STREAM ORDER AND COMMUNITY STRUCTURE OF BENTHIC MACROINVERTEBRATES AND FISHES IN AN INTERMITTENT STREAM

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PREFACE

This study of stream order and community structure in an intermittent Oklahoma stream was made to determine the correlation between stream order and the morphometry of the drainage basin, physico-chemical conditions and community structure of benthic macroinvertebrates and fishes.

Professor Troy C. Dorris served as major adviser. Calvin G. Beams, William A. Drew, L. Herbert Bruneau and Rudolph J. Miller served on the advisory committee and criticized the manuscript. Robert G. Easterling wrote the computer program for community structure and analyses of variance. Billy J. Mathis, John H. Carroll and J. Kenneth Beadles helped make field collections. Billy J. Davis helped collect, identify and count fishes.

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CHAPTER I

INTRODUCTION

Stream classifications commonly used by biologists have been based on many variables such as source of water, size, velocity, slope, elevation, temperature, substrate, permanence, oxygen and carbon dioxide, productivity or combinations of several of the above (Steinmann, 1907; Theinemann, 1912; Klugh, 1923; Carpenter, 1928; Muttkowshi, 1929; Ricker, 1934; Pearse, 1939; Huet, 1949, 1950, 1959; Illies, 1952; Elton and Miller, 1954; Schmitz, 1955; Beck, 1965; Thorup, 1966).

Thompson and Hunt (1930) classified streams according to size of area drained, permanence, depth, width, velocity, substrate, amount of vegetation and debris, turbidity and faunal associations. Margalef (1960) based a biological classification on floral associations. Usinger (1963) grouped California streams in biotic zones related to altitude, temperature, precipitation, vegetation, faunal origins, source and permanence of water. These systems are somewhat subjective and are generally useful only in the area in which they were developed.

Streams are susceptible to outside influences and are almost infinitely variable (Ricker, 1934; Usinger, 1963). However, certain habitats such as riffles, runs and pools occur repeatedly in nearly every stream in the world. Species inhabiting these areas are different in each part of the world, but the main groups, or their ecological equivalents, are similar.

Organisms distribute themselves into distinct, but overlapping communities along the length of a stream. Between the source and the mouth, there is a gradual change in faunal composition resulting in a longitudinal succession of species (Woodworth, 1894; Adams, 1901; Shelford, 1911, 1913). The only general and unifying characteristic of all lotic systems is the spatial pattern assumed by the stages of succession. Successional stages have been described by listing organisms characteristic of each stage (Shelford and Eddy, 1929; Gersbacher, 1937; Margalef, 1960).

Using conventional stream classification systems an ecologist would have difficulty in comparing streams in separate areas or even portions of the same drainage basin. Subjective criteria would be used to determine what constitutes comparable location in the basin, successional status, etc.

Throughout its linear extent, a stream may dissect such a variety of geographic and geologic environments resulting in such a variety of stream types, that seemingly generalizations about the entire system would be difficult. However, not only is unity displayed by similarities among streams in different regions, but also an organization results from balance between the forces of erosion and resistance (Leopold, 1962). This unity is demonstrated in the stream channels, valleys and drainage net.

The history of existing stream channels can be retraced through the hierarchy of tributaries within the drainage basin. Attempts to classify stream systems on the basis of stream bifurcation began with Gravelius (1914). Gravelius designated the stem stream of a drainage basin as an order one stream. Smaller tributary streams were assigned increasingly higher order numbers. The smallest unbranched tributaries were given the highest ordinal number. Although these unbranched streams were similar in different basins, they were designated as different orders.

Horton (1945) devised a system of stream orders which was the inverse of the Gravelius system. The entire length of the longest channel, from source to mouth, was given the highest order number. Tributaries which emptied into this stem stream were assigned order numbers based on branching. Unbranched tributaries were designated first order streams. Where two first order streams joined a second order stream was formed; where two second order streams joined a third order stream was formed; etc. Junction of a stream by a lower order stream did not affect the ordinal designation. Horton showed that in any drainage basin the number and average lengths of streams of each order, basin size and gradient are related to stream order.

Strahler (1954, 1957) modified Horton's stream order system, designating the various sections of the stem stream by order numbers as indicated by branching. Ordinal designation was then uniform throughout the basin. According to Strahler, order number is directly proportional to relative watershed dimensions, channel size and stream discharge at that place in the system. Order number is dimensionless, thus two drainage basins differing in linear scale can be equated or compared with respect to corresponding points in their geometry. Leopold (1964) defined stream order as a measure of position in the hierarchy of tributaries.

Abell (1961) suggested the use of stream order in biological studies. Kuehne (1962) correlated stream order with distribution of fishes in Eastern Kentucky and discussed its biological applications.

In the present study species diversity indices of stream fauna were correlated with stream order. Diveristy indices derived from information theory by Margalef (1951, 1958) and Patten (1962) make it possible to summarize large amounts of information about numbers and kinds of organisms. Diversity and information are considered to be synonymous and may be calculated directly from numbers of individuals and species collected in a sample (Margalef, 1961). These indices do not attempt to explain causal phenomena, but only estimate the amount of information required to define the community structure. Diversity is usually expressed in bits, with one bit representing the information required to specify one of two equally probable states. Margalef (1951, 1956, 1958), Patten (1962), Wilhm (1965) and Mathis (1965) have shown that diversity indices may be used as valid ecological parameters to describe changes in community structure and to denote successional status.

CHAPTER II

DESCRIPTION OF AREA

General Description of Basin

Otter Creek drainage basin is a sixth order, intermittent system located in Northcentral Oklahoma. The main channel originates approximately 8 km northwest of Covington, flows 41.8 km southward through Garfield and Logan Counties and empties into Skeleton Creek, a tributary of the Cimarron River.

Formations exposed in the basin were laid down during the Permian period and are called "Permian red beds" because of their color (Fitzpatrick et al., 1939). The Hennessey formation, exposed in the upper reaches of the basin, consists mostly of shales with some gypsum and lenticular sandstone. The Garber formation, exposed in the middle and lower reaches of the basin, consists of alternating sandstone and shales with interstratified beds of limestone and gypsum (U S G S, 1945). Garber sandstone is one of the most important aquifers in the state, however, the water is hard and high in sulfates and chlorides (U S G S, 1945).

Soils of the uplands are sandy or clayey silts and loams (Fitzpatrick et al., 1939). Soils along the stream channels and covering most of the lowlands are fine clay and silt loams (Galloway, 1960).

Otter Creek is in the mixed-grass prairie association. Dominant grasses are little blue stem, Indian grass, Johnson grass, field sandbur and windmill grass. Much of the land is cultivated or pastured. American elm, chinquapin oak, blackjack oak, hackberry and cottonwood trees line the stream banks.

The climate is long-summer continental and characterized by wide fluctuations in temperatures. The mean annual temperature is 16 C and the average wind velocity is 17.6 kmph. Precipitation averages about 81 cm per year, but there are great annual differences and severe droughts are common (Fitzpatrick et al., 1939; Galloway, 1960).

Morphometry

Morphometric data were taken from U. S. Department of Agriculture ground and aerial photographic maps (1935, 1951, 1964) with scales of 1:62,500, 1:20,000 and 1:7,812, and U. S. Geologic Survey topographic sheets (1893, 1956).

Otter Creek drainage basin has an elongated, irregular perimeter of 106.2 km with an axial length of 36.4 km and occupies an area of 302.1 km^2 (Fig. 1). The elevation is 363 m at the source and 287 m at the mouth, with an average gradient of 1.8 m/km. The stream pattern is dendritic and highly developed with narrow valleys which reach a depth of 22.8 m along the sixth order stream.

Stream-Order Analysis

The structure of a stream system can be expressed quantitatively by stream-order analysis (Horton, 1945; Strahler, 1954, 1957; Leopold et al., 1964). The stream-order analysis of Otter Creek is shown on Table I.

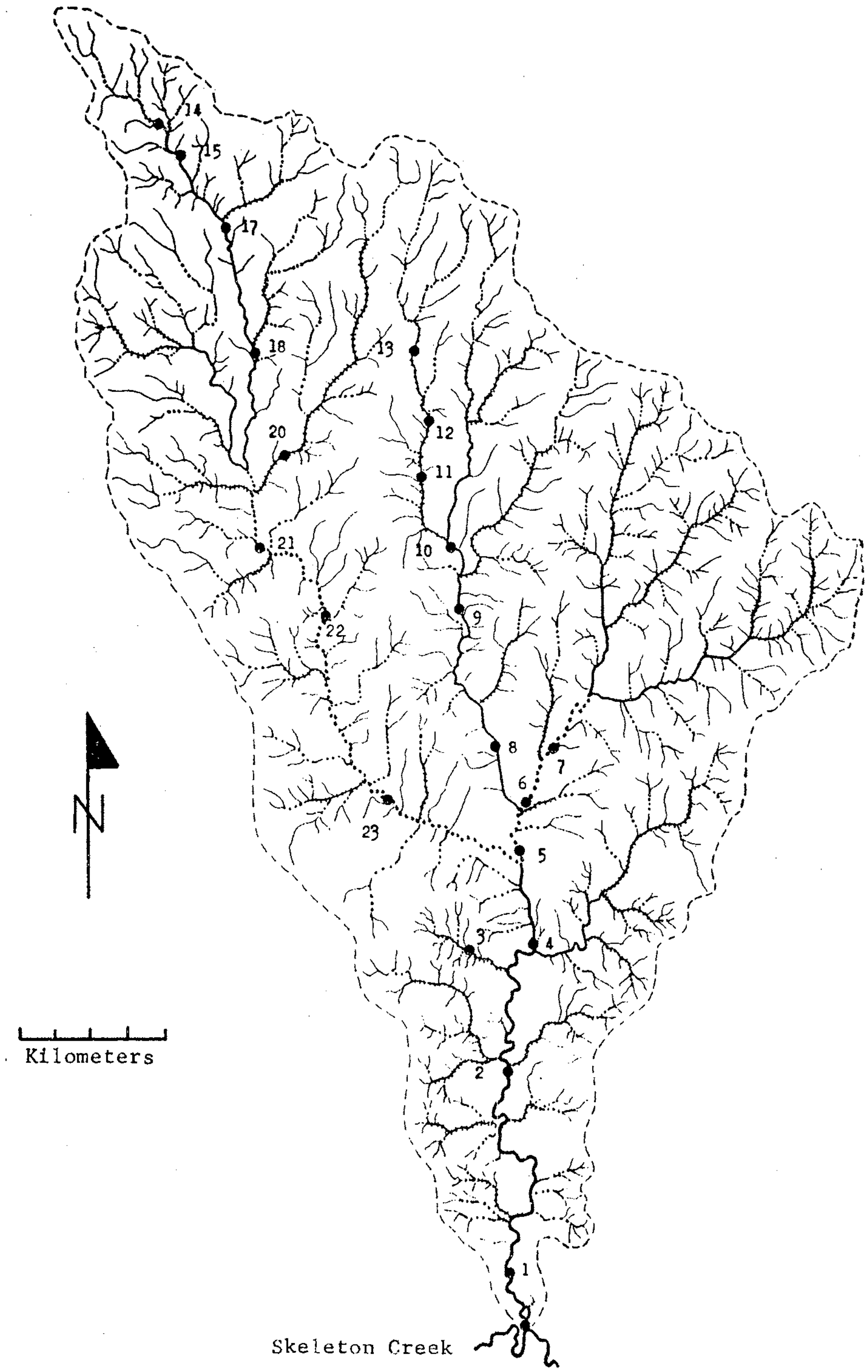

Fig. 1. Otter Creek Drainage Basin and Collecting Stations. First Order Stream = (——), Second Order = (—•••—), Third Order = (++++), Fourth Order = (▬▬), Fifth Order = (••••), Sixth Order = (▬▬)

TABLE I

STREAM-ORDER ANALYSIS OF OTTER CREEK DRAINAGE BASIN

Order	Number of Streams	Total Length (km)	Average Length (km)	Mean Drainage Area (km^2)
1	744	300.6	0.40	
2	189	163.8	0.87	
3	39	83.4	2.14	5.3
4	7	35.2	5.04	27.9
5	2	19.5	9.75	126.2
6	1	14.6	14.60	302.1
Bifurcation Ratio		3.97		
Stream-length Ratio		2.08		
Drainage Density		2.04		
Stream Frequency		3.25		

Stream order displays geometric relationships with a number of stream parameters. The number of streams of each order in a drainage basin exhibits an inverse geometric progression (Fig. 2). The ratio of the number of streams of a certain order to the number of streams of the next lower order is the bifurcation ratio. Theoretically, the number of streams should double with each decrease in stream order giving a bifurcation ratio of two. However, adventitious streams, low order streams which enter larger streams directly and not through the hierarchy of tributaries, make the bifurcation ratio greater than two. Horton (1945) and Leopold (1954) found bifurcation ratios of about two for flat or rolling basins and three or four for mountainous or highly

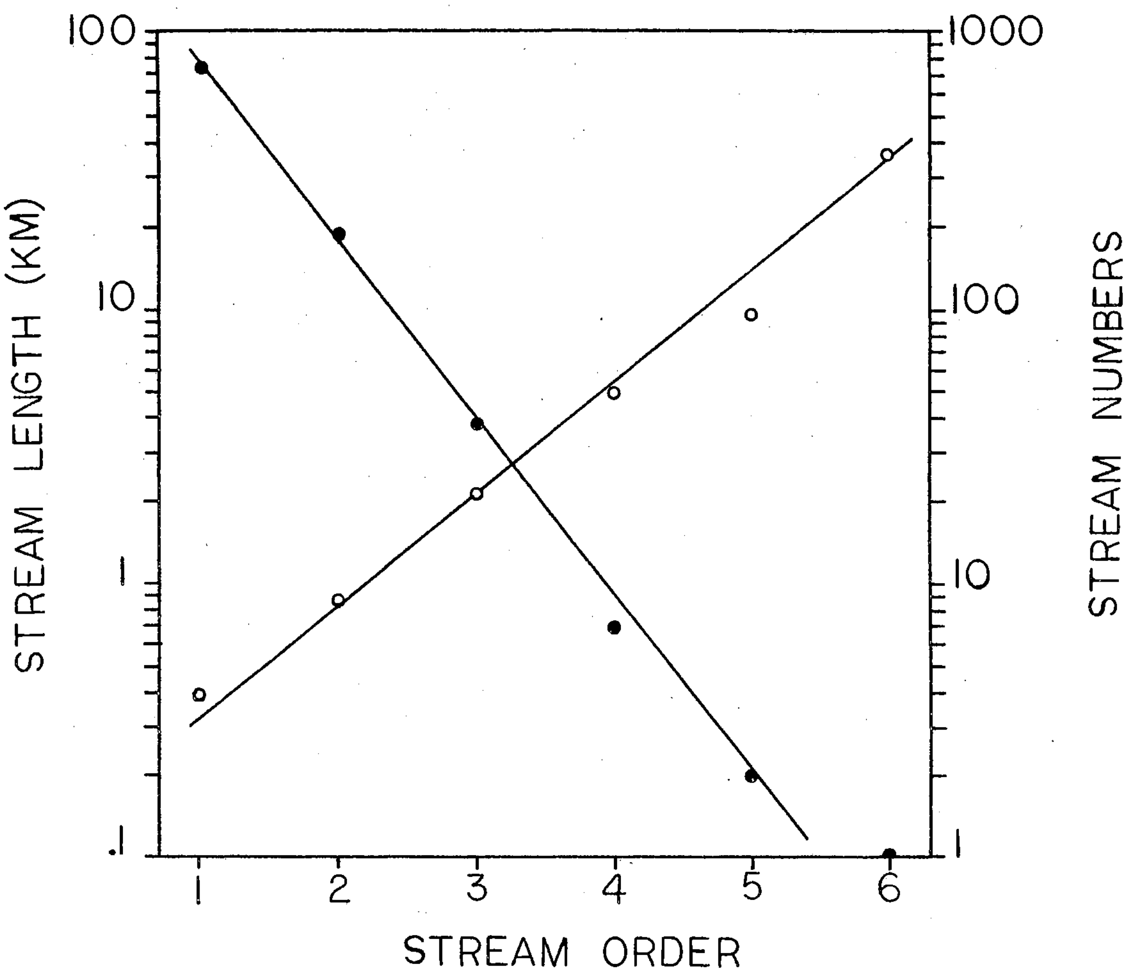

Fig. 2. Number (●) and Average Lengths (O) of Streams in Relation to Stream Order

dissected basins. Otter Creek drainage basin is more thoroughly dissected than other basins in this region (Fitzpatrick et al., 1939) and the bifurcation ratio is 3.97.

The average lengths of streams of each order in a drainage basin tend toward a direct geometric series (Fig. 2). The ratio of average length of streams of a given order to that of the next lower order is the stream-length ratio. Low stream-length ratios (1-2) are characteristic of well-drained basins, and high ratios (3-4) are characteristic of poorly-drained basins (Horton, 1945). Otter Creek basin is well drained, with an average stream-length ratio of 2.08.

Drainage density (stream length/area) and stream frequency (number of streams/area) further quantifies the drainage pattern. Low drainage density and high stream frequency occur in a well-drained basin. Drainage density and stream frequency range from less than one to 1000. Since these indices utilize both linear (mi or km) and quadratic (mi^2 or km^2) units, values derived from metric units are not comparable with those derived from English units. Drainage density and stream frequency in the Otter Creek basin were 2.04 and 3.25 respectively, using the metric system, and 3.28 and 8.42 using English units.

Drainage basin area increases exponentially as stream order increases (Schumm, 1956). Normally, drainage area increases four to five times with each increase in stream order (Leopold, 1962). Drainage area increased approximately four times with each increase in stream order in the Otter Creek system (Fig. 3).

Average gradient of streams of each order exhibits an inverse geometric series with increase of order (Fig. 3). However, adventitious streams exhibit the reverse relationship. Generally, in adventitious streams of similar order, gradient increases as the order of the stream into which it flows increases. Adventitious streams generally do not develop simultaneously with the larger streams, but develop later as the stream system matures (Horton, 1945). Adventitious streams located

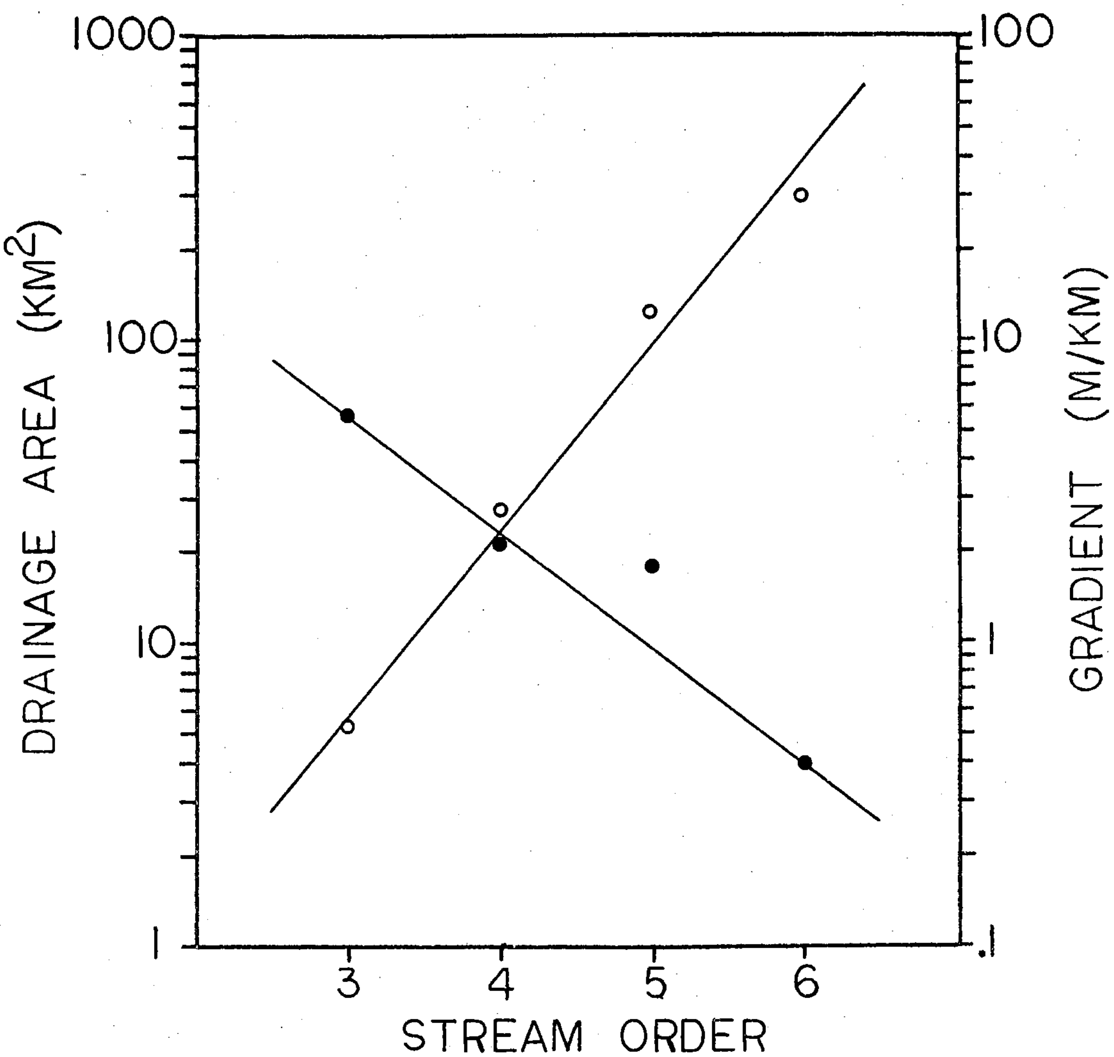

Fig. 3. Average Gradient (●) and Basin Size (O) in Relation to Stream Order

in the lower reaches of Otter Creek basin had steeper gradients and longer periods of stream flow than those located in the upper reaches of the basin.

Descriptions of Stations

Twenty-one stations were selected in nine streams in the Otter Creek basin, for collection of benthic macroinvertebrates, fishes and physico-chemical data (Fig. 1). Fishes were collected at an additional station near the mouth of Otter Creek.

Six stations were selected in each of third, fourth and fifth order streams. Four stations were selected in the sixth order stream. Stations were selected in the upper, middle and lower portion of each stream order for analyses of variance of species diversity between and within stream orders. Stations were designated by numbers corresponding to the order of sampling. Numbers in parentheses following station numbers indicate stream order.

Width of pools ranged from 1.4 m at station 12(3) to 6 m at station 1(6). Average depth of pools varied from 23 cm at station 11(3), 12(3), 8(4) and 10(4) to 90 cm at station 4(6)(Table II).

Cover along the stream banks varied from open, unshaded banks along stations 11(3), 13(3), 14(3), 15(4) and 17(4) to densely tree-lined banks at all fifth and sixth order stations, except station 22(5). Stations 8(4), 10(4) and 12(3) also had densely tree-lined banks. Remaining stations had moderate tree cover.

Sediment size ranged from cobbles to clay. Fine and coarse sands and silts were dominant in pools, except at station 2(6) where silt, gravel and cobbles were dominant and at stations 2(6), 9(4), 11(3), 14(3) and 21(5) where the bottom consisted mostly of clay and silt. Riffle sediments consisted of coarse gravel and pebbles, with some cobbles at stations 1(6), 2(6) and 9(4). The riffle areas at station

TABLE II

CHARACTERISTICS OF STREAMS AND SAMPLING STATIONS
(Different Streams are Separated by Lines)

Station and Order	Drainage Area	Drainage Density		Stream Frequency		Gradient	Flow*	Pool Width	Pool Depth
	km^2	mi	km	mi	km	m/km	m^3/sec	m	cm
14(3)**	5.34	2.72	1.69	5.34	2.06	4.74	trace	1.9	51
20(3)**	16.52	2.83	1.76	6.11	2.36	4.33	trace	1.8	31
3(3)	3.21	4.84	3.00	17.74	6.85	10.93	trace	2.8	41
11(3)								2.8	23
12	18.28	2.85	1.77	5.81	2.24	3.25	none	1.4	23
13								2.7	31
8(4)								4.1	30
9	59.67	3.01	1.87	6.38	2.46	2.61	0.04	5.2	46
10								3.3	23
15(4)								2.3	31
17	31.00	2.94	1.83	7.35	2.84	1.81	0.02	3.1	41
18								2.5	31
21(5)								3.1	70
22	129.53	2.72	1.69	6.52	2.51	2.07	0.03	3.8	41
23								4.0	56
5(5)								4.3	56
6	122.53	3.35	2.08	8.32	3.21	1.70	0.05	3.6	43
7								4.1	31
4(6)								5.3	91
2	302.12	3.28	2.04	8.42	3.25	0.42	0.08	4.3	41
1								6.1	51

*Flow measurements taken in riffle areas

**Adventitious streams

17(4) were on calcareous shale and those at station 9(4) were on bare sandstone.

Generally, drainage density, stream frequency and flow increased, while gradient decreased downstream (Table II). However, station 3(3) was located in an adventitious stream which flowed directly into the sixth order stream, and had the steepest gradient (10.93 m/km) and highest stream frequency (6.85) and drainage density (3.0).

Stations 9(4) and 22(5) received oil field brines and were excluded from the stream order-species diversity analyses.

CHAPTER III

PROCEDURES

Physico-chemical measurements and benthic macroinvertebrate collections were made monthly at all stations from June 1964 to May 1965.

Physico-Chemical

Water and air temperature were measured with a mercury thermometer. Phenolphthalein and methyl orange alkalinity were determined by titration with 0.02 N sulphuric acid (A P H A, 1960). Hydrogen ion concentration was estimated with a Hellige pH comparator or a Beckman pocket pH meter. Turbidity was measured with a Bausch and Lomb spectronic 20 colorimeter calibrated against a Jackson turbidimeter. Conductivity was measured at 25 C with an Industrial Instruments Wheatstone Bridge. Duplicate water samples were taken from each station from November through May for determination of dissolved oxygen. Each sample was fixed by the Alsterberg (Azide) modification of the Winkler method and titrated with 0.016 sodium thiosulfate (A P H A, 1960).

Biological

Four Ekman dredge hauls were taken monthly from pools at each station. Two riffle samples were collected each month from sixth order stations with a Surber sampler. Bottom samples were preserved in the field with 10% formalin. Samples were washed in a #40 U. S. Standard soil sieve and organisms preserved in 80% isopropyl alcohol. When large numbers of organisms were present they were removed by sugar solution flotation (Anderson, 1959).

Fishes were collected from all stations 10 June 1965 and 28 September 1965 with minnow seines. Approximately 137 m of both pool and riffle areas were seined at each station, when possible. Many stations had no riffles. Collected fishes were fixed in 10% formalin for three days, washed in water and stored in 50% isopropyl alcohol.

Species Diversity and Heterogeneity

Species diversity (H), diversity per individual ($\bar{H}$), maximum diversity (Hmax), minimum diversity (Hmin) and redundancy (R) were determined by equations of Patten (1962).

$$H = \sum_{i=1}^{m} n_i \log_2 \frac{n_i}{N}$$

$$\bar{H} = \sum_{i=1}^{m} \frac{n_i}{N} \log_2 \frac{n_i}{N}$$

$$Hmax = \log_2 N! - m \log_2 (N/m)!$$

$$Hmin = \log_2 N! - \log_2 \left[N - (m-1)\right]!$$

$$R = \frac{Hmax - H}{Hmax - Hmin}$$

In these equations (N) is total number of individuals, (n_i) is number of individuals of species i and (m) the number of species per unit area.

Species diversity (d) and heterogeneity (IH) were determined by equations of Margalef (1958).

$$d = \frac{s-1}{\ln N}$$

$$IH = d(A + B) - \frac{dA + dB}{2}$$

In these equations (s) is the number of species, (N) is the total number of individuals, (dA) is diversity at station A and (dB) is diversity at station B.

Analyses of variance of H, $\bar{H}$ and R were made using a completely randomized design (Ostel, 1963).

Computations were made with an IBM Type 7040 data-processing machine.

CHAPTER IV

PHYSICO-CHEMICAL CONDITIONS

Rainfall occurred irregularly throughout the year (Table III). Monthly precipitation varied from 15.72 cm in August to 1.45 cm in February. The longest period without rain extended from 13 July to 7 August. A rain of over 2.54 cm in a short period of time caused scouring of the stream bed. Rains of this magnitude occurred between collection dates in June and July, August and September, September and October, October and November and April and May.

TABLE III

MONTHLY PRECIPITATION IN CENTIMETERS

Summer		Fall		Winter		Spring	
Jun	6.17	Sep	10.57	Dec	1.47	Mar	3.84
Jul	1.68	Oct	2.59	Jan	1.50	Apr	3.10
Aug	15.72	Nov	12.62	Feb	1.45	May	15.44

Mean annual discharge increased with stream order (Fig. 4; Table IV). The only flow observed during July and August was a trace at station 1(6). In August all third and fourth order stations except 3(3), 11(3), 18(4) and 9(4) were dry. Station 7(5) was also dry during August. During spring and fall the stream flowed below stations 9(4) and 21(5), and pools existed above these stations. During winter, the

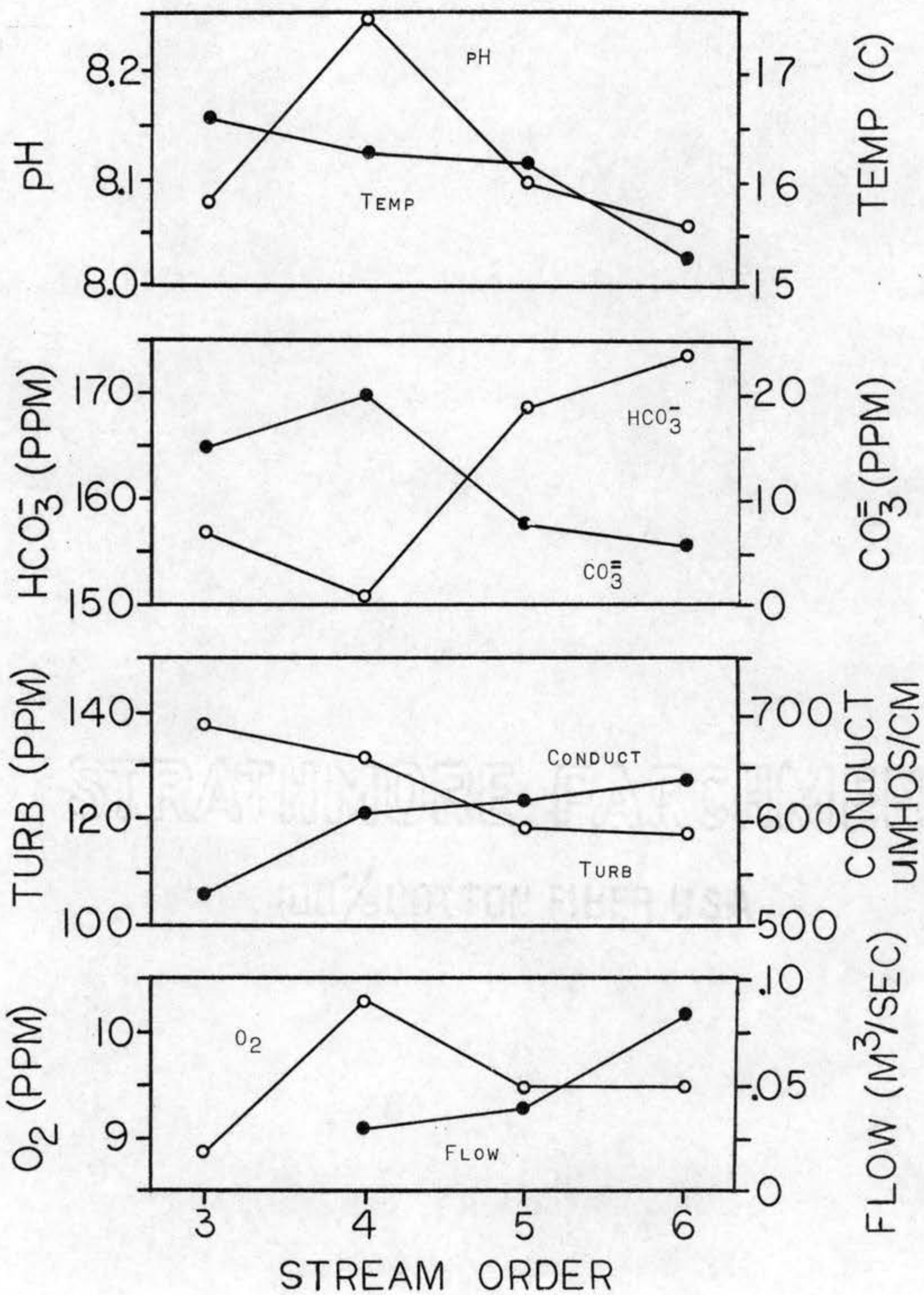

Fig. 4. Mean Annual Physico-Chemical Conditions in Relation to Stream Order

TABLE IV

MEAN ANNUAL PHYSICO-CHEMICAL CONDITIONS AND EXTREMES OF STREAM ORDERS

Stream Order	Temperature C	pH	Alkalinity HCO_3 ppm	Alkalinity CO_3 ppm	Oxygen ppm	Turbidity ppm	Conductivity umhos/cm	Discharge m^3/sec
3	16.6	8.08	157	15	8.86	138	533	Trace
	2-39	6.8-9.8	39-341	0-219	0.6-17.5	8-310	120-1640	0-.006
4	16.3	8.25	151	20	10.32	132	608	3.03
	1-34	7.4-9.4	69-276	0-180	2.4-17.3	11-310	178-1412	0-.08
5	16.2	8.10	169	8	9.51	117	616	0.04
	1-33	7.2-8.5	57-296	0-42	1.0-13.1	10-310	184-2103	0-.17
6	15.0	8.06	174	6	9.52	116	640	0.08
	1-26	7.4-8.4	78-294	0-24	5.3-12.3	11-310	210-1163	0-.32

season of least precipitation, flow was continuous at all stations except 11(3), 12(3) and 13(3), where flow was observed for a short period only during or directly after rainfall. Increased flow during winter may be attributed to lower evaporation, less plant activity and a higher ground water table.

Turbidity decreased and conductivity increased with stream order (Fig. 4; Table IV). The increase in conductivity may have been due to increased leaching of soluble minerals with greater stream flow and depth of stream channels. Sulfates and chlorides increase with depth in the Garber and Hennessey formations (U S G S, 1945). When the water level receded after a rain or during dry weather a white precipitate of calcium sulfate was commonly observed on the stream bed. Esmay et al. (1955), Keeton (1959) and Mathis (1966) showed that turbidity decreases as conductivity and hardness of water increases. Turbidity was low and conductivity was high during winter, the reverse being true during fall. Intermediate turbidity and conductivity occurred during spring and summer.

The stream was rich in carbonates and bicarbonates, a condition which favors high productivity (Huet, 1950; Gaufin, 1958). Bicarbonates increased and carbonates decreased as stream order increased (Fig. 4). Bicarbonates were leached from the substrate and converted to monocarbonates in association with high pH values. Monocarbonates were then converted to bicarbonates down stream as the pH lowered. Carbonate alkalinity was not observed at stations 3(3) and 12(3), where pH did not exceed 8.2, and much allochthonous plant material was present. Hydroxide alkalinity was observed on one occasion, at station 10(4) in association with an algal bloom and a pH of 9.4.

Variation in hydrogen ion concentration decreased as stream order increased (Table IV). Hydrogen ion concentration ranged from 6.8 at station 12(3) in December to 9.8 at station 14(3) in July. The more alkaline pH at fourth order stations was due to calcareous shale in the stream bed at station 17(4) and a layer of gypsum along the stream channel at station 10(4).

Dissolved oxygen varied from 0.6 ppm at station 12(3) in May to 17.5 ppm at station 12(3) in February. High oxygen and pH values were associated with algal blooms, and low oxygen and pH occurred in pools where allochthonous plant material was abundant.

Mean annual water temperature decreased as stream order increased (Fig. 4). Water temperature varied from 1 C in January to 39 C in July in a small pool. The greatest daily, seasonal and annual fluctuations occurred among third order stations, and decreased as stream order increased (Table IV). Much of this observed variation was due to differences in shading and time of sampling.

Physico-chemical fluctuations decreased as stream order increased, indicating higher stability in higher order streams (Table IV).

CHAPTER V

COMMUNITY STRUCTURE OF BENTHIC MACROINVERTEBRATES

Numbers of Individuals and Species

One hundred and twenty-one species of benthic macroinvertebrates were collected (Table V; Appendix). Five species were collected only at stations 9(4) and 22(5) which received oil field brine and ten species were collected only from riffles. These localities were excluded from the stream-order analyses. The ectoproct, Fredericella sultana and crayfishes, Procambarus simulans and Orconectes nais were not quantitatively sampled and were not considered in the species diversity calculations.

Oligochaetes (9 species, 70%) and dipterans (46 species, 22%) formed 92% of the total pool fauna. Limnodrilus sp. formed 66% and tendipedid larvae (24 species) formed 19% of the total numbers. Naididae (6 species), Hirudinea (3 species), Ephemeroptera (5 species), Coleoptera (12 species), Ceratopogonidae (4 species) and Mollusca (6 species) each formed over 1% of the total numbers.

Numbers of species increased from 75 in third order pools to 86 in fifth order pools. Only 68 species were collected from sixth order pools. This decrease was attributed to heavy siltation which reduced the number of available microhabitats. Otter Creek empties into Skeleton Creek which has considerably more discharge than Otter Creek.

TABLE V

NUMBERS OF BENTHIC MACROINVERTEBRATES PER M^2 (ANNUAL)*

ORDER			3							4							5							6	
STATION	14	20	3	13	12	11	$\bar{X}$	15	17	18	10	9**	8	$\bar{X}$	21	22**	23	7	6	5	$\bar{X}$	4	2	1	$\bar{X}$
PLATYHELMINTHES																									
Dugesia tigrina			4				1			1	1			1		1	1	3			1				
NEMERTEA																									
Prostoma rubrum												2		1		7		1			1	1			1
NEMATODA				1	1		1	1	1	3	3	8	6	3	4	4	7	2	5	2	4	1		1	1
ECTOPROCTA																									
Fredericella sultana			P						P	P		P	P		P	P	P	P	P	P		P	P	P	
OLIGOCHAETA																									
Dero digitata	106	7	231	5	5	38	65	99	11	50	59	1005	18	47	30	37	79	82	88	27	61	31	7	6	15
Nais variabilis		1					1		36	5	8	300	20	14	3		42	1	18	13	15	17	9	5	10
Pristina breviseta															1						1				
Pristina longiseta												2													
Pristina longidentata																		7			1				
Pristina sp. 1			2				1			1	1	193		1								1	1		1
Pristina sp. 2	3		1				1		1		1	4		1	1		1	5			1				
Branchiura sowerbyii			4				1								2		2	4	1		2	10	330	323	.221
Limnodrilus sp.	1225	545	552	1500	812	1127	960	3789	1408	1049	1579	2147	2971	2159	878	5620	682	1787	996	540	977	700	442	199	. 447
Tubifex sp.	74	3	30		1	42	25	1		24	53	154	6	17	48	32	16	7	5	7	17	5	6	2	. 4
Enchytraeidae												1													
HIRUDINEA																									
Helobdella nepheloidea	34	6		1	18	74	22	177	6	3	7	19	2	39	31	5	38		1	1	14	52			17
Helobdella fusca											1			1			1				1				
Dina microstoma	12	1		1	1	31	8	49	1	2	1	1		11	3	2					1				
CRUSTACEA																									
Caenestheriella belfragei				19			3	1						1											
Hyalella azteca			13				2					25	1	1	5	4	38	1	5	18	13		2		1
Procambarus simulans	P	P		P	P	P		P	P	P	P				P			P	P					P	
Orconectes nais			P							P		P	P			P	P	P	P	P		P	P	P	
EPHEMEROPTERA																									
Hexagenia sp.		1	20	1			4			3		4	5	2	9	13	8	12	4	20	11	4	2	8	5
Callibaetis sp.	8		7				3	9	1			4	2	2		2	15	3			4	1	1	1	1
Baetis sp.														1				1	1	1	1		3	1	1
Caenis sp.	1	1	16	1	2	1	4	4	27	76		136	14	24	60	76	68	38	11	41	44	15	20	31	22
Stenonema sp.			2				1	1					1	1			1	1		1	1	1	3	2	2

TABLE V (Continued)

ORDER	3							4							5							6			
STATION	14	20	3	13	12	11	$\bar{X}$	15	17	18	10	9**	8	$\bar{X}$	21	22**	23	7	6	5	$\bar{X}$	4	2	1	$\bar{X}$
ODONATA																									
Nehalennia sp.	13		1				2	4	1			2	1	1	1	2	3	1	1	1	2	2			1
Lestes sp.						1	1	2				1		1											
Telleallagma sp.										1				1											
Argia sp.																2	2	2			1	1	4	1	2
Orthemis sp.	1		1				1																		
Gomphus sp.			1				1									4		1	1	1	1	2	2	1	2
Macrothemis sp.			1				1			1				1			1				1				
Tetragoneuria sp.			1				1																		
Libellula sp.																		1			1				
Cordulia sp.																	1				1				
Aeschna sp.																	1				1				
Didymops sp.																	1				1				
HEMIPTERA																									
Trichocorixa calva	7			5		2	3	23				1	1	5	1	1	15	9	1	19	9	1	2	13	5
Belostoma flumineum																	1				1				
NEUROPTERA																									
Sialis sp.			1				1			1	1	5	3	1	30	3	13	9	2	5	12	1			1
TRICHOPTERA																									
Cheumatopsyche sp.			3				1	2					2	1				1	2	1	1	1	1	4	2
Oecetis inconspicua												2	1	1			7	2		2	2	2			
COLEOPTERA																									
Enochrus nebulosus																	1				1			2	1
Berosus peregrinus			1				1			2	1		4	1	2	21	13	12	5	5	7	3	5	4	4
Tropisternus lateralis	2						1		3			5		1					1		1				
Copelatus chevrolatis																			1		1				
Agabus semivittatus								2						1		1			2	2	1		1		1
Laccophilius fasciatus	2	1			2	5	2	6	4	1				2			1	4	3		1	1			1
Hydroporus sp.	103	1	47			4	26		4		1	6	2	1	4		1	9	8	5	5	8	1	6	5
Cyphon sp.			3			1	1											2			2				
Peltodytes littoralis								2			1	1		1			1			2	3	2		3	2
Dineutus assimilis								3															1		1
Dubiraphia vittata			2				2					8	1	1	3	10	74	8		26	22	14	22	11	16
Stenelmis sp.																		1			1	1			1
DIPTERA																									
Tipula furca			1				1		1					1								1		1	1
Limnophila sp.																	1				1				
Limonia sp.												1													
Gonomyia sp.		1					1		1	1		1		1	2	1		1			1				
Erioptera sp.	2						1	1	1	1	2	1	2	1		1		1		1	1	1			1
Megistocera sp.																1									

TABLE V (Continued)

ORDER			3								4							5					6		
STATION	14	20	3	13	12	11	$\bar{X}$	15	17	18	10	9**	8	$\bar{X}$	21	22**	23	7	6	5	$\bar{X}$	4	2	1	$\bar{X}$
DIPTERA (Continued)																									
Anopheles punctipennis			1				1		2			1	1	1					1		1				
Culiseta inornata		1			4		1																		
Psorophora signipennis					1		1																		
Aedes vevans					2		1																		
Chaoborus sp.	12	1		2		64	13	1	3	109	74	2	32	44	26	8	21	18	5	18	18	7	22	1	10
Odontomyia sp.												1										1			1
Tabanus sp.	1	1	2	1		6	2	1	4	7	2	8	6	4		5	6	10	4	5	5	1	3	1	2
Ephydra sp.												5							2		1				1
Notiphila sp.											1			1											
Limnophora sp.													1	1		1								1	1
Cecidomyiidae		3	2		4		2			15	1		4	4		2			2		1	4		3	2
Asilidae			1				1																		
Mycetophilidae		1					1	2	2	1			2	1		1			3	1	1				
Simulium vittatum		1	16			6	4	1		7	19	1	5	8			20	3	4	8	7	9	16	7	11
Bezzia sp.	1		1				1	1	1	2	1			1	1		2	1	1		1	1	3		1
Stilobezzia sp.	17	1	9	5		17	8	9	10	18	12	90	11	12	21	50	30	70	33	33	37	27	16	13	19
Culicoides sp.	1		4				1		1	3	4	2		2	6	13	1	1	2	3	3		4	1	2
Palpomyia sp.	2					1	1	1			3	4	1	1	3	6		8	5	1	3	1	2		1
Atrichopogon sp.												2													
Procladius bellus	40	2	14	83	1	121	44	49	167	265	80	161	19	116	192	64	28	133	37	33	85	22	6	11	13
Pelopia sp. B	29		12	22	1	24	15	32	9	118	2	27		32	96	20	32	52	67	226	95	57	9	27	31
Ablabesmyia mallochi	1		18	2			4			10	2	12	6	4	10	14	6	10	3	13	8	2	12	15	10
Orthocladius sp.	3	17	1	1		2	4		12	20	3	70	76	22	40	286	126	5	25	87	57	72	43	113	76
Orthocladius nivoriundus	16	13	4				6	10	22	26	1	12	65	25	37	250	85	7	39	48	43	66	22	59	49
Metriocnemus sp.	3	6	4				2		11	35	6	53	44	19	10	117	37	6	23	10	17	32	27	60	40
Psectrocladius sp.			2				1									2			4		1			6	1
Smittia nr. atterrima												2	6	1			3	1	2		1				
Pseudosmittia sp.	2	2	2				1	25	8	4	16	16	18	14	23	27	19			7	10	21	4	31	19
Cricotopus sp.	4						1	11	4	13		1		6											
Tendipes attenuatus	35	72	112	47	2		45	21	36	118	162	31	33	74	30	105	5	3	5	5	10	8		1	2
Pseudochironomus fulviventris												14						1	1		1				
Polypedilum halterale			79	1			13	3		5	8	22	6	4	11	19	20	8	13	10	12	24	6	16	15
Polypedilum parascalaenum									2		1			1								5			1
Polypedilum illinoense			6	1		3	3		2	15	2	25	2	4	3	31	14	1	3	29	10	12	8	27	16
Tanytarsus flavipes			4				1		3	6		2	2	2					6		1			1	1
Stictochironomus devinctus	6	1	41	3	1	1	9	10	17	76	2	17	109	43	53	7	2	17	5	3	16	10	5	3	5
Glyptotendipes sp.									3			6		2	8	4				1	2				
Glyptotendipes nr. senilis	4	3	83	228			53	6	1	15	1	90	10	7	9	89	27	6	4	16	12	59	20	20	33

TABLE V (Continued)

ORDER	3							4							5							6			
STATION	14	20	3	13	12	11	$\bar{X}$	15	17	18	10	9**	8	$\bar{X}$	21	22**	23	7	6	5	$\bar{X}$	4	2	1	$\bar{X}$
DIPTERA (Continued)																									
Harnischia nr. pseudotener				66			11			6				1	1	2	2	4		6	3	1	2	7	2
Cryptochironomus nr. fulvus	13	5	38	10	1	8	13	28	24	41	12	45	20	25	65	32	15	10	8	24	24	21	6	14	14
Dicrotendipes sp.	1	7	40				8	2		6	3	7	10	4	11	12	13		10	9	9	16	12	22	17
Paratendipes nr. albimanus			119				20																		
Calopsectra nr. guerla	9	1	124	26		4	27	5	4	48	1	216	1	12	7	28	17	11	9	13	11	72	4	35	37
MOLLUSCA																									
Ferrissia shimekii			9				2					1													
Physa anatina	27	9	5	1	3	3	8	23	18	36	8	36	19	21	18	23	5	58	10	5	19	9	2	3	5
Lymnaea humilus	10	1					2	1	4			1		1				2			1				
Helisoma anceps	4						1	21	1		3			5	2						1				
Sphaerium transversum		4	8				2	9	3	37		68	5	11	143	3	50	5	4	14	43	30	17	14	30
Uniomerus tetralasmus								1						1	1	1					1		1	1	1

*Rounded to the nearest whole number except when less than $1/m^2$, these are shown as $1/m^2$.

**Excluded from stream-order analyses.

During periods of increased stream flow the level of Skeleton Creek rises causing a decrease in velocity and heavy siltation in the lower reaches of Otter Creek.

Seasonal variations in numbers of species and individuals were evident (Fig. 5). Maximum numbers of species and individuals occurred during spring following several months of continuous stream flow. Minimum numbers of individuals occurred during fall, following heavy rains which caused flooding and scouring of the stream bed. Maximum numbers of individuals occurred in fourth order streams throughout the year. Minimum numbers of individuals were collected in the sixth order stream during fall, winter and spring, and in third order streams during summer. The greatest annual variation in numbers of species was in third and fourth order streams and the least variation was in the sixth order stream. During summer and fall more species were collected in fifth order streams. During winter the numbers of species were similar in all stream orders. During spring the numbers were similar in third, fourth and fifth order streams, but decreased in the sixth order stream.

Distinct longitudinal segregation of benthic invertebrates was not as evident in this natural stream as in polluted streams reported by other workers. Several species were collected from streams of a single order, but these were taken so infrequently that no inferences could be drawn concerning their distribution. Certain common species were definitely more abundant in a particular stream order (Table V).

Effects of Drought and Flooding

During summer, as the water level receded, tendipedid larvae, mainly predatory species, replaced *Limnodrilus* sp. as the dominant

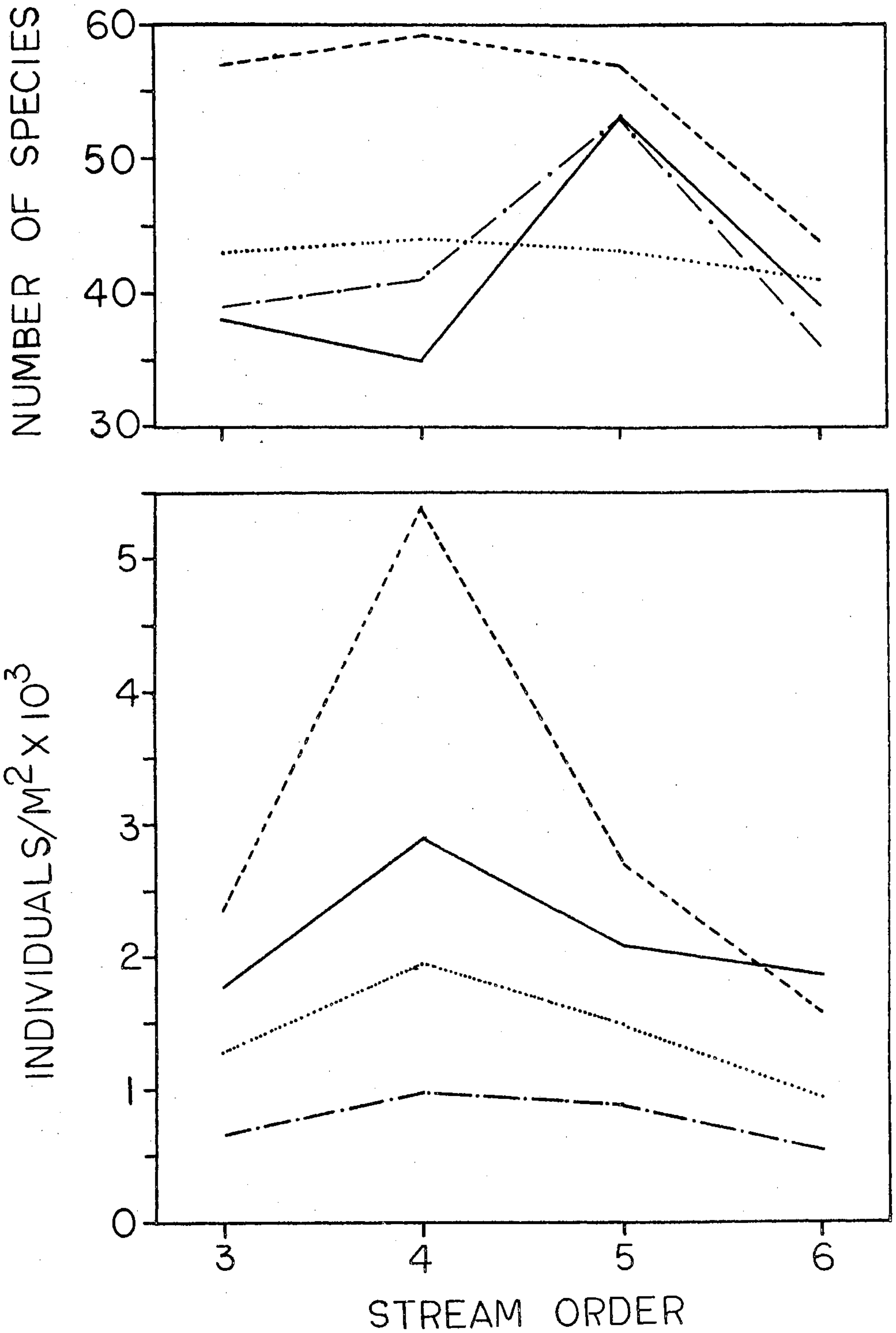

Fig. 5. Seasonal Variations in Numbers of Species and Individuals in Relation to Stream Order. Fall = (–·–), Winter = (····), Spring = (– – – –), Summer = (——).

organism (Fig. 6). Tendipedid larvae increased from 13% ($158/m^2$) of the total pool fauna in June, when much of the stream was running, to 48% ($1049/m^2$) in August, when small stagnant pools were common. Limnodrilus sp. decreased from 65% ($820/m^2$) in June to 15% ($358/m^2$) in August.

During July and August, leeches, adult beetles, Chaoborus sp., Calopsectra nr. guerla, Glyptotendipes nr. senilis, Harnischia nr. pseudotener and the predatory tendipedids Pelopia sp. B., Procladius bellus and Ablabesmyia mallochi increased to maximum density.

Predatory tendipedid larvae have wider ranges of adaptability to varying environmental conditions than most species (Paine and Gaufin, 1956). In Otter Creek, Pelopia sp. B seemed more resistant to crowding and stagnant water than other invertebrates, replacing Limnodrilus sp. as the most numerous species during August.

Several investigators have studied invertebrate drought survival. Larimore et al., (1959) reported that some mayfly nymphs, beetles, snails, caddis fly larvae and dipterous larvae burrowed in sand and gravel following moisture as the stream bed dried up. Some mayfly nymphs, crustaceans and beetles survive dry spells in interstitial spaces containing water-saturated air (Clifford, 1965). Hynes (1958), while studying a stream with a rocky bed, found that worms and small crustaceans could survive prolonged drought, most insect nymphs and larvae were killed, but the eggs of most species survived. Some leeches and snails are able to tide over dry periods by burrowing into the mud and constructing mucus-lined cells in which they aestivate (Pennak, 1953). Some caddis flies are adapted for surviving drought as

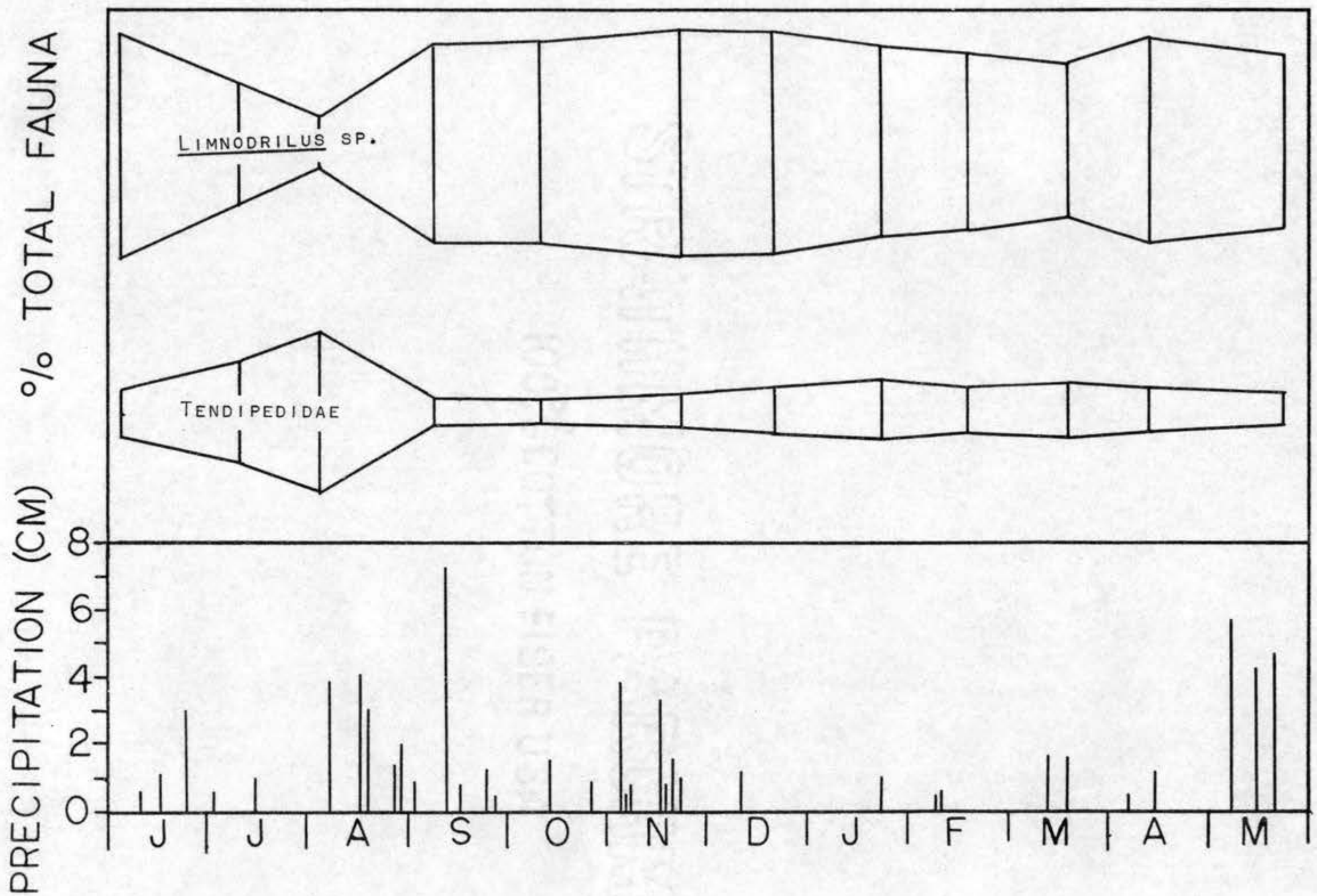

Fig. 6. Seasonal Variations of Limnodrilus Sp. and Tendipedid Larvae as Percentages of Total Fauna, with Daily Precipitation

aestivating larvae or pupae in semi- or truly-terrestial environment (Clifford, 1965). Adult insects and crayfishes migrate from one body of water to another when the water becomes stagnant. Procambarus simulans, a common resident of third and fourth order streams in Otter Creek, survives fluctuating water levels by burrowing down to the water table (Williams and Leonard, 1952).

Between the August and September collections more than 16 cm of rain fell, causing flooding and scouring of the stream bed. Total numbers of organisms were reduced from $2470/m^2$ in August to $565/m^2$ in September. Similar erosional effects have been observed in other streams (Moffett, 1936; Stehr and Branson, 1938; Tarzwell, 1938; Jones, 1951; Sublette, 1956; Clifford, 1965).

Limnodrilus sp. increased from 15% ($358/m^2$) of the total pool fauna in August to 59% ($334/m^2$) in September, following the flood. Tendipedid larvae decreased from 48% ($1049/m^2$) in August to 8% ($47/m^2$) in September (Fig. 6). The most abundant species of tendipedid larvae during the August collections were greatly reduced or absent in the September collections. These observations suggest that Limnodrilus sp. was more resistant to flooding than tendipedid larvae. However, between the September and October, October and November, and April and May collections floods occurred which were comparable in size to the summer flood. Before these floods the stream had been running and the dominant tendipedids were tube-dwelling species. Numbers of organisms were reduced, but the relative percentages of Limnodrilus sp. and tendipedid larvae changed very little. Before the summer flood the dominant tendipedids were free-living, predatory species. Species which inhabit stagnant water, as were present before the summer flood, are unsuited for repopulation of flowing water (Larimore et al., 1959).

Following flood, repopulation of some benthic insects may occur by upstream flight of fertilized females (Müller, 1954). Many entirely aquatic organisms such as molluscs and annelids may have sufficiently high reproductive rates to maintain populations despite torrential floods (Stehr and Branson, 1938). Some amphipods and crayfishes, which have relatively low reproductive rates, repopulate streams by upstream migration (Minckley, 1964; Momot, 1966).

Species Diversity

Species diversity (H) reflects the manner in which individuals are distributed among species in the community. Maximum diversity (Hmax) exists if all individuals belong to different species. Minimum diversity (Hmin) occurs if all individuals are of one species. Species diversity usually lies between Hmax and Hmin. Diversity per individual ($\bar{H}$) becomes smaller as the probability of selecting a particular species becomes a certainty, and larger as the choice becomes more uncertain. Redundancy (R) is maximal when no choice exists and minimal when there is more choice (Patten, 1962).

Seasonal species diversity, diversity per individual and redundancy were calculated from the numbers of species and individuals collected during each season. Annual values were calculated from numbers of species and individuals collected throughout the year.

Species diversity (H) was maximal and exhibited similar patterns during summer and spring (Fig. 7). During summer only small pools

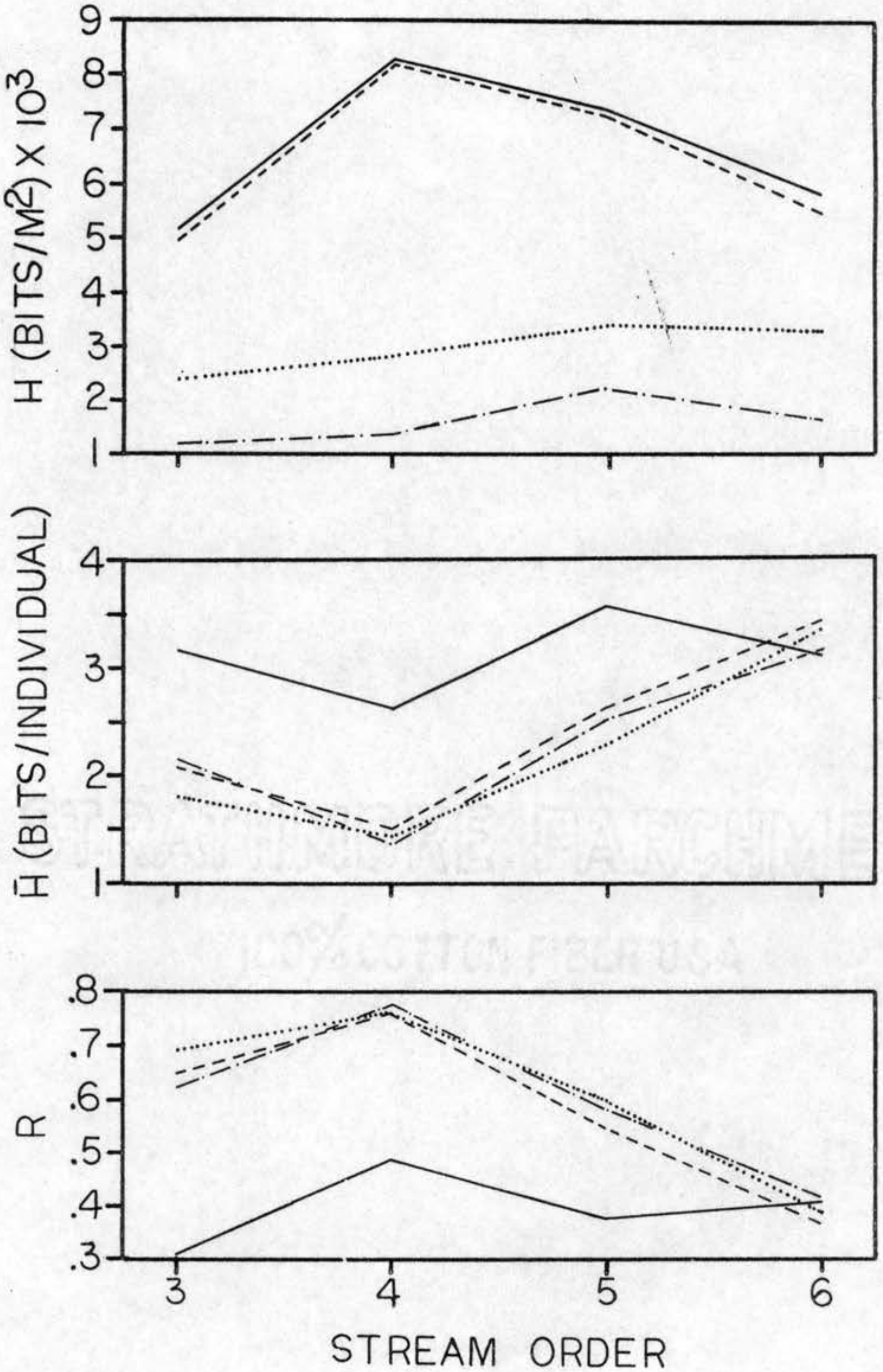

Fig. 7. Seasonal Variations in Species Diversity (H), Diversity Per Individual ($\bar{H}$), and Redundancy (R) in Relation to Stream Order. Fall = (— · —), Winter = (....), Spring = (----), Summer = (——)

existed and all organisms were concentrated into small areas. During spring, following the longest period of continuous stream flow, more individuals and species were present than during other seasons. Species diversity was minimal in all stream orders during fall, a period of flooding. During fall and winter diversity was similar in all stream orders.

Diversity per individual ($\bar{H}$) was maximal and redundancy (R) was minimal during summer, except in the sixth order stream where these values were similar during all seasons (Fig. 7). During summer diversity per individual and redundancy were similar in all stream orders. During fall, winter and spring diversity per individual increased and redundancy decreased in higher order streams, indicating more random distribution of species. Highest diversity per individual and lowest redundancy occurred during summer in third, fourth and fifth order streams, and during spring in the sixth order stream. Low diversity per individual and high redundancy usually resulted when large numbers of *Limnodrilus* sp. or some tendipedid species formed most of the community.

Annual species diversity (H) increased from third to fifth order streams, then decreased in the sixth order stream (Fig. 8). Diversity per individual ($\bar{H}$) increased and redundancy (R) decreased in the higher order streams.

Ranges of species diversity, diversity per individual and redundancy for individual stations decreased as stream order increased, indicating more uniform community structure in higher stream orders (Table VI).

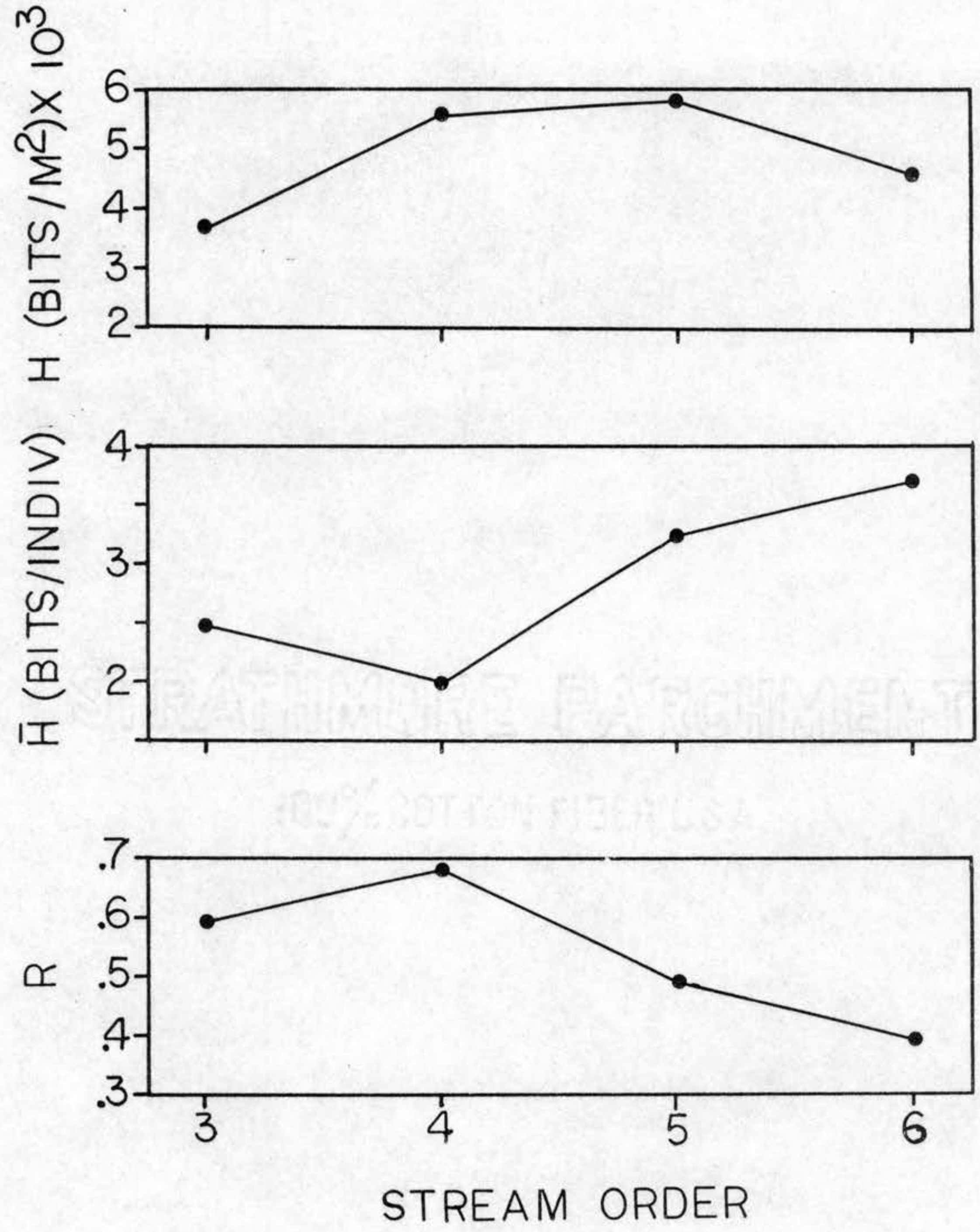

Fig. 8. Annual Species Diversity (H), Diversity Per Individual ($\bar{H}$) and Redundancy (R) in Relation to Stream Order

TABLE VI

EXTREMES OF SPECIES DIVERSITY (H), DIVERSITY PER INDIVIDUAL ($\bar{H}$) AND REDUNDANCY (R), AND RANGES FOR STREAM ORDERS

Order	H (Bits/M^2)	$\bar{H}$ (Bits/indiv)	R
3	6,293 - 512 5,781	3.70 - 0.59 3.11	0.90 - 0.36 0.54
4	7,441 - 3,418 4,023	3.25 - 1.19 2.06	0.80 - 0.43 0.37
5	6,612 - 3,650 2,962	3.84 - 2.07 1.77	0.67 - 0.34 0.33
6	5,056 - 3,491 1,565	3.84 - 3.03 0.76	0.47 - 0.33 0.14

At third order stations, species diversity and diversity per individual were usually maximal and redundancy minimal at station 3(3). This station was located in an adventitious stream which flowed directly into the sixth order stream. Species diversity values here were more similar to higher order stations than to other third order stations.

Species diversity, diversity per individual and redundancy values for Otter Creek, a natural stream, showed the same general pattern as reported for streams which received pollutional effluents (Wilhm, 1965; Mathis, 1965). However, in Otter Creek, the pattern was associated with physiographic stream succession, rather than the influence of effluents.

Analyses of variance of species diversity, diversity per individual and redundancy were determined testing the null hypothesis that the means were equal between and within stream orders. Annually, there were significant differences for species diversity at the 75% confidence level, diversity per individual at the 95% level and redundancy at the 90% level (Table VII).

TABLE VII

CALCULATED F VALUES FROM ANALYSES OF VARIANCE OF SPECIES DIVERSITY (H), DIVERSITY PER INDIVIDUAL ($\bar{H}$) AND REDUNDANCY (R)*

Season	H ($Bits/M^2$)	$\bar{H}$ (Bits/indiv)	R
Annual	2.18	8.82	3.06
Summer	1.63	1.95	0.74
Fall	1.35	3.59	0.72
Winter	0.81	2.81	2.27
Spring	0.94	3.17	2.67

*Theoretical F (3.15) at: 95% confidence level = 3.29, 90% level = 2.49, 75% level = 1.52, 50% level = 0.83

Seasonally, species diversity was significantly different at the 75% confidence level during summer and fall, and the 50% level during winter and spring. Diversity per individual was significant at the 75% level during summer, 95% level during fall, and 90% level during winter and spring. Significance of redundancy increased from the 25% level in summer to the 90% level during spring.

Heterogeneity

The index of heterogeneity (IH) reflects differences in distribution of individuals into species between stations. A low index number indicates similar community structures, while the converse is true for a high index number.

Heterogeneity is always higher in standing water than in turbulent water and is often a consequence of diversity of the first occupants, when time has not been sufficient for randomizing distribution (Margalef, 1958). Heterogeneity of later successional stages is more random and results from adjustment to local ecological conditions (Margalef, 1960). The natural successional trend in flowing water is toward more random distribution and decreased heterogeneity. However, an annual cycle of heterogeneity may exist in intermittent streams.

The regular seasonal occurrence of drought and flooding in Oklahoma caused an annual cycle of heterogeneity in Otter Creek (Fig. 9). Summer and fall heterogeneity patterns were similar. During summer only small pools existed at most stations and all organisms were concentrated into small areas reducing the heterogeneity. Heavy rainfall and floods in fall distributed the organisms throughout the system into discontinuous patches, causing an increase in heterogeneity. Margalef (1960) stated that both crowding and diffusion work against heterogeneity. During winter, a period of constant stream flow, heterogeneity increased in third and fourth order streams, and decreased in fifth and sixth order streams. Winter indices of heterogeneity were similar for all streams orders. During spring, following several months of continuous stream flow, heterogeneity decreased as stream order increased (Fig. 9).

Mean annual heterogeneity decreased as stream order increased (Fig. 9; Table VIII). Mathis (1965) reported that heterogeneity decreased downstream.

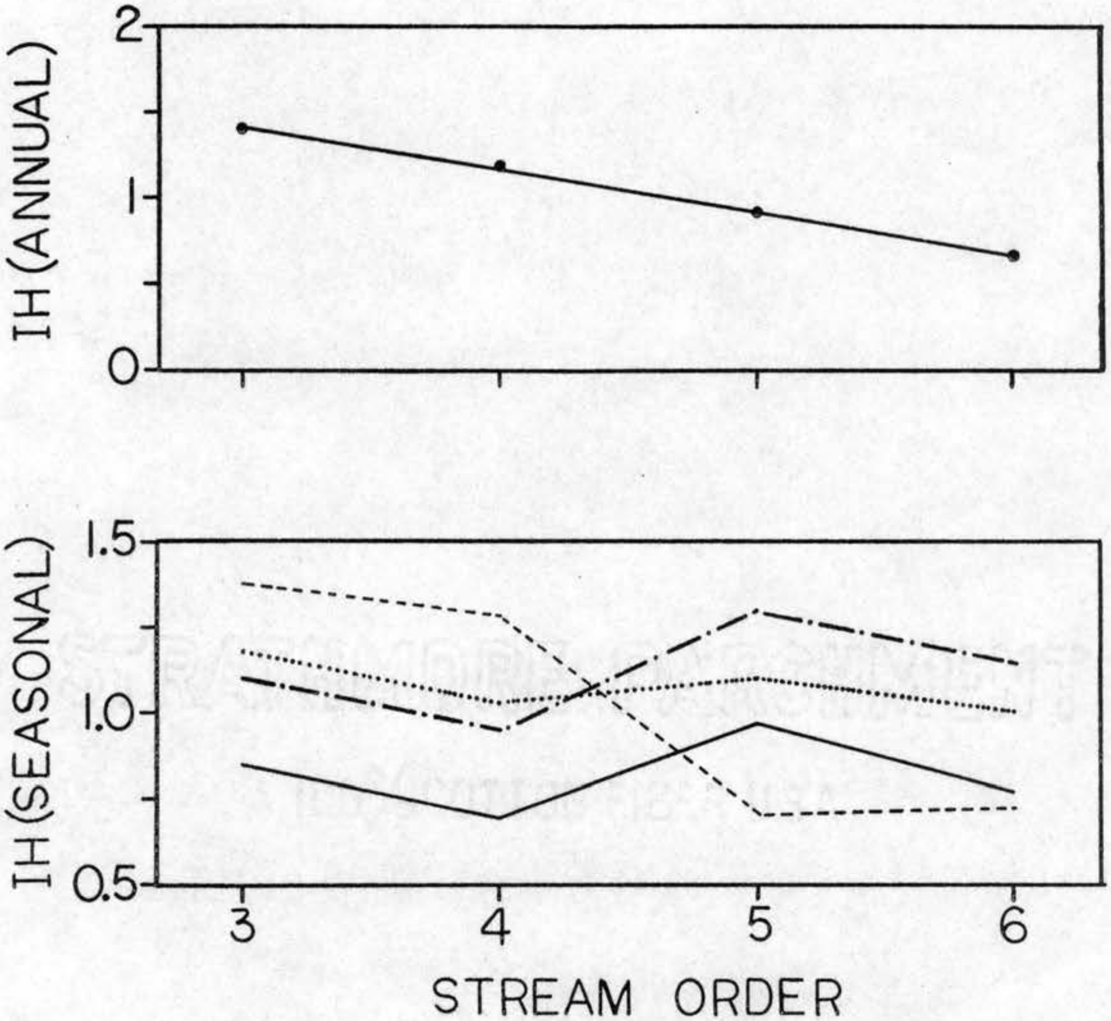

Fig. 9. Mean Seasonal and Annual Heterogeneity in Relation to Stream Order. Fall = (-.-), Winter = (....), Spring = (----), Summer = (——)

Heterogeneity was greater between station 3(3), located in an adventitious stream which flowed directly into the sixth order stream, and other third order stations than between this station and stations located in higher order streams (Table VIII). This indicates more

TABLE VIII

ANNUAL INDICES OF HETEROGENEITY FOR OTTER CREEK

ORDER	3						4					5					6	
STATION	14	20	3	11	12	13	8	10	15	17	18	21	23	7	6	5	4	6
20	0.90																	
3	1.81	2.00																
11	1.00	0.83	2.26															
12	1.58	1.12	2.79	0.87														
13	1.15	0.98	2.16	0.64	0.91													
8	1.41	0.97	0.94	1.76	2.16	1.45												
10	1.06	1.30	1.58	1.52	1.85	1.31	1.32											
15	0.74	0.97	2.10	1.21	1.59	1.27	1.41	1.46										
17	0.64	1.01	2.01	1.57	1.93	1.48	1.36	1.38	1.15									
18	1.22	0.70	1.36	1.56	1.76	1.12	0.91	0.65	1.28	1.06								
21	0.99	1.23	1.50	1.56	2.04	1.11	1.01	1.01	1.38	1.19	0.93							
23	0.66	1.86	0.34	2.12	2.78	1.77	0.80	1.43	1.72	1.99	1.22	1.00						
7	1.64	1.91	1.43	1.99	2.84	1.89	1.06	1.78	1.76	1.72	1.45	1.11	0.92					
6	1.49	1.46	1.30	1.70	2.37	1.60	0.62	1.50	1.43	1.46	1.04	1.07	1.40	1.00				
5	1.46	1.42	1.39	1.66	2.46	1.32	0.24	1.35	1.06	1.55	1.01	0.67	0.88	0.84	0.71			
4	1.72	1.71	1.40	1.93	2.62	1.70	0.83	1.37	1.41	1.93	1.15	1.17	1.02	0.74	0.98	0.45		
2	1.53	1.66	1.10	1.61	2.69	1.50	0.87	1.54	1.22	2.00	1.31	0.86	1.08	0.91	1.04	0.51	0.78	
1	1.75	1.51	1.07	1.82	2.41	1.34	0.59	1.62	1.40	1.72	1.56	1.06	1.04	1.12	1.01	0.73	0.88	0.44

similarity in community structure between station 3(3) and higher order stations than between station 3(3) and other third order stations. Many species collected at station 3(3) were taken in higher order streams, but at no other third order stations (Table V).

Effects of Oil Field Brines

Stations 9(4) and 22(5) received oil field brines by seepage through the soil from oil wells located approximately 180 m from the streams above these stations. These stations are compared here with stations of the same stream order above and below the influx.

Marked increases in sodium chloride and sulfates occurred at stations 9(4) and 22(5). Conductivity was consistently higher and turbidity was lower than at other stations (Table IX). Conductivity was higher at station 22(5) than at station 9(4), signifying the presence of more concentrated brines at station 22(5). Total alkalinity and dissolved oxygen were also higher at these stations.

Algae were more abundant at stations which received brines than at other stations, probably because of decreased turbidity. Spirogyra sp. was dominant at station 9(4) and Vaucheria sp. was dominant at station 22(5).

Benthic invertebrate numbers were larger at stations 9(4) and 22(5) than at other stations (Table XI). More species (62) were collected at station 9(4) than at any other station. The number of species (52) collected at station 22(5) resembled other fifth order stations.

Limonia sp., Atrichopogon sp., Pristina longiseta and enchytraeids were collected only at station 9(4). Prostoma rubrum, Ephydra sp. and

Pseudochironomus fulviventris were collected here, but at no other fourth order station. Otherwise, they were collected in fifth or sixth order stations. In comparison with other fourth order stations, species most numerous at station 9(4) were Dero digitata, Nais variabilis, Tubifex sp., Hyalella azteca, Caenis sp., Nehalennia sp., Sialis sp., Oecetis inconspicus, Tropisternus lateralis, Hydroporus sp., Dubiraphia vittata, several dipterans, Physa anatina and Sphaerium transversum.

Megistocera sp. was collected only at station 22(5). Limnophora sp. was collected here, but at no other fifth order station. In comparison with other fifth order stations, Prostoma rubrum, Limnodrilus sp., Caenis sp., Orthemis sp., Berosus peregrinus and several dipterans were most abundant at station 22(5).

TABLE IX

MEAN ANNUAL PHYSICO-CHEMICAL CONDITIONS AT STATIONS WHICH RECEIVED OIL FIELD BRINES AND AT STATIONS OF THE SAME ORDER ABOVE AND BELOW THE BRINE INFLUX

Station	pH	Alkalinity (ppm)	Oxygen (ppm)	Turbidity (ppm)	Conductivity (micromhos/cm)
*10(4)	8.3	114	10.3	147	536
9(4)	8.2	235	13.6	50	607
**8(4)	8.1	141	8.9	171	520
*21(5)	8.1	188	9.4	113	662
22(5)	8.0	198	9.6	34	2,462
**23(5)	8.0	157	8.6	121	864

*Stations located 2 km above the influx

**Stations located 4 km below the influx

The presence of Polypedilum illinoense was considered to be a positive indicator of an unpolluted habitat by Paine and Gaufin (1956). However, in Otter Creek this species reached its highest densities at stations which received oil field brines.

Indices of heterogeneity (IH) showed that the benthic fauna at station 9(4) was more similar to the fauna of downstream station 8(4) than to that at upstream station 10(4)(Table X). By this index, the fauna of station 22(5) was more similar to the fauna of upstream station 21(5) than to that of downstream station 23(5).

TABLE X

ANNUAL HETEROGENEITY AND COMMUNITY STRUCTURE AT STATIONS WHICH RECEIVED OIL FIELD BRINES AND AT STATIONS OF THE SAME ORDER ABOVE AND BELOW THE BRINE INFLUX

Station	Number of Species	Number of Individuals	Heterogeneity (IH)	Diversity (H)	Diversity Per Indiv. ($\bar{H}$)	Redundancy (R)
*10(4)	44	2196		356	1.78	.70
			1.58			
9(4)	62	5669		1490	3.15	.48
			.89			
**8(4)	47	3651		458	1.37	.77
*21(5)	46	2169		607	3.36	.41
			.59			
22(5)	52	7881		1037	1.58	.73
			1.07			
**23(5)	57	1917		614	3.84	.34

*Stations located 2 km above brine influx

**Stations located 4 km below the brine influx

Generally, species diversity (H) was higher at stations 9(4) and 22(5) than at any other station. However, moderate oil field brines at station 9(4) seemed to improve the stream by decreasing turbidity and increasing primary productivity. The increase in diversity per individual ($\bar{H}$) and decrease in redundancy (R) indicates more random distribution of species and improved stream conditions (Table X).

More concentrated oil field brines at station 22(5) did not seem to exclude species, but did allow certain species (Limnodrilus sp. and several tendipedids) to become superabundant. Diversity per individual ($\bar{H}$) decreased and redundancy (R) increased at station 22(5), denoting less random distribution and greater repetition.

Wilhm (1965) suggested that diversity per individual ($\bar{H}$) and redundancy (R) appeared to be more adequate in evaluating stream conditions than other parameters. Numbers of species and individuals, benthic associations and species diversity (H) indicated that stations 9(4) and 22(5) had increased productivity. However, diversity per individual and redundancy distinguished between harmful and beneficial effects.

CHAPTER VI

COMMUNITY STRUCTURE OF FISHES

Fishes were collected from all stations on two occasions. The first collections were taken on 10 June 1965 following approximately eight months of continuous stream flow at all stations, except 11(3), 12(3) and 13(3). During summer 1965 a severe drought occurred, and all third and most fourth order stations were dry by September. Remaining stations existed as small, stagnant pools. On 21 September approximately 6 cm of rain fell causing continuous stream flow throughout the basin for two or three days. The second collections were taken on 28 September.

Species Diversity

Species diversity (d) expresses the linear relationship between the number of species and logarithm of total number of individuals (Margalef, 1951). This parameter is applicable to samples that are too small for analysis by other methods.

Eighteen species of fishes were collected in June (Table XI). Numbers of species collected from third, fourth, fifth and sixth order streams were 7, 12, 16 and 17, respectively. Numbers of species for individual collections ranged from 1 to 5 in third order streams, 6 to 11 in fourth order streams, 8 to 13 in fifth order streams and 5 to 13

TABLE XI

DISTRIBUTION OF FISHES IN OTTER CREEK DRAINAGE BASIN, 10 JUNE 1965

STREAM ORDER	3						4						5						6			
STATION NUMBER	14	20	3	13	12	11	15	17	18	10	9*	8	21	22*	23	7	6	5	4	2	1	M
Notemigonus crysoleucas	91		4				51	10	1	8	5	2	41		4	5			2			
Pimephales promelas	241	1				272		110	51	123	301	311	208	155	1	147	65	44	25			
Ictalurus melas	3		6				5		9	3		4	8	7	1	6	9	3	5	2		
Lepomis macrochirus	27		3				8	26	2	1	12	4	1		1	1	1	2		4		
Lepomis cyanellus			27						11	7	1	2				3	9			2		
Gambusia affinis			1	1	2	10		5	4	100	2	12	21	7	2	72	30	17	1	6	4	13
Lepomis humilis	6						11	1	13	12	2	41	22		4	1	4	3	3	2		
Notropis lutrensis							1		6	14	110	29	77	62	11	33	76	157	152	72	146	34
Lepomis megalotis									4		4	12	3	8	4	19	23	4	10	13	3	1
Micropterus salmoides											10	1			7	1	11	8	2			1
Pomoxis annularis								8			1				68	46	4	13	7	2		
Phenacobius mirabilis												1			1	3	3	23	9	2		6
Ictalurus punctatus																	1	1	1	2		
Carpiodes carpio															1			1	1			
Pylodictis olivaris																	1					
Notropis percobromus															1						18	33
Hybognathus placita																			2	4	4	73
Lepisosteus osseus																						1
No. of Individuals (N)	341	1	410	1	2	10	348	160	101	268	448	419	381	239	106	337	237	276	220	111	175	168
No. of Species (S)	5	1	5	1	1	1	6	6	9	8	10	11	8	5	13	12	13	12	13	11	5	8
Species Diversity (d)	0.69	0	0.66	0	0	0	0.85	0.99	1.73	1.25	1.47	1.66	1.18	0.73	2.57	1.89	2.19	1.96	2.22	2.12	0.77	1.38
Combined N	765						1296						1337						668			
Combined S	7						12						16						17			
Combined d	0.90						1.54						2.08						2.46			

*Excluded from stream-order analysis

in the sixth order stream. Except for a single specimen of Pylodictus olivaris at station 6(5), all species collected in low stream orders were taken also from each higher stream order. Species diversity (d) for increasing stream orders were 0.90, 1.54, 2.08 and 2.46 (Table XI).

Sixteen species were collected in September (Table XII). No fish were collected from four of the third order stations. However, from the remaining two stations, five of the seven species taken in June were again collected. Numbers of species collected from fourth, fifth and sixth order streams were 8, 14 and 15, respectively. Numbers of species in individual collections ranged from 0 to 4 in third order streams, 1 to 8 in fourth order streams, 8 to 13 in fifth order streams and 9 to 12 in the sixth order stream. Species diversity values (d) for increasing stream orders were 0.87, 1.38, 1.93 and 2.06. Again, except for the occurrence of Ictalurus natalis at station 5(5), all species taken at low order streams were collected from each higher stream order. Fourteen of the 18 species collected in June were collected in September.

Increase in species diversity with increase in stream order may be attributed to increased available habitat and decrease in environmental fluctuations. Species which inhabited the lower order streams may be more adaptable to environmental extremes than those restricted to higher order streams.

TABLE XII

DISTRIBUTION OF FISHES IN OTTER CREEK DRAINAGE BASIN, 28 SEPTEMBER 1965

STREAM ORDER	3						4						5						6			
STATION NUMBER	14	20	3	13	12	11	15	17	18	10	9*	8	21	22*	23	7	6	5	4	2	1	M
Notemigonus crysoleucas	1		10						3		14	10	21	2	5	2	2	3	1		1	
Pimephales promelas	8								1	7	3	4	6	53	3	1	14	26	4			2
Ictalurus melas			5						1	3		29	6	2		11	8	1	5		4	6
Lepomis macrochirus			6								2			2	4	3		6	9	26		26
Lepomis cyanellus			82						14	2	18	8	4	11	18	8	2	29	13	5	12	17
Lepomis humilis							3		17		17	11	10	16	35		4	51	35	24	9	19
Gambusia affinis								1	7		35	27	6	44	24	7	45	47	38	15	17	13
Notropis lutrensis									2		78	4	9	148	12		57	208	102	26	98	29
Lepomis megalotis									2		47	5	2	79		2	9	111	88	28	104	
Micropterus salmoides											6				1	1	2	3	2	4		
Pomoxis annularis															2		2	1	46	4	2	2
Ictalurus punctatus															1			1		2	4	2
Ictalurus natalis																		1				
Carpiodes carpio															1							6
Dorosoma cepedianum																			1		1	35
Notropis percobromus																						4
No. of Individuals (N)	9	0	103	0	0	0	3	1	47	12	220	98	64	357	106	35	145	488	344	134	252	161
No. of Species (S)	2	0	4	0	0	0	1	1	8	3	9	8	8	9	11	8	10	13	12	9	10	12
Species Diversity (d)	0.46	0	0.65	0	0	0	0	0	1.82	0.80	1.48	1.53	1.14	1.36	2.14	1.97	1.81	1.94	1.88	1.63	1.63	2.17
Combined N	112						161						838						891			
Combined S	5						8						14						15			
Combined d	0.87						1.38						1.93						2.06			

*Excluded from stream-order analysis

Effect of Drought

Species diversity values from the June and September collections were remarkable similar (Fig. 10). After only two or three days of stream flow, areas which were previously uninhabited were reinvaded by most species which were collected following eight months of stream flow. If flow had existed longer, Gambusia affinis, Notropis percobromus, Phenacobius mirabilis and Hybognathus placita probably would have extended their distribution up stream as before the drought. After a drought different species move up stream and become re-established at different rates (Larimore et al., 1959).

Paloumpis (1958) concluded that survival of fishes during drought was possible only because pools persisted and remained inhabitable. In Otter Creek, few fishes survived drought conditions in pools because of stagnation and increased predation. Repopulation of Otter Creek was probably by migration of fishes from Skeleton Creek and from overflowing adjacent farm ponds.

Effects of Oil Field Brines

Species diversity (d) of fishes at stations 22(5) and 9(4), which received oil field brines, were similar with other stations of the same order, with one exception (Tables XI and XII). During June, species diversity (d) decreased from 1.18 at upstream station 21(5) to 0.73 at station 22(5), then increased to 2.57 at downstream station 23(5). Numbers of species decreased from eight at station 21(5) to five at station 22(5), then increased to 13 at station 23(5). The June collections were taken following several months of continuous stream flow,

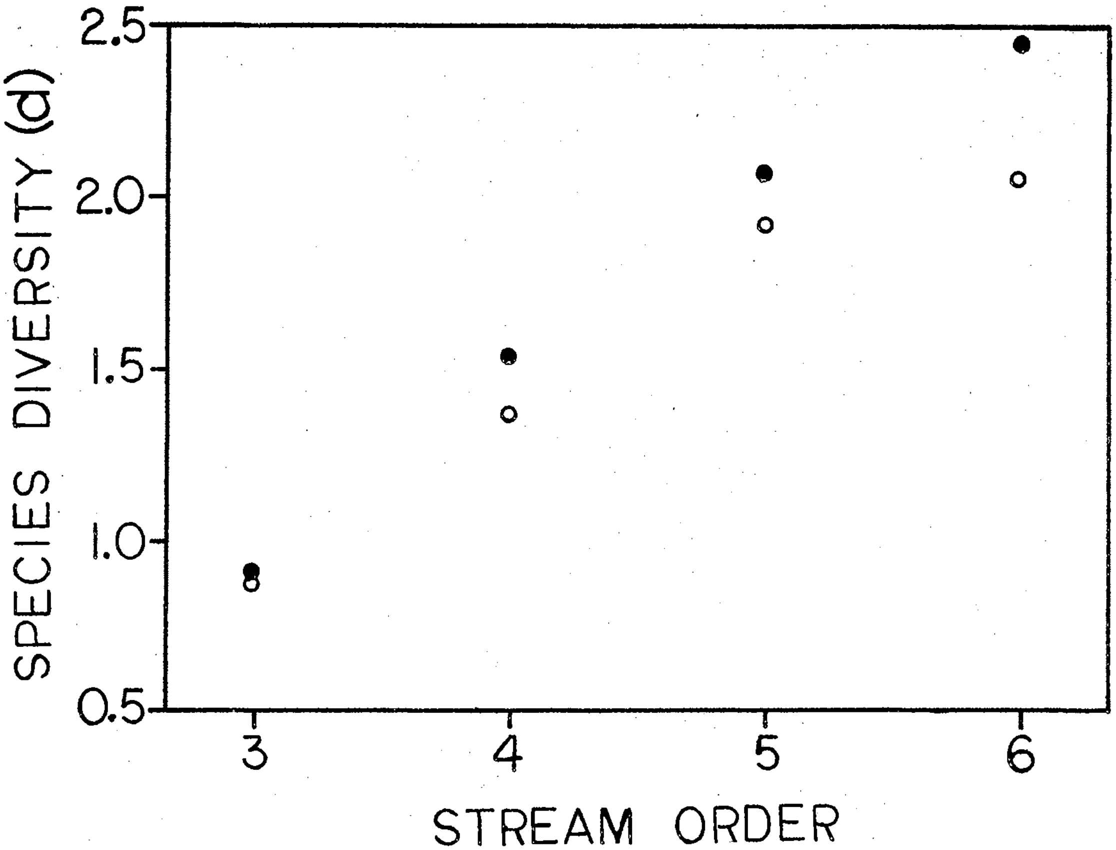

Fig. 10. Species Diversity (d) of Fishes in Relation to Stream Order. ● = June Collections, 0 = September Collections

during which the conductivity and presumably the concentration of brines was nearly maximal.

CHAPTER VII

STREAM ORDER AND COMMUNITY STRUCTURE IN COMPARATIVE STUDIES

Stream order provides a widely applicable, objective basis of stream classification. Stream-order analysis permits a quantitative description of drainage basins. Gradient, flow, stream size, basin size, and community structure are closely correlated with stream order. In natural streams environmental fluctuations decrease as stream order increases, resulting in more random distribution of organisms and more complex community structure.

In Otter Creek, physico-chemical conditions and community structure were closely related to stream order. Gradient decreased, while stream depth, width and flow increased as stream order increased. Water temperature, pH and turbidity decreased, while alkalinity and conductivity increased as stream order increased. Abundance of allochthonous plant material seemed to increase with stream order, but was influenced more by the location of the stream in the drainage basin than by stream order. Most streams in the upper reaches of the basin were open or sparsely lined with trees and had little allochthonous material. Streams in the lower reaches had moderate or dense tree cover and usually contained more allochthonous material.

Benthic macroinvertebrate diversity per individual ($\overline{H}$) increased and redundancy (R) decreased as stream order increased. Species diversity (d) of fishes increased progressively with stream order. Annually, the numbers of invertebrate species and species diversity (H) increased in third, fourth and fifth order streams, and decreased in the sixth order stream. Siltation in the sixth order stream may have reduced the number of microhabitats available for invertebrates.

Location of a stream in a drainage basin may be more important than stream order in the regulation of community structure. Station 3(3), located in an adventitious stream which flowed directly into the sixth order stream, had species diversity values and faunal assemblages more similar to stations in higher order streams than to stations in other third order streams. In addition, drainage density and stream frequency were higher, gradient was steeper and more permanent water and allochthonous plant material were present in the adventitious stream.

Drought and seepage of oil field brines upset the stream order-community structure relationship in Otter Creek. During drought all animals were concentrated into small pools and community structure was similar in all stream orders. Introduction of oil field brines at stations 9(4) and 22(5) caused increased conductivity and decreased turbidity. Where brine concentration was less extreme, diversity per individual ($\overline{H}$) increased and redundancy (R) decreased indicating more random distribution of species as a result of improved stream conditions. More concentrated brines caused diversity per individual ($\overline{H}$) to decrease and redundancy (R) to increase denoting less random distribution and greater repetition of selected species.

Use of biocoenoses to describe community structure involves long, cumbersome lists and descriptions, are generally subjective and usually comparable only on regional bases. Species diversity indices derived from information theory summarize community structure clearly and concisely, by providing comparable numerical values.

Comparative studies may be made in streams of the same or distant basins utilizing stream order classification and information theory diversity indices. Streams of the same order with similar geometrical locations in drainage basins may be compared. Many investigators have attempted to evaluate stream pollution utilizing the concept of self purification with stream succession, but have not separated effects of pollution from effects of natural succession. Stream-order analysis and diversity indices may make it possible to distinguish between effects of pollution and physiographic succession.

CHAPTER VIII

SUMMARY

1. A sixth order, intermittent stream system was studied between June 1964 and September 1965. Morphometry, physico-chemical conditions and community structure were quantitatively related to stream order classification.

2. Average drainage area and average length of streams of each order increased, and stream numbers and average gradient decreased exponentially as stream order increased.

3. Physico-chemical fluctuations decreased as stream order increased. Ranges of water temperature, pH and alkalinity decreased as stream order increased. Turbidity decreased, while flow, alkalinity and conductivity increased as stream order increased.

4. One hundred and twenty-one species of benthic invertebrates were collected. Numbers of species increased from 75 in third order pools to 86 in fifth order pools. Only 68 species were collected from sixth order pools. This decrease was attributed to siltation.

5. Annually, species diversity increased in third, fourth and fifth order streams, and decreased in the sixth order stream. Diversity per individual increased and redundancy decreased as stream order increased. Diversity per individual was significantly different between and within stream orders at the 95% confidence level. Redundancy was significantly different at the 90% confidence level.

6. During fall, winter and spring, diversity per individual increased and redundancy decreased as stream order increased. Diversity per individual and redundancy were similar in all stream orders during summer. Diversity per individual was significantly different between and within orders at the 95% confidence level during fall and 90% level during winter and spring. Significance of redundancy increased from the 25% level during summer to the 90% level during spring.

7. Ranges of species diversity, diversity per individual and redundancy decreased as stream order increased indicating more uniform community structure in higher stream orders.

8. Mean annual indices of heterogeneity (IH) between stations of similar order decreased as stream order increased, indicating that similarity of faunal assemblages increased progressively with stream order.

9. A station located in a third order adventitious stream had a community structure and faunal assemblage more similar to stations in higher order streams than to other third order streams.

10. Influx of low concentrations of oil field brines caused diversity per individual to increase and redundancy to decrease, indicating more random distribution of species and improved stream conditions. More concentrated brines caused diversity per individual to decrease and redundancy to increase, indicating less random distribution and greater repetition of selected species.

11. Fishes were collected after eight months of continuous stream flow and again after a severe drought. Species diversity values for both collections were remarkably similar. Species diversity of fishes

increased as stream order increased. Twenty-one species of fishes were collected.

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APPENDIX

APPENDIX

Annotated List of Benthic Macroinvertebrates

PLATYHELMINTHES

Turbellaria

Dugesis tigrina (Girard) was collected sparsely during winter and spring. Maximum numbers were taken at stations 3(3) and 7(5). No distribution pattern was noted.

NEMERTEA

Prostoma rubrum (Leidy) was collected on eight occasions from six stations (Table XIII). Seasonal occurrence (October through April) corresponded closely with the period of continuous stream flow. Maximum density and frequency occurred at station 22(5), characterized by high conductivity, low turbidity and abundant algal growth.

TABLE XIII

DISTRIBUTION OF PROSTOMA RUBRUM IN OTTER CREEK AND LIMNOLOGICAL CONDITIONS AT COLLECTING STATIONS

Date	Station	Density	Temp. (C)	Oxygen (ppm)	pH	Alkalinity (ppm)	Turbidity (ppm)	Conductivity (mhos/cm)
10 Oct. 64	23(5)	11	13	----	8.0	110	250	380
22 Nov. 64	4(6)	11	16	7.7	7.8	85	310	274
22 Dec. 64	22(5)	54	8	10.3	7.6	197	32	1966
22 Dec. 64	7(5)	11	6	11.1	8.2	285	14	580
23 Jan. 65	22(5)	22	2	12.5	8.0	281	29	2612
18 Feb. 65	22(5)	11	11	11.3	7.8	275	29	3530
13 Apr. 65	9(4)*	22	17	10.5	8.3	303	66	701
13 Apr. 65	2(6)	11	14	7.6	8.3	247	102	861

*= collected in a riffle

Specimens collected in winter were covered in cyst-like cases of sand and slime. Child (1901) postulated that P. rubrum encysted during winter. However during laboratory experiments he failed to show that encystment enabled the animal to resist freezing or desiccation.

Coe (1959) gave the range of P. rubrum as, "... from New England to Florida and westward to Washington and California." These are the first records of P. rubrum in Oklahoma.

NEMATODA

Nematodes of the family Mermithidae were collected throughout the year. Maximum numbers occurred during late winter and spring in fourth and fifth order streams. Several specimens were collected while emerging from Orthocladius larvae during March and April.

ECTOPROCTA

Fredericella sultana (Blumenbach) was observed during all monthly collections except August. Maximum numbers occurred at stations 9(4) and 2(6) during April. Colonies were larger and more widely distributed during March and April. F. sultana exhibits a great tolerance to fluctuating environmental conditions (Bushnell, 1966).

ANNELIDA

Oligochaeta

Limnodrilus sp. was taken in all collections at every station. Minimum average density ($334/m^2$) occurred during August and maximum density ($3539/m^2$) occurred in May. Maximum numbers were collected from fourth order streams and minimum numbers were taken in the sixth order stream. Density was always greatest at station 22(5), where 33,720/m^2 occurred in May.

Tubifex sp. was collected throughout the year. Density decreased as stream order increased, when stations which received oil field brines were excluded. Highest density occurred at station 9(4) throughout the year. Maximum average density (71/m^2) occurred during March.

Branchiura sowerbyi Beddard was taken in every collection at stations 1(6) and 2(6), and during summer and fall it was collected at stations 3(3), 6(5), 7(5) and 4(6). Maximum density (1905/m^2) occurred at station 1(6) during July. Larger numbers were taken at station 2(6) during fall, winter and spring, and station 1(6) during summer. Pennak (1953) considered B. sowerbyi a rare species in the U. S. A., but Schaefer, Harrel and Mathis (1965) found it to be common in Northcentral Oklahoma ponds and streams.

Seven species in the family Naididae were collected. These are the first known records of this group in Oklahoma (Harman, personal communication).

Dero digitata O. F. Müller was collected throughout the year. Minimum average density (3/m^2) occurred in September and maximum density (156/m^2) occurred in May. A density of 10,408/m^2 was observed at station 9(4) during May. Budding individuals were collected the year round, but more were observed during late winter and spring. Many specimens were collected in tubes constructed of sand grains.

Nais variabilis Piguet was collected from November to May. Density increased from 1/m^2 in November to 74/m^2 in April, then decreased to 5/m^2 in May. Larger numbers usually occurred at station 9(4).

Five species of *Pristina* were collected. *Pristina breiviseta* Bourne was collected at station 21(5) during September. *P. longiseta* Leidyi was collected at station 9(4) during October. *P. longidentata* Harman was collected at station 7(5) in June, September, November and February. *Pristina* sp. 1 and *Pristina* sp. 2 are new to science and are presently being studied by Dr. Harman. Both species had scattered distributions.

One unidentified specimen in the family Enchytraeidae was collected at station 9(4) during March.

Hirudinea

Helobdella fusca (Castle) was collected at station 10(4) during March and at station 23(5) during October.

Helobdella nepheloidea (Graf) was collected during summer, fall and spring. Maximum density occurred at stations 14(3), 11(3), 15(4), 21(5), 23(5) and 4(6) during July and August. During July and August several specimens were collected carrying from 5 to 41 young.

Dina microstoma Moore was common in third and fourth order streams, and was occasionally taken at stations 21(5) and 22(5). Seasonal occurrence was the same as *H. nepheloidea*. During July and August specimens were observed carrying from two to nine young. Several specimens were collected with worms in their mouths and one had a larval fish in its mouth.

Placobdella sp. was collected from a riffle at station 1(6) during May.

ARTHROPODA

Crustacea

Caenestheriella belfragei (Packard) was collected at station 15(4) during July and station 13(3) during October. During both collections the pools were small and turbid, and the pH was 8.6 and 8.7.

Hyalella azteca (Saussure) was collected from all fifth order stations and at stations 3(3), 9(4), 8(4) and 2(6), throughout the year. Higher numbers occurred during spring.

Crayfish were collected from all stream orders during summer, fall and spring. Procambarus simulans (Faxon) a burrowing form, occurred throughout the basin, but was more abundant in third order pools and at stations 15(4) and 10(4). Orconectes nais (Faxon) was common in fifth and sixth order streams and at station 3(3). It was never observed above stations 9(4) and 18(4). O. nais may construct burrows during drought, but is usually found under rocks in open water (Williams and Leonard, 1952). Orconectes nais has a tendency to migrate upstream, and this is the principal method of resettling an area following drought or flood (Momot, 1966).

Insecta

Ephemeroptera

Caenis sp. average density increased from $4/m^2$ in third order streams to $44/m^2$ in fifth order streams. Density decreased to $22/m^2$ in the sixth order stream. This species occurred throughout the year, but larger numbers were taken during spring.

Hexagenia sp. was common at all fifth order stations and was collected in all stream orders. Larger numbers were collected at stations 3(3), 22(5), 7(5) and 5(5), where mud or organic debris was abundant, during July and August.

Callibaetis sp. and Baetis sp. were collected sporadically throughout the year. Callibaetis sp. was taken in all but third order streams.

Stenonema sp., a common riffle form, was occasionally collected in pools. Larger numbers were taken at stations 3(3), 2(6) and 1(6) during summer.

Odonata

Nehalennia sp., Argia sp. and Gomphus sp. were collected throughout the year. Nehalennia sp. was collected from all fifth order stations and in all stream orders. Maximum density ($97/m^2$) occurred at station 14(3) during August. Argia sp. was collected in fifth and sixth order streams. Maximum density ($21/m^2$) occurred at station 23(5) during March. Gomphus sp. was taken from fifth and sixth order stations and at station 3(3). Maximum density ($21/m^2$) occurred at stations 22 (5) and 2(6) during February and August.

Telleallagma sp. was collected at station 18(4) during May. Lestes sp. was collected at stations 11(3), 15(4) and 9(4) during May. Macrothemis sp. was collected at stations 18(4) and 23(5) during July, and station 3(3) during August. Cordulia sp., Aeschna sp. and Didymops sp. were collected at station 23(5) during summer. Tetragoneuria sp. was collected at station 3(3) during August. Libellula sp. was collected at stations 14(3) and 3(3) in May and November.

Ophigomphus sp. and Hetaerina sp. were collected from riffles at station 1(6) during May and July.

Hemiptera

Trichocorixa calva (Say) was collected from all stream orders, but was more common in fifth and sixth order streams. Maximum density occurred at station 15(4) during July.

Belostoma flumineum (Say) was collected at station 23(5) during August.

Megaloptera

Sialis sp. was collected from all fifth order stations and stations 3(3), 18(4), 10(4), 9(4), 8(4) and 4(6) during summer, fall and spring. Maximum density ($172/m^2$) occurred at station 21(5) during August.

Corydalus cornutus Linnaeus was collected from a riffle at station 1(6) during July.

Trichoptera

Cheumatopsyche sp. was abundant in riffles and was collected in pools during summer and spring. During July and August, when most riffles were dry, specimens were collected only at stations 3(3) and 1(6) indicating a high mortality during drought. Newly hatched individuals were collected during September after the drought had ended. Apparently, the eggs had survived and were the principal means of repopulating the stream.

Oecetis inconspicura (Walker) was collected from fourth, fifth and sixth order streams during summer. Maximum density ($75/m^2$)

occurred at station 23(5) during August.

Coleoptera

Sixteen species were collected. Occurrence of all species was so sporadic no inferences could be made concerning seasonal distribution.

Laccophilius fasciatus Aubè was collected in all stream orders, but was more numerous in third and fourth order streams, Tropisternus lateralis (Say) was collected in third, fourth, and fifth order streams, but was more abundant in fourth order streams. Berosus peregrinus Herbst, Dubiraphia vittata Melshiemer and Agabus semivittatus LeConte were more numerous in fifth order streams and were collected in fourth and sixth order streams. B. peregrinus and D. Vittata were collected at station 3(3) during winter and spring. Hydroporus sp. was common in all stream orders. Higher annual density in third order streams was due to concentrated numbers in small pools at stations 14(3) and 3(3) during July and August. Peltodytes littoralis (Matheson) was collected in fourth, fifth and sixth order streams but was more abundant in the sixth order stream. Stenelmis sp. and Enochrus nebulosus (Say) were common in riffles and were occasionally collected in fifth and sixth order pools.

Copelatus chevrolati (Aubè) was collected at station 6(5) during October. Cyphon sp. was collected at stations 3(3), 11(3) and 7(5) from July through February. Dineutus vittata (Kirby) was collected at stations 15(4) and 2(6) during May and December. Helichus lithophilus (Germar), Paracymus subcupreus (Say), Cymbiodyta fimbriata Melsh and Heloporus sp. were collected only from sixth order riffles.

Diptera

Tipulidae

Erioptera sp. and *Gonomyia* sp. were collected throughout the year and were most common in fourth order streams. *Tipula* sp. was collected at stations 17(4) and 4(6) during December and station 3(3) during January. *Limnophila* sp. was collected at station 23(5) during October. *Limonia* sp. was collected at station 9(4) during October. *Megistocera* sp. was collected at station 22(5) during May.

Culicidae

Four species of mosquitoes were collected. *Culiseta inornata* (Williston) and *Aedes vevans* (Meigen) were collected at station 12(3) during August. *Psorophora signipennis* (Coquillett) was collected at station 12(3) and 20(3) during July. *Anopheles punctipennis* (Say) was collected at station 3(3), 17(4), 9(4), 8(4) and 6(5) during September and October.

Chaoborus sp. was collected throughout the year in all stream orders. Maximum numbers were taken from fourth order stations during July and August. A density of $1151/m^2$ occurred at station 18(4) during August.

Simuliidae

Simulium vittatum Zett., a typical riffle form, was taken from pools in all stream orders throughout the year. New generations occurred seasonally and females were observed depositing their eggs at the lower end of pools during most collections. During April all riffle areas were black with larvae and a density of $74,512/m^2$ was found at station 2(6).

Tabanus sp. was collected throughout the year and at all stations except 12(3) and 21(5). Density increased in third, fourth and fifth order streams, and decreased in the sixth order stream.

Chrysops sp. was collected from a riffle at station 2(6) during October.

Tenipedidae

Twenty-five species in the subfamilies Peolopiinae (3 species), Orthocladiinae (7 species) and Tendipedinae (15 species) were collected. Relative numbers increased as stream order increased, forming 19% of the total in third order streams and 31% in the sixth order stream. Certain species were significantly abundant to indicate preference for the conditions in a particular stream order (Table V). Seasonal variation in species composition was evident (Table XIV).

Ceratopogonidae

Stilobezzia sp., Culicoides sp., Palpomyia sp. and Bezzia sp. were collected throughout the year in all stream orders. Stilobezzia sp., Culicoides sp. and Palpomyia sp. were most numerous in fifth order streams. Bezzia sp. was equally numerous in fourth, fifth and sixth order streams.

Atrichopogon sp. was collected at station 9(4) during October and occasionally in sixth order riffles.

TABLE XIV

SEASONAL ABUNDANCE OF TENDIPEDID LARVAE (NO./M^2)*

Species	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Pelopiinae												
Pelopia sp. B (Joh.)	3	125	603		3					1	1	16
Procladius bellus (Loew)	25	448	244	8	14	3	2	3	18	14	7	70
Ablabesmyia mallochi (Wall.)	4	20	3	4	4	1	1	1	3	9	3	18
Orthocladiinae												
Orthocladius sp.	1					6	29	116	103	126	20	1
O. nr. nivoriundus (Joh.)						3	29	97	67	107	7	
Metriocnemus sp.	1				3	5	31	13	29	92	18	7
Cricotopus sp.	1	8								1	8	1
Psectrocladius sp.								1	1	1		
Smittia nr. atterrima (Meig.)				1			1	1	1	3	1	
Pseudosmittia sp.					3		3	33	74	2		
Tendipedinae												
Tendipes attenuatus (Walk.)	83	16	7	1	8	13	24	11	18	10	16	216
Glyptotendipes sp.	2	1						1			1	
G. nr. senilis (Joh.)	5	142	1	2	3	8	1	6	15	54	27	57
Cryptochironomus nr. fulvus (Joh.)	19	43	32	16	14	10	3	7	12	15	19	53
Stictochironomus devinctus (Say)	2	48	11	3	7	3	2	3	7	7	39	108
Calopsectra nr. guerla Roback	1	62	111	5	10	1	1	4	20	36	28	16
Polypedilum illinoense (Mall.)	2	1	2	2	29	1	1	1	1	2	8	36
P. halterale (Coq.)	6	8	21	3	8	5	2	6	6	14	18	18
P. parascalaenum Beck			5			1		1		1	1	
Dicrotendipes sp.	1	2		1	3	3	12	12	13	41	5	7
Harnischia nr. pseudotener (Goetg.)	2	51	6	1		1				1	1	5
Tanytarsus flavipes (Meig.)							1	1	2	1	3	6
Pseudochironomus fulviventris (Joh.)							1					1
Paratendipes albimanus (Meig.)											133	
Stenochironomus sp.**	2											

*Rounded off to the nearest whole number

**Collected only in riffles

Stratiomyiidae

Odontomyia sp. was collected at station 9(4) during March and at station 4(6) during December.

Ephydridae

Ephydra sp. was collected at station 9(4) during June and October, and at station 4(6) during October.

Notiphila sp. was collected at station 8(4), 22(5) and 1(6) during November, March and February, respectively.

Cecidomyiidae

Gall gnat larvae were collected sporadically throughout the year. Larger numbers occurred during spring and a density of $172/m^2$ was observed at station 18(4) during April.

Mycetophilidae

Fungus gnat larvae were collected during fall, winter and spring. Larger numbers occurred during spring.

Asilidae

A single specimen was collected at station 3(3) during April.

Empididae

Hemerodromia sp. was collected from riffles at stations 1(6) and 2(6) throughout the year.

MOLLUSCA

Gastropoda

Ferrissia shimekii (Pilsbry) was collected frequently at stations 3(3) and 9(4) during June.

Physa anatina Lea was collected from all stations throughout the year. No stream order preference was noted.

Helisoma anceps (Menke) was collected from stations 14(3), 15(4), 17(4), 10(4) and 21(5) indicating a preference for conditions in fourth order streams. Maximum annual density ($21/m^2$) occurred at station 15(4).

Lymnaea humilus (Say) was collected in third, fourth and fifth order streams. It was collected in more fourth order streams, but highest annual density was at station 14(3).

Pelecypoda

Sphaerium transversum (Say) was collected at all stations, except 14(3), 13(3), 12(3), 11(3) and 10(4). Numbers were similar during spring, summer and fall, and low during winter. A density of $570/m^2$ occurred at station 21(5) during May.

Uniomerus tetralasmus (Say) was collected at stations 15(4), 21(5), 22(5), 2(6) and 1(6) during spring and summer.

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