RELATED TO TURBIDITY

Species Collected

A total of 50 species of benthic macroinvertebrates was collected
from all ponds during the study period. Forty-four species were col-
lected from Pond A, 40 from B, 34 from C, and 29 from D. The range of
the number of species taken at any sampling date was more narrow, and
the annual mean number of species was lower in the more turbid ponds
(Table III). Seasonal differences in the number of species showed
similar trends (Fig. 5).

Although the number of species collected was inversely related to
turbidity, most of the species were common to two or more of the ponds.
Species collected exclusively from Pond A included three odonates, one
coleopteran, and four dipterans, while species unique to Pond B were one
nematode, two oligochaetes, and one dipteran. All species found in C
and D were also present in either A or B or both (Table IV).

Seasonal Changes in Numbers and Biomass of Benthic Fauna

The seasonal and annual mean numbers of individuals and the biomass
of the benthic macroinvertebrates were similarly associated with tur-
bidity. Maximal number of individuals and the greatest biomass occurred
in Pond A (least turbid), and the minimal numerical abundance of

TABLE III

ANNUAL MEAN VALUES AND RANGES OF THE NUMBER OF SPECIES, INDIVIDUALS,
AND BIOMASS OF ORGANISMS COLLECTED FROM FOUR FARM PONDS

Pond	A	B	C	D
MEAN NUMBER OF SPECIES	22	14	13	10
Range	(9-26)	(7-21)	(5-18)	(5-18)
MEAN NUMBER OF INDIVIDUALS/m^2	1519	607	1032	435
Range	(266-4804)	(113-1344)	(532-2562)	(20-1035)
MEAN BIOMASS mg/m^2	821	423	460	205
Range	(139-1541)	(90-794)	(231-1260)	(65-501)

TABLE IV

MEAN ANNUAL NUMBER OF INDIVIDUALS AND BIOMASS OF BENTHIC MACROINVERTEBRATES

Taxon	Individuals/m^2 Pond				Biomass (mg/m^2) Pond				Taxon	Individuals/m^2 Pond				Biomass (mg/m^2) Pond			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
NEMATODA	NC*	P*	NC	NC		0.01			DIPTERA	894	76	634	27	139.87	13.74	80.51	5.35
OLIGOCHAETA	114	21	3	229	31.34	2.14	0.91	63.62	CERATOPOGONIDAE								
Branchiura sowerbyi	NC	P	NC	NC		0.12			Palpomyia sp.	43	2	9	3	16.01	0.90	3.55	1.60
Dero sp.	76	16	NC	1	4.64	0.90		0.03	CULICIDAE								
Limnodrilus sp.	36	4	3	228	26.70	1.10	0.91	63.59	Chaoborus punctipennis	693	13	578	2	79.15	1.81	68.31	0.24
Nais sp.	NC	P	NC	NC		0.02			TABANIDAE								
CRUSTACEA									Chrysops sp.	9	NC	NC	NC	24.08			
Hyalella azteca	209	2	1	4	31.40	0.20	0.14	0.51	TENDIPEDIDAE	149	61	27	22	20.63	11.03	8.65	3.51
EPHEMEROPTERA	133	488	307	135	187.42	323.09	290.15	85.16	Calospectra sp.	54	1	NC	NC	4.15	0.06		
Caenis sp.	35	4	1	P	5.74	0.89	0.12	0.08	Clintotanypus sp.	2	2	2	P	0.30	0.49	0.29	0.03
Callibaetis sp.	7	P	P	P	3.24	0.08	0.08	0.17	Coelotanypus sp.	11	11	10	1	3.51	3.24	2.98	0.40
Hexagenia limbata	91	484	306	134	178.44	322.12	289.95	84.91	Cryptochironomus sp.	P	4	1	1	0.02	0.53	0.10	0.17
ODONATA	61	5	3	4	282.75	34.57	9.71	39.29	Dicrotendipes sp.	3	5	1	2	0.40	0.73	0.15	0.28
Argia sp.	P	P	NC	NC	0.06	1.56			Endochironomus sp.	1	1	P	NC	0.06	0.08	0.06	
Enallagma sp.	20	NC	NC	NC	20.39				Glyptotendipes sp.	1	2	1	1	0.01	0.03	0.06	0.01
Epicordula sp.	6	2	1	P	79.42	1.75	0.87	2.55	Metirocnemus sp.	P	4	3	NC	0.04	0.52	0.38	
Gomphus sp.	7	2	1	3	71.25	31.06	8.02	35.74	Paralauter borniella sp.	1	1	P	NC	0.09	0.08	0.02	
Ischnura sp.	15	NC	1	1	25.83		0.82	1.00	Pelopia sp.	23	NC	2	P	4.34		0.36	0.07
Libellula sp.	12	NC	NC	NC	82.05				Pentanura sp.	7	14	12	2	1.33	2.38	2.22	0.41
Macromia sp.	P	P	NC	NC	3.55	0.20			Polypedium sp.	P	2	1	2	0.04	0.64	0.09	0.26
Pachydiplax longipennis	P	NC	NC	NC	0.20				Procladius sp.	19	4	9	6	1.97	0.52	1.11	0.74
NEUROPTERA									Pseudotendipes	NC	P	NC	NC		0.05		
Sialis sp.	P	7	22	10	0.22	8.15	24.16	8.80	Stenochironomus sp.	P	3	P	1	0.05	0.46	0.06	0.23
TRICHOPTERA	4	1	P	P	3.03	0.74	0.11	0.11	Stictochironomus sp.	2	2	2	4	0.30	0.44	0.35	0.76
Oecetis sp.	3	P	P	P	1.17	0.11	0.11	0.11	Tendipes nr. attenuatus	2	2	1	P	0.23	0.23	0.13	0.04
Psychomyia sp.	1	P	NC	NC	1.86	0.63			Tendipes plumosus	20	3	2	1	3.76	0.55	0.29	0.11
COLEOPTERA	39	1	P	2	31.02	1.28	0.27	0.91	Tendipes (Einfeldia) sp.	P	NC	NC	NC	0.01			
Agabus sp.	P	NC	NC	P	0.15			0.15	Tendipes sp.	P	NC	NC	NC	0.02			
Berosus striatus	15	P	P	2	12.08	0.10	0.27	0.76	MOLLUSCA	68	3	56	P	112.00	2.48	54.20	0.21
Halipus sp.	2	NC	NC	NC	2.19				Gyraulus sp.	1	1	NC	NC	0.10	0.02		
Hydrophorus sp.	22	1	NC	NC	16.60	1.18			Physa sp.	67	1	P	P	111.90	1.47	0.93	0.21
									Sphaerium sp.	NC	1	56	NC		0.99	53.27	

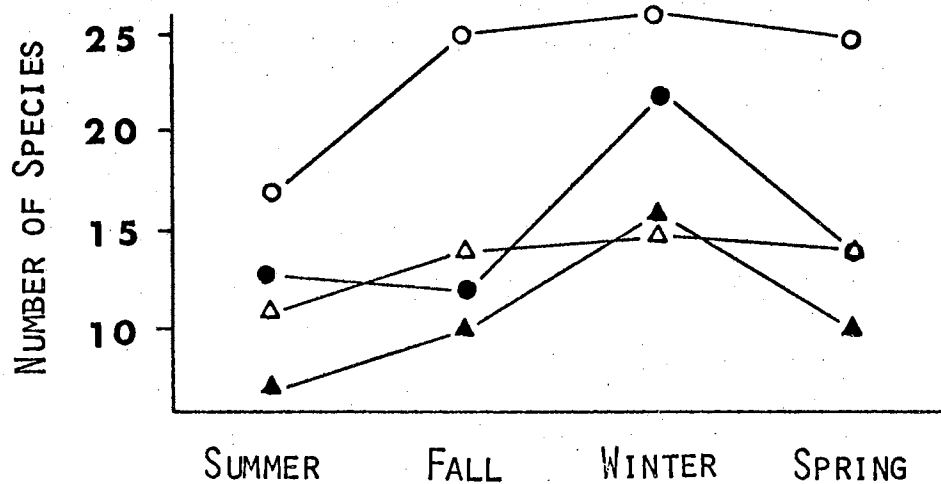*P = Present but less than 1 individual/m^2; NC = Not collected

Figure 5. Seasonal Mean Numbers of Benthic Species Collected. Pond A-open circles; Pond B-closed circles; Pond C-open triangles; Pond D-closed triangles.

individuals and lowest biomass occurred in Pond D, which was extremely turbid (Table III, Fig. 6). Ponds B and C were similar in biomass content, but the numerical abundance was greater in C. Biomass and numbers of individuals from these two ponds were intermediate between Ponds A and D. Generally, the species with the bulk of individuals contained a large portion of the biomass, but some less numerically abundant species of greater size, odonates for example, also contributed a large share of the biomass (Table IV). The seasonal changes in numbers of individuals and biomass were caused by seasonal changes in growth, reproduction, and emergence of many benthic species.
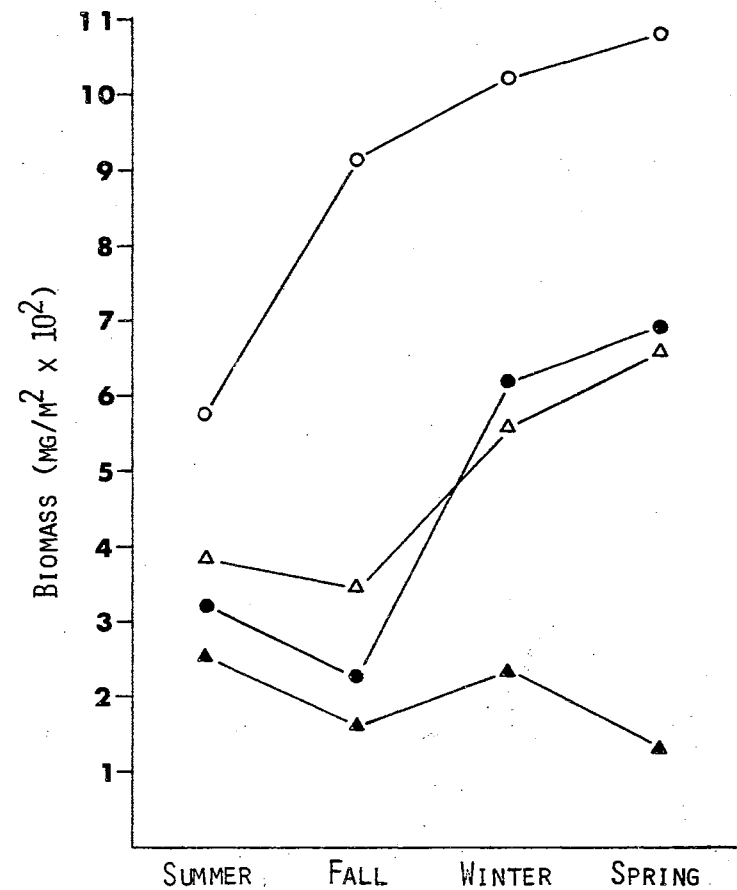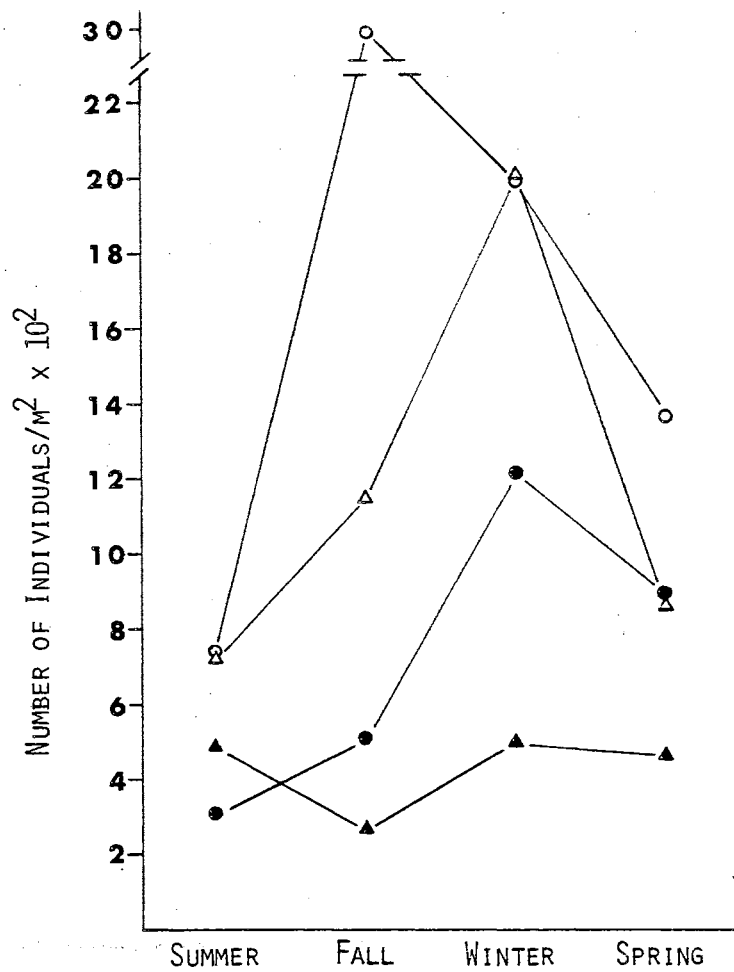
Figure 6. Seasonal Mean Numbers of Individuals and Biomass of Benthic Organisms. Pond A-open circles; Pond B-closed circles; Pond C-open triangles; Pond D-closed triangles.

Diversity Indices Using Numbers of Individuals

and Biomass Units

Diversity is equated with uncertainty regarding the random selection of an individual of a particular species present in the community. Uncertainty is greater and redundancy is reduced when the number of species is large or when the number of each species within the community is nearly the same (i.e., distribution of species is relatively homogeneous). When the distribution of species is unequal or when one or two species dominate the community, a larger probability exists that an individual selected at random will belong to the dominating species. Thus, considerable repetition or redundancy of information exists and information per individual is low, reflecting a low diversity value and a high redundancy value. Redundancy (r) is inversely related to diversity, yet it is not a mirror image, and the values range from 0 to 1.

Diversity of species of macroinvertebrates in each pond was calculated for each of the 14 sampling dates and a comparison of seasonal values using numbers of individuals and biomass units was made (Fig. 7). Diversity per individual ($\bar{d}$), obtained by using numbers of individuals, was irregular and similar seasonal trends were not evident in any two ponds (Fig. 7). Diversity based on numbers of individuals was influenced equally by species which differ greatly in size. For example, in Pond A the phantom midge, Chaoborus punctipennis Say, comprised a mean annual number of 693 individuals/m^2, but the average ash-free weight was only 0.11 mg/individual. The average organic weight of the dragonfly naiad, Gomphus sp., was 14.08 mg/individual and the mean annual number was only seven individuals/m^2. Thus, 128 C. punctipennis were required to equal the biomass of one Gomphus sp., but
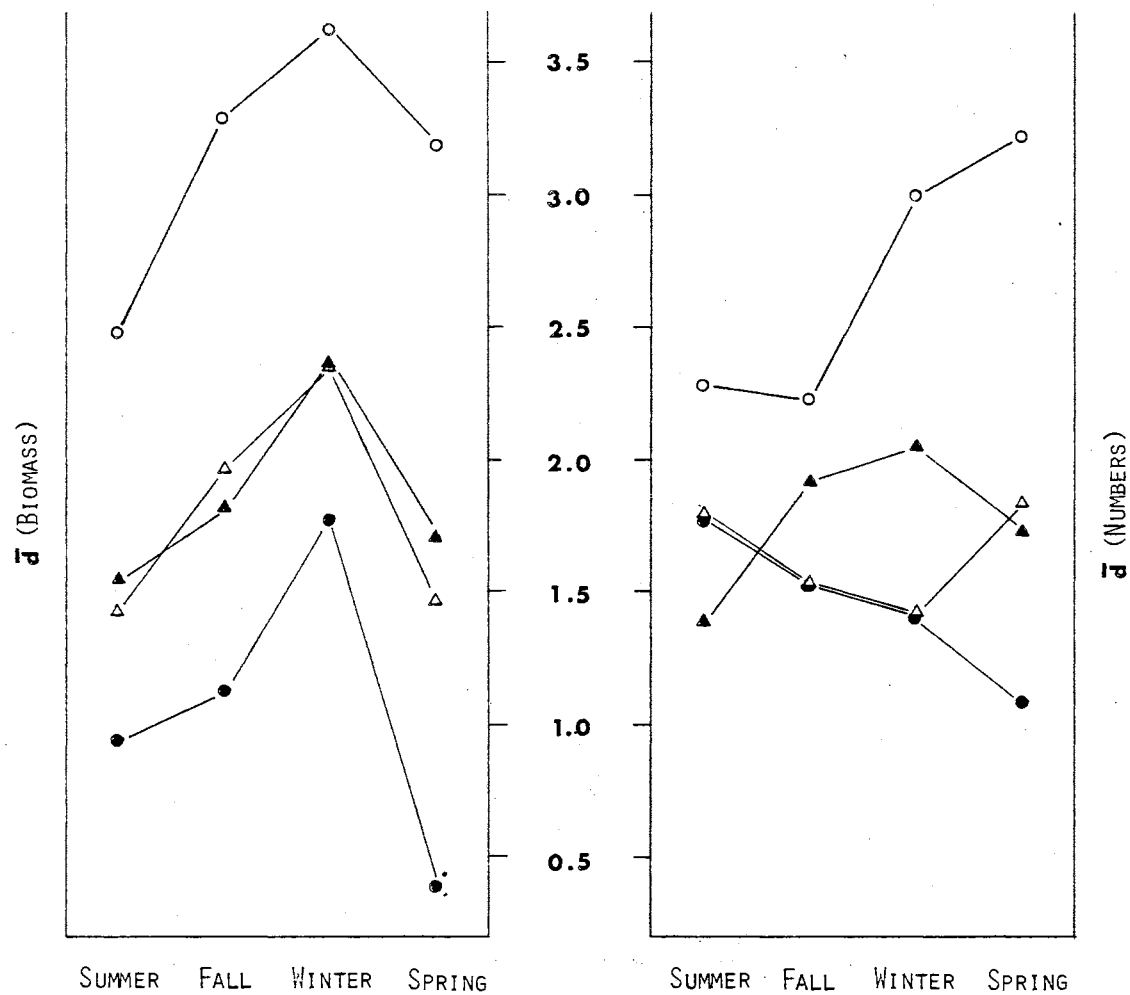
Figure 7. Seasonal Mean Diversity per Individual (d̄) Using Biomass and Numbers of Individuals as Basic Data. Pond A-open circles; Pond B-closed circles; Pond C-open triangles; Pond D-closed triangles.

C. punctipennis was slightly less than 100 times more abundant numerically. Also, when numbers of individuals were used to calculate diversity, no consideration was given to the variation of size which existed among species. A range of biomass content from 0.49 mg/individual to 13.44 mg/individual of the burrowing mayfly, Hexagenia limbata (Serville), occurred in Pond A. Consequently, one C. punctipennis had the same influence on diversity indices as one Gomphus sp., and one pre-emergent H. limbata had no more influence than a newly hatched larva when numbers of individuals were used as basic data in calculating the diversity index. Wilhm (1968) showed that the discrepancy could be corrected by using biomass units instead of numbers when calculating species diversity indices. This redefines diversity in terms of biomass, and is therefore more closely related to energy distribution among species; thus, diversity is equated with uncertainty regarding biomass instead of numbers. Since considerable variation existed between and among species in the four ponds, the relative importance of each species was more adequately expressed in biomass units rather than in numbers.

When biomass units were used to calculate $\overline{d}$, the seasonal values formed an inverted "u" configuration for all ponds, with values higher in fall and winter and lower in summer and spring (Fig. 7). The reverse trend was expressed by redundancy (Fig. 8). In general, more homogeneity was expressed when biomass units were used rather than numbers of individuals. This was true because the less numerous yet larger individuals of some species were more heavily weighted on the basis of biomass than the more abundant yet smaller organisms which dominated on a numerical basis. Diversity per individual, using biomass as basic data, exemplified similar seasonal trends as the seasonal
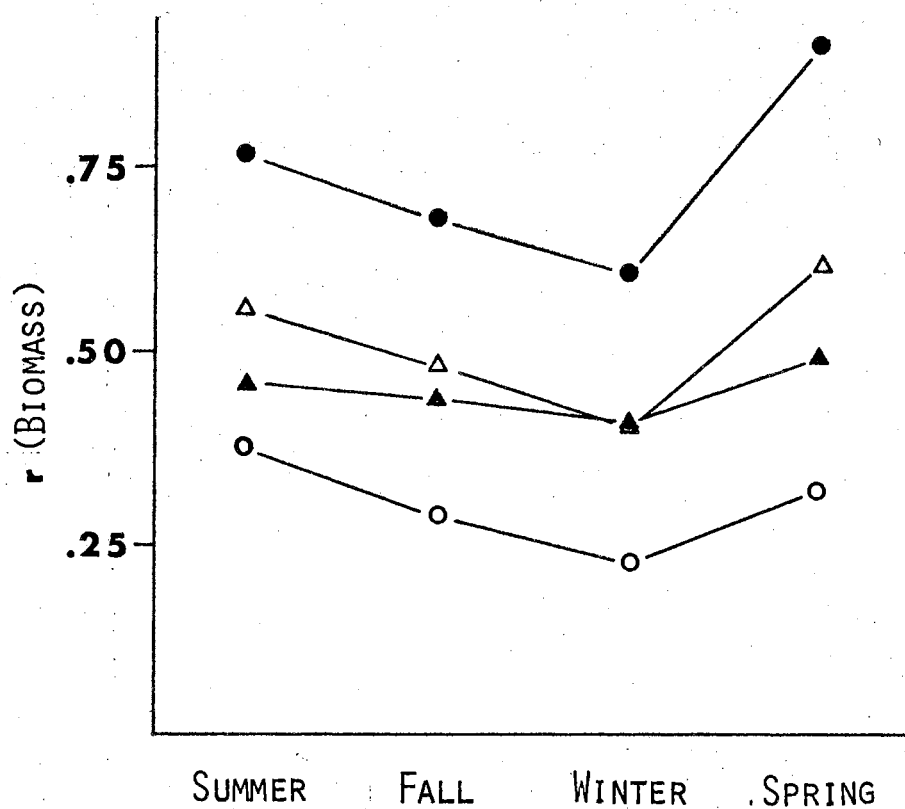
Figure 8.   Seasonal Mean Values of Redundancy (r). Pond
            A-open circles; Pond B-closed circles; Pond
            C-open triangles; Pond D-closed triangles.

number of species (Fig. 5), but the differences between ponds in each

case were not necessarily of the same magnitude or in the same order

(e.g., Pond B ranked second in the number of species but had the lowest

$\bar{d}$ values throughout the year).

Comparisons of Diversity in Ponds Studied

Patten (1962) stated that species diversity (d) reflected the

compositional richness of mixed aggregates of organisms. However,

Wilhm (1967) found that d was closely associated with numbers of indi-

viduals and inadequately associated with the wealth of species. The

species diversity (d) values of the macroinvertebrates in the ponds investigated appeared to be closely related to biomass. Both d and biomass were highest in Pond A, while these values were slightly greater in Pond C than in Pond B (Figs. 9 and 6). Pond D had the lowest d values and biomass throughout the investigation. Diversity per individual $(\bar{d})$ and redundancy (r) are more closely associated with the wealth of species and their values are also smaller (Wilhm, 1967). Therefore, diversity per individual $(\bar{d})$ and redundancy (r) provided easier and better means of evaluating community structure than species diversity (d).

Using biomass units, the greatest diversity per individual $(\bar{d})$ and the lowest redundancy (r) occurred in Pond A during all seasons (Figs. 7 and 8). The lowest $\bar{d}$ values occurred in the summer because fewer species were collected then, rather than because of the unequal distribution of biomass among the different species. The summer redundancy value for Pond A was only 0.32 (Fig. 8). Six species contributed five per cent or more of the organic weight: Hexagenia limbata (27%), Chaoborus punctipennis (14%), Physa sp. (10%), Libellula sp. (8%), Gomphus sp. (6%), and Chrysops sp. (6%). The average number of species collected increased in the fall and the continued relative homogeneity of biomass among six species accounted for the increased diversity per individual (Figs. 5 and 7). The larger H. limbata had emerged before fall and their newly hatched larvae reduced the biomass content of this species to eight per cent, but C. punctipennis increased in abundance and accounted for 22% of the biomass. During the winter months, the mean number of species increased only slightly, but the distribution of weight was divided among eight species. Physa sp., Libellula sp.,

Figure 9. Seasonal Mean Values of Species Diversity (d).
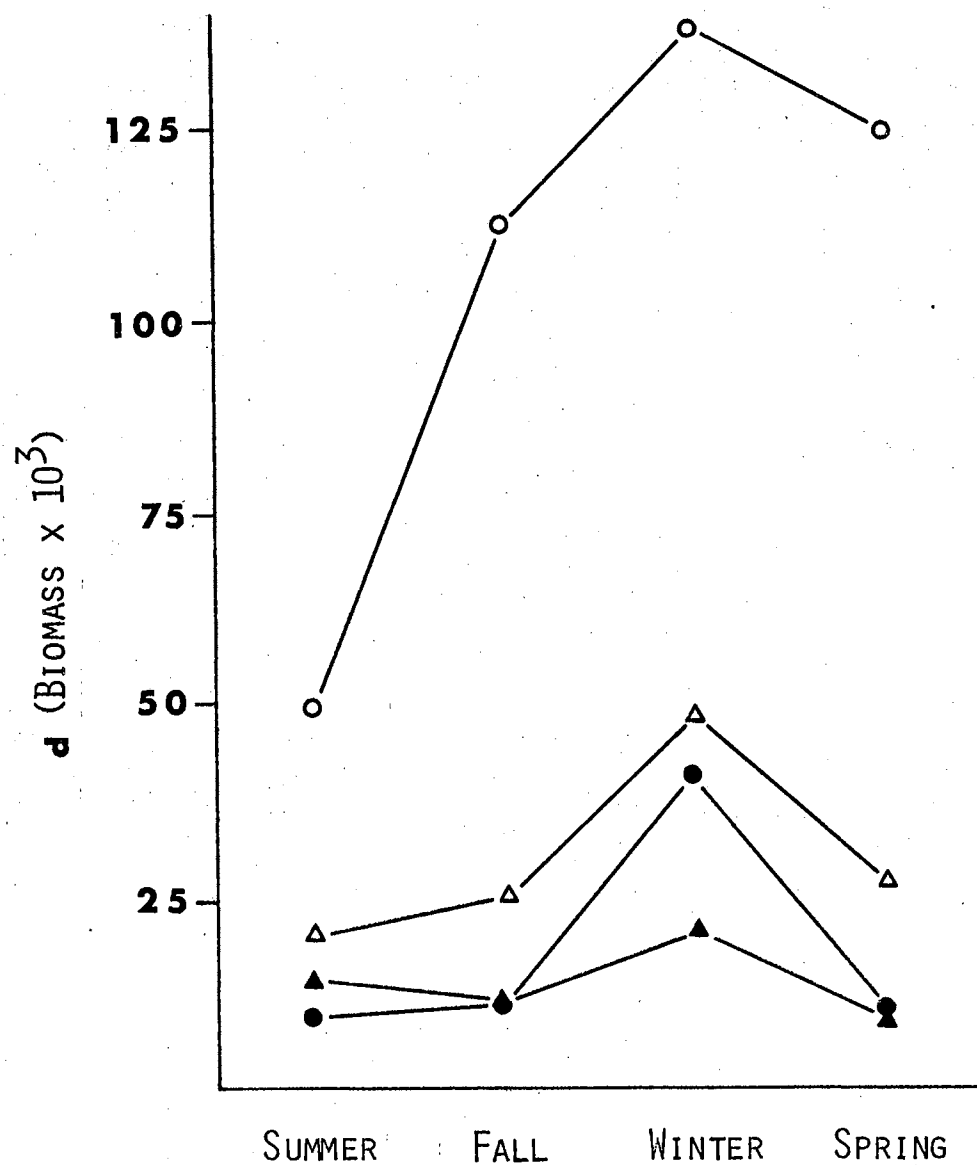Pond A-open circles; Pond B-closed circles;
Pond C-open triangles; Pond D-closed triangles.

H. limbata, Epicordula sp. C. punctipennis, Hyallela azteca, Palpomyia sp. and Hydrophorus sp. contributed 17, 12, 10, 9, 8, 6, 5, and 5% of the ash-free weight, respectively. This relatively equal distribution was reflected in the increased diversity and reduced redundancy. The

reduced diversity per individual in spring was the result of the pres-
ence of the larger pre-emergent individuals of H. limbata, which ac-
counted for 23% of the biomass.

Throughout the investigation, the biomass of the different species
was unequally distributed in Pond B (Table IV). Although the number of
species collected from Pond B was exceeded only by Pond A, seasonal
diversity per individual was the lowest of all ponds and redundancy was
the greatest. The $\bar{d}$ and r values reflected the dominance of H. limbata
during all seasons (Figs. 7 and 8). During the summer this species
composed 90% of the biomass, and no other species accounted for more
than three per cent of the biomass. The smaller individuals of H.
limbata in fall accounted for only 60% of the biomass, and two addi-
tional species, Gomphus sp. (23%) and Sialis sp. (6%), shared in the
biomass distribution. The higher $\bar{d}$ values during winter (Fig. 7) were
probably due to the sharp increase in the number of species present
(Fig. 5). The bulk of the biomass was shared by H. limbata (62%) and
Gomphus sp. (18%). The drastic drop from winter to spring in diversity
per individual can be attributed again to the dominance of H. limbata,
which comprised 96% of the organic weight, and to a reduction of the
species collected. This profusion of H. limbata increased redundancy
to its maximum annual value of 0.90 in spring.

Ponds C and D were similar in $\bar{d}$ and r for all seasons, the values
being intermediate between A and B (Figs. 7 and 8). The mean number of
species collected from each of the above ponds also fluctuated propor-
tionately, although Pond C in most instances contained more species
(Table III). Three species had a greater influence on uncertainty in
these two ponds during summer and fall. H. limbata was the dominant

species in Pond C and contributed 68% and 47% of the organic weight for summer and fall, respectively. The biomass distribution in Pond D during these two seasons was mainly attributed to H. limbata, Limnodrilus sp., and Gomphus sp., which comprised relative per cent biomass content values of 68, 14, and 11 in summer and 47, 24, and 11 in fall for the respective species. The peak of the $\bar{d}$ values for Ponds C and D occurred in winter and declined in spring, which was also true for Ponds A and B. This decline was caused by the winter-to-spring growth of H. limbata and by a reduction in the number of species collected. The influence exerted by the dominating species caused the r values to be lower in winter and higher in spring.

Duncan's multiple range test (p = 0.05) showed that diversity per individual in Pond A (annual average of 2.98) was significantly different from the other three ponds. Pond B had the lowest mean value (0.98) and was significantly different from C and D. Ponds C and D had mean annual values of 1.69 and 1.78, respectively, but were not significantly different from each other.

CHAPTER V

ECOLOGICAL CONSIDERATIONS

Keup et al., (1966) stated that as the concentration of a given pollutant increases, the more sensitive species are eliminated until only the more tolerant species survive and remain in the adverse environment. Since the total number of species collected from the ponds declined with decreasing transparency, it might be assumed that the "more sensitive" species were being eliminated as turbidity levels increased and that only the "more tolerant" species survived the more adverse turbid conditions. However, such an assumption might be in error. A consideration of the habitat requirements of some benthic species provides a more realistic assessment of the effect of turbidity on the diversity of macroinvertebrates.

A great abundance of benthic fauna has been shown to be closely related to the presence of aquatic plants (Needham, 1938; Pate, 1932, 1934; Surber, 1930; Shelford, 1918). Several of the species found in the "clear" pond (A) which contributed significantly to the diversity values were largely dependent upon rooted aquatic plants that provided living space, food, shelter, and attachment site for reproductive purposes. Many of the species were rare or absent from the other ponds which contained sparse or no vegetation.

Odonata, for example, utilize emergent vegetation for resting sites as adults and their eggs are often attached to or inserted into

plants (Smith and Prichard, 1963). In Pond A, eight odonate species were collected and three of these species were influential on the diversity values throughout the year. The odonates in Pond A comprised more than seven times the biomass content of that in any of the other three ponds. Only five odonate species were found in the three non-vegetated ponds, in which _Gomphus_ sp., a burrowing form, was the only odonate collected throughout the year (Table IV).

Pennak (1963) stated that _Hyalella azteca_ reacts negatively to light and that during the daytime they can be found in vegetation or under debris. Mackin (1941) and Buscemi (1961) also found _H. azteca_ associated with vegetation in shallow situations. _Caenis_ spp. inhabits stagnant bodies of water, such as vegetation-choked backwater of streams of bays (Burks, 1953). The dipterans _Chrysops_ sp., _Palpomyia_ sp., and many tendipedid species are also found more abundantly in waters favored by a heavy growth of aquatic plants (Wirth and Stone, 1963). The taxa mentioned above were also more common in the vegetated Pond A than in the other ponds (Table IV).

The more common species found in the turbid, nonvegetated ponds (B, C, and D) were generally burrowing forms and not associated with aquatic macrophytes. _Hexagenia limbata_, commonly collected from all ponds but more abundant in the three turbid ponds, are usually found in a variety of habitats (Hunt, 1951). _Limnodrilus_ sp., most frequently collected from the pond with the highest sediment organic content (D), feed on bottom mud and usually are concentrated in organically enriched water (Pennak, 1953). Freshwater mussels are generally found on many substrate types but usually inhabit substrata free of rooted vegetation (Pennak, 1953). _Sphaerium_ sp., a fingernail clam, was abundant only in

Pond C. Chaoborus punctipennis was frequently collected from Pond A and C but was scarce in B and D. Ponds A and C maintained a larger area of greater depth throughout the year than did B and D. C. punctipennis has been reported as a typical profundal benthic organism in lakes (Sublette, 1957; Ransom, 1969). Therefore, depth rather than the presence or absence of aquatic plants was probably the major factor relating to the abundance of C. punctipennis.

Wilhm (1968) found that species diversity was higher in vegetated areas as opposed to open areas of the same constant temperature spring, with $\bar{d}$ values of 1.85 and 0.98 for the vegetated and open areas, respectively. Turbidity was not, however, a factor limiting the aquatic plant growth in open areas.

It is apparent that benthic faunal associations in Ponds A, B, C, and D were not "more tolerant" or "more sensitive" to the suspended soil particles; but rather, the greater assemblage of organisms, hence a greater diversity, should be attributed to the greater number of habitats provided by the aquatic macrophytes. Thus, turbidity acted indirectly on the benthic macroinvertebrates by eliminating sufficient light for the success of rooted aquatic plants, the habitat of many benthic species.

Species diversity indices derived from information theory have distinct advantages over traditional methods of evaluating benthic communities. Diversity indices can be briefly defined in terms of precise numerical values which can be compared with or among different aquatic environments. Information theory describes but does not explain the observed phenomena in terms of causal factors.

A major objection to using specific organisms as "indicators of pollution" is that not all organisms are equally affected by all pollutants. However, consideration of the abundance of the assemblage of the specific taxa in a community may facilitate a better understanding of differences in diversity values found in the ponds studied. Some organisms collected from Pond A were closely associated with aquatic plants. The absence or scarcity of these organisms in Ponds B, C, and D indicated the lack of aquatic plants. Consequently, the use of diversity indices derived from information theory and determining the habitat requirements of the more common species enable an investigator to evaluate the effect of a pollutant on a community more adequately than by using either method by itself.

CHAPTER VI

SUMMARY

A study of physicochemical conditions and community structure of

benthic macroinvertebrates in four farm ponds was conducted from June,

1966, through May, 1967. Community structure of the benthic fauna was

analyzed by species diversity indices derived from information theory

and was subjected to traditional qualitative methods to evaluate tur-

bidity as a pollutant. Causal relationships for the different community

structures were established based on physicochemical features, organic

content of sediments, and primary productivity estimates.

Turbidity differences among ponds appeared to be governed by rain-

fall and runoff rate, condition of the vegetation in the watershed,

ionic concentration, extent of aquatic macrophyte abundance, wave action,

and roiling by livestock. Conductivity was inversely related to tur-

bidity. Suspended soil particles may have been reduced by the formation

of hydroxides by aquatic macrophyte photosynthesis. Photosynthetic rates

and P/R ratios were directly related to the transparency of the water

while organic content of the sediments showed an inverse relationship

to transparency. Primary productivity, organic content of sediments,

and physicochemical conditions indicated that the primary variable

causing stress present in the ponds was suspended inorganic matter.

Fifty species of benthic macroinvertebrates were collected during

the year. Numbers of species and individuals and biomass content was

maximal in the least turbid pond (A) and minimal in Pond D, which was most turbid. Seasonal changes in numbers and biomass coincided with life history stage of the organisms. Generally, the species which were numerically abundant accounted for a large portion of the biomass, but some less abundant species of greater size also contributed a large share of the biomass content.

Species diversity indices based on biomass units expressed the relative importance of each species and were more closely related to energy distribution than indices based on numerical abundance. Generally, greater homogeneity was expressed when biomass units were used as basic data. Diversity per individual ($\overline{d}$) was high and redundancy (r) low during fall and winter for the four ponds. Greatest $\overline{d}$'s and lowest r's occurred in Pond A during all seasons while Pond B reflected the opposite conditions. Duncan's multiple range test (p = 0.05) revealed mean annual $\overline{d}$ values of Ponds C and D were not significantly different from each other, while significant differences were shown between A and all other ponds and B and all other ponds.

Pond A maintained a heavy growth of aquatic macrophytes, but the other ponds contained sparse or no rooted aquatic plants. Several of the benthic organisms which contributed significantly to the higher diversity values in Pond A were largely dependent upon the aquatic plants for living space, food, shelter, and attachment site for reproductive purposes. Many of these benthic species were rare or absent from the other ponds. The different benthic faunal associations were attributed to the greater number of habitats provided by aquatic plants. Thus, turbidity acted indirectly in Ponds B, C, and D by eliminating sufficient light for the growth of aquatic plants, resulting in a less

diverse benthic community.

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