STREAM ORDER, COMMUNITY STRUCTURE OF FISH POPULATIONS, AND PHYSICO-CHEMICAL CONDITIONS IN A TRIBUTARY OF KEYSTONE RESERVOIR, OKLAHOMA

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PREFACE

This investigation was instituted to determine correlation between stream order and drainage basin morphometry, physico-chemical conditions, temporal and spatial variation in composition of fish populations, and community structure of fishes. The usefulness of the stream order-community structure approach for detecting and describing the effects of artificial environmental stresses upon a natural drainage system was examined.

Dr. Rudolph J. Miller served as major adviser. Drs. Calvin G. Beams, Troy C. Dorris, Robert D. Morrison, and Dale W. Toetz served on the advisory committee and criticized the manuscript. Dr. George A. Moore verified the identification of fishes.

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TABLE OF CONTENTS

Chapter		Page
I.	INTRODUCTION	1
II.	DESCRIPTION OF AREA	7
	General Description of Keystone Reservoir Basin	7
	General Description of House Creek Drainage Basin	8
	Morphometry	10
III.	PROCEDURES	12
	Selection and Designation of Stations	12
	Physico-Chemical	12
	Biological	13
	Community Structure Indices	15
IV.	STREAM ORDER ANALYSIS	16
V.	PHYSICO-CHEMICAL CONDITIONS	22
	General	22
	Major Subdivisions of the House Creek Basin	25
	Physico-Chemical Parameters and Stream Order	28
VI.	DISTRIBUTION, SPECIES COMPOSITION, AND COMMUNITY STRUCTURE OF FISHES	60
	Distribution of Fishes by Sub-Basin	60
	Stream Order and Distribution of Fishes	65
	Comparison of Drought and Post-Drought Fish Populations	74
	Community Structure of Fishes	79
	Relationships Between Fish Communities and Physico-Chemical Conditions	91
	The Community Structure - Stream Order Basis For Ichthyo-Fauna Descriptions	95
VII.	SUMMARY	97
LITERATURE CITED		102
APPENDIX		112

LIST OF TABLES

Table		Page
I.	Stream Order Analysis of House Creek Drainage Basin . . .	17
II.	Average Isolated Pool Volume in Relation to Stream Classification	25
III.	Ranked Conductivity Means for Regularly Sampled Stations in the House Creek Basin	52
IV.	Correlation Coefficients Between Stream Order and Certain Physico-Chemical Parameters	58
V.	Numerical Distribution of Fishes in Major Subdivisions of the House Creek Basin	61
VI.	Most Abundant Species and Percent of Total Catch in the Major Subdivisions of House Creek	63
VII.	Numerical Distribution of Fishes by Stream Order in the House Creek Basin	68
VIII.	Most Abundant Species Collected by Seine During the Post-Drought Period in the Fifth Order Hierarchic Basins	88
IX.	The Post-Drought Rotenone Samples Taken at Stations 44(4A) and 53(4A)	91
X.	Annual Means and Ranges of Physico-Chemical Conditions in the Northern Fifth Order Hierarchic Basin	113
XI.	Annual Means and Ranges of Physico-Chemical Conditions for Certain Ephemeral Pools in the Northern Fifth Order Hierarchic Basin	115
XII.	Annual Means and Ranges of Physico-Chemical Conditions in the Western Fifth Order Hierarchic Basin	116
XIII.	Annual Means and Ranges of Physico-Chemical Conditions in the Fifth Order Adventitious Basin	118
XIV.	Annual Means and Ranges of Physico-Chemical Conditions in the Calf Creek Drainage	119

Table		Page
XV.	Annual Means and Ranges of Physico-Chemical Conditions for House Creek Cove and Sixth Order Stations	120
XVI.	Ranges of Physico-Chemical Conditions by Stream Order in the House Creek Drainage Basin	122
XVII.	Analysis of Water Samples Collected August, 1967, From Representative Natural and Unnatural Stream Conditions in the House Creek Basin	124
XVIII.	Comparison of Brine Tolerances of Fishes in Laboratory and Field	125

LIST OF FIGURES

Figure		Page
1.	Location of Collecting Stations in the House Creek Drainage Basin and Cove	9
2.	Longitudinal Stream Profile of House Creek as Described by Mean Elevation at Origin of Each Hierarchic Stream Order	11
3.	Average Gradient of Adventitious and Hierarchic Streams	19
4.	Average Gradient and Stream Length of Adventitious Streams in Relation to the Ordinal Rank of Receiving Streams	20
5.	Hierarchic and Adventitious Stream Number and Average Length in Relation to Stream Order	21
6.	Total Monthly Rainfall in the House Creek Basin and Temporal Variation in Inflow and Volume of Keystone Reservoir	23
7.	Mean Seasonal Pool Volume of Sixty-One Representative Isolated Pools	24
8.	Mean Annual Physico-Chemical Conditions in Relation to Stream Classification	30
9.	Mean Monthly Temperature in House Creek Cove and Tributaries	31
10.	Mean Annual Physico-Chemical Conditions for Major Subdivisions of the House Creek Basin	32
11.	Mean Monthly and Seasonal Dissolved Oxygen in House Creek Cove and Tributaries	33
12.	Certain Mean Winter and Summer Physico-Chemical Conditions for Stations Below and Immediately Above the Jennings Sewage Outfall	36
13.	Mean Annual Physico-Chemical Conditions for Stations in the Fifth Order Adventitious Basin and Two Natural Sixth Order Stations	37

Figure		Page

14. Mean Monthly and Seasonal pH in House Creek Cove and Tributaries 39

15. Mean Monthly and Seasonal Carbon Dioxide in House Creek Cove and Tributaries 41

16. Mean Monthly and Seasonal Carbonates in House Creek Cove and Tributaries 42

17. Mean Monthly and Seasonal Bicarbonates in House Creek Cove and Tributaries 44

18. Mean Annual Physico-Chemical Conditions for Stations in the Northern Fifth Order Hierarchic Basin and Two Natural Sixth Order Stations 46

19. Mean Monthly and Seasonal Turbidity in House Creek Cove and Tributaries 48

20. Mean Monthly and Seasonal Conductivity in House Creek Cove and Tributaries 51

21. Early 1900 Photograph of Spring at Station 63(3A) 57

22. Total Species and Mean Number of Individuals and Biomass per Station in Relation to Stream Order 66

23. Summarization of Repopulation Data for the More Common Fishes of the Periodically Seined Pools 77

24. Mean Diversity and Redundancy for Stream Orders and House Creek Cove 80

25. Drought and Post-Drought Diversity Indices and Annual Redundancy in the Western Fifth Order Hierarchic Basin . . 81

26. Annual Diversity and Redundancy of Rotenone, Seine, Barrel Trap, and Shocker Samples from the Western Fifth Order Hierarchic Basin 83

27. Mean Diversity and Redundancy of Drought and Post-Drought Seine Collections for Major Subdivisions of the House Creek Basin 86

28. Mean Diversity and Redundancy of Drought and Post-Drought Seine Collections from Habitat Regions 87

CHAPTER I

INTRODUCTION

Ecological investigations of biotic communities historically have been encumbered by the lack of quantitative analytical procedures. An additional problem arises in stream limnology where an objective stream classification scheme has yet to become widely accepted.

During the past decade ecologists have become increasingly interested in mathematical expressions of community structure, placing considerable emphasis on diversity indices derived from information theory. Similarly, the trend in fluvial morphometry has been toward quantification of landform description (Morisawa, 1962). The concomitant use of Horton's (1945) stream order analysis and diversity indices provides an objective basis for the analysis of physico-chemical and biological data and a framework for comparative ecological studies. Stream classifications based upon habitat descriptions and non-quantitative community descriptions are difficult to interpret objectively and are generally useful only in the area in which they were developed.

Gravelius (1914) first classified tributaries on the basis of bifurcation. The stem stream of a basin was designated as order one, and its tributaries were assigned increasingly higher numbers. Although unbranched channels and the hierarchy below them were similar in different basins, their ordinal rank varied from basin to basin, and geometric comparisons between basins were impossible.

In Horton's (1945) system, the entire length of the longest channel was given the highest order number, and ultimate headwater rivulets were designated first order streams. The confluence of two first order streams formed a second order stream, where two second order streams joined a third order stream was formed, etc. Tributaries adventitious to the stem stream were assigned order numbers based on branching. Adventitious tributaries, low order channels which enter higher order streams directly and not through the hierarchy, did not affect the ordinal designation.

Strahler (1954, 1957) modified Horton's system by designating all ultimate headwaters as order one and extending the branching criterion to all sections of the stem stream. Thus geometric constancy was established within and among basins. Being dimensionless and a measure of position in the tributary hierarchy, ordinal rankings permit comparisons between drainage basins of various sizes with respect to corresponding points in their geometry.

Abell (1961) first proposed application of the stream order concept to ecological studies, and Hynes (1972) has suggested that the concept "may prove to be of considerable value in biological studies if only to serve as an objective way of classifying watercourses."

In the present study, quantification of fish assemblages and their spatial and temporal properties was accomplished by use of community structure indices derived from information theory. Such indices are concise summarizations of information concerning diversity of multispecies aggregations (Patten, 1962).

Many different indices of diversity have been proposed, and currently, one has a choice of several complex measures (Fisher et al., 1943; Preston, 1948; Shannon and Weaver, 1948; Simpson, 1949; Margalef, 1958a; Brillouin, 1960; Whittaker, 1961; Patten, 1962). Margalef (1958a) was the first to demonstrate the use of information theory in the analysis of natural communities. Margalef used the original information expression of Shannon and Weaver (1948) as a means of condensing large amounts of information into one figure representative of community diversity. The Shannon-Weaver function ($\bar{d}$) can be dissected into a species richness component and a component of evenness or the apportionment of individuals among species (Pielou, 1969). However, the $\bar{d}$ index combines the variety and evenness components as one overall index of diversity that is one of the best for making comparisons (Odum, 1971; Kricher, 1972).

Diversity indices derived from information theory are theoretical measurements of uncertainty (Margalef, 1958a; MacArthur, 1965). "The information content of a community is equivalent to the uncertainty involved in predicting which species an animal would be confronted with by the next random encounter" (Lloyd et al., 1968). A community of many species but with an equable distribution of individuals is considered to be high in information. Information declines as the probability of selecting a particular species becomes more certain, and increases as the choice becomes more uncertain. The Shannon-Weaver index ($\bar{d}$) measures diversity per individual and is considered synonymous with information. Accordingly, $\bar{d}$ is expressed in bits, one bit being the information required to specify one of two equally probable events.

In the present study, the Brillouin (1960) form of the original Shannon-Weaver expression and the redundancy expression of Patten (1962) were used to describe community structure. The properties of and the rationale for using the Brillouin form have been discussed by Pielou (1966a, 1966b) and Lloyd et al. (1968).

Certain properties of $\bar{d}$ make it particularly useful in community analysis. The index is reasonably independent of sample size, and it is dimensionless (Pielou, 1966a; Odum, 1971). The latter property makes the index appropriate for the study of fish populations because sampling effort and procedure is often variable. Moreover, various "importance values" (Odum, 1971) (i.e., numbers, biomass, productivity, etc.) are easily substituted into the dimensionless diversity expression, and the choice of unit does not affect the result (Wilhm, 1968). The importance of values considered in this study were numbers of individuals and biomass. Use of biomass redefines diversity by equating it with uncertainty regarding biomass instead of numbers. Odum (1971) stated that biomass distribution will generally give a rough picture of the overall effect of the food chain relationships, and Wilhm (1968) pointed out that biomass diversity is more closely related to energy distribution among species than number diversity. Nonetheless, biomass may overemphasize large organisms, while use of numbers alone will tend to overemphasize small organisms (Odum, 1971). Thus, it appears desirable that both importance values be used in the analysis of community structure. Bechtel and Copeland (1970) found that both biomass and numerical diversity of fishes were useful indicators of environmental stress; however, finding that biomass and numerical diversity differed significantly for the same sample, they recommended the use of both parameters.

Number and biomass values were used to calculate an additional dimensionless function known as redundancy (Patten, 1962). Redundancy is an expression of the dominance of one or more species and is inversely proportional to the wealth of species. Redundancy is zero when uncertainty is maximal (i.e., each individual belongs to a different species) and one when uncertainty is minimal (i.e , all individuals belong to the same species) (Wilhm, 1967). Informational diversity ($\bar{d}$) expresses overall compositional richness, while redundancy is an expression of the evenness component.

The application of information theory to community analysis has been found suitable for the study of a variety of different organisms and communities (Hariston, 1959; Kohn, 1967; Monk, 1967; Coulson et al., 1971; Kochsiek et al., 1971). Margalef (1958b), Patten (1962), Wilhn (1967), Mathis and Dorris (1968), and Dahlberg and Odum (1970) have shown community structure indices to be valid ecological parameters for describing spatial and temporal succession and the effects of environmental stress upon natural communities.

Rigorous ecological application of stream order analysis has seldom been attempted, and few have dovetailed this approach with quantitative methods of community analyses. Kuehne (1962, 1966) related stream order to physiographic stream succession and found that fish distribution fit the stream order model well. Carter and Jones (1969) and Jones (1970) presented faunal lists, stream order rankings, and several chemical and physical characteristics for Kentucky streams but did not develop possible fish fauna-stream order relationships. Sheldon (1968) related fish species diversity to longitudinal stream succession with nominal treatment of the stream order concept. Sheldon concluded, however, that such a ranking system was applicable to his data. More explicit ecological treatment of stream order was provided by Harrel et al. (1967), Harrel and Dorris (1968), and Whiteside and McNatt (1972). These authors have shown that species diversity indices for fishes and benthic macroinvertebrates were correlated with stream order. Others applying mathematical expressions of community structure to fish populations include McErlean and Mihursky (1968), Laser et al. (1969), Dahlberg and Odum (1970), and Smith and Powell (1971).

This study was an attempt to correlate stream order with drainage morphometry, physico-chemical conditions, species composition and community structure of fish populations in House Creek. The House Creek basin was small, allowing for rather thorough sampling of the stream system. Intra-basin comparison of physico-chemical conditions was possible because such data could be gathered from throughout the basin within a brief span of time. Environmental stresses were imposed upon the drainage by domestic effluent, brine wastes, and the formation of Keystone Reservoir which partially impounded the lower basin. The usefulness of the stream order-community structure approach for detecting and describing these perturbations on stream communities is examined herein.

CHAPTER II

DESCRIPTION OF AREA

General Description of Keystone Reservoir Basin

Keystone Reservoir, located 20 km west of Tulsa, Oklahoma, was formed in 1964 by impoundment of the Arkansas River 3.3 km below the confluence with the Cimarron River. At power pool level (220 m mean sea level) the reservoir inundates approximately 47 km each of the old narrow and meandering valleys of the Cimarron and Arkansas Rivers and has a surface area of 10,648 ha (Eley et al., 1967). The formations inundated are primarily late Pennsylvanian, with easily eroded shales being the predominant type. Prior to impoundment, erosion along the watershed of both rivers was extensive, and the main channels, being formed in unstable sand, constantly oscillated within their flood plains (Linton, 1961).

The Cimarron River contributes highly mineralized water from the salt and gypsum deposits of the Permian redbeds in western Oklahoma (Dover et al., 1968). This salt heavy water may form an underflow along the bottom of the reservoir, undercutting the lighter water of the Arkansas River origin. Although the Arkansas River carries salts derived from the salt plains of western Oklahoma and industrial and municipal effluents from Kansas and Oklahoma, the dissolved solid load is less than that of the Cimarron (Eley, 1970). The Arkansas River overflow may extend 30 km into the Cimarron arm (Eley, 1970).

General Description of House Creek Drainage Basin

The House Creek drainage basin is a sixth order, intermittent system located in north-central Oklahoma. The principal stream originates approximately 3 km southwest of Hallet, flows 26.7 km southeastward through Pawnee County, and originally emptied into the Cimarron River in extreme northeastern Creek County. However, the Cimarron arm of Keystone Reservoir now inundates the lower reaches of the basin, and the resulting embayment is known as House Creek Cove (Fig. 1).

Formations exposed in the basin were laid down during the Pennsylvanian and Permian ages: gray and brown shales with sandstone beds of varying thicknesses (Gould, 1925; Galloway, 1959). Characteristic of upland soils are dark, grayish-brown loams with chips and slabs of limestone and sandstone. Alluvial soils are present along the larger drainageways and cover most of the lowlands. Deposits are neutral to alkaline and range from clays to clay loams, and from silt loams to sandy loams (Galloway, 1959).

Dominant plant communities in the House Creek basin are the blackjack-post oak forests which interrupt the prairie of eastern Oklahoma, openings of hilly grasslands (bluestems and other medium tall grasses), and bottom land forests in which much hardwood growth still remains (Galloway, 1959). The dominant land use in the basin is grazing of beef cattle.

The climate is long-summer continental and characterized by low humidity and erratic fluctuations in temperature and precipitation. The mean annual temperature is 16 C, and precipitation averages about 93 cm per year; however, great annual differences and severe droughts

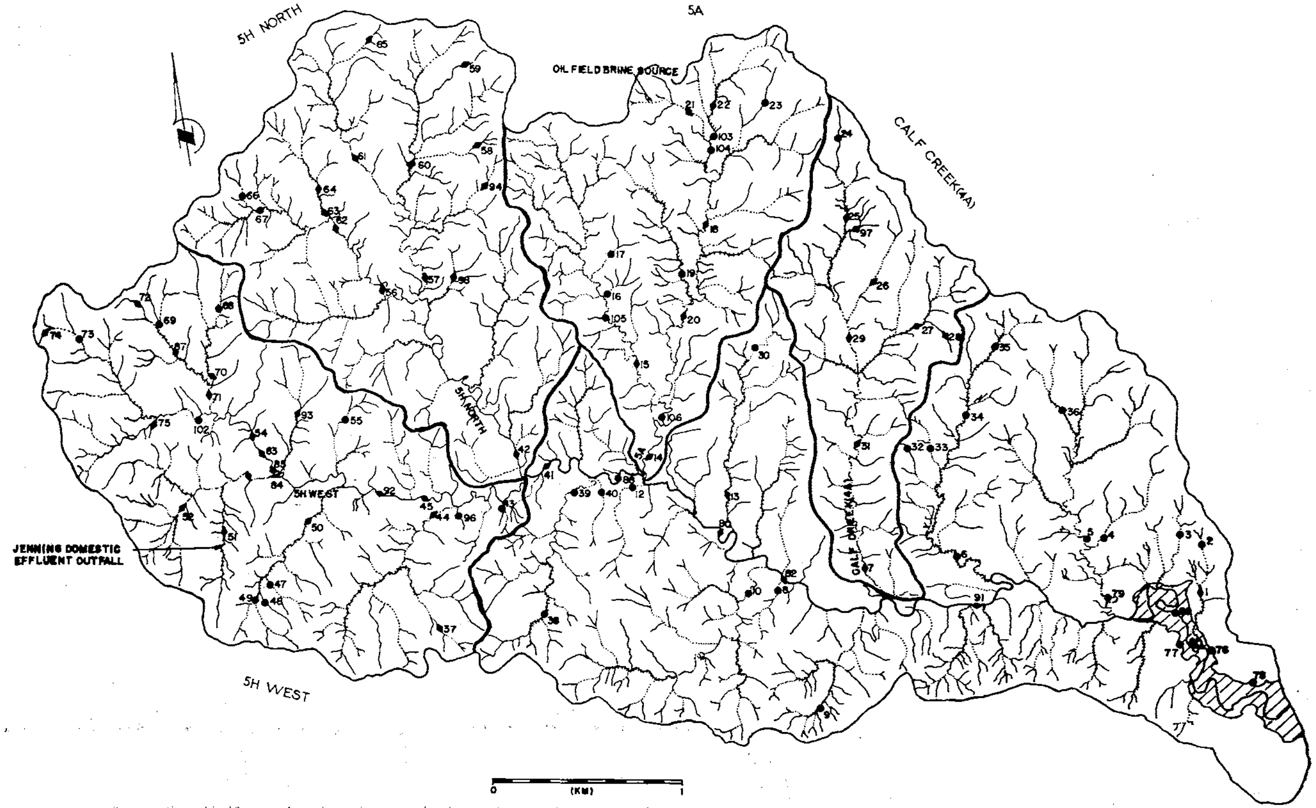

Figure 1. Location of Collecting Stations in the House Creek Drainage Basin and Cove. Stations Designated for Collections of Fishes Only = ●, Stations Designated for Sampling of Water Only = O, Stations Designated for Both Collection of Fishes and Sampling of Water = ◆; Stream Order Designations: First Order = (——), Second Order = (---), Third Order = (++++), Fourth Order = (—·—··—), Fifth Order = (▬▬), Sixth Order = (▬▬); House Creek Cove = ▨.

are common (Galloway, 1959; U. S. Department of Commerce, 1966, 1967).

The principal tributaries of sixth order House Creek are two fifth order hierarchic streams and one fifth order adventitious stream (Fig. 1). One hierarchic basin received domestic effluent from Jennings, Oklahoma, while the other carried primarily natural waters. The fifth order adventitious basin received oil field brines. Localized brine contamination occurred at several stations in the House Creek basin.

Except for spring branches, the streams of the House Creek system flowed intermittently. Many pools in stream orders one through four became dry during droughts. Stream cover varied from open, unshaded banks along first and second order hierarchic streams to densely tree-lined banks at most fourth and all fifth and sixth order stations. Third order stations typically had moderate tree cover. Bottom composition varied from limestone bedrock to sediments ranging from boulders to clay; however, sands and silts were dominant.

Morphometry

Morphometric data were taken from U. S. Department of Agriculture aerial photographic maps, scaled 1:20,000 (Galloway, 1959) and U. S. Geologic Survey topographic sheets (1929).

House Creek basin has a perimeter of 53.1 km, an axial length of 17.4 km, and an area of 110 km^2. The elevation is 310.9 m at the source and 198.1 m at the mouth, with an average gradient of 4.2 m/km (Fig. 2). Valleys reach an approximate depth of 20 m along the lower sixth order stream.

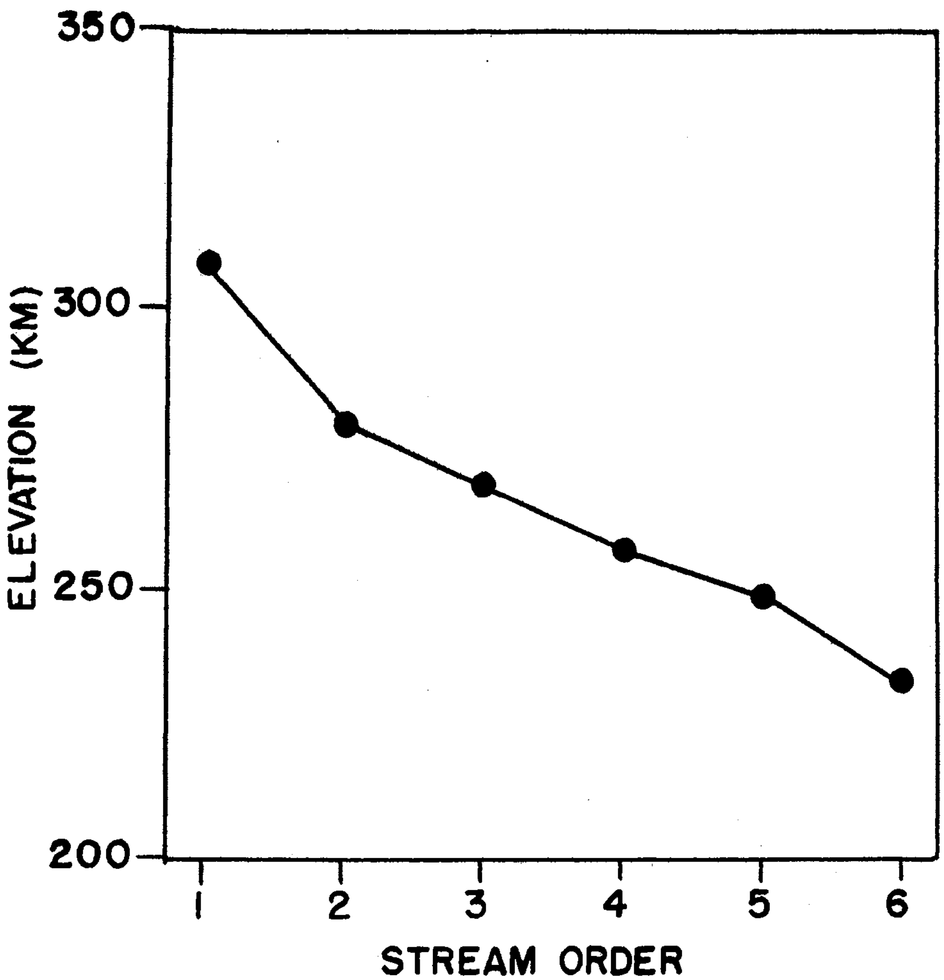

Figure 2. Longitudinal Stream Profile of House Creek as Described by Mean Elevation at Origin of Each Hierarchic Stream Order.

CHAPTER III

PROCEDURES

Selection and Designation of Stations

Ninety-two stations for sampling fish populations were selected to represent characteristic and anomalous stream conditions among all orders. Stations are identified by numbers followed in parentheses by the ordinal rank and the letters "A", "H", "I", or "R". Letters "A" and "H" denote adventitious and hierarchic stream categories, "I" refers to impounded waters of the lower sixth order, and "R" denotes reservoir stations in House Creek Cove.

Physico-Chemical

Physico-chemical data were gathered periodically from twenty-five stations during seven three-day sampling periods between October, 1966 and August, 1967. Occasional measurements were taken at twenty-nine additional stations. During each sampling period, all measurements were made between 1:00 and 4:00 P.M. under similar weather conditions in an attempt to draw valid comparisons between stations. Changes in dissolved oxygen concentration, which generally exhibits a pronounced diel fluctuation, are relatively small during this time period (Odum and Hoskin, 1958; Copeland and Dorris, 1962; Baumgardner, 1966; Hannan and Anderson, 1971).

Water temperature was taken with a Yellow Springs telethermometer and a mercury thermometer. Phenophthalein and methyl purple alkalinity were determined by titration with 0.02 N sulphuric acid (A.P.H.A. 1960). Free carbon dioxide was estimated from a nomograph using pH and bicarbonate alkalinity (Moore, 1939). Hydrogen ion concentration was estimated with a Hellige pH comparator. Turbidity was expressed as "turbidity units" (roughly equivalent to g suspended solids m^{-3}) and measured with a Bausch and Lomb Spectronic 20 colorimeter calibrated against a Jackson trubidimeter. An Industrial Instruments Wheatstone Bridge was used to obtain conductivity measurements. Water samples for dissolved oxygen determination were fixed by the Alsterberg (azide) modification of the Winkler method (A.P.H.A. 1960) and titrated with 0.025 N phenylarsene oxide (Hach Chemical Co., 1968). Volume of stream flow was estimated by the method of Robins and Crawford (1954). Estimated pool volume was calculated from mean pool length, width, and depth.

Biological

Seins, barrel traps, gill nets, a Great Lakes trap net, a boom-type fish shocker, and rotenone were employed during the investigation. Seines with 3.2 mm mesh, 1.5 to 9.1 m long and 1.2 to 1.8 m deep, were used along the cove shoreline and in stream pools. Collapsible, 19 mm mesh barrel traps (Houser, 1960) were placed in the cove, in lower impounded House Creek, and in eight of the deeper stream pools. The Great Lakes trap net was employed only in the cove. Dimensions of the pocket were 2.7 x 1.5 x 1.2 m and the mesh was 19 mm. The central lead was 45.7 m long, and the lateral wings were 15.2 m in length.

Each of two stations in the cove were sampled with three 45.7 m experimental gill nets in August, 1967. Each net was composed of three 15.23 m sections with a mesh size of 25.4, 51.0, and 76.0 mm, respectively. A 230 volt, 180 cycle, boat-mounted shocker as described by Ming (1964) was employed at three cove stations, in impounded House Creek, and in three deep pools of the drainage network. During August, 1967, a 5 percent emulsion of thermocline-penetrating rotenone was used to sample fish populations at thirty-two sites in both the drainage network and House Creek Cove. To assure a total kill, the emulsion was applied at a concentration of 3 mg/1 (Kinney, 1965).

Pools were seined monthly as conditions permitted, and the shocker boat was employed twice each season. Seining effort was standardized by making four similar seine hauls per collection at each pool. Diversity measurements ($\bar{d}$) of pooled seine catches have been reported to become asymptotic with the third sample (Whiteside and McNatt, 1972). The shocking procedure involved six similar passes along the pool shoreline. Barrel traps and the Great Lakes trap net were lifted weekly during the warmer months and biweekly during the cooler months.

Fishes collected by seines were preserved in 10 percent formalin and stored in 40 percent isopropyl alcohol. Fishes killed by rotenone were weighed with a straight spring scales or a dietary balance calibrated to grams; smaller specimens not readily identifiable were preserved in the field for later identification and weighing. All rotenone samples included a second day collection. Fishes collected by netting, trapping, and shocking were fin-clipped for station identification and released.

Community Structure Indices

The community structure models of Patten (1962) and Brillouin (1960) were employed to estimate species diversity per individual ($\bar{d}$), theoretical maximum diversity ($\bar{d}$ max), theoretical minimum diversity ($\bar{d}$ min), and redundancy (R). The total number of individuals in the sample is n, n_i is the number of individuals of the ith species, and s is the number of species. When computing community structure from biomass, n is replaced by w (sample weight), and w_i becomes the sample weight of the ith species. The equations are as follows:

$$d = (\frac{1}{n})\ (\log_2 n! - \sum \log_2 n_i!)$$

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

$$\bar{d}\ \min = (\frac{1}{n}) \log_2 n! \ - \log_2 \left[n-(2-1) \right] !$$

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

Computations were made on an IBM 360 (model 50) computer at Oklahoma State University.

CHAPTER IV

STREAM ORDER ANALYSIS

A number of geometric relationships exist between stream order and certain drainage basin parameters (Horton, 1945; Schumm, 1956; Strahler, 1957; Smith, 1958; Morisawa, 1962; Leopold, 1962; Leopold et al., 1964). The ratio of the number of streams of a given order to the number of streams of the next higher order is the bifurcation ratio. Theoretically, the stream number should double with each decrease in stream order giving a bifurcation ratio of two. However, adventitious streams, streams which drain interbasin areas and enter higher order streams directly and not through the tributary hierarchy, increase bifurcation ratios above two. Bifurcation ratios commonly fall between three and five (Strahler, 1971). The House Creek basin is highly dissected with a bifurcation ratio of 4.02 (Table I).

Average stream length increases with stream order for a given basin. The ratio of average stream length of a given order to that of the next lower order is the stream-length ratio. Well drained basins have low stream-length ratios (1-2), while poorly drained basins have high ratios (3-4) (Horton, 1945). The House Creek basin is well drained with an average ratio of 2.44 (Table I).

Drainage density (total stream length/unit area) and stream frequency (stream number/area) further describe drainage development. Poorly drained basins in regions of extremely resistant rock have low

TABLE I

STREAM ORDER ANALYSIS OF HOUSE CREEK DRAINAGE BASIN

Order	Number of Streams	Total Length (km)	Average Length (km)	Mean Drainage Area (km^2)	Mean Gradient (m/km)
1	1024	249.5	0.24	-	-
2	266	116.5	0.44	-	-
3	63	63.8	1.01	1.0	17.1
4	13	36.3	2.80	5.3	7.1
5	3	14.1	4.70	19.0	3.6
6	1	17.0	17.02	110.0	1.3
Cimarron (original river channel)					0.4

Drainage Basin Ratios

Bifurcation Ratio = 4.02	Drainage Density = 4.52
Stream-length Ratio = 2.44	Stream Frequency = 12.45

drainage density values (1.0 - 2.5), while regions with easily eroded soils have high values (120-250) (Strahler, 1971). Drainage density and stream frequency for the House Creek basin were 4.5 and 12.5, respectively, indicating a medium density. Drainage area normally increases four or five times with each increase in stream order (Leopold, 1962). The area ratio constant for House Creek was 4.9. Average stream gradient varied inversely with stream order (Table I).

Contrasts between hierarchic and adventitious streams have generally been omitted from stream order analyses. Several such relationships for the House Creek basin are described below.

Mean hierarchic and adventitious gradients varied inversely with stream order, and lower order adventitious gradients were greater than lower order hierarchic gradients (Fig. 3). Harrel and Dorris (1968) found a direct relationship between adventitious stream order and gradient in Otter Creek, Oklahoma. Referring to the Otter Creek basin, Harrel et al. (1967) stated that adventitious gradients among streams of the same order increased with stream order of the receiving tributary. However, among third and fourth order adventitious streams in the House Creek system, gradients tended to vary inversely with receiving stream order (Fig. 4)

Mean hierarchic and adventitious stream lengths increased with stream order (Fig. 5). Among like adventitious orders, mean channel length increased linearly with ordinal rank of the hierarchic receiving stream (Fig. 4). Both hierarchic and adventitious stream number varied inversely with stream order, and among lower orders, adventitious streams outnumbered hierarchic streams (Fig. 5).

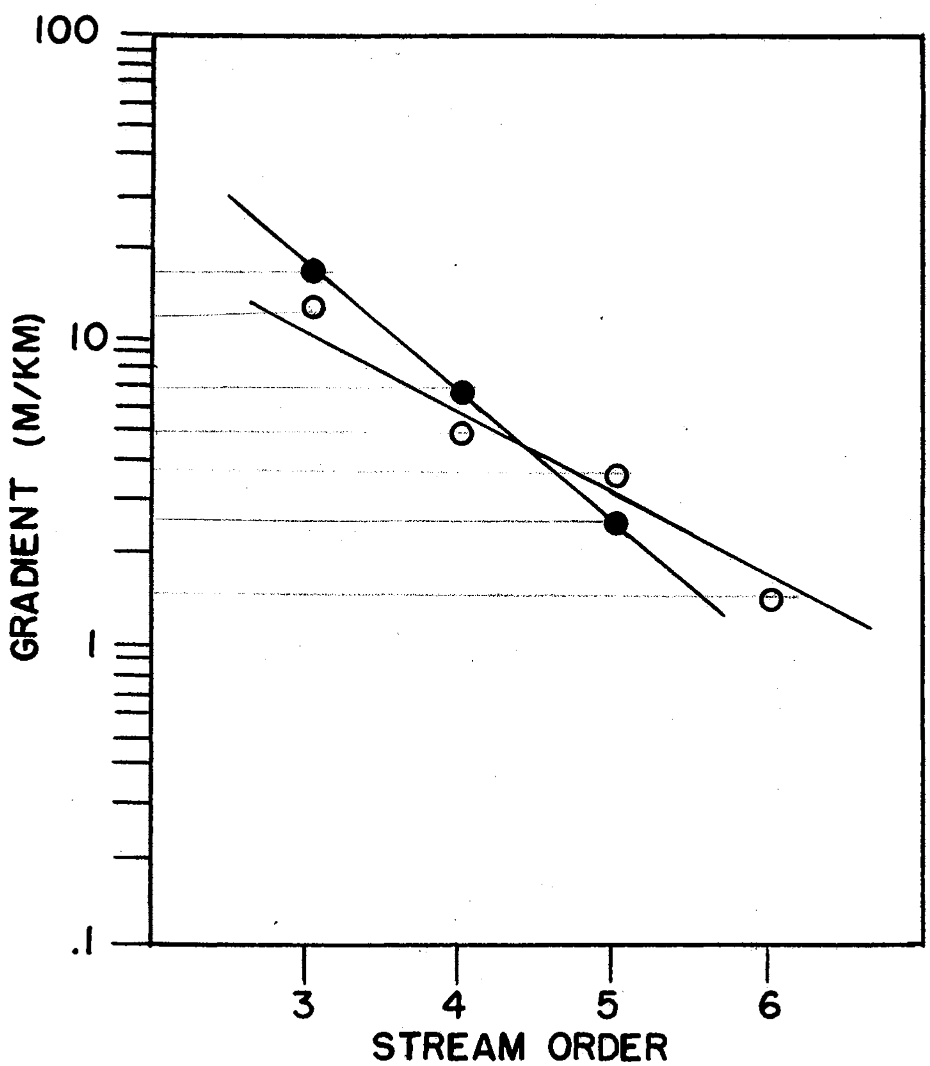

Figure 3. Average Gradient of Adventitious (•) and Hierarchic (o) Streams.

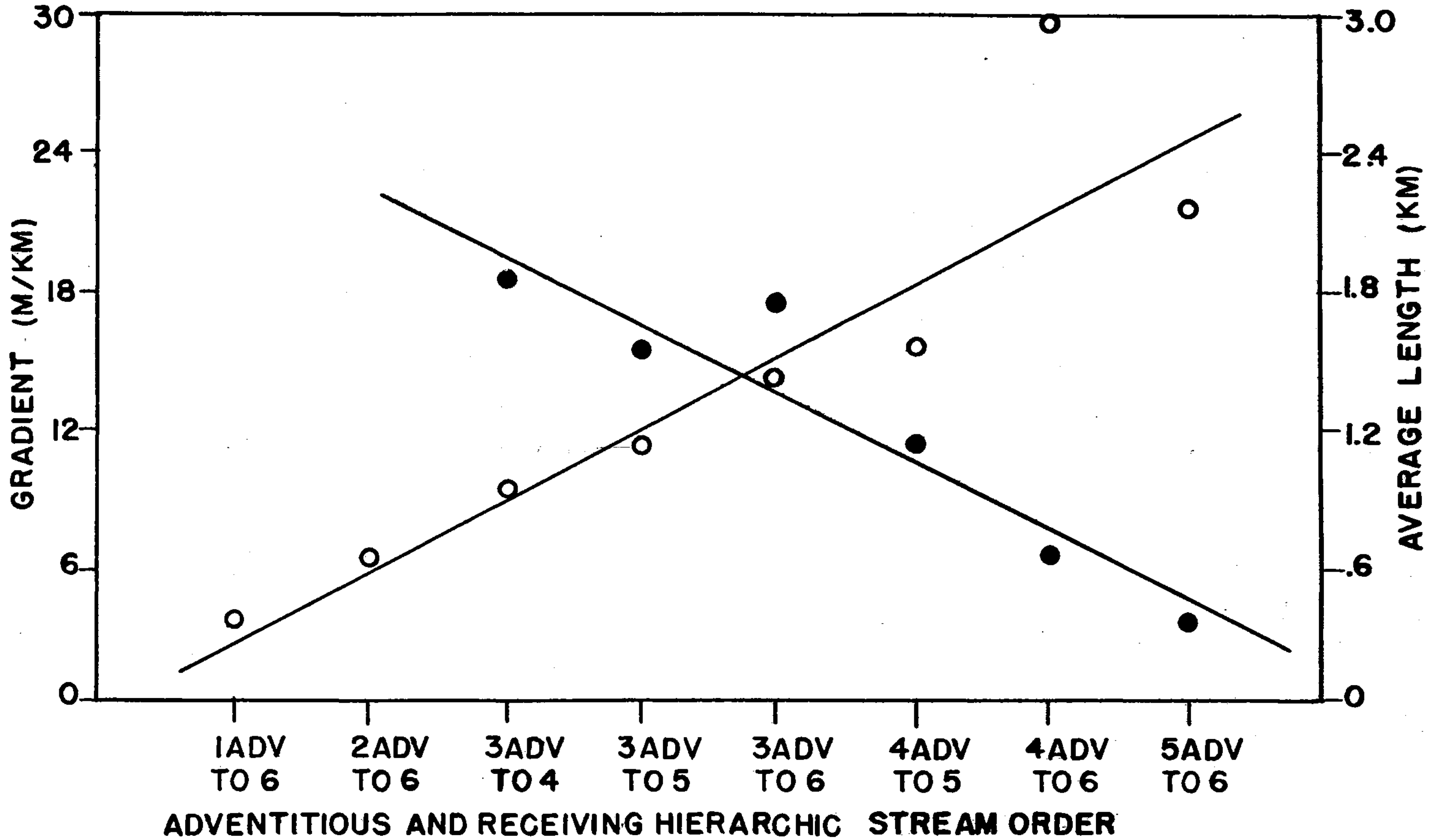

Figure 4. Average Gradient (●) and Stream Length (o) of Adventitious Streams in Relation to the Ordinal Rank of Receiving Streams

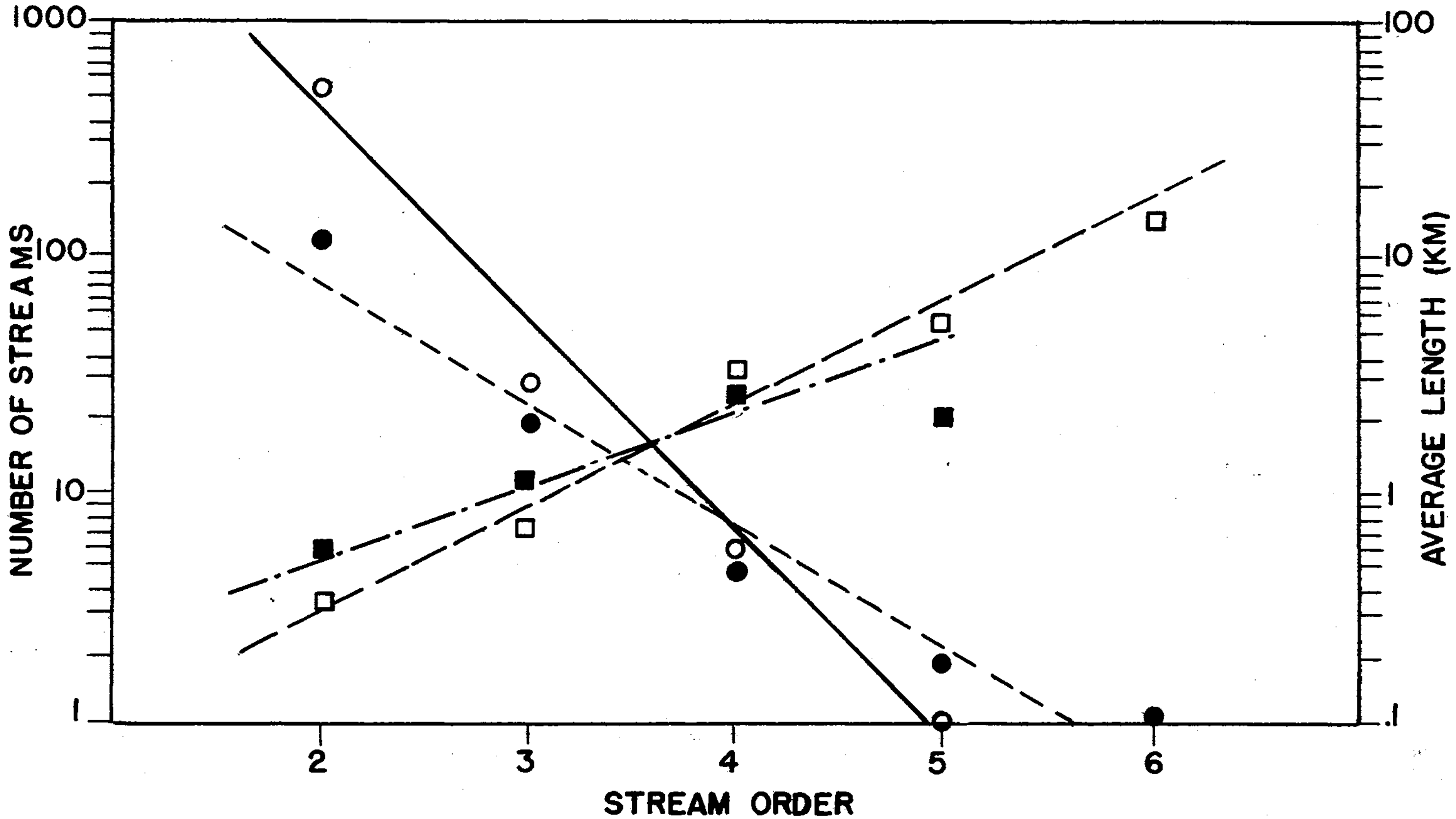

Figure 5. Hierarchic and Adventitious Stream Number and Average Stream Length in Relation to Stream Order. Given Below is the Symbol for the Inferred Relationship Followed by the Symbol for Observed Data: Adventitious Stream Number = (——— , ○); Average Adventitious Length = (— — — — , □); Hierarchic Stream Number = (- - - - - - - , ●); Average Hierarchic Length = (— - — - — - —, ■).

CHAPTER V

PHYSICO-CHEMICAL CONDITIONS

General

Precipitation over the House Creek basin occurred irregularly throughout the year, with monthly rainfall varying from 0.7 cm in November, 1966 to 14.9 cm in June, 1967 (Fig. 6). A severe drought began during the summer of 1966 and continued until April, 1967. The longest period without rain extended from 11 October to 17 November. Total rainfall between July, 1966 and April, 1967 was 31.5 cm, 27.6 cm below the mean for the same period (U. S. Department of Commerce, 1966, 1967).

By November, 1966, the water level of Keystone Reservoir had dropped 2.5 m below power pool level, resulting in a reduction in storage volume of over 200 x 16^6 m^3. The reservoir returned to power pool level in May, 1967. During June, 1967, flood waters entered the reservoir increasing the volume 133 x 10^6 m^3 over normal storage capacity (Eley, 1970). In July the reservoir once again returned to normal power pool level (Fig. 6).

Mean seasonal isolated pool volumes in the drainage network reflected the drought conditions and onset of spring rains (Fig. 7). The summer 1967 mean volume probably was somewhat greater than normal because of the unusually heavy summer rains. Excluded from the seasonal

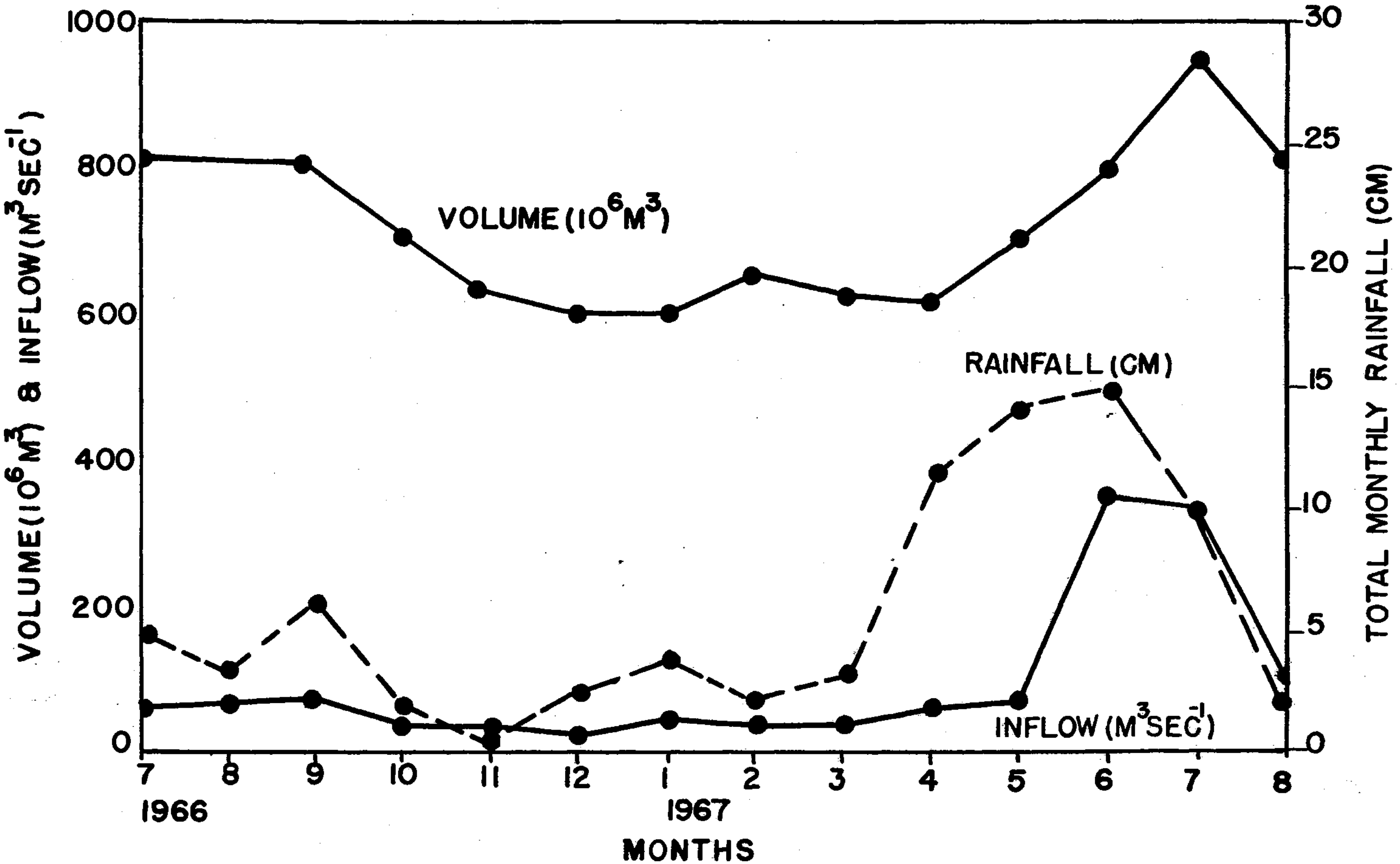

Figure 6. Total Monthly Rainfall in the House Creek Basin and Temporal Variation in Inflow and Volume of Keystone Reservoir (U. S. Dept. of Commerce, 1966, 1967; U. S. Army Corps of Engineers, 1967).

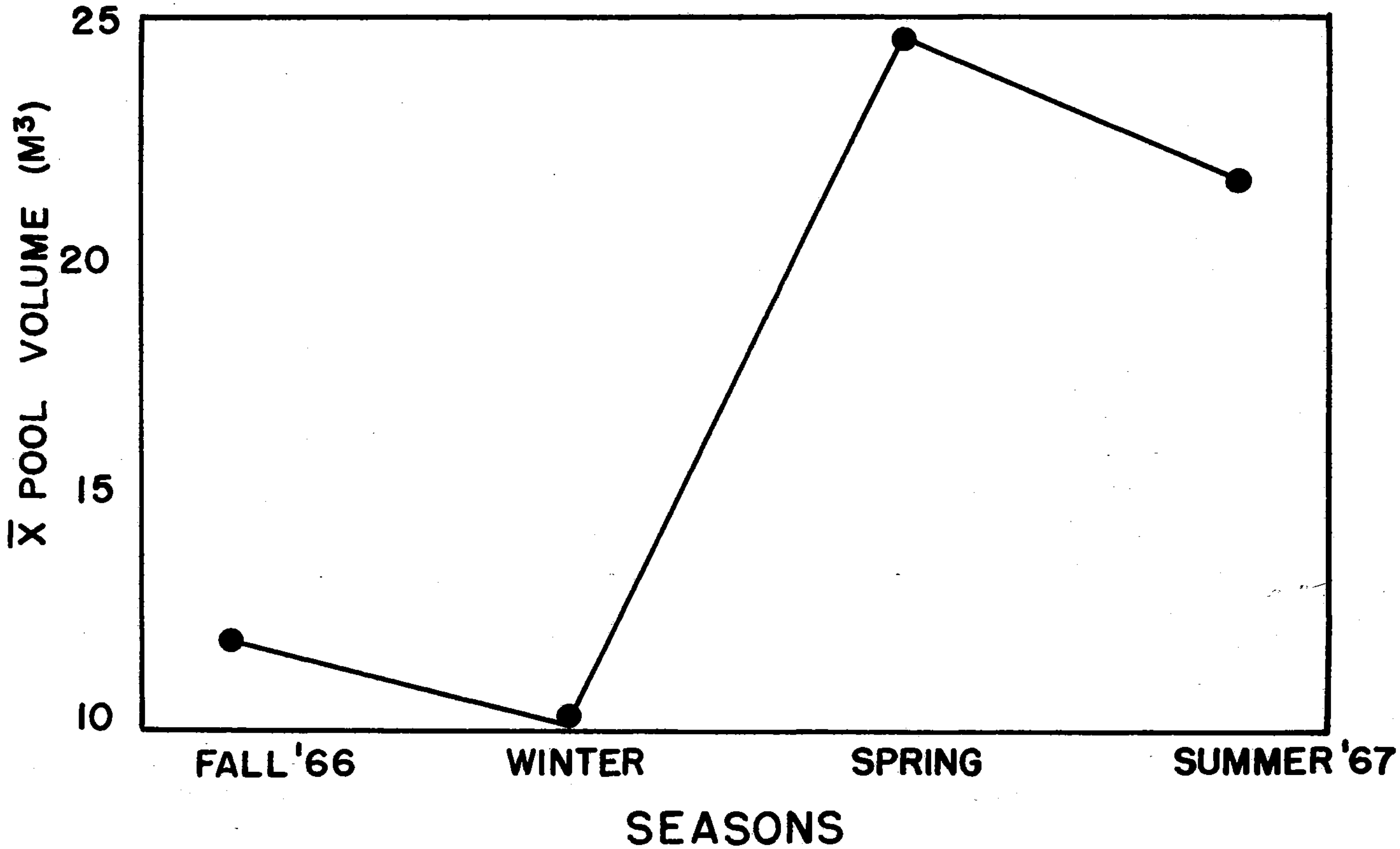

Figure 7. Mean Seasonal Pool Volume of Sixty-One Representative Isolated Pools.

means were the large continuous water masses which occasionally appeared in the fifth and sixth orders, and rarely in the fourth order. Mean hierarchic and adventitious pool volumes tended to increase exponentially with stream order (Table II). Mean volume for second and third order adventitious pools was larger than mean volume for corresponding hierarchic pools. First order tributaries were characteristically dry; however, occasional first order springs resulted in a higher mean volume for order one than for order two.

TABLE II

AVERAGE ISOLATED POOL VOLUME IN RELATION TO STREAM CLASSIFICATION

Stream Order	Hierarchic Volume m^3	Hierarchic n^*	Adventitious Volume m^3	Adventitious n^*
1	0.5	(4)	0.3	(4)
2	0.1	(9)	0.2	(9)
3	6	(8)	8.5	(9)
4	174	(7)	19	(6)
5	1,251	(4)	73	(2)
6	36,000	(4)	--	--

*Number of pools sampled.

Major Subdivisions of the House Creek Basin

The northern fifth order hierarchic basin (5H-N) had an area of 19.8 km^2 and, among the three fifth order tributaries in the basin, appeared to carry the most natural water. Oil field brines occasionally collected in pools at stations 59(1A) and 60(3A), but the effects were of local significance. Thirteen stations were selected for physicao-chemical analysis in the basin. Nine had permanent pools and were sampled periodically (Table X, page 113). Four other stations lacked permanent pools and were sampled as presence of water permitted (Table XI, page 115).

The western fifth order hierarchic basin (5H-W) had an area of 22.9 km^2 and received domestic effluent from septic tanks of Jennings, Oklahoma (Fig. 1). Eighteen stations were established for gathering physico-chemical data, but only six had permanent pools which could be sampled periodically. The remaining twelve stations were sampled occasionally as conditions permitted (Table XII, page 116).

Sixth order House Creek received one fifth order adventitious (5A) tributary which drained 15.1 km^2. Substantial quantities of oil field brines periodically entered this basin at a second order channel 6.9 km above the confluence of House Creek and the fifth order tributary (Fig. 1). Unlike local brine contamination in the other basins, the volume at this source was of such magnitude as to alter water quality at all downstream stations. Periodic sampling was possible at six pools (Table XIII, page 118).

The fourth subdivision of the basin was composed of the lower order streams adventitious to the sixth order. Fourth order Calf Creek, the largest such stream, drained 9.3 km^2 and entered House Creek 7.6 km above the original Cimarron River Channel. Five of the Calf Creek stations had permanent pools and were sampled periodically (Table XIV, page 119). Two additional third order adventitious basins were occasionally sampled at stations 1(3A) and 13(3A).

The sixth order channel and House Creek Cove comprised the fifth morphological division of the House Creek basin. Stations 90(R) and 99(R) were located in the House Creek Cove of Keystone Reservoir (Fig. 1). Stations 90(R) was outside of the original creek channel and in open water 1 km above the cove mouth. Stations 99(R) was in the upper end of the cove 2.3 km above the original confluence of House Creek and the Cimarron River. The trees of the original stream bank, though dead, provided a partial wave and wind break at this stations. At power pool level, stations 90(R) and 99(R) were 4.0 and 6.5 m deep, respectively, and the cove encompassed approximately 70 ha. House Creek Cove, because of its southeast-northwest orientation, was exposed to high annual wind velocities. The waters were continually churned by the prevailing southerly flow or the strong northwest winds behind passing weather fronts.

Station 91(6I) was located in lower sixth order House Creek 7 km above the Cimarron arm (Fig. 1). At power pool stage, reservoir backwater impounded the lower 8 km of House Creek. Station 91(6I) was a 457 m section of the impounded House Creek channel. Maximum depth was 2.5 m at power pool level. Because of the falling reservoir level, this station had become totally isolated from the reservoir by mid-October, 1966. Pool length was reduced to 250 m and depth to 1 m.

Stations 80(6H) and 41(6H) represent natural sixth order pools. Station 80(6H), 11.6 km above the Cimarron-House Creek confluence, was located in the largest natural water mass (over 2 km long) of the House Creek drainage. Station 41(6H), a considerably less stable pool than 80(6H), was located 16.7 km above the Cimarron arm, just below the confluence of the two fifth order hierarchic tributaries. Data for the above stations are summarized in Table XV, page 120.

Physico-Chemical Parameters and Stream Order

Information on stream order and physico-chemical relationships is scant. Harrel and Dorris (1968), Carter and Jones (1969), Jones (1970) and Whiteside and McNatt (1972) presented physico-chemical parameters within a stream order framework, but the degree to which these parameters were a function of sampling time and climatic conditions is unclear. In the present study all monthly physico-chemical data were gathered during the mid-afternoon under similar weather conditions; hence, more valid intra-basin comparisons were possible.

Data from 28 regularly sampled stations are discussed. Included are two reservoir stations in House Creek Cove, three sixth order pools, four fifth order pools including one fifth order adventitious (5A) pool, six fourth order hierarchic (4H) stations, five fourth order adventitious (4A) stations, one third order hierarchic (3H) station, five third order adventitious (3A) stations, one second order hierarchic (2H) station, and one second order adventitious (2A) station. Because of their ephemeral nature, all first order and several second and third order stations established to gather physico-chemical data were excluded from mean calculations. Data from pools which were appreciably altered by domestic sewage, brine wastes, or reservoir impoundment and other unique stream situations were also excluded from mean calculations, but are discussed individually.

Water Temperature

In the House Creek basin, the spatial temperature regime was primarily influenced by degree of cover, pool volume, and ground water influxes. Mean reservoir and sixth order temperatures were highest, fourth and fifth order means were intermediate, and temperatures in the second-third order group were lowest (Fig. 8). The correlation coefficient (r) between stream order and pool temperature was 0.98. Comparisons between adventitious and hierarchic pools were possible only in order four. The mean 4H temperature was 15.2 C, while the 4A mean was 16.7 C. Fourth order hierarchic means were generally lower than 4A means because of greater cover along 4H streams and the emergence of ground water in the vicinity of stations 56(4H) and 62(4H). Annual station means ranged from 12.8 C at station 22(3H), a spring-fed pool, to 20.1 C at station 52(4A), an unshaded upland pool. Average monthly water temperature was highest in July and lowest in January for every stream category (Fig. 9). Mean basin water temperature was lowest in 4A Calf Creek and highest in the 5H-W basin (Fig. 10). The cooler temperatures of Calf Creek were attributed to substantial influxes of ground water.

Dissolved Oxygen

Mean seasonal dissolved oxygen concentration in House Creek was highest in winter, lowest in spring, and intermediate in autumn and summer. Dissolved oxygen declined during autumn and increased moderately during summer in most stream classes (Fig. 11). In the reservoir and second-third order waters dissolved oxygen did not conform to this

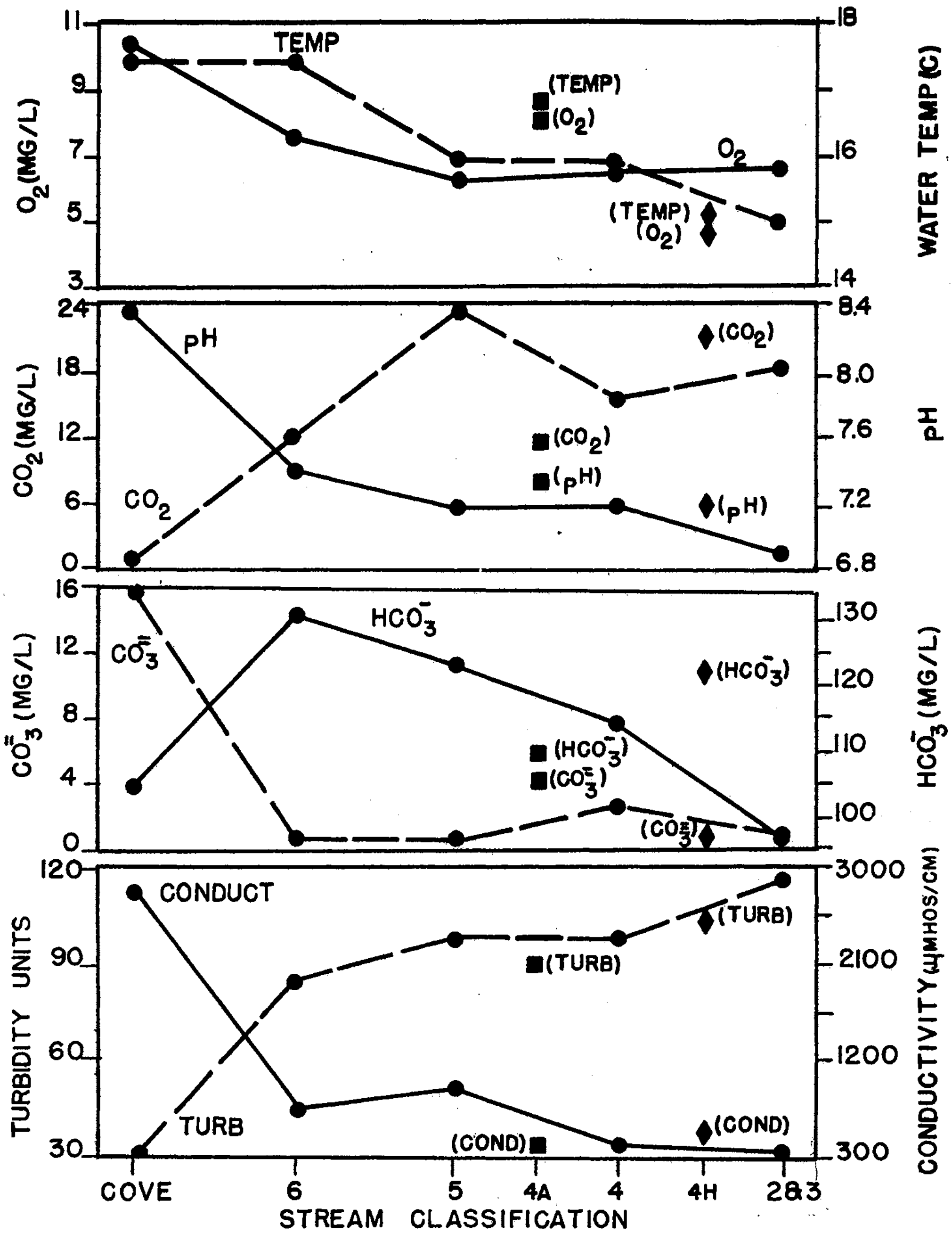

Figure 8. Mean Annual Physico-Chemical Conditions in Relation to Stream Classification. (■ = 4A Stations, ♦ = 4H Stations).

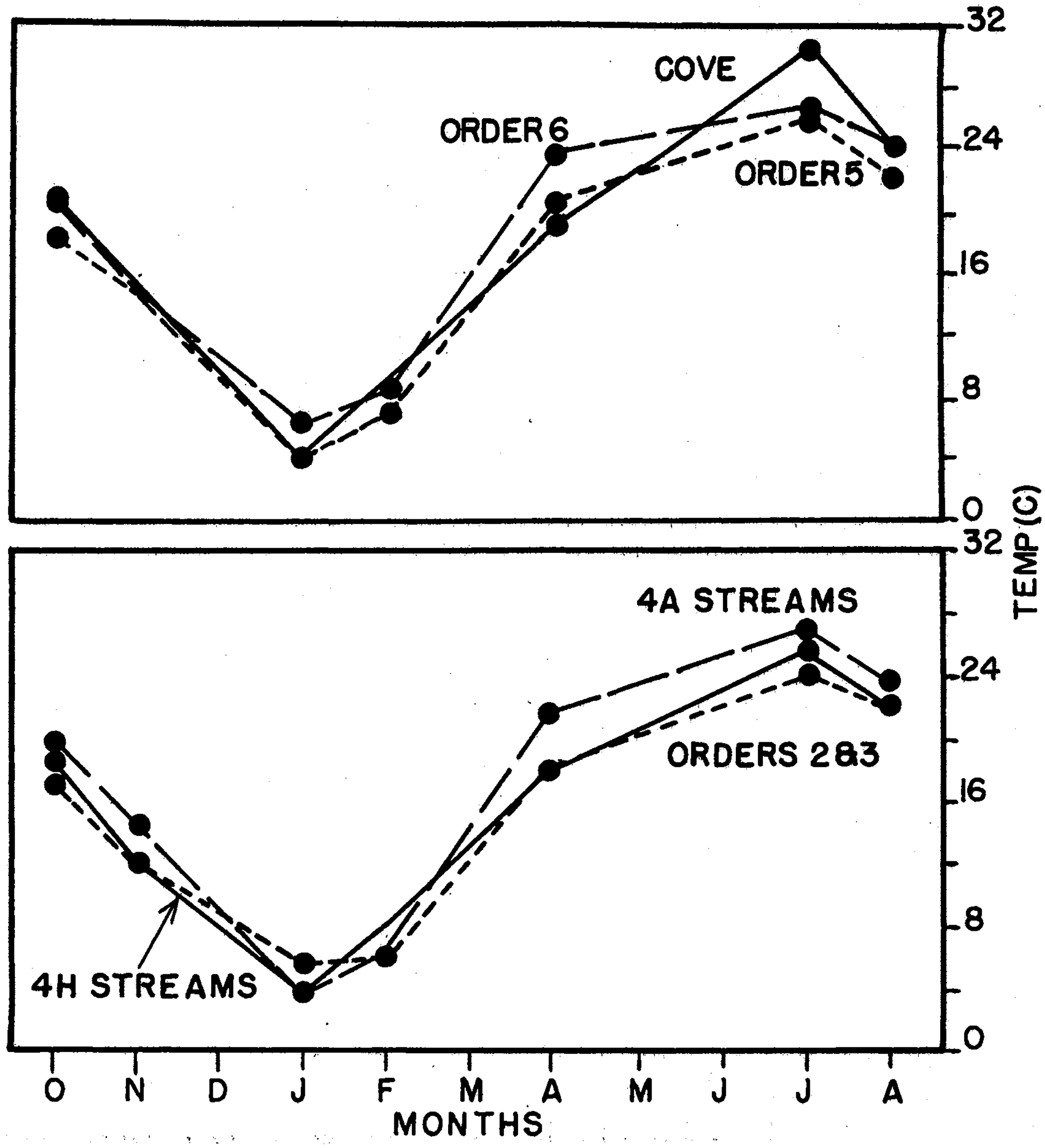

Figure 9. Mean Monthly Temperature in House Creek Cove and Tributaries.

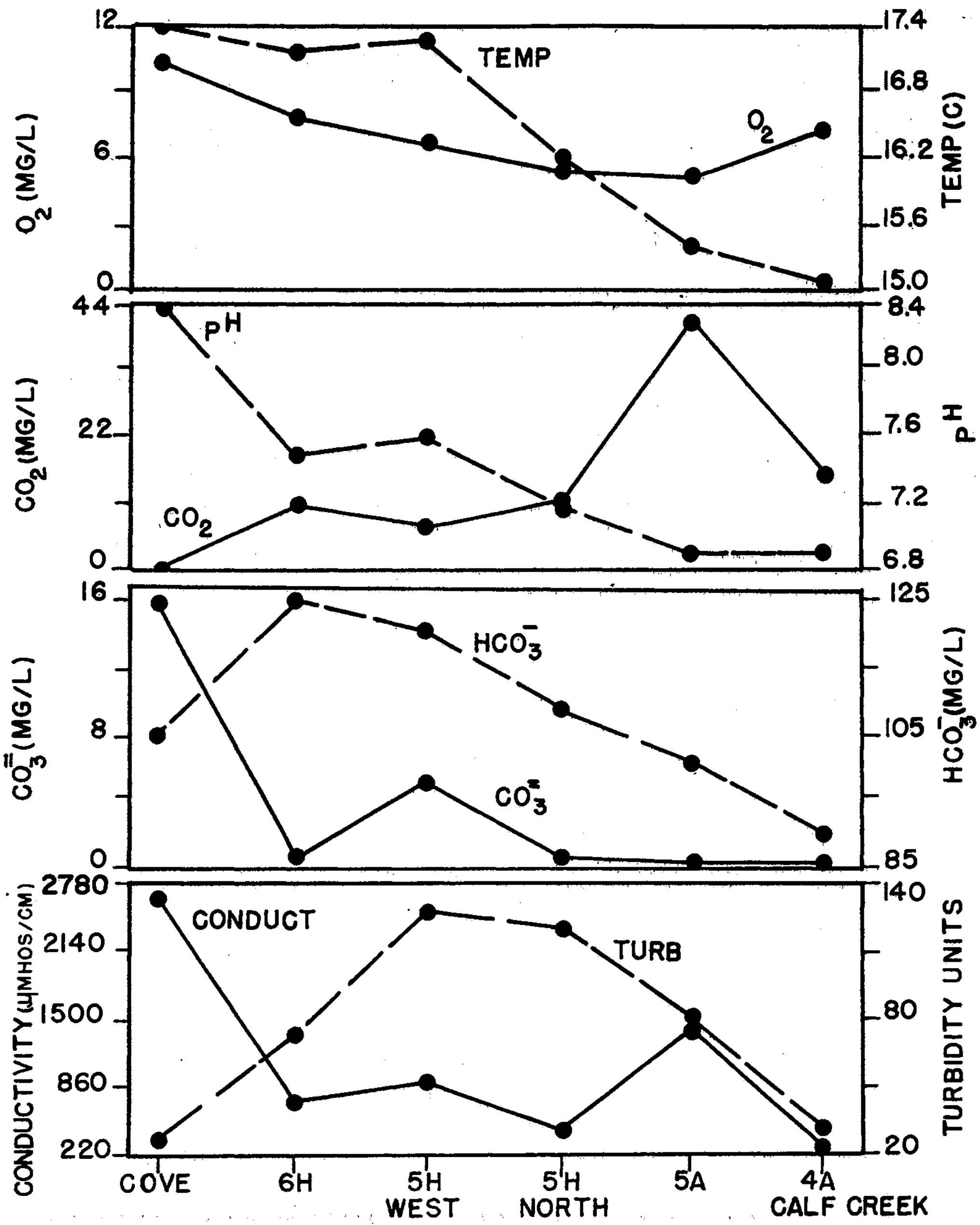

Figure 10. Mean Annual Physico-Chemical Conditions for Major Sub-divisions of the House Creek Basin.

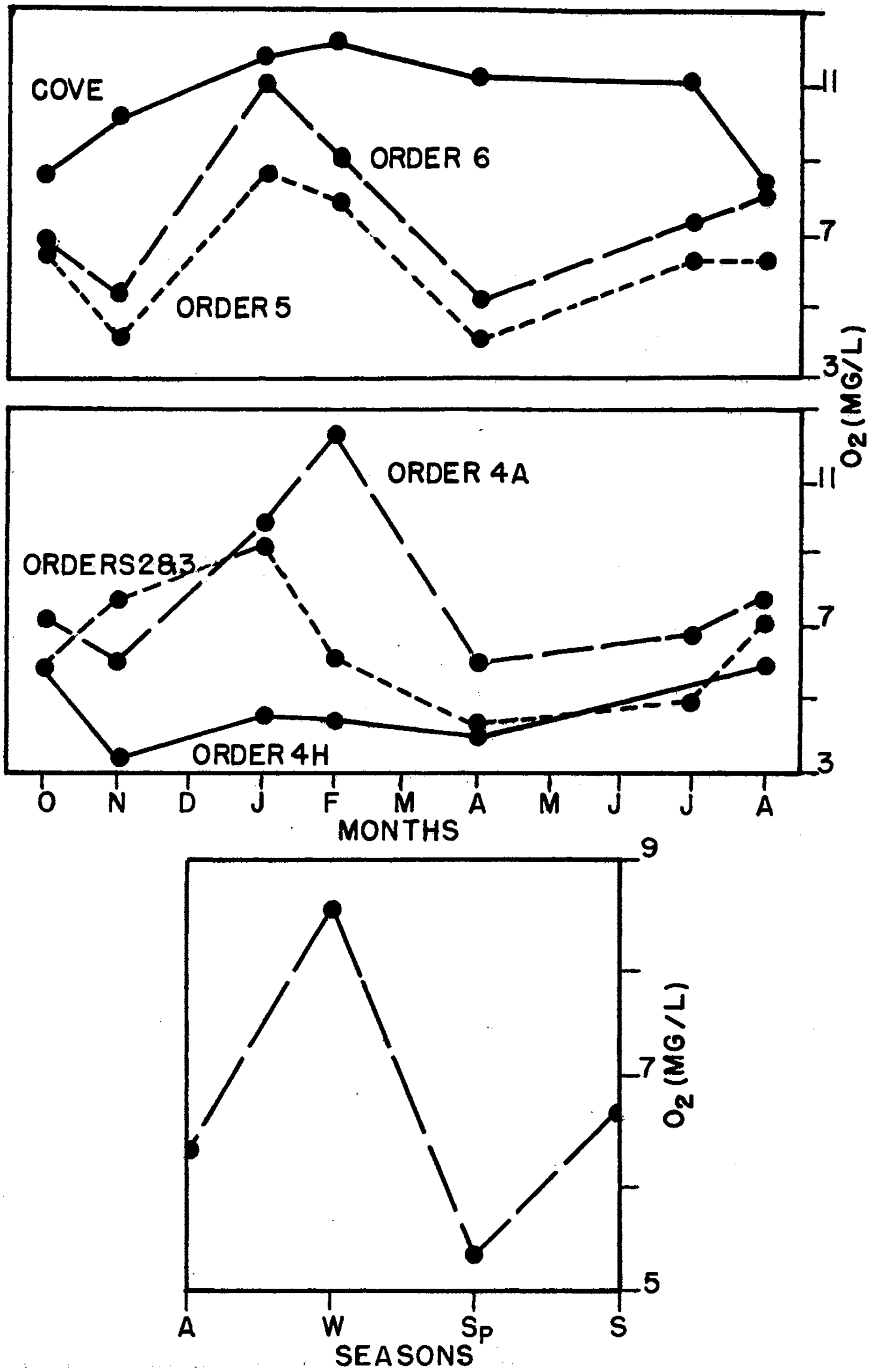

Figure 11. Mean Monthly and Seasonal Dissolved Oxygen in House Creek Cove and Tributaries.

seasonal pattern. Most second and third order pools were permanent springs or located in spring branches, and thus, displayed greater stability than pools typical of an intermittent drainage. Temporal variation in House Creek Cove was similar to that described for Keystone Reservoir by Eley (1970) and Ransom and Dorris (1972).

The autumnal oxygen depression was attributed to the "black-water" condition which develops in streams when droughts coincide with autumnal fall of leaves (Schneller, 1955). This condition was prevalent throughout the House Creek basin by late autumn and characterized by low pH values, little or no oxygen, and high concentrations of carbon dioxide. High wintertime dissolved oxygen concentrations are typical of temperate zone streams (Reid, 1961).

The vernal decline in dissolved oxygen was associated with high turbidity and stream flow. This inverse relationship between turbidity and stream flow on one hand, and dissolved oxygen on the other has been reported by Ricker (1934), Minckley (1963), Carter and Eley (1967), and Harrel and Dorris (1968). Reid (1961) stated that vernal decline in dissolved oxygen may be related to removal of vegetation by spring floods and organic decomposition of material washed into pools in conjunction with lower photosynthetic rates due to high turbidity.

Average dissolved oxygen was highest in the Reservoir and tended to increase with stream order ($r = 0.80$) (Fig. 8). The small increases for the four and second-third order categories resulted from high dissolved oxygen concentrations in 4A pools and the necessity to sample permanently flowing spring branches to obtain monthly second and third order data. During summer and autumn, flow was typically arrested in 4H channels and widespread pool stagnation occurred; thus, mean dissolved oxygen in 4A pools exceeded that of 4H pools. Station means ranged from 2.8 mg O_2/l at pool 51(3A) just below the sewage outfall to 10.4 mg O_2/l in the cove at station 99(R). Means among the natural stream stations ranged from 3.0 mg O_2/l at station 20(4H), a shaded pool in which fallen leaves accumulated, to 10.2 mg O_2/l at station 26(2A), a small rippling spring branch.

An oxygen sag occurred in the 5H-W watershed below the Jennings sewage outfall (Fig. 12). In the 5A basin, mean annual dissolved oxygen was highest at station 21(2A) just below the major brine waste source (Fig. 13). The exceedingly conductive waters of pool 21(2A) may have triggered an increase in primary production as suggested by high oxygen concentrations and frequent algal blooms. Harrel and Dorris (1968) suggested that brine wastes may permit higher primary productivity by reducing turbidity. Station 1(3A), located low in the basin, received reservoir floodwater during the summer. Prior to reservoir encroachment, dissolved oxygen measurements were low (1.4 - 3.7 mg O_2/l) and turbidity was high (318 - 566 units). Following the entry of floodwaters, oxygen concentration remained low (3.3 mg O_2/l), but turbidity decreased to 28 units and the conductivity rose sharply. Organic decomposition in the floodwater may have contributed to the low oxygen concentration. As reservoir waters receded, oxygen and turbidity increased and conductivity decreased.

Differences between basin oxygen means were not pronounced; however, lowest means occurred in the 5H-N and 5A basins where waters were most evanescent (Fig. 10).

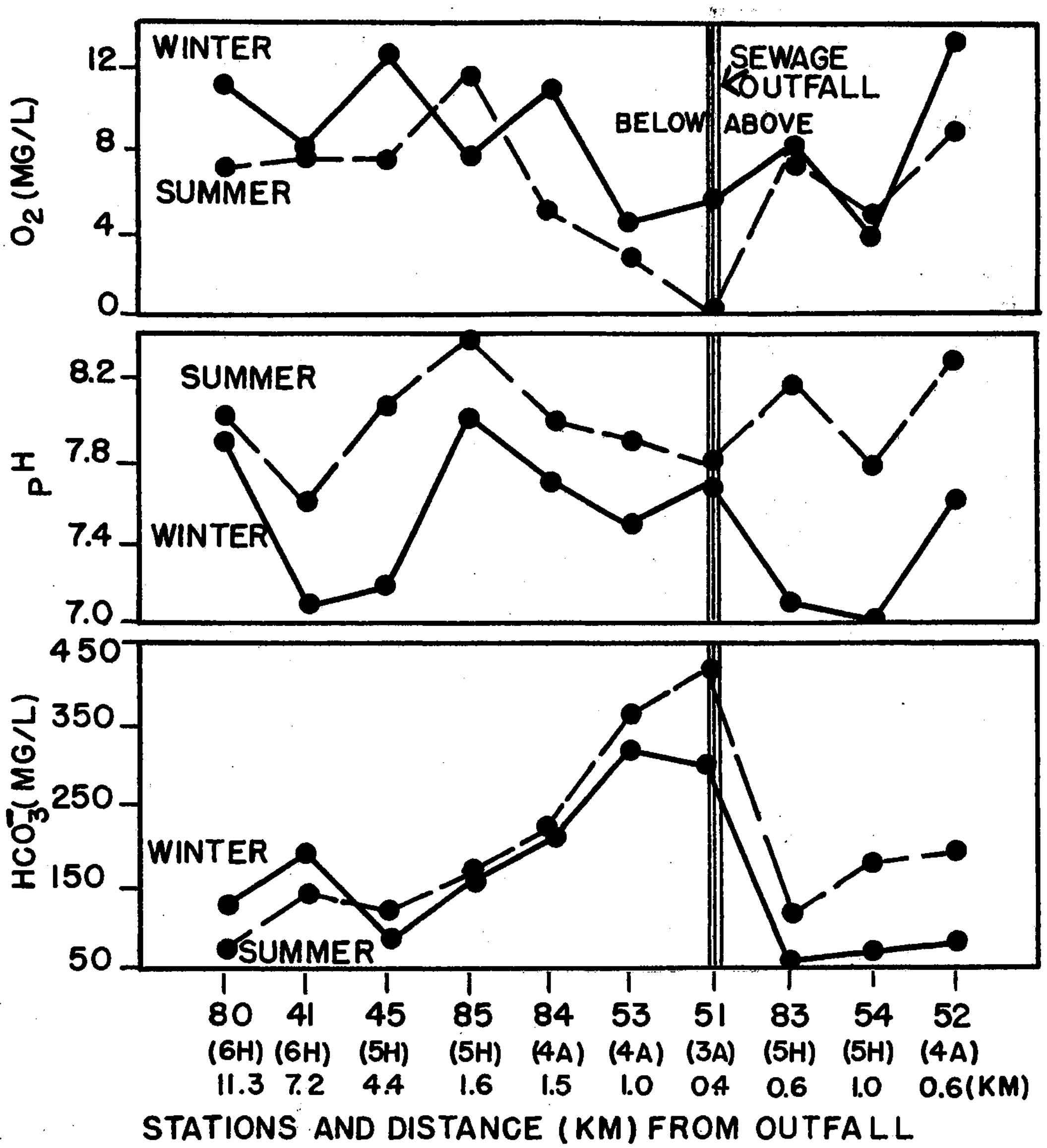

Figure 12. Certain Mean Winter and Summer Physico-Chemical Conditions for Stations Below and Immediately Above the Jennings Sewage Outfall.

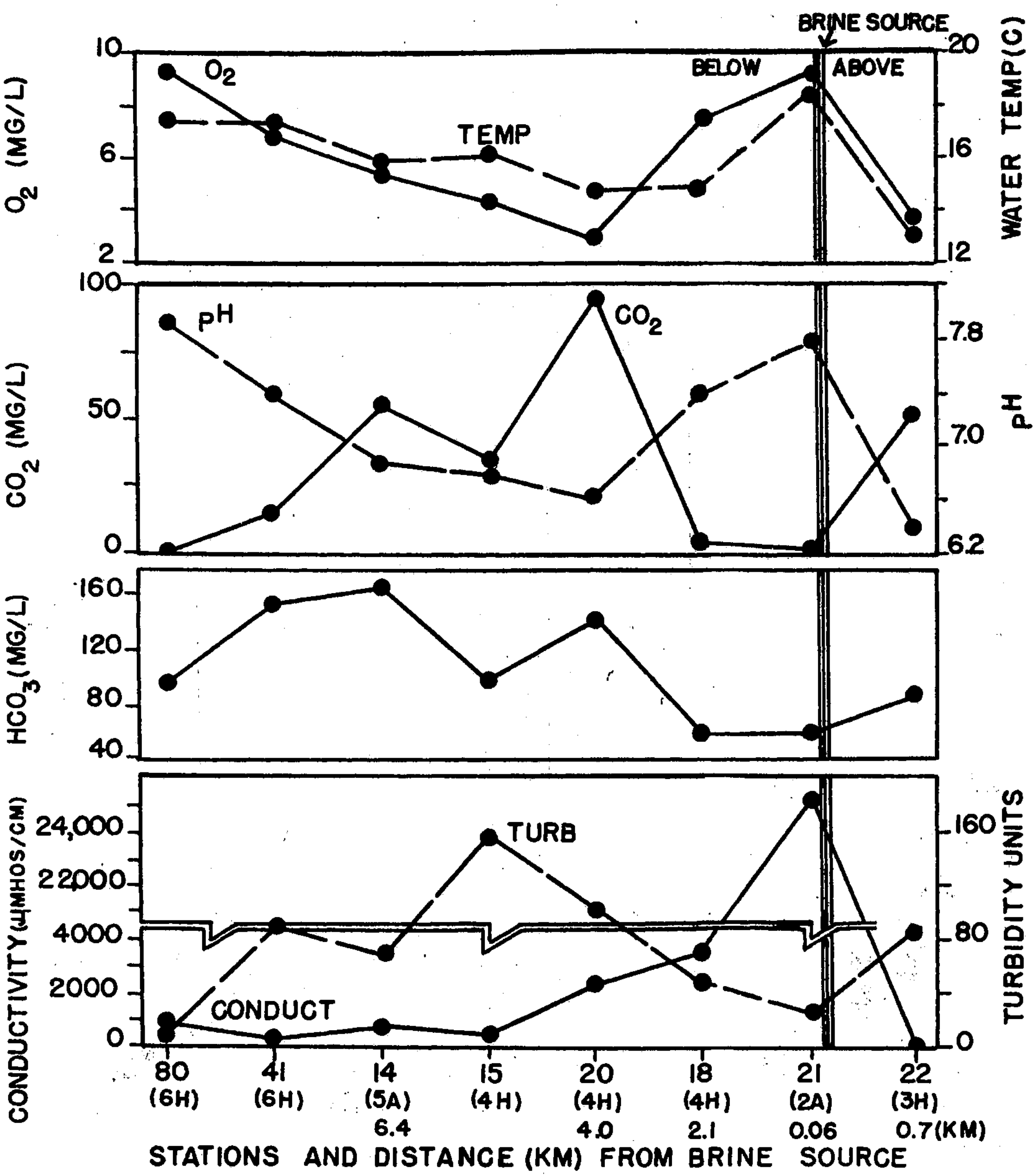

Figure 13. Mean Annual Physico-Chemical Conditions for Stations in the Fifth Order Adventitious Basin and Two Natural Sixth Order Stations.

Hydrogen Ion Concentration

Mean seasonal pH was lowest during autumn and winter in association with widespread pool stagnation and highest in summer (Fig. 14). Generalizations regarding temporal pH regimes in streams cannot readily be formulated. Ricker (1934) and Sprague and Carson (1964) reported lowest pH values during spring for two Canadian streams, while Brinley (1942), Wallen (1954), Slack (1955), and Wilhm and Dorris (1966) failed to detect definite seasonal pH patterns in certain Indiana and Oklahoma streams.

The pH increased with stream order ($r = -0.94$ for pH values expressed as hydrogen ion concentrations) and was highest in the reservoir (Fig. 8). Station means ranged from pH 6.4 at station 22(3H), a shaded spring-fed pool, to pH 8.5 at station 90(R) in the cove. The highest mean among stream pools was pH 8.1 at station 44(4A). Whiteside and McNatt (1972) found a relatively constant pH throughout all orders in a fifth order Texas basin.

Average pH was higher in 4A pools than in 4H and fifth order pools (Fig. 8). Several adventitious pools were unshaded and characterized by frequent algal blooms, high pH and dissolved oxygen values, and low carbon dioxide and bicarbonate concentrations: e.g., stations 64 (Table X, page 113) and 44 and 52 (Table XII, page 116). Mean pH was maximum in the 5H-W basin and minimum in the 4A and 5A basins (Fig. 10). Widespread fouling of pools during the drought contributed to the low pH in the 5A basin. Poorly buffered spring water may have contributed to the low pH in 4A Calf Creek.

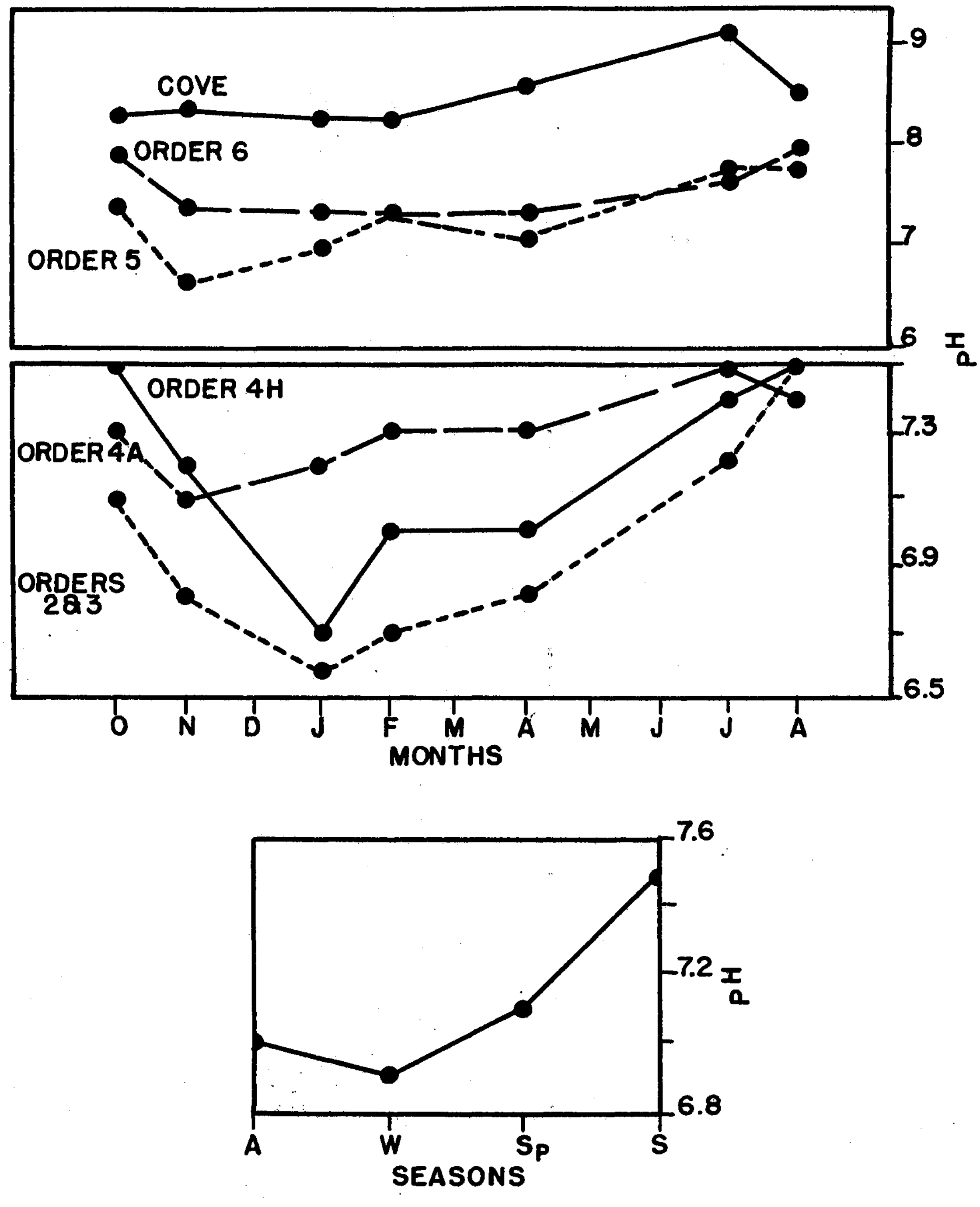

Figure 14. Mean Monthly and Seasonal pH in the House Creek Cove and Tributaries.

Carbon Dioxide

Temporal carbon dioxide fluctuations were pronounced in the stream network, but slight in the cove (Fig. 15). In general, carbon dioxide concentration increased during autumn and winter under drought conditions and decreased during late winter, spring, and summer.

Carbon dioxide varied inversely with pH, both temporally and spatially. There was little correlation between stream order and carbon dioxide concentration (r = -0.29); however, lowest concentrations occurred in the cove in association with maximum pH values (Fig. 8). Station means ranged from 0.4 mg CO_2/l at station 90(R) in the reservoir to 97.7 mg CO_2/l at station 20(4H). The minimum average among tributary stations was 1.6 mg CO_2/l and occurred immediately below the major brine influx at station 21(2A). The minimum average among natural stream pools was 1.7 mg CO_2/l and occurred at station 44(4A). Photosynthetic activity may have contributed to the carbon dioxide depression in the brine contaminated pool and other unshaded pools. Mean basin carbon dioxide was highest for the ephemeral 5A drainage. Other major basin means were substantially lower (Fig. 10).

Carbonates

Carbonate alkalinity was much higher in the reservoir than in the House Creek tributaries (Fig. 16). Basin means were exceedingly low for all except the 5H-W drainage (Fig. 10). Relatively high carbonate concentrations in 4A pools were responsible for a weak negative stream order-carbonate correlation (r = -0.35) (Fig. 8). An inverse relationship between carbonates and stream order was reported by Harrel and

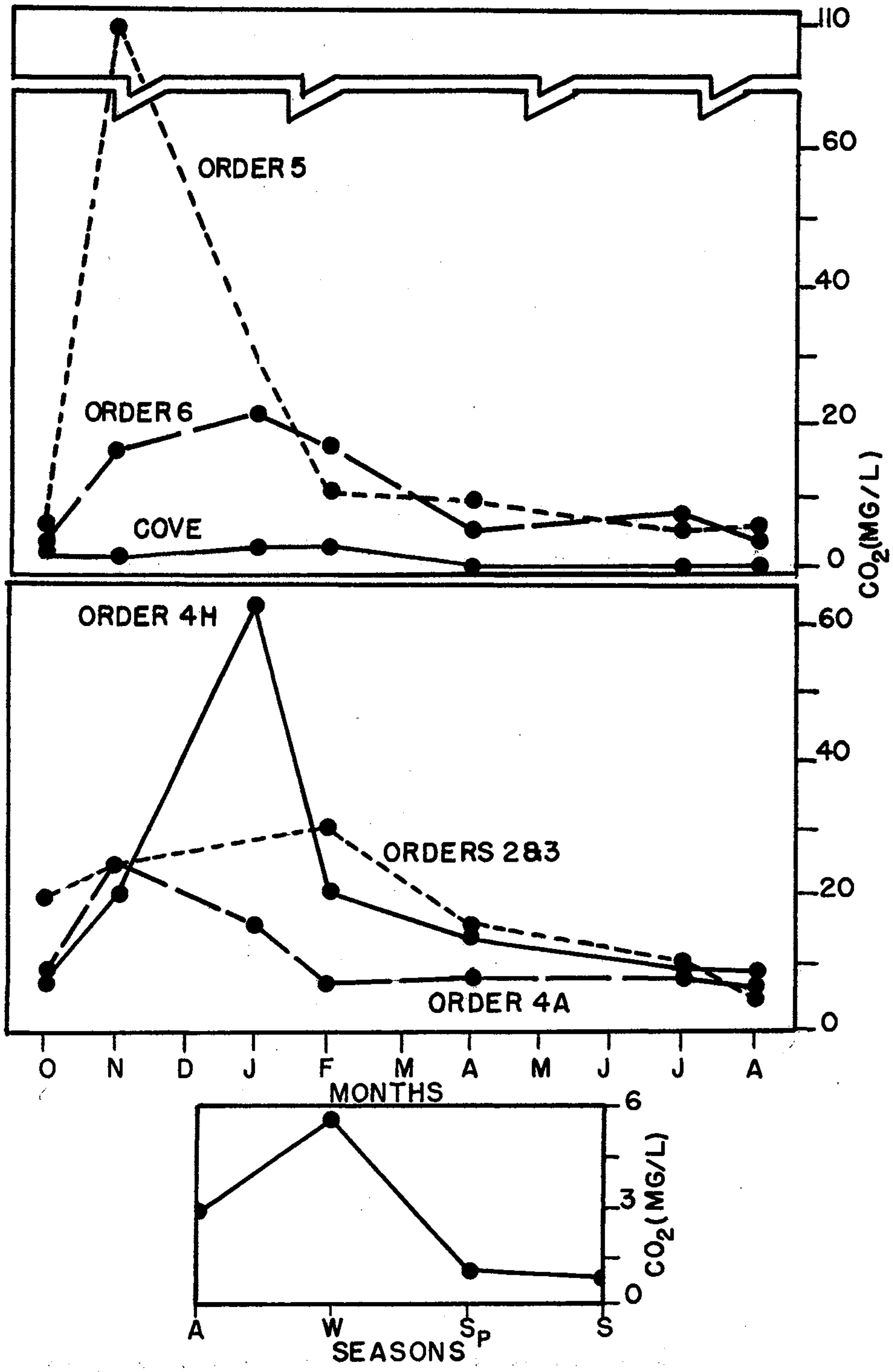

Figure 15. Mean Monthly and Seasonal Carbon Dioxide in House Creek Cove and Tributaries.

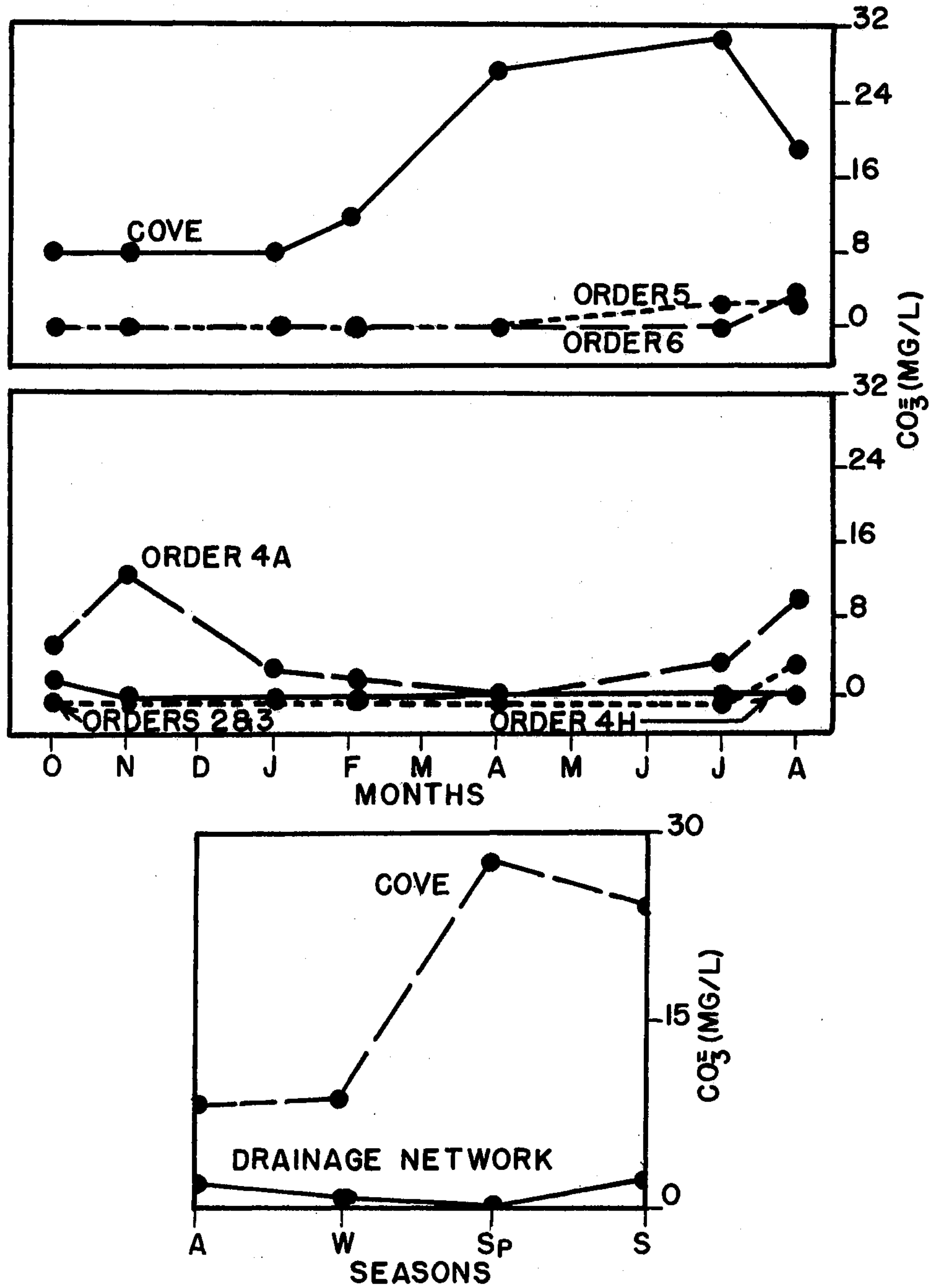

Figure 16. Mean Monthly and Seasonal Carbonates in House Creek Cove and Tributaries.

Dorris (1968) for another intermittent Oklahoma stream. House Creek station means ranged from zero at numerous pools to 13.7 mg $CO_3^{=}$/l at station 52(4A). Carbonates varied with pH, and highest concentrations occurred in the reservoir and concomitant with algal blooms in adventitious and brine contaminated pools: e.g., station 64 (Table X), 44 and 52 (Table XII), 21 (Table XIII), and 90 and 99 (Table XV). High carbonate alkalinity may have resulted from the total depletion of carbon dioxide by algae and the consequent dissociation of bicarbonates (Ruttner, 1963).

Temporal carbonate variation in the reservoir differed considerably from that in the drainage network (Fig. 16). Reservoir carbonates were lowest during autumn and winter and highest in spring and summer. In the stream system, mean carbonate alkalinity declined through autumn, winter, and spring but increased in the summer. All streams were devoid of carbonates in April after the spring rains.

Bicarbonates

Seasonal bicarbonate means for stream pools were generally high during the autumn and winter, low in spring, and high again during summer. Reservoir bicarbonates were lowest in the summer (Fig. 17).

Bicarbonate alkalinity increased with stream order ($r = 0.98$) but was higher in the tributaries than in the cove (Fig. 8). Harrel and Dorris (1968) and Whiteside and McNatt (1972) found direct relationships between bicarbonate concentration and stream order. Harrel and Dorris (1968) suggested that bicarbonates accumulate in higher orders from upstream substrate leaching. Mean cove bicarbonate alkalinity was low, exceeding only the second-third order mean. Reservoir

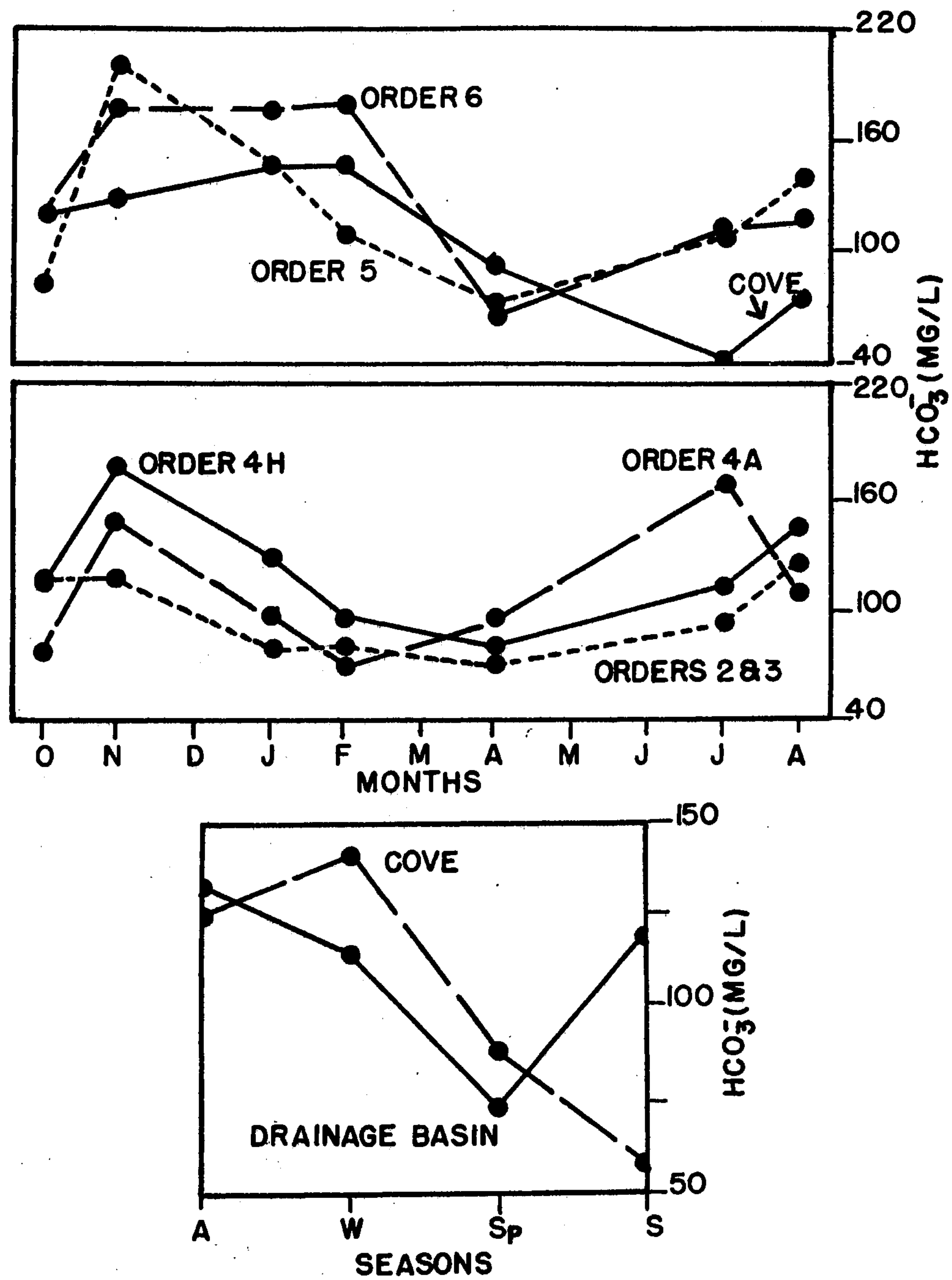

Figure 17. Mean Monthly and Seasonal Bicarbonates in House Creek Cove and Tributaries.

bicarbonates may have been converted to monocarbonates in association with high photosynthetic rates. When oxygen production was high in Keystone Reservoir, bicarbonate and carbon dioxide concentrations were low or absent and pH and carbonate values were high (Eley, 1970). Station means among the natural stream pools ranged from 36 mg HCO_3^-/1 at station 26(2A), a small spring branch, to 177 mg HCO_3^-/1 at station 56(4H), located 1.6 km below the large pothole spring.

The alkalinity of spring water at station 63(3A), the large pothole spring, may have influenced downstream water quality. The water of spring 63(3A) was apparently well-buffered. A circumneutral pH and relatively high carbon dioxide and bicarbonate concentration was recorded throughout the year, notwithstanding large accumulations of allochthonous material. Downstream, carbon dioxide decreased as bicarbonate alkalinity and pH increased (Fig. 18). Minckley (1963) described a similar pattern for a well-buffered spring system. Other spring waters in the House Creek drainage were apparently poorly buffered, having low pH and bicarbonate values: e.g., stations 65 (Table X), 22 (Table XIII), and 26 (Table XIV).

Domestic effluent from Jennings, Oklahoma, produced anomalously high bicarbonate alkalinity at stations 51(3A) and 53(4A) (Fig. 12). The highest carbon dioxide means in the 5H-W basin also occurred at these stations (Table XII). Bicarbonates averaged 346 mg HCO_3^-/1 at these two stations, more than twice the maximum mean among natural pools. Bicarbonates decreased with increasing distance below the outfall (Fig. 12). Baumgardner (1966), Jones (1968), and Laflin (1970) found high bicarbonate alkalinities immediately below domestic sewage outfalls and reductions downstream.

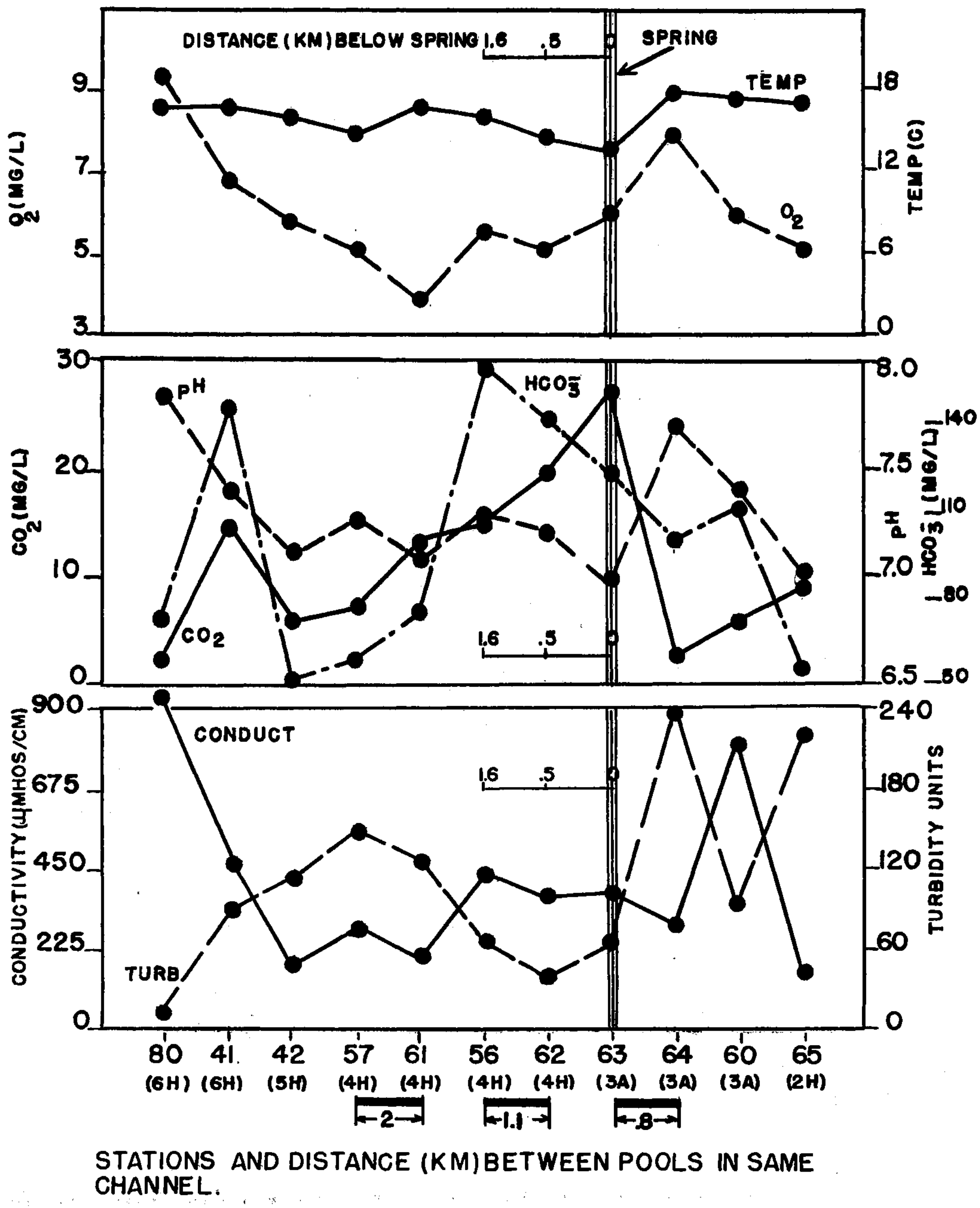

Figure 18. Mean Annual Physico-Chemical Conditions for Stations in the Northern Fifth Order Hierarchic Basin and Two Natural Sixth Order Stations.

Brine wastes appeared to enhance primary production. In the 5A watershed, site of the major influx, brine contamination was associated with minimum bicarbonate and carbon dioxide concentrations and maximum pH and dissolved oxygen content (Fig. 13).

Mean basin bicarbonate alkalinity was minimum in 4A Calf Creek, which received relatively large quantities of weakly buffered spring water, and maximum in the 5H-W basin which received domestic effluent (Fig. 10).

Turbidity

In general, stream turbidity decreased through autumn and winter, was maximum after spring rains, and reached minimum values during summer (Fig. 19). The decline in stream turbidity through autumn and winter, as drought conditions prevailed, may have resulted from the concentration of electrolytes capable of precipitating turbid particles (Irwin and Stevenson, 1951; Knudson, 1971). Seasonal turbidity fluctuations tended to increase with stream order but were smallest in the cove. Temporal turbidity patterns in the cove were similar to those described by Eley et al. (1967) and Ransom and Dorris (1972) for Keystone Reservoir. Ransom and Dorris (1972) found House Creek Cove to be the most turbid and least productive of all bays studied; they attributed the low productivity to high turbidity.

Stream order and turbidity were inversely related (r = -0.94), with reservoir waters being the least turbid (Fig. 8). Harrel and Dorris (1968) reported an inverse stream order - turbidity relationship in an Oklahoma basin, while Whiteside and McNatt (1972) found a direct relationship among the lower orders of a fifth order Texas stream.

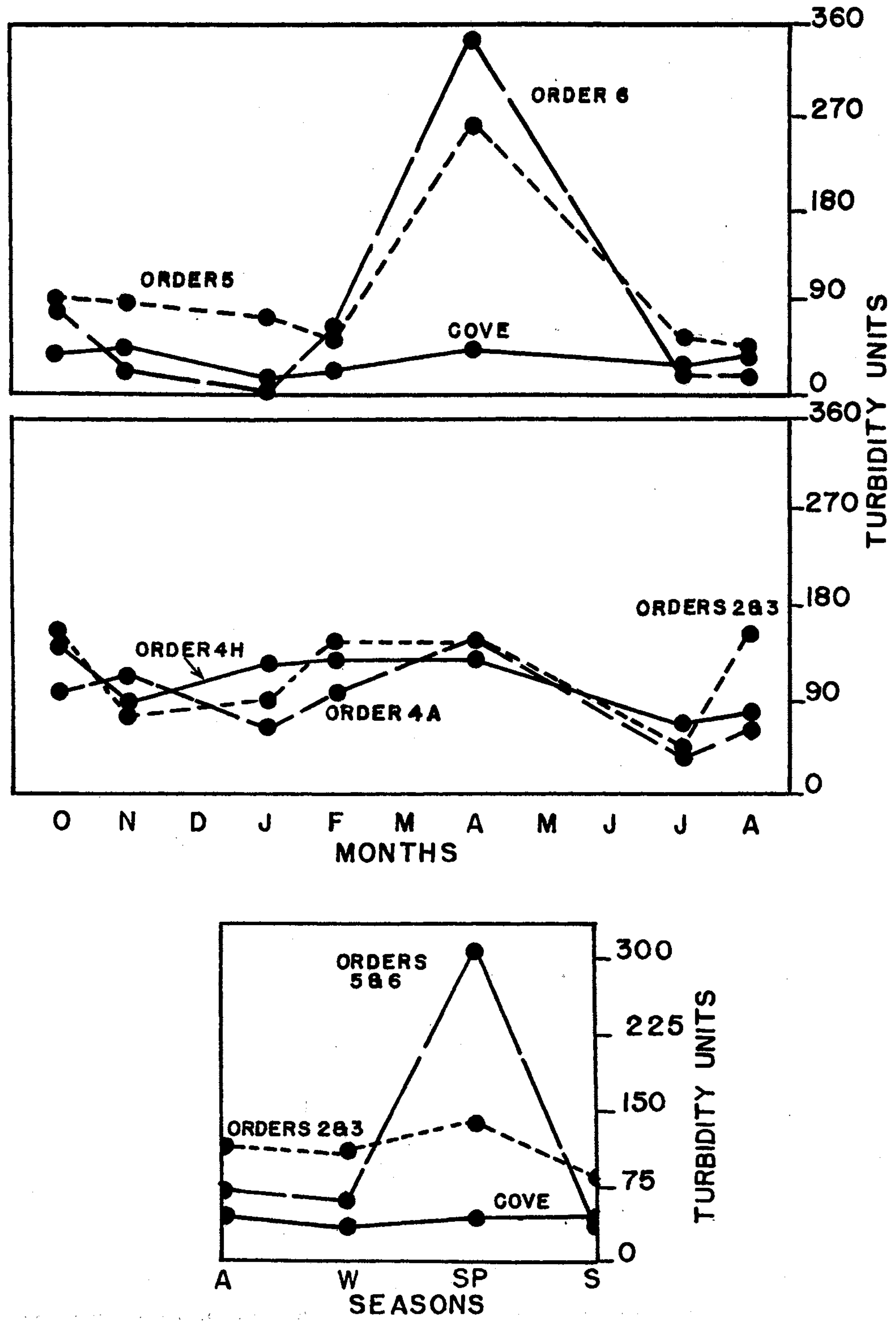

Figure 19. Mean Monthly and Seasonal Turbidity in House Creek Cove and Tributaries.

Station turbidity means in House Creek ranged from 10 units in the spring branch at station 26(2A) to 232 units at pool 64(3A).

A pronounced inverse relationship between turbidity and conductivity emerged in the tributaries with the introduction of brine wastes and highly conductive reservoir waters. The lowest mean turbidity in the 5A basin occurred at station 21(2A), located immediately below the major brine influx (Table XIII, page 118). As conductivity decreased downstream by dilution, the turbidity increased (Fig. 13). Above the flow of brines, conductivity was low and turbidity was high. In both 5H basins localized brine contamination occurred, resulting in the clearing of isolated pools; e.g., stations 60 (Table X), 58 and 59 (Table XI), and 50 and 83 (Table XII). The ability of oil field brines to depress turbidity has been discussed by Keeton (1959), Mathis and Dorris (1968), and Harrel and Dorris (1968).

Entry of reservoir floodwaters into low-lying drainageways also increased conductivity and reduced natural turbidity. For example, at pool 1(3A) mean turbidity for autumn, winter, and spring was 340 units. With the entry of reservoir water during the summer flood, mean turbidity fell to 26 units as mean conductivity increased from 168 to 2,170 umhos/cm.

Domestic effluent resulted in unusually low turbidities in the 5H-W drainage. Minimum turbidity for the basin occurred at stations 51(3A) and 53(4A), immediately below the outfall (Table XII). Baumgardner (1966) found lower turbidities below a sewage outfall, though increases have been reported (Beak, 1964; Kussat, 1969).

Highly transparent waters were not always the result of high conductivity. Exceptionally low turbidities occurred in the largely spring-fed Calf Creek drainage where mean basin turbidity and conductivity measurements never exceeded 133 umhos/cm.

Specific Conductance

On the average, conductivity increased during the drought, declined through late winter and spring, and increased again in the summer (Fig. 20). During the drought, conductivity increased with pool stagnation and concentration in all orders except second and third order spring branches. Flow increased in the spring branches during the drought and conductivity decreased. Minimum conductivity occurred with the torrential, turbid stream flow of spring. Eley et al. (1967) and Imevbore (1970) have associated low conductivity measurements with major increases in water level.

Stream order and conductivity varied directly (r = 0.82) (Fig. 8). Station means where brine contamination was not apparent ranged from 119 umhos/cm at pool 26(2A) to 453 umhos/cm at pool 41(6H) (Table III). An inverse relationship existed between conductivity and turbidity (Fig. 8). Similar relationships between stream order, conductivity, and turbidity have been described (Harrel and Dorris, 1968; Whiteside and McNatt, 1972). Average conductivity for House Creek Cove was 2,776 umhos/cm or approximately six times that of natural stream conductivity (Fig. 20). Temporal variation in cove conductivity was similar to that described for House Creek Cove and other reaches of Keystone Reservoir by Eley et al. (1967) and Ransom and Dorris (1972). The summer conductivity minimum was attributed to dilution by the reservoir flood.

The conductive property of natural waters was altered by the influx of brine wastes, domestic sewage, and reservoir backwater (Table

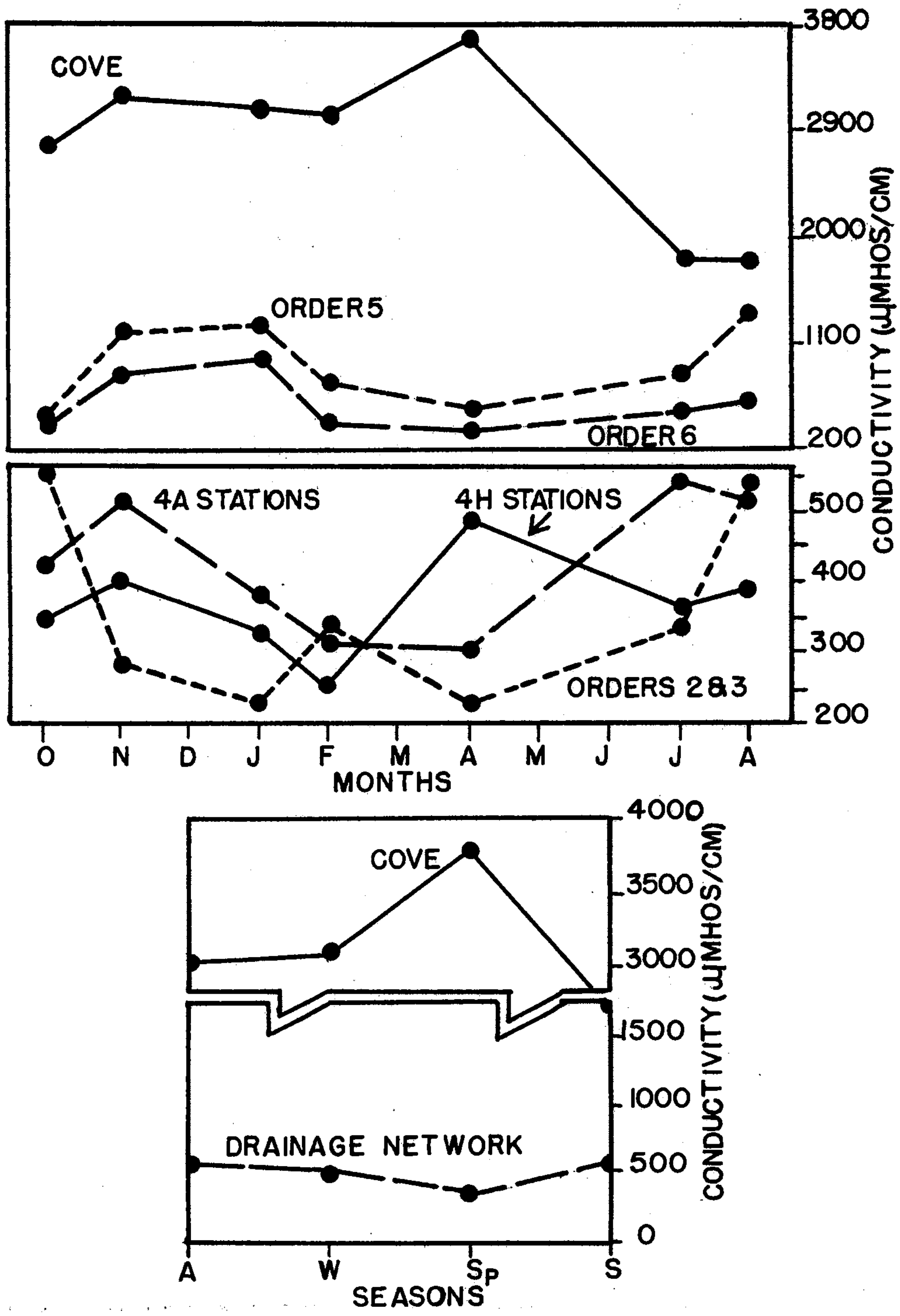

Figure 20. Mean Monthly and Seasonal Conductivity in House Creek Cove and Tributaries.

TABLE III

RANKED CONDUCTIVITY MEANS FOR REGULARLY SAMPLED STATIONS IN THE HOUSE CREEK BASIN

Station	Location/Description	Mean Conductivity umhos/cm
26(2A)	spring branch	119
42(5H)	representative pool	176
29(4A)	representative pool	187
22(3H)	spring fed pool	192
31(4A)	representative pool	223
64(3A)	representative pool, upland	242
57(4H)	representative pool	273
62(4H)	representative pool	340
63(3A)	spring fed pool	373
44(4A)	representative pool, upland	404
7(4A)	representative pool	409
56(4H)	representative pool	439
41(6H)	representative pool	453
15(4H)	below brine source	527
14(5A)	below brine source	776
52(4A)	below brine source	902
91(6I)	lower impounded House Creek	993
51(3A)	sewage outfall	1,188
53(4A)	below sewage outfall	1,251
45(5H)	below brine source	1,803
20(4H)	below major brine source	2,374
99(R)	House Creek Cove	2,754
90(R)	House Creek Cove	2,798
18(4H)	below major brine source	3,551
21(2A)	immediately below major brine source	25,164

III). Oil wells in the House Creek basin pumped a mixture of oil and brines. The brines were removed in a separator and either released in a nearby stream or stored in an evaporation pit. Such pits are known to permit brine seepage into subsurface formations and finally into surface streams (Williams, 1940). Oil field brines from producing formations in central Oklahoma have been analyzed (Wright et al., 1957). The conductivity and ion concentration is considerably higher in brines than in fresh water Oklahoma streams and even sea water. Acceptable conductivity standards for western fresh water streams have been based upon the conclusion of Ellis (1937) which declares that "pollution" should be expected when conductivity exceeds 2,000 umhos/cm. Ellis generally found "well developed" fish faunae in western streams when conductivity did not exceed 2,000 umhos/cm. Brine receiving streams exhibit conductivities that exceed the above maximum suggested by Ellis. Sampling brine receiving streams in Oklahoma, Clemens and Finnel (1957) and Mathis and Dorris (1968) observed conductivities ranging between 2,700 and 40,000 umhos/cm. In the four kilometer stretch below the principal brine source of House Creek, mean station conductivity ranged between 2,374 and 25,164 umhos/cm (Fig. 13).

Although local brine contamination occurred in both 5H basins, the principal brine influx occurred in the 5A basin. The source was a large evaporation pit approximately 60 m above station 21(2A). Mean conductivity at station 21(2A) was approximately nine times greater than cove conductivity (Table III). Mean conductivity in the fourth order hierarchic channel below the brine source (stations 18 and 20) was nearly triple the maximum conductivity of uncontaminated pools. The minimum 5A basin average (192 umhos/cm) occurred above the brine drainage at pool 22(3H). Conductivity measurements were minimum during spring following dilution by heavy rains and highest during the drought when an overall maximum reading of 40,660 umhos/cm occurred at pool 21(2A).

Harrel and Dorris (1968) and Mathis and Dorris (1968) suggested that oil field brines may act as a clearing agent by increasing conductivity, and thereby enhance productivity. In all brine contaminated pools of House Creek, exceptionally high conductivity, dissolved oxygen, and pH occurred concomitantly with low turbidity and conspicuous algal blooms. However, similar characteristics were occasionally observed in unshaded, adventitious pools where turbidity was high and conductivity low: e.g., stations 64 (Table X) and 44 (Table XII).

Domestic effluent was responsible for a moderately high mean conductivity (1,120 umhos/cm) in the reaches of stations 51(3A) and 53(4A) (Fig. 12). Conductivity measurements also reflected the presence of reservoir waters in the natural drainageways. After the autumnal separation of station 91(6I) from the cove, conductivity decreased from 1,300 to 360 umhos/cm. With the return of reservoir backwater during spring, a nearly sixfold increase in conductivity occurred.

Mean basin conductivity was lowest for Calf Creek and highest for the brine-contaminated 5A basin (Fig. 10). Calf Creek was devoid of brine seepage but carried large quantities of spring water. Conductivity declined with upstream distance in Calf Creek, reflecting proximity with major ground water influxes.

Discharge

The House Creek system was highly intermittent. General stream flow occurred only in association with widespread precipitation. Local permanent flow occurred in the lower sixth order and below several springs. Permanent springs were most numerous in the Calf Creek drainage. Excluding high flow rates following spring rains, surface discharge from the springs ranged from 25 cm^3 sec^{-1} in July at station 27(3A) to 5,800 cm^3 sec^{-1} at station 29(4A) in January. Temporally, discharge increased during the autumn and winter drought, was maximum in spring, and decreased to minimum values during the summer. The increase during the drought was attributed to a decrease in transpiration rates and a consequent rise of the water table (Personal communication from Dr. Tom Aley, hydrologist, Mark Twain National Forest). High summer transpiration rates may have contributed to the minimum summer discharges. Permanent flow originating with the Jennings sewage outfall occurred at stations 51(3A) and 53(4A). Average discharge at the outfall was 710 cm^3 sec^{-1} (Oklahoma State Dept. of Health, 1965).

The upper half of the sixth order channel was no less ephemeral than lower orders, excluding spring branches. Stream flow was detected, however, at station 91(6I) which became isolated during the reservoir drawdown. Average discharge during the autumn and winter was 4,000 cm^3 sec^{-1}. It was probable, therefore, that a permanent density current of House Creek origin flowed through the impounded waters of lower House Creek.

There is evidence suggesting that the overall ephemeral nature of stream flow in House Creek is a recent phenomenon. Since the settlement of what is now Pawnee County, vast changes in land usage have occurred (Galloway, 1959). Presumably, stream characteristics have also changed. G. W. Taylor, owner of the large spring at station

63(3A), spoke of a day when streams remained relatively clear after rains and flowed "nearly the year around" (personal communication). According to Taylor, the third order channel above spring 63(3A) once flowed continuously except during periods of extreme drought. The photograph in Figure 21, taken around 1900, shows water flowing into the spring basin from the third order channel. During the present study, a turbid flow entered the spring only for brief periods following rains.

Summary of Physico-Chemical Relationships

Average dissolved oxygen, pH, carbonates and conductivity were higher in the reservoir than in the tributaries, while the converse was true for turbidity, and carbon dioxide. Mean bicarbonates were maximum in the sixth order, while mean temperatures were highest in both reservoir and sixth order waters. In general, dissolved oxygen, pH, bicarbonates, conductivity, and water temperature increased with stream order as turbidity decreased (Table IV). Overall, physico-chemical conditions reflected a trend toward more productive and chemically stable pools with increasing stream order. Low order pools typically contained spring water or direct run-off and, therefore, were weakly buffered and often quite turbid and poorly conductive. Fourth order adventitious streams were generally warmer, more alkaline, and higher in dissolved oxygen and carbonates than fourth order hierarchic and fifth order pools. Mean carbon dioxide, bicarbonates, and turbidity were higher in 4H streams than 4A streams (Fig. 8).

Figure 21. Early 1900 Photograph of Spring at Station 63(3A)

TABLE IV

CORRELATION COEFFICIENTS (r) BETWEEN STREAM ORDER AND CERTAIN PHYSICO-CHEMICAL PARAMETERS

Item	r
Water temperature	0.98
Bicarbonates	0.98
Conductivity	0.82
Dissolved Oxygen	0.80
Hydrogen Ion Concentration	-0.94*
Turbidity	-0.94
Carbonates	-0.35
Carbon Dioxide	-0.29

*Equivalent to a positive pH-stream order relationship.

Harrel and Dorris (1968) and Whiteside and McNatt (1972) described decreases in physico-chemical fluctuations with increasing stream order, owing to increased environmental stability in higher orders. In House Creek, however, physico-chemical ranges generally varied directly with orders two through four and inversely with higher orders and the cove (Table XVI, page 122). Exceptions occurred for water temperature, conductivity, and turbidity. A higher range for water temperature occurred in the cove than in orders five and six, and due to the influence of brine wastes, the conductivity range was maximum for order five. Turbidity ranges failed to display a definite relationship with stream order. Dissolved oxygen, pH, carbon dioxide, and turbidity ranges were smallest in the cove. Regarding fourth order streams, all physico-chemical ranges except carbon dioxide and conductivity were greater in adventitious pools than hierarchic pools (Table XVI, page 122). Smaller ranges in the lower orders reflected the drying of most first, second, and third order pools during the drought and the resulting high proportion of springs and spring branches where environmental variation is often suppressed.

In August, 1967, thirteen water samples were collected for analysis by the Soil and Water Service Analytical Laboratory, Oklahoma State University. The results reflect variation between natural waters and the influence of the reservoir, oil field brines, and sewage enrichment upon water chemistry (Table XVII, page 124).

CHAPTER VI

DISTRIBUTION, SPECIES COMPOSITION, AND COMMUNITY STRUCTURE OF FISHES

Distribution of Fishes by Sub-Basin

Thirty-nine species of fish and 67,086 individuals were collected from 57 stations in the House Creek basin. The 5H-N basin collection consisted of thirteen species which formed the basic assemblage in all major divisions of the House Creek stream system (Table V). The 5H-W basin was the larger of the two 5H drainages and was characterized by relatively long and deep fifth order pools. The fauna of this basin included two additions to the basic thirteen-species assemblage: *Cyprinus carpio* and *Pimephales vigilax*. Both were lacustrine forms and taken in large fifth order pools. Average numbers of *Gambusia affinis*, *Notropis lutrensis*, *Lepomis megalotis*, and *Pimephales notatus* per station were substantially higher in the 5H-W basin (Table V). These species were abundant in relatively deep and clear 5H pools. Such pools were rare in the 5H-N basin. The greater abundance of *Ictalurus melas* in the 5H-N basin was due primarily to successful spawnings in small, turbid fourth order pools. Fish populations in the two hierarchic basins were basically similar, although differences in relative abundance occurred (Table VI).

TABLE V

NUMERICAL DISTRIBUTION OF FISHES BY MAJOR SUBDIVISIONS OF THE HOUSE CREEK BASIN

Species	Basin 5H North		Basin 5H West		Basin 5A		Basins Adv. to 6th Order & Cove		6th Order Natural		6th Order Impounded	House Creek Cove		Total
	T[a]	$\bar{X}$[b]	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	T	$\bar{X}$	
Ictalurus melas	1,888	(210)	1,350	(90)	115	(12)	484	(32)	425	(106)	2,058	9,611	(3,204)	15,931
Lepomis cyanellus	2,521	(280)	3,887	(259)	1,615	(162)	2,518	(168)	1,645	(411)	566	233	(78)	12,985
Dorosoma cepedianum							66	(4)[c]			2,614	7,656	(2,552)	10,336
Gambusia affinis	46	(5)	780	(52)	2,083	(208)	890	(59)	1,147	(287)	60	14	(5)	5,020
Lepomis macrochirus	485	(54)	1,037	(69)	131	(13)	319	(21)	906	(227)	606	413	(138)	3,897
Notemigonus crysoleucas	806	(90)	1,363	(91)	27	(3)	570	(38)	174	(44)	14	2	(< 1)	2,956
Notropis lutrensis	4	(<1)	341	(23)	214	(21)	148	(10)	304	(76)	693	833	(278)	2,537
Lepomis megalotis	140	(16)	843	(56)	27	(3)	157	(10)	736	(184)	418	194	(65)	2,515
Pomoxis annularis	32	(4)	21	(1)	42	(4)	5	(<1)	107	(27)	874	927	(309)	2,008
Pimephales notatus	3	(<1)	554	(37)	46	(5)	51	(3)	679	(170)	1	1	(< 1)	1,335
Cyprinus carpio			5	(<1)[c]			44	(3)[d]	14	(4)[c]	264	787	(262)	1,114
Aplodinotus grunniens											62	813	(271)	875
Ictalurus natalis	13	(1)[c]	38	(3)[c]	27	(3)[c]	187	(12)[d]	92	(23)[c]	378	135	(45)	870
Micropterus salmoides	68	(8)	212	(14)	42	(4)	21	(1)	100	(25)	172	255	(85)	870
Pimephales promelas	24	(3)	112	(7)	586	(59)	16	(1)	5	(1)	4			747
Carpiodes carpio									11	(3)[c]	113	504	(168)	628
Lepomis humilis	3	(<1)[c]	5	(<1)[c]	22	(2)[c]	163	(11)[d]	22	(5)[c]	52	320	(107)	587
Ictalurus punctatus									4	(1)[c]	24	270	(90)	298
Labidesthes sicculus							46	(3)[c]			183	38	(13)	267
Ictiobus bubalus											43	214	(71)	257
Notropis percobromus							1	(<1)[c]	2	(< 1)[c]	2	199	(66)	204
Pomoxis nigromaculatus					1	(<1)[c]			2	(< 1)[c]	65	93	(31)	161
Fundulus notatus							1	(<1)	65	(16)	81			147
Pimephales vigilax			1	(<1)[c]							17	116	(39)	134
Chaenobryttus gulosus							5	(<1)[c]			115	1	(< 1)	121
Hybognathus placitus							9	(<1)[c]			1	99	(33)	109
Roccus chrysops											5	41	(14)	46
Hybopsis storeriana												45	(15)	45
Pimephales tenellus												22	(7)	22
Ictiobus cyprinellus											8	8	(3)	16
Lepisosteus osseus											1	12	(4)	13

TABLE V (Continued)

Species	Basin 5H North		Basin 5H West		Basin 5A		Basins Adv. to 6th Order & Cove		6th Order Natural		6th Order Impounded	House Creek Cove		Total
	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	T	$\bar{X}$	
Pilodictus olivaris											2	8	(3)	10
Lepomis microlophus											4	4	(1)	8
Lepisosteus plastostomus											1	6	(2)	7
Lepisosteus oculatus											3	1	(< 1)	4
Ictiobus niger											2	1	(1)	3
Hiodon alosoides												1	(< 1)	1
Notropis buchanani												1	(< 1)	1
Notropis umbratilis									1	(< 1)				1
Total and $\bar{X}$ number of individuals	6,033	(670)	10,549	(703)	4,978	(498)	5,701	(380)	6,441	(1,610)	9,506	23,878	(7,959)	67,086
Total stations with fishes	9		15		10		15		4		1	3		57
Total species	13		15		14		20		20		34	36		39

[a]T = Total number of individuals.

[b]$\bar{X}$ = Mean number of individuals per station.

[c]Species collected in tributaries but more characteristic of impounded waters.

[d]Primarily young-of-the-year which entered tributaries with or were spawned in summer flood waters.

TABLE VI

MOST ABUNDANT SPECIES AND PERCENT OF TOTAL CATCH
IN THE MAJOR SUBDIVISIONS OF HOUSE CREEK

Basin 5H North		Basin 5H West		Basin 5A		Basins Adv. to 6th Order		6th Order Natural		6th Order Impounded		House Creek Cove	
Species	%	Species	%	Species	%	Species	%	Species	%	Species	%	Species	%
L. cyanellus	42	L. cyanellus	37	G. affinis	42	L. cyanellus	44	L. cyanellus	26	D. cepedianum	27	I. melas	40
I. melas	31	N. crysoleucas	13	L. cyanellus	32	G. affinis	16	G. affinis	18	I. melas	22	D. cepedianum	32
N. crysoleucas	13	I. melas	13	P. promelas	12	N. crysoleucas	10	L. macrochirus	14	P. annularis	9	P. annularis	4
L. macrochirus	8	L. macrochirus	10	N. lutrensis	4	I. melas	8	L. megalotis	11	N. lutrensis	7	N. lutrensis	3
L. megalotis	2	L. megalotis	8	L. macrochirus	3	L. macrochirus	6	P. notatus	11	L. macrochirus	6	A. grunniens	3
M. salmoides	1	G. affinis	7	I. melas	2	I. natalis	3	I. melas	7	L. cyanellus	6	Cyprinus carpio	3
								N. lutrensis	5	L. megalotis	4	Carpiodes carpio	3

Among the major drainages of House Creek, tributaries of the 5A basin were the most ephemeral and severely affected by stagnation during the drought. Moreover, heavy brine contamination resulted in the highest mean conductivity and lowest mean turbidity among fifth order basins. The fundamental differences between 5A and 5H fish populations was a shift in relative abundance of fish species. Only three of the most abundant species in the 5H basins appear among the six most abundant species in the 5A basin (Table VI). The large populations of G. affinis and Pimephales promelas and the paucity of Notemigonus crysoleucas and I. melas may be attributed, in part, to brine contamination. The 5A fauna included one addition to the basic thirteen-species assemblage: Pomoxis nigromaculatus. This typically lacustrine form was represented by a single specimen from a large 4H pool.

Lower order tributaries adventitious to the sixth order comprised a further division of the House Creek system. Fourth order Calf Creek was the largest such drainage and the location of the most persistent stream flow in the House Creek system. In the extreme lower House Creek basin, adventitious channels were partially or totally inundated by Keystone Reservoir at power pool level. Along the middle and upper reaches of the sixth order, first and second order tributaries were typically dry, while lower stretches of third and fourth order channels contained intermittent pools. The fish fauna of the adventitious basins included seven additions to the thirteen-species assemblage: Chaenobryttus gulosus, Cyprinus carpio, Dorosoma cepedianum, Fundulus notatus, Hybognathus placitus, Labidesthes sicculus, and Notropis percobromus. Only Cyprinus carpio was present in a fifth order basin. All seven species were more characteristic of reservoir and lower sixth order assemblages. With the exception of *Ictalurus natalis*, the most abundant species were among the most abundant in the fifth order drainages (Table VI).

Seven additions to the thirteen-species assemblage were collected in the natural stretch of six order House Creek. Five additions were lacustrine and generally uncommon in the natural sixth order: *Carpiodes carpio*, *Cyprinus carpio*, *Ictalurus punctatus*, *N. percobromus*, and *P. nigromaculatus*. The remaining two species, *Notropis umbratilis* and *F. notatus*, were collected only in the sixth order (Table V).

Thirty-eight species were collected from the impounded waters of sixth order House Creek and its cove with the dominant forms being *D. cepedianum* and *I. melas* (Table V). Overall, the dominant stream species were *G. affinis*, *I. melas*, *Lepomis cyanellus*, and *N. crysoleucas*.

Stream Order and Distribution of Fishes

General Distribution Patterns

The average number of individuals collected per station increased exponentially with stream order except in the highest hierarchic and adventitious ranks where the relationship became linear (Fig. 22). Mean number of individuals increased nearly fivefold between 6H stations and those in impounded waters (Table V). However, sampling technique and effort in impounded waters was not comparable with that in the streams. Total number of species increased linearly with stream order in hierarchic and lower order adventitious streams (Fig. 22). Similar patterns for numbers of individuals and species were observed

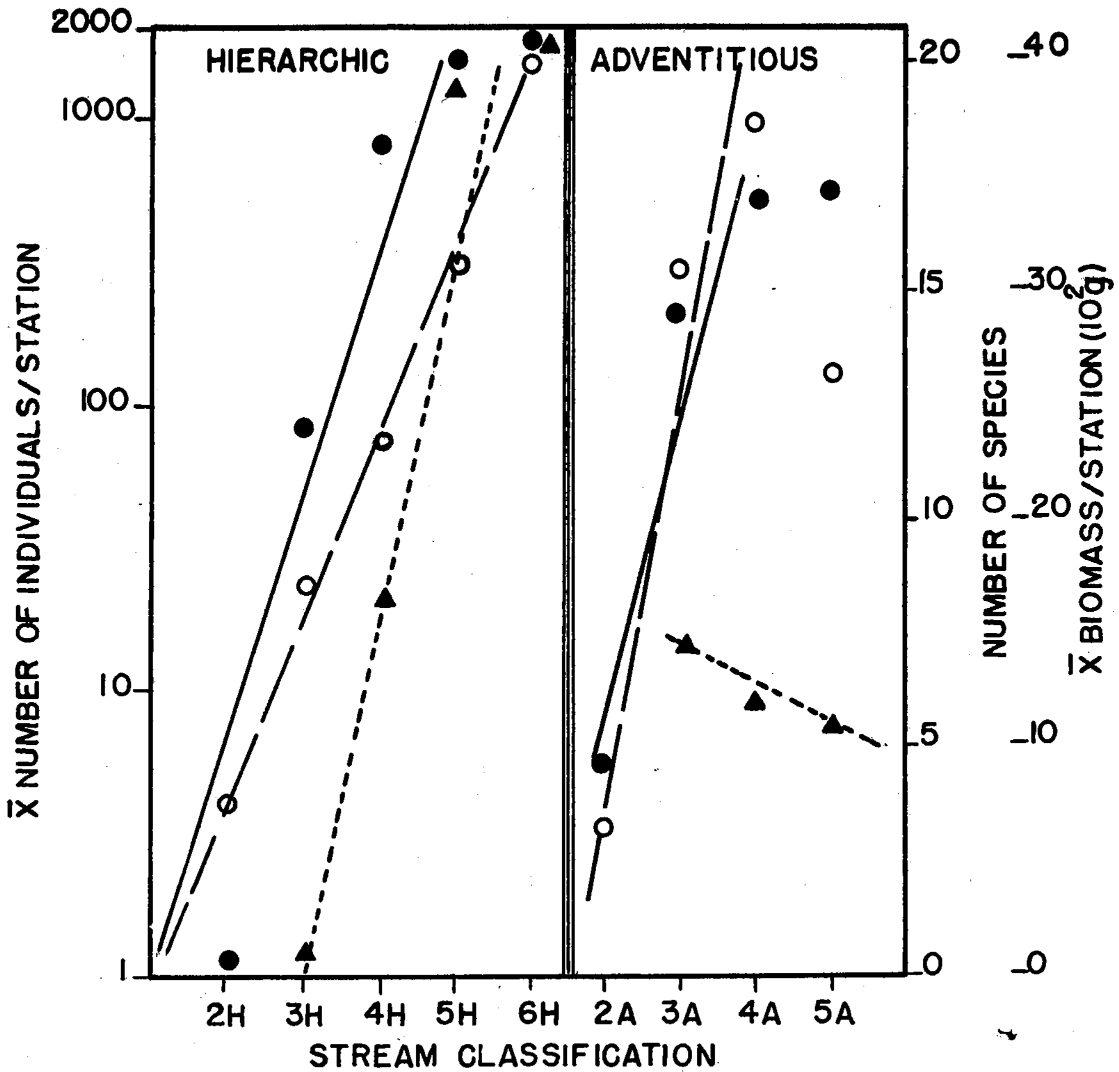

Figure 22. Total Species and Mean Number of Individuals and Biomass per Station in Relation to Stream Order. Given Below is the Symbol for the Inferred Relationship Followed by the Symbol for Observed Data: Mean Number of Individuals = (——— , ●); Number of Species = (— — — , ○); Mean Biomass = (- - - - - - , ▲).

by Kuehne (1962), Harrel et al. (1967), and Whiteside and McNatt (1972), although hierarchic and adventitious distinctions were not made. A nearly twofold increase in species occurred between stream and impounded waters (Table V). The eight stations on first order tributaries were devoid of fishes. Except for a few spring branches, first order channels were typically dry.

Based upon rotenone collections, biomass tended to increase with hierarchic stream order and vary inversely with adventitious stream order (Fig. 22). The inverse adventitious relationship was attributed to ingression of reservoir fishes in lower basin adventitious tributaries. More species were collected in third and fourth adventitious orders than in corresponding hierarchic orders.

Thompson and Hunt (1930) stated that species number and biomass increase downstream, while number of individuals per unit area decreases downstream. Larimore and Smith (1963) substantiated these postulates in certain north-central Illinois streams, and the House Creek data were in general agreement with the same.

Habitat Regions as Described by Stream Order

The headwater habitat. In House Creek the headwater habitat was defined as the drainages of hierarchic orders one through three, where pools were typically small and ephemeral. Seven species occurred in the headwaters but only *L. cyanellus*, *G. affinis*, and *P. promelas* were abundant and possibly were the only successful residents (Table VII). These species are tolerant of intense crowding and extreme environmental fluctuations, and they often have been observed in small, stagnant upper basin pools (Paloumpis, 1958; Strawn, 1958; Deacon and Metcalf,

TABLE VII

NUMERICAL DISTRIBUTION OF FISHES BY STREAM ORDER IN THE HOUSE CREEK BASIN

Species	2H		2A		3H		3A		4H		4A		5H		5A		6H (Natural)		6I (Impounded)	House Creek Cove	
	T[a]	$\bar{X}$[b]	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	$\bar{X}$	T	T	$\bar{X}$
I. melas					10	(<1)	376	(27)	1,655	(184)	397	(38)	1,331	(222)	68	(34)	425	(106)	2,058	9,611	(3,204)
L. cyanellus	11	(1)	34	(3)	673	(61)	1,343	(96)	2,879	(320)	1,836	(184)	3,439	(573)	333	(167)	1,645	(411)	566	233	(78)
D. cepedianum							54	(4)[c]			12	(1)[c]							2,614	7,656	(2,552)
G. affinis					121	(11)	69	(5)	1,545	(172)	1,032	(103)	607	(101)	425	(213)	1,147	(287)	60	14	(5)
L. macrochirus			34	(3)			234	(17)	165	(18)	329	(33)	1,194	(199)	8	(4)	906	(227)	606	413	(138)
N. crysoleucas	1	(<1)			43	(4)	497	(36)	581	(65)	498	(50)	1,132	(189)	15	(8)	174	(44)	14	2	(<1)
N. lutrensis					5	(<1)	6	(<1)	174	(19)	295	(30)	181	(30)	46	(23)	304	(76)	693	833	(278)
L. megalotis							12	(<1)			160	(16)	968	(161)	27	(14)	736	(184)	418	194	(65)
P. annularis									41	(5)	5	(<1)	53	(9)	1	(<1)	107	(27)	874	927	(309)
P. notatus									1	(<1)	61	(6)	546	(91)	46	(23)	679	(170)	1	1	(<1)
Cyprinus carpio							43	(3)[d]			1	(<1)[c]	5	(<1)[c]			14	(4)[c]	264	787	(262)
A. grunniens																			62	813	(271)
I. natalis							17	(1)[c]			170	(17)[d]	51	(9)[d]	27	(14)[c]	92	(23)[c]	378	135	(45)
M. salmoides							6	(<1)	54	(6)	47	(5)	218	(36)	17	(9)	100	(25)	172	255	(85)
P. promelas			7	(<1)	120	(11)	35	(3)	446	(50)	29	(3)	88	(15)	13	(7)	5	(1)	4		
Carpiodes carpio																	11	(3)[c]	113	504	(168)
L. humilis							155	(11)[d]	12	(1)[c]	11	(1)[c]	5	(<1)[c]	10	(5)[c]	22	(5)[c]	52	320	(107)
I. punctatus																	4	(1)[c]	24	270	(90)
L. sicculus							4	(<1)[c]			42	(4)[c]							183	38	(13)
I. bubalus																			43	214	(71)
N. percobromus											1	(<1)[c]					2	(<1)[c]	2	199	(66)
P. nigromaculatus									1	(<1)[c]							2	(<1)[c]	65	93	(31)
F. notatus											1	(<1)					65	(16)	81		
P. vigilax													1	(<1)[c]					17	116	(39)
C. gulosus							1	(<1)[c]			4	(<1)[c]							115	1	(<1)
H. placitus							9	(<1)[c]											1	99	(33)
R. chrysops																			5	41	(14)
H. storeriana																				45	(15)
P. tenellus																				22	(7)
I. cyprinellus																			8	8	(3)
L. osseus																			1	12	(4)
P. olivaris																			2	8	(3)

TABLE VII (Continued)

Species	2H T	2H X̄	2A T	2A X̄	3H T	3H X̄	3A T	3A X̄	4H T	4H X̄	4A T	4A X̄	5H T	5H X̄	5A T	5A X̄	6H (Natural) T	6H (Natural) X̄	6I (Impounded) T	House Creek Cove T	House Creek Cove X̄
L. microlophus																			4	4	(1)
L. plastostomus																			1	6	(2)
L. oculatus																			3	1	(< 1)
I. niger																			2	1	(< 1)
H. alosoides																				1	(< 1)
N. buchanani																				1	(< 1)
N. umbratilis																	1	(< 1)			
Total and X̄ number of individuals	12	(1)	75	(6)	973	(89)	2,861	(204)	7,554	(839)	4,931	(493)	9,819	(1,637)	1,026	(513)	6,441	(1,610)	9,506	23,878	(7,959)
Total designated stations	11		13		11		14		9		10		6		2		4		1	3	
Total species	2		3		7		16		12		19		15		13		20		34	36	

[a]T = Total number of individuals.

[b]X̄ = Mean number of individuals per station.

[c]Species collected in tributaries but more characteristic of impounded waters. Such species collected in 3A and 4A channels were taken from pools near the sixth order cove.

[d]Primarily young-of-the-year which entered these tributaries with or were spawned in summer floodwaters.

1961; Copes and Tubb, 1966; Cross, 1967; Summerfelt, 1967; Zach, 1967). The occasional inhabitants were *I. melas*, *Lepomis macrochirus*, *N. crysoleucas*, and *N. lutrensis*.

The mid-basin habitat. The drainages of hierarchic orders four and five, the upper quarter of the sixth order channel, and the middle reaches of drainages adventitious to the sixth order and cove constituted the mid-basin habitat. Pools here were generally larger and less ephemeral than those of the headwaters, although the drought brought about drying of smaller pools and extensive fouling in all but very large pools.

Fifteen species, including the seven present in headwaters, occurred in the mid-basin. The eight additions were *I. natalis*, *Lepomis humilis*, *L. megalotis*, *Micropterus salmoides*, *P. notatus*, *P. vigilax*, *Pomoxis annularis*, and *P. nigromaculatus*. The most abundant mid-basin species were those that also occurred in the headwaters: *G. affinis*, *I. melas*, *L. cyanellus*, *L. macrochirus*, *N. crysoleucas* and *N. lutrensis* (Table VII). Like the three headwater residents, these species are tolerant of high turbidity and the environmental extremes associated with intermittent flow (Paloumpis, 1958; Metcalf, 1959; Brown, 1960; Deacon, 1961; Deacon and Metcalf, 1961; Branson, 1967; Alpaugh, 1972). *L. macrochirus* was also an important member of base-level and reservoir assemblages. Prior to impoundment, *L. macrochirus* was common in House Creek and other turbid streams in the reservoir basin (Linton, 1961; Hicks, unpublished field data). *M. salmoides* also occurred from headwaters to cove but was most abundant in the latter. In the tributaries, *M. salmoides* preferred the larger mid-basin and base-level pools. Hicks (unpublished field data) collected *M.*

salmoides from such "very turbid" House Creek pools prior to impoundment of Keystone Reservoir. The eight additions to the mid-basin assemblage were more characteristic of base-level and impounded habitats.

The base-level habitat. This habitat included approximately the middle third of the sixth order channel and the lower drainages of its adventitious tributaries where natural pools reached their greatest size and stability. The fauna included 22 species, fourteen of which were also members of the mid-basin assemblage. The eight additions were *Carpiodes carpio*, *C. gulosus*, *D. cepedianum*, *F. notatus*, *I. punctatus*, *L. sicculus*, *N. percobromus*, and *N. umbratilis*. Excluding *N. umbratilis*, these species were more characteristic of impounded waters and entered the base-level area during periods of heavy stream flow. Thus, because of ingression by the above species and other lacustrine forms such as *Cyprinus carpio*, *P. annularis*, and *P. nigromaculatus*, the base-level fauna was somewhat transitional between stream and reservoir assemblages.

The assemblages of the sixth order and its adventitious tributaries were similar; thus the faunae of adventitious pools were generally distinct from those of hierarchic pools of like ordinal rank. Similar relationships between hierarchic and adventitious streams have been discussed for benthic macroinvertebrates and fishes in other basins (Harrel and Dorris, 1968; Whiteside and McNatt, 1972).

Although dominant species are nearly identical in the mid-basin and base-level habitats, the basic faunistic characteristics of each region were distinctive. *L. megalotis* and *P. notatus* were more widely distributed in the base-level habitat, with *P. notatus* replacing *P.*

promelas in higher orders. In the mid-basin, L. megalotis and P. notatus were restricted to permanent, less turbid pools of the fifth order. These species appear to seek out the clearer, stable pools of intermittent systems (Starret, 1950; Metcalf, 1959; Cross, 1967; Zach, 1967; Laser et al., 1969). L. megalotis was also abundant in impounded waters. G. affinis was most abundant in the sixth order, although distributed from headwaters to cove. Smith and Powell (1971) found G. affinis restricted to the lower reaches of a Lake Texoma tributary and considered it a lacustrine species. However, the species was uncommon in Keystone Reservoir during the present study and in the surveys of Mensinger (1970).

The reservoir habitat. This region included the lower impounded stretch of the sixth order, House Creek Cove, and the lower drainages of tributaries adventitious to impounded waters. The 34-species assemblage of the impounded sixth order was transitional between stream and reservoir, but it was influenced to a greater extent by reservoir fishes than the natural sixth order assemblage. The fauna included 38 species, 23 of which occurred in stream habitats (Table VII). The fifteen additions were lacustrine forms which are common in lower mainstreams of the Arkansas and Cimarron drainages.

L. humilis and I. natalis were principally reservoir species but with distributions extending into the House Creek tributaries, particularly lower basin adventitious channels (Table VII). Although L. humilis seemingly preferred the reservoir habitat, it commonly occurs in small, turbid and intermittent pools (Gerking, 1945; Branson, 1967; Cross, 1967; Smith and Powell, 1971). Its cephalic lateral line system seems specifically adapted for turbid water (Moore, 1956).

Degeneration of lateral line canals was observed, with the most extensive deterioration occurring in 4H pools. Degeneration in cove specimens was slight and rare. Normal and anomalous individuals appeared equally healthy. Although canal degeneration appeared to be related to turbidity, Curd (1959) was unable to correlate the anomaly with any particular habitat.

I. natalis, a clear-water stream and lake species, is generally far less abundant than I. melas in intermittent systems of the plains (Metcalf, 1966; Cross, 1967; Harrel et al., 1967). Throughout the House Creek basin, I. natalis was taken in smaller numbers than I. melas. Conspicuous downstream replacement of I. melas by I. natalis, as observed by Brown (1960) and Smith and Powell (1971) did not occur in House Creek. The stress of high turbidity may have been responsible for the low I. natalis populations (Trautman, 1939).

The enormous populations of I. melas in impounded House Creek and the cove may have represented an early stage of species succession characteristic of artificial impoundments. Large I. melas populations may flourish for a short time following impoundment but later decline to obscure levels or vanish completely (Harrison, 1962; Houser and Collins, 1962; Walburg, 1969).

N. lutrensis, an important member of the intermittent stream assemblage, was the most abundant cyprinid in impounded waters. N. lutrensis often becomes common in artificial impoundments within its range (Harlan and Speaker, 1956). L. sicculus was also common in impounded waters. It is primarily a clear-water stream species but often becomes abundant in reservoirs (Cross, 1967). F. notatus occurred in both natural and impounded sixth order waters but was more common in the latter. The species is characteristic of clear impoundments and stable, base gradient streams (Trautman, 1957; Larimore, et al., 1959; Smith and Powell, 1971).

Longitudinal Succession

In general, downstream longitudinal succession in the ordinal hierarchy occurred by species additions. The pattern was disrupted in adventitious orders because of their affinities with higher order receiving streams. Kuehne (1962), Harrel, et al. (1967), and Whiteside and McNatt (1972) found that most species collected in low order streams were also taken in each higher order stream. Shelford's (1911) observation that longitudinal succession occurs primarily by species additions rather than replacements has become axiomatic (Thompson and Hunt, 1930; Burton and Odum, 1945; Minckley, 1963; Straskraba, 1966; Sheldon, 1968; Smith and Powell, 1971).

Comparison of Drought and Post-Drought Fish Populations

The Stream System

Cessation of stream flow in most House Creek tributaries occurred between September, 1966 and January, 1967. Fish populations in the periodically seined pools were virtually eliminated by intense seining during this drought period; however, it is likely that all but a few individuals would have succumbed naturally by January, 1967 under the drought conditions. The post-drought period extended from February, 1967 through August, 1967. By February, most pools had reformed by ground water seepage or light runoff, but repopulation did not occur until spring and summer periods of widespread stream flow. Reestablishment of fish populations was examined in pools seined periodically during the drought and post-drought periods.

Species reestablishment was generally incomplete at stations in the 5H watersheds. G. affinis, N. lutrensis, and P. notatus did not occur in post-drought collections from the 5H-N basin, and L. humilis was absent from post-drought collections in the 5H-W basin. Three post-drought species additions occurred in the latter sub-basin: Cyprinus carpio, P. promelas, and P. vigilax. In the sixth order immediately below the fifth order confluence, only L. humilis did not reappear in the post-drought period, and P. promelas was a post-drought addition.

Total species reestablishment occurred in the adventitious sub-basins of the sixth order and cove, with most stations experiencing complete reestablishment of drought period populations. Post-drought additions in the 5A sub-basin were L. humilis and I. natalis. Three species characteristic of impounded waters occurred in the post-drought collections from lower basin adventitious streams: Cyprinus carpio, D. cepedianum, and P. annularis. The lower reaches of adventitious tributaries were continuous with the deeper waters of the sixth order during periods of stream flow. Cove waters flowed into adventitious channels in the extreme lower basin when the reservoir exceeded power pool elevation. The affinity between adventitious streams and their receiving channels was reflected by repopulation trends in adventitious basins. Receiving waters appeared to be major supply sources for repopulation of their tributaries. Overall, the extent of repopulation was greater in the lower hierarchy and adventitious drainages than in the upper basin drainage (Fig. 23).

Repopulation of House Creek drainageways varied with the species and pool position in the drainage basin. Populations of dominant species were generally replenished in proportions similar to those that existed during the drought, but total populations were usually smaller. Moreover, the tendency for pools to regain populations similar to their drought populations was inversely related to distance above the sixth order. Exceptions occurred in basin 5A where there was little relationship between extent of pool repopulation and distance from the sixth order, and similarity between drought and post-drought assemblages was least. For example, the highest correlation between drought and post-drought population density ($r = 0.92$) occurred at upper basin pool 18(4H). After resumption of stream flow, large populations of G. affinis occurred in the lower 5A channel and in upper basin pool 18(4H). A marked increase in the post-drought P. promelas population occurred in 4H pools, but the species was rare or absent in upper and lower reaches of basin 5A.

Larimore, et al. (1959) found that new post-drought populations were dominated by young-of-the-year. In House Creek, only L. cyanellus and I. melas were consistently represented by young in post-drought populations. Young of the above species accounted for most of the repopulation in the headwaters. Adults apparently survived in residual pools and spawned successfully with the onset of stream flow. Repopulation of N. crysoleucas, P. promelas, and P. notatus was generally not by young. However, N. crysoleucas did spawn successfully in the large pothole spring. N. lutrensis, a normally successful intermittent

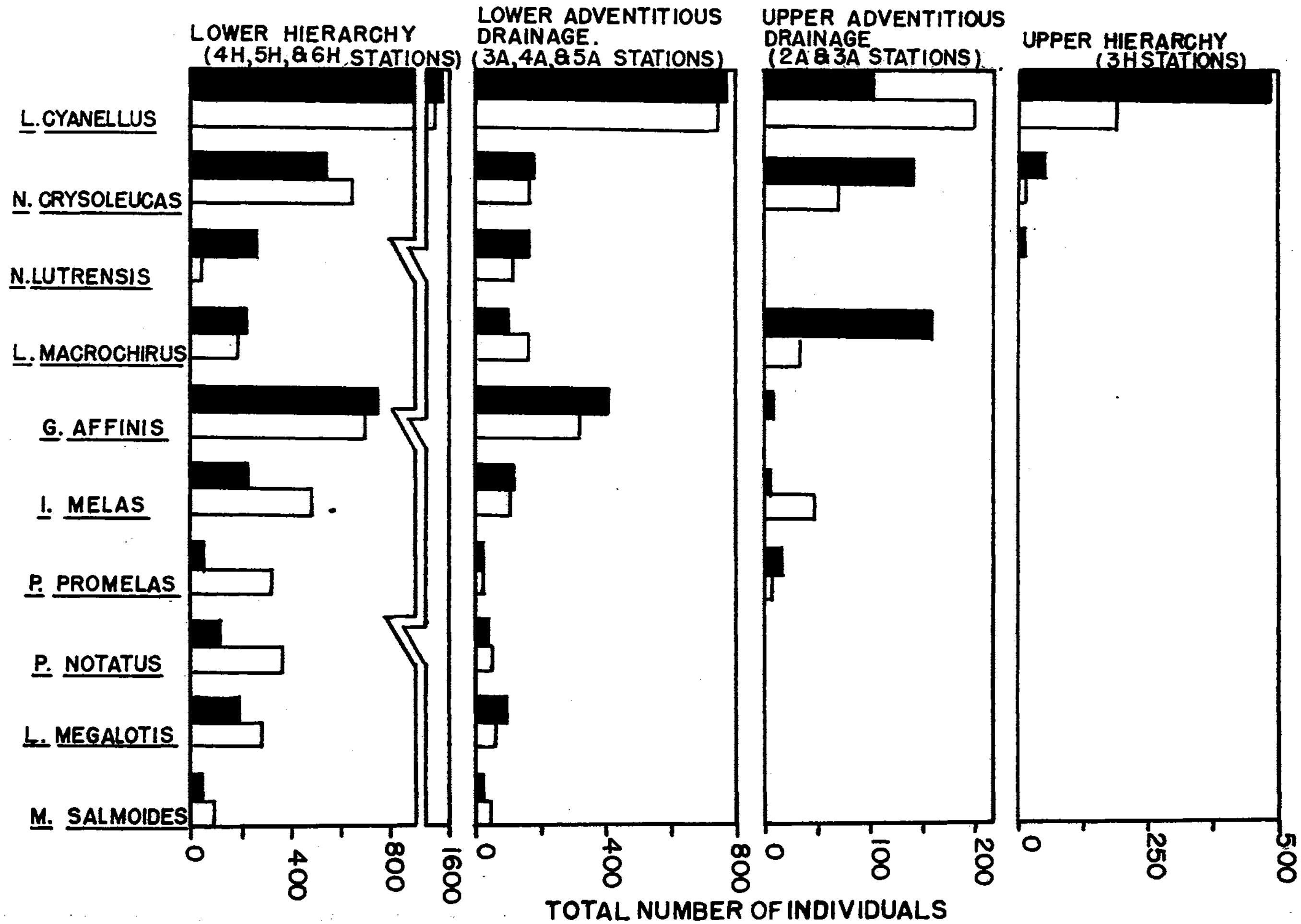

Figure 23. Summarization of Repopulation Data for the More Common Fishes of the Periodically Seined Pools. Shaded Bars = Drought Period, Unshaded Bars = Post-Drought Period.

stream inhabitant, experienced poor repopulation throughout the basin and failed to expand its distribution during periods of stream flow. I. natalis and L. humilis were considerably more abundant in post-drought samples from adventitious tributaries of the lower sixth order. These species were generally represented by young, suggesting that cove and lower House Creek populations of I. natalis and L. humilis may spawn in adventitious channels when possible. Other post-drought species in adventitious channels were typically represented by adults.

The responses of stream fishes to drought have been described by Wickliff (1945), Paloumpis (1958), Larimore et al. (1959), and Deacon (1961). Droughts in intermittent basins compound the severity of the habitat and expose fishes to predation, suffocation, disiccation, and other extreme environmental conditions. Seasonal drought periods are generally terminated by heavy, local rains which transform intermittent drainageways into raging torrents. Paloumpis (1958) has shown that alternate periods of flooding and drought reduce fish populations, but that some fishes always survive to repopulate the drainageways. Survival depends upon tolerances for environmental extremes and movement into sanctuaries such as quiet adventitious tributaries and backwater during floods and springs and deeper downstream pools during droughts. Tributaries denuded of aquatic organisms are rapidly repopulated with resumption of stream flow (Stehr and Branson, 1938; Kennedy, 1955; Larimore et al., 1959; Harrel et al., 1967). However, Larimore et al. (1959) observed that fishes repopulate positions in a stream system at different rates and discussed numerous factors which influence such rates. Larimore et al. also found that post-drought fish populations were roughly similar in composition to those of a drought period, but lower in total numbers.

The Lower Impounded Sixth Order

The most abundant species at station 91(6I) was the same for the drought and post-drought periods (Table VI). However, changes occurred in the station 91(6I) assemblage during spring as the reservoir returned to power pool elevation and inundated the station. Marked increases over isolated pool populations occurred for *Carpiodes carpio*, *Cyprinus carpio*, *D. cepedianum*, *Ictiobus bubalus*, *I. punctatus*, *P. annularis*, and *P. vigilax*. *C. gulosus*, *Lepisosteus platostomus*, and *Roccus chrysops* occurred only in the post-drought impounded waters. Other species declined in abundance as concentrated pool populations were dispersed by reservoir back-flow.

Ingression of the above lacustrine forms with the reservoir backwater may not have been entirely fortuitous. *Cyprinus carpio* and *Ictiobus* species follow floodwaters into shallow areas to spawn, and many mainstream and lacustrine species ascend small tributaries in the spring for the same purpose (Johnson, 1963; Cross, 1967). The springtime increase of *Carpiodes carpio* at station 91(6I) coincided with its sudden decline in the cove, suggesting such a seasonal migration.

Community Structure of Fishes

Stream Order and Community Structure

In general, species diversity of fishes increased with stream order and downstream within tributaries to a maximum in the impounded sixth order (Figs. 24 and 25). Reflecting the preponderance of *D.*

Key
† Permanent spring.
* Tributaries adventitious to fourth and fifth order channels in the upper basin.
**Tributaries adventitious to the sixth order and lower reaches of the fifth order channels.

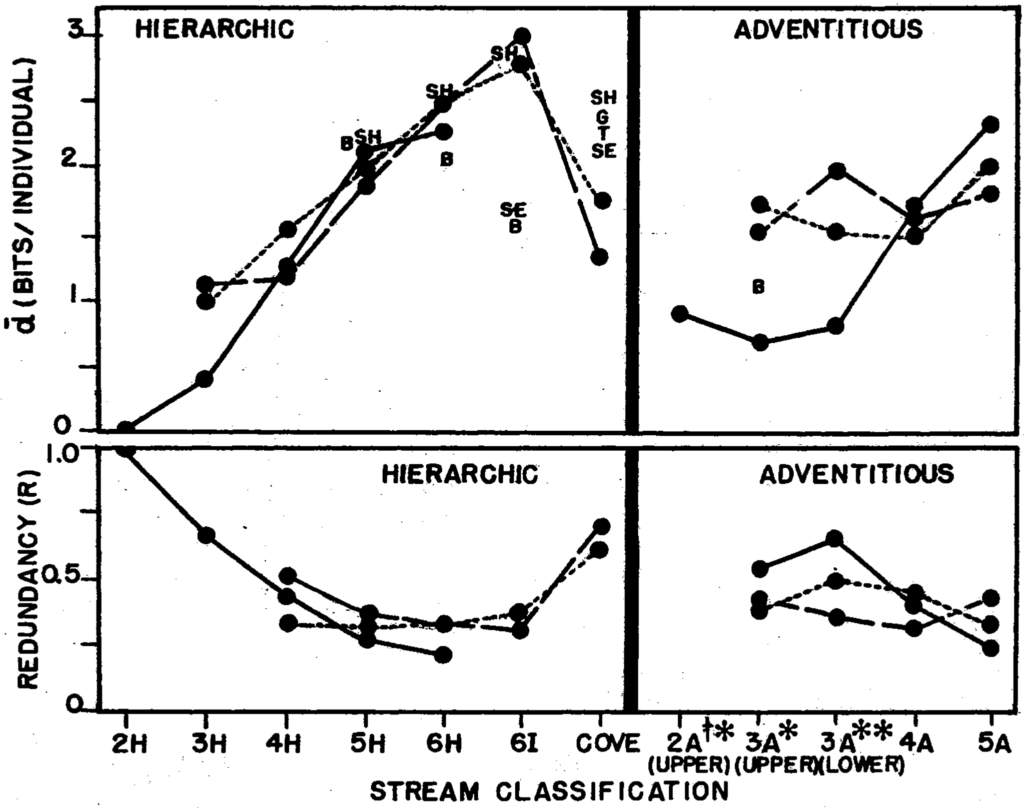

Figure 24. Mean Diversity ($\bar{d}$) and Redundancy (R) for Stream Orders and House Creek Cove. Numerical $\bar{d}$ and R of Seine Samples = (——), Numerical $\bar{d}$ and R of Rotenone Samples = (– – –), Biomass $\bar{d}$ and R. of Rotenone Samples = (----); Numerical $\bar{d}$ is Illustrated for the Annual Catch of the Following Gear: Barrel Trap (B), Gill Net (G), Seine (SE), Shocker (SH), Trap Net (T).

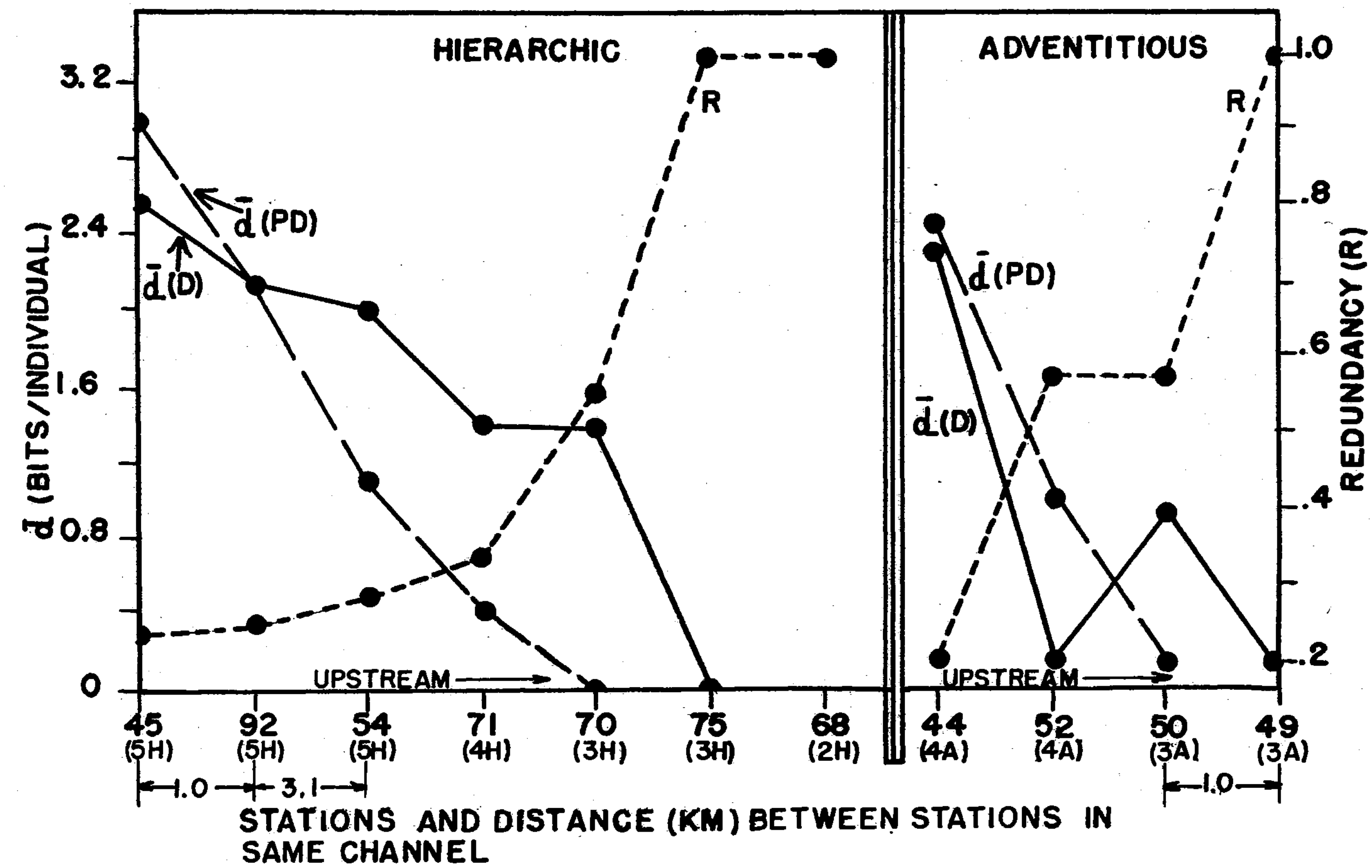

Figure 25. Drought (D) and Post-Drought (PD) Diversity ($\bar{d}$) Indices and Annual Redundancy (R) in the Western Fifth Order Hierarchic Basin.

cepedianum in the reservoir, diversity indices of rotenone samples were lower in the cove than the sixth order. Depression of diversity by a few abundant non-stream species has been noted in base-level regions of a reservoir tributary and estuarine system (Dahlberg and Odum, 1970; Smith and Powell, 1971).

Overall, redundancy varied inversely with diversity and stream order. Redundancy is an expression of numerical or biomass dominancy of one or more species. Thus, increasing redundancy along with declining diversity would indicate a decreasing trend in species wealth and community intricacy. In certain drainage units there was a tendency for both diversity and redundancy of biomass to decrease with distance upstream (Fig. 26). This pattern was interpreted as a decrease in species wealth with a trend toward equal distribution of biomass among fewer species.

Among adventitious pools, numerical diversity of the annual seine catch increased from upper basin to higher order base-level pools (Fig. 24). Means for adventitious orders were higher than means for corresponding hierarchic orders. Diversity indices indicated that adventitious streams may display a greater similarity to their hierarchic receiving waters than with streams of like ordinal rank. Because of strong positional effects, adventitious orders should be grouped by position in the basin for comparative purposes. In the upper basin, adventitious and hierarchic channels were often equally ephemeral, while in the base-level region many adventitious channels contained pools more characteristic of their receiving waters than their ordinal rank.

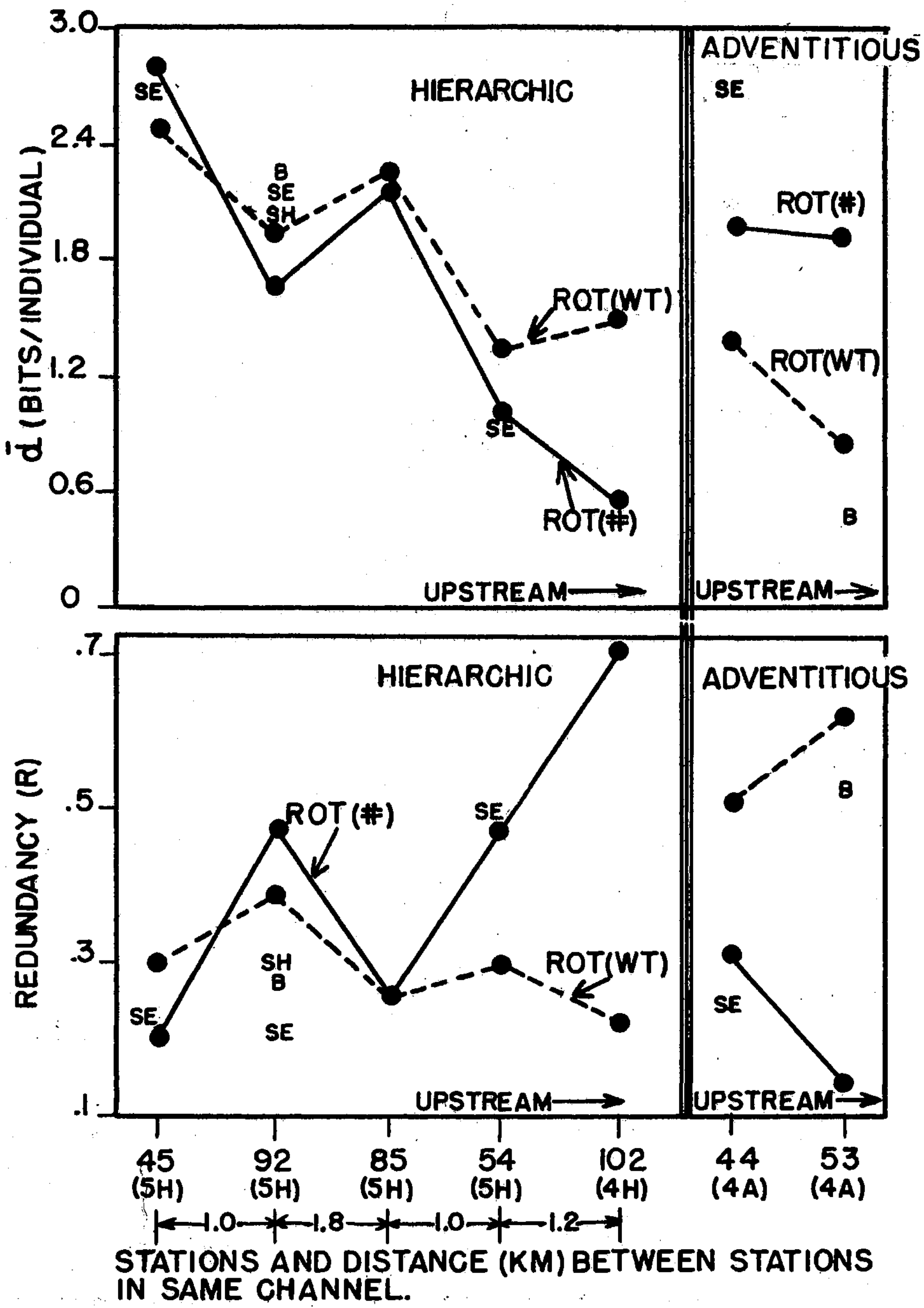

Figure 26. Annual Diversity ($\bar{d}$) and Redundancy (R) of Rotenone (Rot), Seine (SE), Barrel Trap (B), and Shocker (SH) Samples from the Western Fifth Order Hierarchic Basin. Numerical (#) $\bar{d}$ and R of Rotenone Samples = (———), Biomass (wt) $\bar{d}$ and R of Rotenone Samples = (----).

Ordinal biomass and numerical diversity means were generally similar, and both were highly correlated with hierarchic stream order (r = 0.96 and 0.99, respectively). Among adventitious streams, only numerical diversity of the annual seine catch displayed a correlation with stream order (r = 0.91). The lack of correlation between diversity of the post-drought rotenone samples and adventitious stream order was attributed to the ingression and spawning of a few sixth order and reservoir species. Harrel et al. (1967) found a high correlation between fish diversity and hierarchic stream order in Otter Creek, Oklahoma. Whiteside and McNatt (1972) reported a poor fish diversity-stream order correlation in a Texas basin, but diversity in certain adventitious streams varied with diversity in their receiving streams. Laser et al. (1969), Dahlberg and Odum (1970), and Smith and Powell (1971) ignored stream order but found that diversity of stream fishes reflected longitudinal succession and stream modifications by human agency.

The high correlation between stream order and species diversity was attributed to an increase in environmental stability and habitat diversity with increasing stream order. Diversity tends to be low in ecosystems subjected to strong physico-chemical limiting factors and high in "biologically controlled" ecosystems (Odum, 1971). Stream diversity indices suggested that the importance of biological limiting factors increased with stream order.

Rotenone diversity assessments were compared with those for other sampling gear (Fig. 24). Although rotenone rarely produces a complete census, it is recognized as the least selective and most reliable means of sampling fish populations (Sanderson, 1960; Henley, 1966; Barry, 1967; Hayne et al., 1967; Sandow, 1970). In the tributaries, there was excellent agreement between shocker and rotenone diversity estimates; however, cove samples taken with the shocker and other gear yielded diversity estimates substantially higher than the rotenone assessment. The enormous reservoir population of D. cepedianum was sampled disproportionately low by all methods except rotenone. Had it been possible to recover a larger percentage of the innumerable D. cepedianum excited by the electrical field, the shocker assessments may have approached those of rotenone. Shocking may, therefore, yield reliable estimates of fish diversity provided that pelagic and other species known to be highly invulnerable to shocking gear are not dominant. The low diversity of barrel traps samples reflected a high gear selectivity. Barrel traps were particularly selective for I. melas and I. natalis in impounded waters.

Drought and Post-Drought Community Structure of Fishes

Overall, post-drought community structure indices were similar to those measured during the drought period (Figs. 27 and 28). Average diversity for the 5H basins was higher during the drought, although scarcely so in the 5A drainage. In the sixth order and its adventitious confluents, post-drought diversity exceeded drought diversity. Mean post-drought redundancy exceeded drought period redundancy in the fifth order watersheds. Comparing mean diversity for the two periods by position in the basin, drought diversity was higher in the headwater and mid-basin regions, but lower in the sixth order and its adventitious streams (Fig. 28).

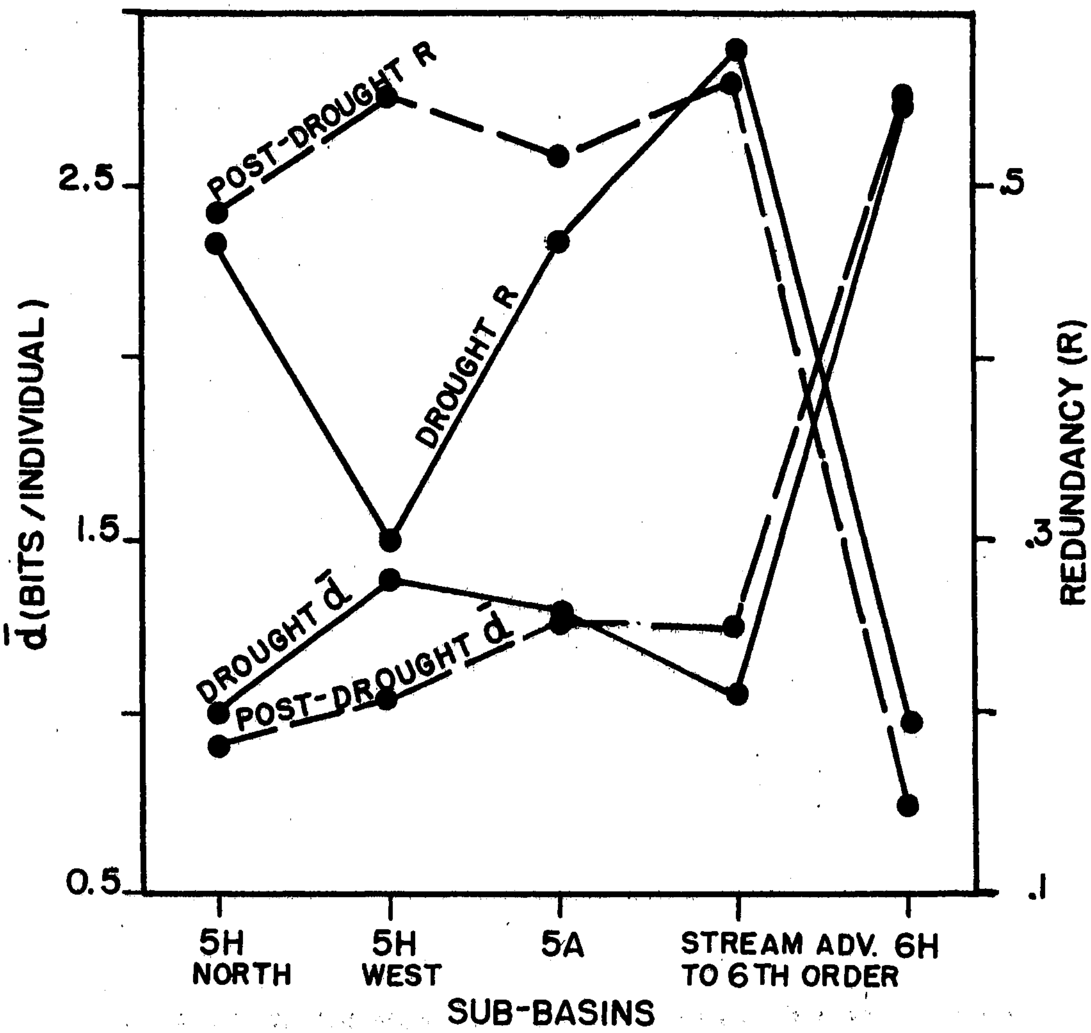

Figure 27. Mean Diversity ($\bar{d}$) and Redundancy (R) of Drought and Post-Drought Seine Collections for Major Subdivisions of the House Creek Basin.

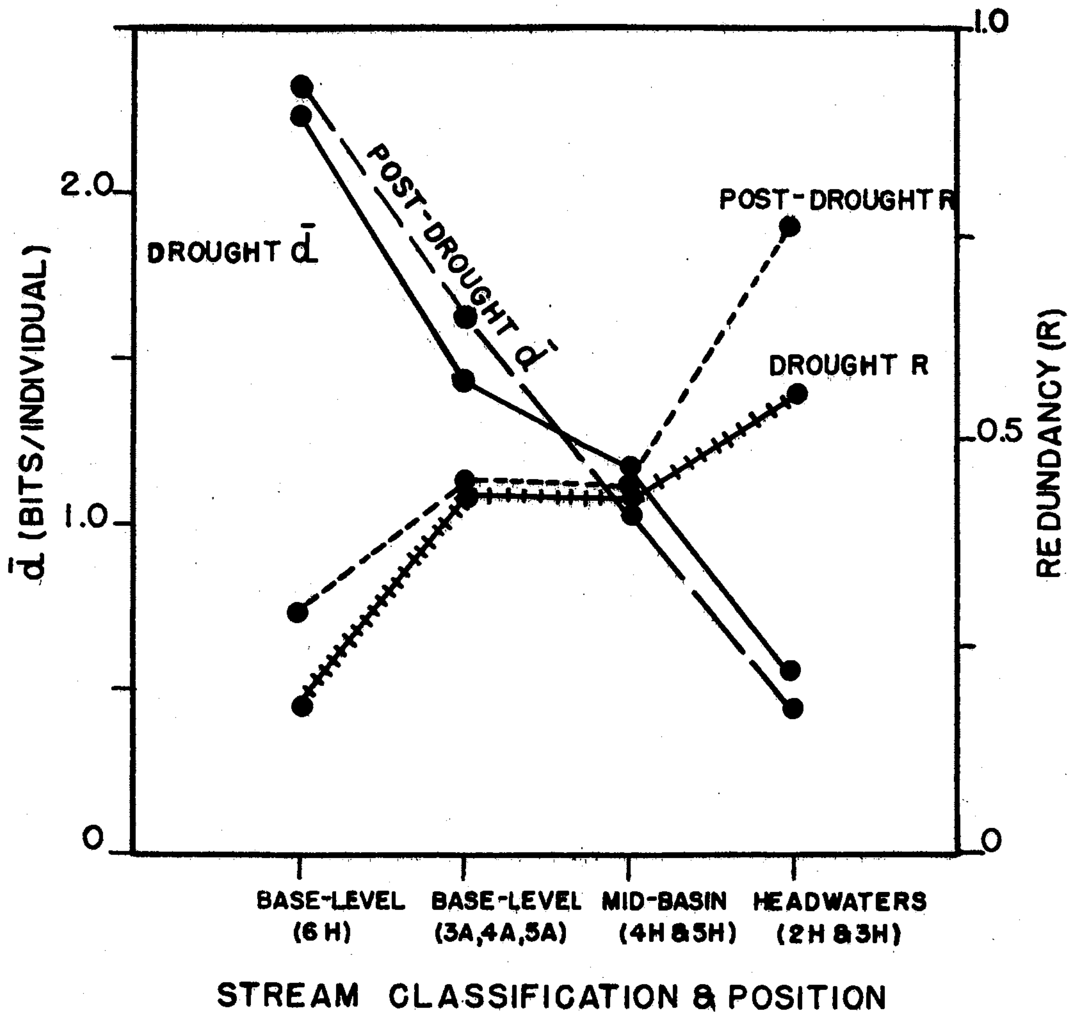

Figure 28. Mean Diversity ($\bar{d}$) and Redundancy (R) of Drought and Post-Drought Seine Collections from Habitat Regions.

Redundancy generally varied inversely with species diversity both during and after the drought. The value of the redundancy expression is illustrated by comparing the mean community structure indices for the 5H watersheds (Fig. 27). Drought period diversity was higher and redundancy lower in the 5H-W drainage, suggesting a greater wealth of species and more equal distribution of individuals among species in the 5H-W basin during the drought. Following post-drought repopulation of the drainageways, both diversity and redundancy were higher in the 5H-W basin. The post-drought indices indicate, and the sampling data confirm, that the western basin maintained a greater wealth of species but with a more equal distribution of individuals among the dominant forms (Table VIII).

TABLE VIII

MOST ABUNDANT SPECIES COLLECTED BY SEINE DURING THE POST-DROUGHT PERIOD IN THE FIFTH ORDER HIERARCHIC BASINS

5H West		5H North	
Species	Number Collected	Species	Number Collected
<u>L</u>. <u>cyanellus</u>	899	<u>L</u>. <u>cyanellus</u>	1,006
<u>P</u>. <u>notatus</u>	365	<u>I</u>. <u>melas</u>	452
<u>N</u>. <u>crysoleucas</u>	352	<u>N</u>. <u>crysoleucas</u>	391
<u>L</u>. <u>megalotis</u>	335	<u>L</u>. <u>macrochirus</u>	243
<u>L</u>. <u>macrochirus</u>	313	<u>L</u>. <u>megalotis</u>	97
Total post-drought individuals	= 2,777	Total post-drought individuals	= 2,264
Total species	= 14	Total species	= 12

The larger post-drought populations of *P. notatus* and *L. megalotis* in the western drainage reflect the greater intimacy between the sixth order and the 5H-W basin. In the western 5H channel, pools were continuous with those of the sixth order. Northern 5H pools were disjoined from the sixth order by approximately 60 m of elevated bedrock in the lowermost stretch of the channel.

Except for sporadic upper and mid-basin reproduction by a few species, reestablishment of fish populations was highly correlated with proximity to base-level pools and the reservoir, and diversity indices reflect this relationship. Post-drought fish diversity was equal to or greater than drought diversity only in the sixth order and its adventitious tributaries. Harrel et al. (1967) examined diversity of stream fishes before and after a drought and found that post-drought indices were consistently lower, though similar diversity patterns existed in both periods.

The 5H-W Basin as a Representative Drainage Unit

Data from the 5H-W basin illustrate the relationships between fish community structure and stream order. With increasing stream order, diversity increased and redundancy decreased; among stations in the same channel, diversity decreased upstream as redundancy increased (Fig. 25). Diversity assessments by seine and shocker were similar to those by rotenone. Except in the lower fifth order, post-drought fish populations in the hierarchy were less diverse than drought period fish populations. In the lower basin, post-drought diversity of adventitious pools exceeded drought period diversity.

Relationships between specific hierarchic and adventitious pools were examined. At station 44(4A), the only adventitious pool near the fifth order stream, numerical community structure indices indicated a fish community more characteristic of lower fifth order pools than fourth order pools (Figs. 25 and 26). However, diversity indices based upon the apportionment of biomass among species suggested that pool 44(4A) harbored a less diverse fish community than lower fifth order pools. The use of biomass units suggests that although a close affinity exists between lower adventitious pools and their hierarchic receiving waters, the distribution of energy among species may be less complex in the adventitious pools.

Located high in the basin, station 53(4A) was considerably farther removed from the fifth order than pool 44(4A). Based upon the rotenone samples, both numerical and biomass diversity was less at station 53(4A), though numerical diversity was slightly so. Numerical redundancy was less at station 53(4A), while redundancy of biomass was greater (Fig. 26). These indices suggest fewer species and a more equal distribution of individuals with a greater concentration of biomass in one or more species at station 53(4A). This description of community structure was verified by the rotenone samples from the two pools (Table IX). Thus, the fish community of upper basin pool 53(4A) was less diverse than that of pool 44(4A). More than one importance value may be necessary to adequately describe community structure.

TABLE IX

THE POST-DROUGHT ROTENONE SAMPLES TAKEN AT STATIONS 44(4A) AND 53(4A)

Species	44(4A)		53(4A)	
	Numbers	Biomass (g)	Numbers	Biomass (g)
L. cyanellus	62	550	75	109
I. melas	7	702	75	1,808
N. crysoleucas	3	13	56	70
G. affinis			205	145
L. megalotis	5	8		
P. notatus	4	7		
P. promelas	1	2	21	11
M. salmoides	13	18		
N. lutrensis	42	57		

Relationships Between Fish Communities

and Physico-Chemical Conditions

In general, fish diversity declined and redundancy increased with upstream distance in the drainage basin. Except for dissolved oxygen, little correlation existed between the assessed physico-chemical parameters and fish community structure. For a given drainage unit, minimum diversity generally occurred in association with limiting concentrations of dissolved oxygen. For example, minimum diversity in the 5H-N basin ($\bar{d}$ = 0.55) occurred at station 61(4H) where dissolved oxygen averaged 3.8 mg O_2/l*. Although maximum diversity generally occurred in the lower reaches of a drainage unit, an unusually high upper basin diversity was occasionally observed in association with isolated brine contamination. The maximum annual diversity in the 5H-N basin ($\bar{d}$ = 2.17) occurred at station 60(3A) where local brine contamination resulted in high conductivity and low turbidity. As discussed previously, it has been suggested that these conditions may enhance productivity.

Domestic Effluent in the 5H-W Basin

Fishes were collected within 1 km of the Jennings sewage outfall at station 53(4A). Located within the oxygen sag zone, mean annual dissolved oxygen at the pool was 4.1 mg O_2/l. Although community structure indices did not indicate that water quality at pool 53(4A) was limiting, the five-species assemblage was composed exclusively of highly tolerant forms. G. affinis, I. melas, L. cyanellus, N. crysoleucas, and P. promelas have all been recognized as residents of recovery and intermittently septic zones below sewage outfalls (Katz and Gaufin, 1953; Trautman, 1957; Larimore and Smith, 1963; Phillips, 1965; Laflin, 1970; Tsai, 1970).

Overall, mean fish diversity was higher in the 5H-W basin than in its northern counterpart. Factors in addition to the unimpeded drainageway between the western fifth order and the sixth order may have contributed to the development of a more complex fish community. Mean carbonate and bicarbonate alkalinity was higher in the western basin.

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*The accepted minimal dissolved oxygen concentration for a warmwater fish habitat is 5.0 mg O_2/l (Doudoroff and Shumway, 1967).

Higher alkalinities are known to favor higher productivity (Tarzwell, 1938; Huet, 1950; Gaufin, 1958). The higher alkalinities of the western basin were widespread and not solely the result of the sewage influx. Instances of isolated brine contamination were also more prevalent in the western drainage.

Oil Field Brine Influx in the 5A Basin

Fish assemblages in highly conductive waters below the brine influx were dominated by *G. affinis* and either *L. cyanellus* or *P. promelas*. Smaller populations of *I. melas*, *L. humilis*, *L. macrochirus*, *M. salmoides*, *N. crysoleucas*, and *N. lutrensis* were usually present. First resident fish populations occurred 0.6 km downstream from the influx at pool 104(3H). The dominant members of the four-species resident assemblage were *P. promelas* and *G. affinis*, each comprising approximately half of the total catch. *I. melas* and *L. cyanellus* occurred rarely. Maximum conductivity and chloride ion concentration at station 104(3H) was 13,400 umhos/cm and 5,538 mg Cl^-/l, respectively. Harrel et al. (1967) found that where brine contamination was greatest in Otter Creek, the fish assemblage was dominated by *P. promelas* and *N. lutrensis*.

The tolerances of fishes to brine wastes may be expressed as chloride ion concentration. Sodium chloride is normally the most toxic component of brines, and chloride concentration is an adequate expression of brine concentration (Clemens and Jones, 1955).

P. promelas has a chloride tolerance in the 4,800 - 7,900 mg Cl^-/l range (Table XVIII, page 125). In an Oklahoma brine contaminated stream, Clemens and Jones (1955) found that *P. promelas* was tolerant to high salinities but most common in waters with a chloride concentration below 4,883 mg Cl^-/l. In North Dakota where natural chloride concentration never exceeds 2,500 mg Cl^-/l, *P. promelas* may shun habitats with a "high" chloride concentration (Kochsiek and Tubb, 1967). Rather than shunning a high chloride concentration, House Creek populations of *P. promelas* appeared to flourish in chloride levels near its purported tolerance threshold.

The abundance of *G. affinis* below the brine influx was consonant with the species response to bring contamination in other streams (Table XVIII). *G. affinis* is capable of surviving in very high salinities and is known to invade marine environments (Chipman, 1959).

Populations of *N. lutrensis* were largest at station 18(4H), the upstream limit of its distribution in the 5A sub-basin. Chloride concentration and conductivity were highest among fourth and fifth order pools at station 18(4H). Although studies have shown that *N. lutrensis* is more tolerant to brine wastes than *P. promelas*, *N. lutrensis* was not collected in pools where chloride concentration exceeded 2,600 mg Cl^-/l, while *P. promelas* was.

Most remaining members of the 5A assemblage, *N. crysoleucas* in particular, appeared to be limited by high brine concentration. *N. crysoleucas* was uncommon in the brine contaminated waters of Otter Creek (Harrel et al., 1967), and various studies have demonstrated its poor tolerance for brackish water (Kilby, 1955; Clemens and Jones, 1955; Chipman, 1959). In the lower reaches of the 5A channel, brines were diluted and probably not limiting.

The response of fishes to brines is not determined by ion concentrations alone. For example, *G. affinis* is known to prefer quiet, clear pools (Trautman, 1957; Cross, 1967). In the 5A basin, G. affinis was most abundant in the quiet, highly conductive waters where clearing had occurred. P. promelas is regarded as particularly resistant to environmental stresses, but is generally least common in pools which support a diverse fish community (Hubbs and Cooper, 1936; Starret, 1950; Cross, 1967). In the 5A basin, P. promelas invaded highly conductive waters which were apparently limiting to most other species.

Overall, fish diversity was greater in the 5A sub-basin than in the 5H watersheds. The higher 5A basin diversity was attributed to the "adventitious effect" though productivity may have been enhanced by oil field brines.

The Community Structure - Stream Order Basis For Ichthyo-Fauna Descriptions

The native ichthyo-fauna of intermittent basins has been determined through time by environmental factors which excluded those species intolerant of extreme stresses. Thus, most members of the House Creek assemblage were tolerant of the environmental extremes which characterize intermittent streams of the plains. Except for a few species associated with the artificial lacustrine habitat, fishes were not generally confined to discrete habitats. There was overlap from upper basin springs and ephemeral pools to the relatively deep base-level waters. Nevertheless, it is likely that a given pool assemblage reflects a physical and physiological screening process of available tolerant forms (Smith and Powell, 1971). All pools were not equally accessible from base-level waters or other fish sanctuaries, and fishes are not equally tolerant of environmental stresses.

Community structure indices provided quantitative descriptions of these screened assemblages and generally were sensitive to variations in the screening process.

Stream order was an objective approach to stream classification and was highly correlated with drainage morphometry and physico-chemical conditions. Stream order may be somewhat analogous to community structure indices in that it appears to be a concise expression regarding basin morphometry and general environmental conditions. The use of community structure indices within the stream order framework provided succinct, objective descriptions of fish communities and their habitats which are comparable within basins and between physiographically distinct basins.

CHAPTER VII

SUMMARY

1. An investigation of House Creek, a sixth order intermittent tributary of Keystone Reservoir, was undertaken to determine correlation between stream order and drainage basin morphometry, physico-chemical conditions, and fluctuations in composition and community structure of fish populations. Stream order, community structure, species composition, and physico-chemical conditions were also used to describe the effects of impoundment and entry of unnatural effluents upon the natural drainage system.

2. Average drainage area and stream length of each hierarchic and adventitious order increased, while stream numbers and average gradient decreased exponentially with increasing stream order. Adventitious gradients generally exceeded hierarchic gradients of corresponding ordinal rank. Among the lower orders, adventitious streams outnumbered hierarchic streams.

3. Among like and increasing adventitious orders, gradients generally decreased and average channel length increased as ordinal rank of the receiving stream increased. Average pool volume increased exponentially with stream order.

4. Average water temperature was highest in July and lowest in January. Dissolved oxygen concentration was generally highest in winter and lowest during spring following heavy rains. Mean seasonal

pH was maximum in summer and minimum in winter, with the converse the rule for carbon dioxide. Average carbonate concentration in the tributaries was maximum during summer and autumn and minimum in spring. Carbonate concentration in the reservoir was highest during spring and lowest in autumn and winter. Tributaries were lowest in bicarbonate concentration during spring and highest in autumn and summer. The reservoir was highest in bicarbonate concentration during autumn and winter and lowest in summer. Turbidity was generally highest in spring and lowest in summer. In the reservoir, conductivity was highest during spring and lowest during summer. In the tributaries conductivity means were highest during autumn, winter, and summer, and lowest in spring following heavy rains.

5. Mean dissolved oxygen, pH, carbonates, and conductivity were higher in the reservoir than in natural tributary waters. Turbidity and carbon dioxide means were lower in the reservoir. Reservoir bicarbonate concentration was low, exceeding only the mean for orders two and three. Mean temperature was highest in the reservoir and sixth order.

6. Temperature, dissolved oxygen, pH, bicarbonate concentration, and conductivity increased with stream order and turbidity decreased.

7. Fourth order adventitious pools were generally warmer and more alkaline, and possessed a higher concentration of dissolved oxygen and carbonates than 4H and fifth order pools. Carbon dioxide, bicarbonate concentration, and turbidity was generally higher in 4H streams than in 4A streams. Physico-chemical fluctuations were generally greater in 4A pools than 4H pools.

8. In general, physico-chemical ranges decreased from the fifth order, through order six, to the reservoir. Exceptions occurred for water temperature and conductivity which varied maximally in the cove. Because of seasonal drying, regularly sampled lower orders were generally represented by springs or spring branches. Thus, physico-chemical ranges tended to decrease with smaller stream order.

9. Entry of domestic sewage reduced water temperature, dissolved oxygen and turbidity and increased bicarbonate concentration. Conductivity was moderately high immediately below the sewage outfall.

10. Dissolved oxygen, pH, and conductivity decreased with increasing distance downstream from an influx of oil field brines, while carbon dioxide, bicarbonate concentration, and turbidity increased. Average conductivity immediately below the outfall was nine times greater than conductivity of cove waters.

11. A total of 67,086 fish among 39 species were collected. Fifty percent of the individuals and 38 species were taken in the reservoir and impounded waters of the sixth order. The remaining 50 percent, including 25 species, were collected in the stream system. Fishes were collected by seining, shocking, gill netting, trapping with barrel traps and a Great Lakes trap net, and by poisoning with rotenone.

12. A thirteen-species assemblage was common to all major subdivisions of the House Creek system, with additional species occurring in all but one fifth order hierarchic basin. In the sixth order and its adventitious tributaries, additional species were typically lacustrine.

13. In descending order of abundance, the dominant species of the stream system were L. cyanellus, G. affinis, I. melas, N. crysoleucas,

and L. macrochirus. Dominant members of the reservoir assemblage were D. cepedianum and I. melas. Only L. cyanellus had a ubiquitous distribution.

14. Number of species increased from four in the second order to twenty in the unimpounded sixth order. The increase was linear in hierarchic and lower order adventitious streams. A nearly twofold increase in total species occurred between the stream and impoundment. Generally, more species were collected in adventitious orders than hierarchic orders of corresponding rank. Longitudinal succession of fishes was characteristically by species additions rather than replacement.

15. Mean number of individuals collected per station increased exponentially with stream order except in the highest hierarchic and adventitious ranks where the relationship became linear. A five-fold increase in mean number of individuals occurred between the stream and impoundment. Mean fish biomass per pool tended to increase with hierarchic stream order.

16. Repopulation of House Creek drainageways varied with the species and pool position in the drainage basin. Populations of dominant species were generally replenished in proportions similar to those that existed during the drought, but total populations were usually smaller. The tendency for pools to regain populations similar to their drought populations was inversely related to distance above the sixth order. Extent of repopulation was much greater in the lower hierarchy and adventitious channels than in the upper basin drainage.

17. Species diversity of fishes was highly correlated with stream order, with maximum diversity occurring in the impounded sixth order.

Reservoir diversity measurements were depressed by large populations of D. cepedianum and I. melas. Mean diversity in adventitious orders was generally higher than in corresponding hierarchic orders. Redundancy generally varied inversely with diversity and stream order.

18. Entry of domestic sewage and brine waters was not clearly reflected in community structure indices, although unique assemblages developed below the effluents. The oxygen sag zone assemblage below the sewage outfall consisted of the most resistant of the native species: G. affinis, I. melas, L. cyanellus, N. crysoleucas, and P. promelas. Heavy concentrations of brine waters favored G. affinis and P. promelas.

19. Post-drought fish diversity was lower in the fifth order hierarchic sub-basins. In the sixth order and its adventitious tributaries, post-drought diversity generally exceeded drought period diversity. Base-level pools were important resupply sources for post-drought assemblages. The close affinity between adventitious tributaries and their receiving channels was reflected in species composition, community structure indices, and repopulation patterns.

20. Informational diversity indices and the stream order ranking system provided an objective basis for analysis of temporal and spatial variation in fish assemblages.

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APPENDIX

TABLE X

ANNUAL MEANS AND RANGES OF PHYSICO-CHEMICAL CONDITIONS IN THE NORTHERN FIFTH ORDER HIERARCHIC BASIN

Station	Water Temperature C	pH	Alkalinity HCO_3	Alkalinity CO_2 mg/1	Alkalinity CO_3	Dissolved Oxygen mg/1	Jackson Turbidity Units	Conductivity umhos/cm	Pool Size* L	Pool Size* W (m)	Pool Size* D
42(5H)	15.7 6.7-23.0	7.1 7.0-8.2	57 15-75	7.4 3-14	0	6.0 1.8-10.8	115 28-427	176 124-251	500		2.0
56(4H)	15.7 5.5-26.0	7.3 7.1-8.0	177 87-266	15.6 4-25	0	5.6 2.3-8.6	65 13-120	439 230-602	42	4	1.0
57(4H)	15.0 1.4-30.0	7.3 6.9-8.0	66 44-103	7.6 1-18	0	5.1 2.7-7.7	155 40-287	273 144-466	35	4	0.7
61(4H)	17.1 6.0-22.0	7.1 6.8-7.3	93 55-176	13 7-17	0	3.8 2.9-5.9	122 45-212	201 133-374	35	2	0.7
62(4H)	14.5 6.1-24.0	7.2 7.0-7.6	153 127-205	20 6-34	0	5.4 2.4-6.9	37 12-96	340 282-441	9	1	0.5
63(3A)	13.4 5.0-22.0	7.0 6.8-7.2	135 82-187	28 11-44	0	5.9 2.6-9.9	66 7-318	373 203-484	20	15	2.0
64(3A)	18.5 8.9-29.0	7.8 7.2-8.8	110 80-163	2.4 0-9	5.4 0-26	8.2 3.8-12.2	232 144-566	242 149-332	20	1.5	0.5
60(3A)	18.3 6.0-27.0	7.4 7.0-7.8	119 72-242	6.2 3-14	0	5.9 2.7-8.4	91 48-1,412	798	36	5	0.8

TABLE X (Continued)

Station	Water Temperature C	pH	Alkalinity HCO$_3$	Alkalinity CO$_2$ mg/l	Alkalinity CO$_3$	Dissolved Oxygen mg/l	Jackson Turbidity Units	Conductivity umhos/cm	Pool Size* L	Pool Size* W (m)	Pool Size* D
65(2H)	17.4	7.0	65	9.5	0	5.1	218	136	2.5	2	0.4
	6.0-24.0	6.6-8.0	45-100	2-26		2.2-8.6	60-479	65-220			

*Measurements were taken August, 1966 and represent maximum pre-drought dimensions of isolated pools.

TABLE XI

ANNUAL MEANS AND RANGES OF PHYSICO-CHEMICAL CONDITIONS FOR CERTAIN EPHEMERAL POOLS IN THE NORTHERN FIFTH ORDER HIERARCHIC BASIN

Station	Water Temperature C	pH	Alkalinity HCO_3	Alkalinity CO_2 mg/l	Alkalinity CO_3	Dissolved Oxygen mg/l	Jackson Turbidity Units	Conductivity umhos/cm	Pool Size* L	Pool Size* W (m)	Pool Size* D	Months Samples
98(2H)	16.7	8.1	82	1	12	10.6	57	712	8	1	.15	October,
	10.0-23.3	7.8-8.6	62-104	0-2	0-24	10.5-10.8	28-86	574-850				January
94(2H)	16.4	7.5	97	5.3		6.7	279	221				October,
	7.2-26.0	7.4-7.8	75-120	4-7	0	4.8-8.1	156-362	204-239	6	1	.40	January, July
58(2A)	36.5	8.5	64	0	8	9.1	48	1,120	2.5	1	.30	July
59(1A)	20.8	8.0	161	3.5	5	8.9	33	2,457				February,
	5.0-36.5	7.8-8.4	106-215	0-7	0-10	7.4-10.4	6-60	1,948-2,965	3	.5	.10	July

*Measurements were taken August, 1966 and represent maximum pre-drought dimensions of isolated pools.

TABLE XII

ANNUAL MEANS AND RANGES OF PHYSICO-CHEMICAL CONDITIONS
IN THE WESTERN FIFTH ORDER HIERARCHIC BASIN

Station	Water Temperature C	pH	Alkalinity HCO_3	Alkalinity CO_2 mg/l	Alkalinity CO_3	Dissolved Oxygen mg/l	Jackson Turbidity Units	Conductivity umhos/cm	Pool Size* L	Pool Size* W (m)	Pool Size* D
45(5H)	16.9	7.4	129	8.9	0	8.2	89	1,803	120	7	0.7
	3.0-27.5	7.0-8.2	81-258	2-20		5.2-13.5	13-362	625-3,116			
85(5H)a,b	16.6	7.9	151	2.6	14.0	8.6	41	1,036	157	20	1.5
	6.6-27.0	7.4-8.7	88-183	0-6	0-44	3.3-15.9	12-118	395-1,560			
83(5H) c	17.4	7.4	80	4.2	0.8	7.5	60	829	7	3	0.3
	7.2-28.5	7.0-8.3	42-117	1-7	0-4	5.1-9.8	11-163	444-1,105			
54(5H) c	17.1	7.4	113	7.0	0	5.6	149	751	43	5	1.0
	8.0-23.5	7.0-8.2	69-186	2-13		4.0-9.4	52-205	424-1,100			
71(4H)c,d	17.6	7.4	84	4.5	2.5	5.2	121	390	30	3	.32
	11.0-24.0	7.1-8.4	56-114	0-9	0-10	2.5-7.3	79-180	194-782			
44(4A) c	16.8	8.1	90	1.7	13.4	8.7	147	404	15	13	1.5
	7.2-30.0	7.8-8.8	47-193	0-6	0-32	5.1-13.3	33-427	175-674			
53(4A) e	14.3	7.7	331	12.4	0	4.1	27	1,251	50	3.4	1.0
	3.3-22.0	7.6-8.0	230-375	4-22		2.2-8.1	19-40	1,167-1,328			
52(4A) c	20.1	7.8	129	4.0	13.7	10.1	173	902	5	1	0.4
	2.5-32.0	7.4-9.2	67-320	0-16	0-68	5.7-18.6	11-362	561-1,221			

TABLE XII (Continued)

Station	Water Temperature C	pH	Alkalinity HCO_3	Alkalinity CO_2 mg/1	Alkalinity CO_3	Dissolved Oxygen mg/1	Jackson Turbidity Units	Conductivity umhos/cm	Pool Size* L	Pool Size* W (m)	Pool Size* D
70(3H)c,d	16.6 6.0-25.5	7.1 6.7-8.2	91 50-122	8.3 1-18	0	4.7 1.4-6.7	86 54-98	327 157-531	35	1	0.2
51(3A) e	13.5 4.5-21.0	7.7 7.6-8.0	362 262-445	13 7-18	0	2.8 0-7.5	49 23-68	1,188 951-1,392	--	.70	.25
50(3A) f	19.1 6.0-27.5	7.5 7.2-7.8	125 95-153	7.6 5-13	0	6.2 5.5-7.3	31 15-72	1,132 385-2,204	12	3	0.3
74(1H) c	15.4 5.5-24.0	7.3 7.9-8.1	151 113-300	14 2-33	0	3.5 0-4.9	99 25-180	481 253-1,158	2.5	2.2	0.6

*Measurements were taken August, 1966 and represent maximum pre-drought dimensions of isolated pools.

[a]Station at confluence of 5H House Creek and 4A stream which carried domestic effluent.

[b]No October and November samples taken.

[c]Outside domestic effluent drainage.

[d]Pools dry during November, January, and August.

[e]Channel carried large quantities of domestic effluent.

[f]Pool dry during November and January.

TABLE XIII

ANNUAL MEANS AND RANGES OF PHYSICO-CHEMICAL CONDITIONS
IN THE FIFTH ORDER ADVENTITIOUS BASIN

Station	Water Temperature C	pH	Alkalinity HCO_3	Alkalinity CO_2 mg/1	Alkalinity CO_3	Dissolved Oxygen mg/1	Jackson Turbidity Units	Conductivity umhos/cm	Pool Size* L	Pool Size* W (m)	Pool Size* D
14(5A)	15.7	6.9	166	56.9	1.4	5.2	68	776			
	3.4-24.5	6.2-8.2	84-275	2-300	0-10	0-8.7	12-205	268-1,640	30	5	0.7
15(4H)	16.1	6.8	99	39.7	0	4.2	159	527			
	2.2-24.4	6.2-8.1	37-160	3-200		1.4-9.1	48-275	155-1,607	15	5	0.7
20(4H)	14.6	6.6	146	97.7	0	3.0	105	2,374			
	2.2-22.5	6.2-7.4	55-275	5-300		0-6.2	7-205	223-5,647	40	5	0.6
18(4H)	14.6	7.4	58	5.0	0	7.3	47	3,551			
	2.8-24.3	7.0-8.2	27-83	0-14		4.1-14.1	14-102	1,579-8,132	60	6	1.2
22(3H)	12.8	6.4	85	54.1	0	4.0	88	192			
	2.8-22.0	6.2-7.2	47-200	9-92		2.2-5.7	16-205	162-226	11	5	0.7
21(2A)	18.6	7.8	58	1.6	.6	9.5	20	25,164			
	10.0-26.8	7.3-8.3	46-86	0-7	0-4	7.0-13.0	7-30	11,671-40,660	8	3	0.9

*Measurements were taken August, 1966 and represent maximum pre-drought dimensions of isolated pools.

TABLE XIV

ANNUAL MEANS AND RANGES OF PHYSICO-CHEMICAL CONDITIONS IN THE CALF CREEK DRAINAGE

Station	Distance Above Mouth km	Water Temperature C	pH	Alkalinity HCO_3	Alkalinity CO_2 mg/l	Alkalinity CO_3	Dissolved Oxygen mg/l	Jackson Turbidity Units	Conductivity umhos/cm	Discharge cm^3sec^{-1}	Pool Size* L	Pool Size* W (m)	Pool Size* D
7 (4A)	1.0	14.1 2.0-23.0	7.1 6.8-7.8	168 78-253	23.4 7-62	0	6.3 4.0-10.8	32 19-56	409 237-635	3,133 0-10,200	18	5.0	0.8
31 (4A)	3.4	15.7 3.3-27.0	7.1 6.6-7.4	81 55-150	15.7 5-67	0	7.0 0-11.9	39 11-105	223 144-333	3,388 0-9,520	15	3.0	0.7
29 (4A)	5.8	16.5 6.5-24.0	7.1 7.0-7.2	73 61-85	11.6 9-17	0	8.3 6.0-11.9	51 14-163	187 151-234	3,439 500-5,500	21	5.0	0.7
25 (3H)	7.7	14.0 3.3-24.0	6.7 6.4-7.1	92 49-157	26.4 22-39	0	5.4 3.1-8.6	35 7-86	2,440 398-3,910	690 0-2,510	3	1.5	0.2
26 (2A)	6.6	15.0 5.7-23.0	6.7 6.4-7.1	36 30-46	12.4 5-27	0	10.2 6.1-15.2	10 2-30	119 109-133	1,286 1,000-1,610	4	1.5	0.3

*Measurements were taken August 1966 and represent maximum pre-drought dimensions of isolated pools.

TABLE XV

ANNUAL MEANS AND RANGES OF PHYSICO-CHEMICAL CONDITIONS FOR HOUSE CREEK COVE AND SIXTH ORDER STATIONS

Station	Depth of Sample m	Water Temperature C	pH	Alkalinity HCO_3	Alkalinity CO_2 mg/l	Alkalinity CO_3	Dissolved Oxygen mg/l	Jackson Turbidity Units	Conductivity umhos/cm
	surface	17.3	8.5	102	0.4	20.1	10.3	29	2,798
		4.5-30.0	8.2-9.1	60-137	0-2	12-32	8.4-12.2	17-43	1,690-3,897
90(R)	0.6-2.3	16.3	8.4	103	0.6	19.0	10.0	33	2,803
		4.5-27.9	8.2-8.6	63-137	0-2	10-32	7.0-12.2	17-58	1,700-3,897
	1.2-4.5	15.7	7.9	116	2.6	10.3	8.0	175	2,747
		4.5-25.6	7.3-8.4	86-137	1-10	0-16	0.6-12.1	26-575	1,400-3,897
	surface	17.4	8.3	107	1.1	12.3	10.6	30	2,754
		4.5-30.8	8.0-9.1	23-155	0-3	0-42	7.9-13.1	14-48	1,750-3,608
99(R)	2.0-3.5	16.0	7.9	119	2.6	8.0	7.9	52	2,778
		4.5-22.2	7.5-8.4	89-156	0-6	0-22	3.2-12.5	15-163	1,635-3,747
	4.0-7.0	14.9	7.6	129	6.8	3.7	5.7	151	2,960
		4.5-22.1	7.3-8.8	51-185	0-17	0-26	2.4-11.0	21-375	820-5,730

TABLE XV (Continued)

Station	Depth of Sample m	Water Temperature C	pH	Alkalinity HCO_3	Alkalinity CO_2 mg/l	Alkalinity CO_3	Dissolved Oxygen mg/l	Jackson Turbidity Units	Conductivity umhos/cm
	surface	17.1 5.0-29.9	7.2 7.9-8.2	122 62-226	14.6 1-34	0	6.9 3.9-8.7	122 15-566	993 357-1,700
91(6I)	0.4-2.0	16.7 5.0-27.1	7.2 7.0-8.2	121 62-226	15.7 2-34	0	6.3 3.5-8.7	122 15-566	987 357-1,700
	0.8-4.0	15.7 5.0-23.5	7.2 7.0-7.9	122 62-226	15.7 2-34	0	5.7 2.7-8.7	125 15-566	928 357-1,700
80(6H)	surface	17.3 6.5-28.0	7.9 7.7-8.2	98 68-131	2.5 1-4	0	9.3 7.0-15.2	14 7-19	967 494-1,536
41(6H)	surface	17.3 7.8-24.5	7.4 7.0-8.2	159 65-242	16 2-41	1.1 0-8	6.8 2.9-9.4	93 10-390	453 266-587

TABLE XVI

RANGES* OF PHYSICO-CHEMICAL CONDITIONS BY STREAM ORDER IN THE HOUSE CREEK DRAINAGE BASIN

Stream Order	Water Temperature C	pH	HCO_3 mg/1	CO_2 mg/1	DO mg/1	Jackson Turbidity Units	Conductivity umhos/cm
2	18.3 (5.7-24.0	1.6 (6.4-8.0)	70 (30-100)	25 (2-27)	13.0 (2.2-15.2)	477 (2-479)	155 (65-220)
3	26.2 (2.8-29.0	2.6 (6.2-8.8)	195 (47-242)	92 (0-92)	10.0 (2.2-12.2)	599 (7-566)	335 (149-484)
4	30.6 (1.4-32.0)	3.0 (6.2-9.2)	293 (27-320)	300 (0-300)	18.6 (0-18.6)	420 (7-427)	1,474 (133-1,607)
5	25.5 (3-28.5)	1.7 (7.0-8.7)	243 (15-258)	20 (0-20)	14.1 (1.8-15.9)	416 (11-427)	2,992 (124-3,116)
6	24.9 (5.0-29.9)	1.2 (7.0-8.2)	180 (62-242)	40 (1-41)	12.3 (2.9-15.2)	559 (7-566)	1,434 (266-1,700)
Cove	26.3 (4.5-30.8)	1.1 (8.0-9.1)	132 (23-155)	3 (0-3)	5.2 (7.9-13.1)	34 (14-48)	2,207 (1,690-3,897)
4H	28.6 (1.4-30.0)	2.0 (6.2-8.2)	248 (27-275)	300 (0-300)	14.1 (0-14.1)	280 (7-287)	1,474 (133-1,607)

TABLE XVI (Continued)

Stream Order	Water Temperature C	pH	HCO_3 mg/1	CO_2 mg/1	DO mg/1	Jackson Turbidity Units	Conductivity umhos/cm
4A	30.0 (2.0-32.0)	2.6 (6.6-9.2)	273 (47-320)	67 (0-67)	18.6 (0-18.6)	416 (11-427)	1,077 (144-1,221)

*Ranges were based on data from 33 regularly sampled stations on 23 streams in which water quality was not appreciably modified by sewage or brines.

TABLE XVII

ANALYSIS OF WATER SAMPLES* COLLECTED AUGUST, 1967, FROM REPRESENTATIVE NATURAL AND UNNATURAL STREAM CONDITIONS IN THE HOUSE CREEK BASIN

Station		Location	Conductivity umhos/cm	Total Dissolved Solids (mg/l)	Total Dissolved Inorganic Solids (mg/l)	Total Dissolved Organic Solids (mg/l)	Na (mg/l)	Cl (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	K (mg/l)	SO_4 (mg/l)
99(R)	surface	Upper House Creek Cove	1,959	975	910	65	290	504	50	13	0.5	5.5	71
	2.5m		2,305	1,075	800	275	308	593	53	13	0.5	5.5	71
	5 m		2,215	1,130	865	265	308	550	50	13	0.5	5.5	71
91(6I)	surface	Lower impounded House Creek	260	210	45	165	24	54	15	4	2.6	4.5	6
	1 m		250	175	5	175	24	55	18	4	3.5	4.0	0
	2 m		275	305	0	305	25	57	18	4	3.5	4.0	0
41(6H)		Upper House Creek	235	125	100	25	18	39	18	4	0.5	4.5	6
71(4H)		Natural pool in western 5-H sub-basin	215	140	70	70	21	32	13	4	2.3	4.0	6
51(3A)		Below sewage outfall	771	395	345	50	87	92	30	9	1.5	7.5	84
21(2A)		Immediately below major brine source	15,100	10,495	8,155	2,340	2,163	5,538	630	206	0.5	17.5	11
20(4H)		4 km below major brine source	2,043	1,105	840	268	268	568	55	11	1.5	8.0	0
15(4H)		Natural pool in 5A sub-basin	480	310	95	212	51	121	23	7	1.5	3.5	0
31(4A)		Natural pool in 4A Calf Creek	250	105	55	50	8	9	13	4	1.5	3.5	17

*Analysis by Soil and Water Service Analytical Laboratory, Oklahoma State University.

TABLE XVIII

COMPARISON OF BRINE TOLERANCES OF FISHES IN LABORATORY AND FIELD

	Lab Data	Field Data--Highest Concentration in Which Species Was Collected (mg/1 Cl$^-$)					
Species	MTT* in Brine Water (mg/1 Cl$^-$)	Salt Creek	Big Wichita River System[e]	Sarpy Refuge Pond[f]	Florida Coastal Marsh[g]	Texas Brackish Waters[h]	House Creek Drainage (5A Sub-Basin)
G. affinis	8,592[a]	5,500[d]		13,700	25,200	20,600	5,538
P. promelas	4,883[a] 5,281[b]**	7,859[a]	4,295				5,538
L. cyanellus	6,330[a]		3,816	8,900			5,538
I. melas	5,802[a]		2,201	18,300***			5,538
N. lutrensis	5,960[a]	8,319[a] 8,500[d]	5,295				2,600
M. salmoides	5,380[a]		1,384	20,600***	11,500		2,600
N. crysoleucas	5,000[c]			18,300***	5,600		2,600
L. macrochirus	6,330[a]			11,900	5,600		2,600

TABLE XVIII (Continued)

Species	Lab Data	Field Data--Highest Concentration in Which Species Was Collected (mg/l Cl^-)					
	MTT* in Brine Water (mg/l Cl^-)	Salt Creek	Big Wichita River System[e]	Sarpy Refuge Pond[f]	Florida Coastal Marsh	Texas Brackish Waters[h]	House Creek Drainage (5A Sub-Basin)
I. natalis					15,000		< 600
P. annularis	7,068[a]						< 600

*Median toxicity threshold.

**mg/l Cl^- in NaCl solution.

***lethal concentration.

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[a]Clemens and Jones, 1955.

[b]Kochsiek and Tubb, 1967.

[c]Wiebe et al., 1934.

[d]Clemens and Finnell, 1957.

[e]Lewis, 1952 (in Clemens and Jones, 1955).

[f]Chipman, 1959.

[g]Kilby, 1955.

[h]Simpson and Gunter, 1955.

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