ECOLOGY OF SPRING CREEK, A LARGE OZARK CREEK IN OKLAHOMA

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November 15, 1988

ECOLOGY OF SPRING CREEK, A LARGE OZARK CREEK IN OKLAHOMA

by

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Everett M. Grigsby, Ph. D., Northeastern State University;
Patricia D. Powell, Oklahoma Water Resources Board; and
Bob Carroll, Judy Fowlkes, Leonard (Len) Lehman, Loma Lindley,
William Meads, and Bo Stone -- students and former students of
the first two principal authors.

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TAXONOMIC REVISIONS

Recent taxonomic revisions recognized by the journal Copia and all of the publications of the American Fisheries Society have resulted in changes in the scientific names of two species of Cyprinidae and family affinity of two species of killifishes that are mentioned in this paper. We used the scientific names and family affinity that were recognized at the time this paper was completed in 1988. The new names and affinity are included here as a minor service to our readers.

AFS recognized Common Name	Scientific Name Used in This Paper	Currently Recognized Scientific Name
Bigeye chub	*Hybopis amblops*	*Notropis amblops*
Duskystripe shiner	*Notropis pilsbryi*	*Luxilus pilsbryi*

Cashner and Matthews (1988) believe that all fishes which have been identified as *N. pilsbryi* in Oklahoma actually are members of a new species, the

Cardinal shiner *Luxilus cardinalis*

However, it is possible that some populations in northeastern Oklahoma may be *L. pilsbryi* which have resulted from capture of tributaries of the White River in southwestern Missouri. It has not been determined whether this population in Spring Creek is *L. pilsbryi* or *L. cardinalis*.

Two killifishes, *Fundulus olivaceus* and *Fundulus sciadicus*, are reported as members of Family Cyprinodontidae. Both Copia and AFS have recognized erection of the Family Fundulidae to partition *Fundulus* from Cyprinodontidae. It follows that *F. olivaceus* and *F. sciadicus* are members of Family Fundulidae, and Family Cyprinodontidae is not known in Spring Creek.

Cashner, R.C., and W.J.Matthews. 1988. Changes in the known Oklahoma fish fauna from 1973 to 1988. Proceedings of the Oklahoma Academy of Science 68:1-7.

ERRATUM

p. 64, line 32 - change 8.1 m/km to 2.4 m/km and (42.5 ft./mi.) to (12.6 ft/mi.).

ECOLOGY OF SPRING CREEK, A LARGE OZARK CREEK IN OKLAHOMA[1]

by

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Introduction

Spring Creek is a common name for creeks in Oklahoma as it is elsewhere. However, this Spring Creek is an uncommon creek because it is representative of large creeks in the western Ozarks which contain large and diverse communities of unique coolwater fishes combined with ubiquitous, tolerant warmwater species. It is named appropriately because it derives and maintains its water supply from peripheral and stream-bottom springs and groundwater return throughout its length.

Spring Creek originates in three ephemeral-flow channels, the longest beginning 1.62 miles (2.59 km) northeast of Kansas, Delaware County, Oklahoma, immediately west of State Highway 10 and 1.25 miles (2.0 km) north of State Highway 33. It becomes a perennial stream as it approaches the city limit of Kansas and remains perennial, except for one unique segment, to its confluence with the Neosho (= Grand) River in Mayes County. A large segment of the creek is in northern Cherokee County. The entire channel is 34 miles (55 km) long[3] and the perennial portion, at least during normal conditions, is approximately 33.5 miles (53.6 km) long. Direction of flow is essentially west, with the mouth of the creek slightly south of the origin. It enters the river near the head of Fort Gibson Reservoir but is isolated from the river and the reservoir by Cedar Crest Dam which is on the creek near its mouth. Except for the small towns of Kansas and Oaks, most of the riparian zone and adjacent watershed are relatively pristine, supporting only low-density rural residences and mostly native forest interspersed with low-intensity livestock agriculture. One small state park which is

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[1]A contribution of Oklahoma Water Resources Board Project 205(j), ECOREGION STUDIES - UPLAND CREEKS, funded by the U.S. Environmental Protection Agency, Grant No. C-400000-25-0 (FY-86)

[2]Bob Carroll, Judy Fowlkes, Leonard (Len) Lehman, Loma Lindley, William Meads, and Bo Stone -- students and former students of the first two principal authors.

[3]USGS, Kansas and Leach Quadrangles Oklahoma-Delaware and Cherokee Counties; Moodys Quadrangle, Cherokee County; Peggs and Rose Quadrangles, Cherokee and Mayes Counties; and Locust Grove and Cedar Crest Quadrangles, Mayes County, 7.5-Minute Series (Topographic).

developed only for picnics and primitive camping straddles the creek at a county-road crossing.

The creek is listed officially as Spring Creek in the state water quality standards (OWRB 1985) where it is protected by criteria for a smallmouth bass fishery and five other uses which require less-stringent criteria than the fishery. It also is listed for limitation (a), for which it is stipulated (Sec. 7.11, OWRB 1985) than no new point-source discharge which increases pollutant loading or increased load from an existing point source is allowed.

Objectives of the ecoregion studies of upland creeks were to determine physical and chemical conditions and community ecology of fishes that may be expected to occur in the range of smaller to larger creeks in the Ozark Biotic District (Blair and Hubbell 1938) or Upland Ecoregion (Jarman 1984) in Oklahoma. Spring Creek is one of the larger creeks and Tahlequah Creek, 13 miles (21 km) to the south, is one of the smaller perennial creeks in the Oklahoma Ozarks. Ecology of Tahlequah Creek as representative of small Ozark creeks is described in a separate report (Jester et al. 1988).

Spring Creek attracted the authors for the same reasons that it has attracted several other investigators (cited in context) in recent years. It appears to be representative of relatively-large, relatively-pristine, very-lightly-impacted Ozark creeks and, thus, affords an opportunity to investigate life histories of species and composition, structure, and ecology of a fish community that are not modified or impaired by anthropogenic impact. Therefore, conditions and the community in Spring Creek may serve as controls or regional references to determine conditions and communities that should occur in different habitats in other large Ozark Creeks. Habitat and community ecology of fishes are described for three stream orders (Horton 1945) which make up both creeks.

Because investigations of the two creeks are reported separately, comparison of small and large Ozark creeks is left to the reader who may be interested in such a comparison. It is sufficient to say here (and in Jester et al. 1988) that the major difference between fish communities in Ozark creeks which differ in size by more than an order of magnitude is that diversity of habitat and fishes extend much farther upstream and into lower stream orders in large creeks than they do in small creeks.

Study Area

Location

The easternmost identifiable point on the Spring Creek channel is located at 95°14'1" West longitude and 36°6'53" North latitude. Although a short segment of the creek extends from the dam to the Neosho River, it is isolated from most of the creek by the dam and is below the flood storage level of Fort Gibson Reservoir. Fishes collected there (Branson 1967) indicate that it is functionally a backwater of the Neosho River ecotone.

Therefore, Cedar Crest Dam is the functional end of the creek and is accepted as the confluence with the river for purposes of this study. Between these points, the creek flows westward through 27'10" and southward only 6'33", or essentially West Southwest (WSW) in more common directional terms.

Location of the creek in northeastern Oklahoma is shown on a locality inset map in Figure 1 under **Methods, Sampling Stations.** More specifically, the creek channel begins in T20N, R24E, in the SE¼ of Sec. 7. It ends at Cedar Crest Dam in T19N, R19E, in the NE¼ of Sec. 24.

Geological and Ecological Localities

Geological. Spring Creek begins in relict prairie which probably is a terrestrial ecotone on the western edge of the Springfield Plateau of the Ozarks, in the general vicinity of sites where the senior author observed a few jackrabbits, roadrunners, and prairie chickens as recently as the late 1950's (They may still be there; the author has not observed the area in detail since 1959.). It flows westerly through the rugged Cookson Hills range of the Ozark highland of southwestern Missouri, northwestern Arkansas, and northeastern Oklahoma. The Cookson Hills are the westernmost range of the Ozarks, bounded on the west and southwest by the Neosho River which separates the hills from prairie and savannah biotic districts (Blair and Hubbell 1938). The highest elevation in the region is approximately 1,500 feet (457 m) MSL, and the maximum elevation of the hills is, with a few exceptions, approximately 400 feet (122 m) above their bases (Blair and Hubbell 1938 and USGS topographic maps cited in Footnote 3). The highest points on the Spring Creek watershed are 1,240 feet (378 m) at the crests of two small hills in Sec. 12, T20N, R23E, approximately two miles (3.2 km) northwest of the origin of the channel and 1,224 feet (373 m) at the corner of Sections 19, 20, 29, and 30, T20N, R24E, on State Highway 10, 2.25 miles (3.6 km) due south of the origin of the creek. Only four small areas exceed 1,200 feet (365.9 m), while the 1,200-foot (365.9-m) contour along two low ridges forms the watershed boundary from east to west approximately two miles (3.2 km) north and from north to south approximately one mile (1.6 km) east of the town of Kansas. Therefore, the highest points on the watershed boundary are a series of ridges which reach elevation 1,200 feet (365.9 m) MSL both north and southeast of the creek.

Ecological. (W.F.) Blair and Hubbell (1938) assigned the Ozark highland in northeastern Oklahoma to the Ozark Biotic District on the basis of physiography and distribution of plant associations, mammals, and orthopterans (Arthropoda, Insecta). (A.P.) Blair (1959) found the terrestrial districts in northeastern Oklahoma to be applicable with regard to distribution of darters (Perciformes, Percidae). Branson's (1967) investigation of fishes in the Neosho drainage produced nothing to refute validity of the aquatic application of the district.

Two rivers drain the Ozark Biotic District in Oklahoma. The Illinois River rises in northwestern Arkansas and remains in the Ozarks almost to its confluence with the Arkansas River. The Neosho River rises in southeastern Kansas with major tributaries from southwestern Missouri. Blair and Hubbell (op. cit.) and Blair (op. cit.) defined the Neosho River as the western boundary of the Ozark Biotic District. Branson (op. cit.) studied distribution of fishes in the Neosho River system and described the main stream as an ecotone, with Ozark fish communities in the eastern tributaries and prairie communities in the western tributaries. Hill et al. (1981) agreed with Branson's conclusions, both thereby strengthening the district boundary concept.

Branson also determined the origins of fishes in the Neosho system and, therefore, in Spring Creek to be the Arkansas River drainage and the White River drainage by stream capture in southwestern Missouri. Species which were not reported from Spring Creek by Branson but were caught in this investigation are attributed to the same origins. Therefore, most of the fish community is composed of an assemblage of species that are relatively unique to Ozark Creeks in Oklahoma.

Jarman (1984) used physiographic and climatic factors which he felt would define boundaries of assemblages of fish species to propose a system of aquatic ecoregions in Oklahoma. Repeated reclustering of fish communities to conform with preconceived physical boundaries casts considerable doubt on validity of the ecoregions as they are presently described. However, part of the Ozark highland which contains both Spring and Tahlequah Creeks is designated as the Upland Ecoregion. It remains to be determined whether such regions are valid and, if so, where the boundaries should be, but this specific region overlaps with the Ozark Biotic District to an extent that the fish communities of Spring and Tahlequah Creeks could serve as controls or "regional reference sites" as defined by Hughes et al. (1986) for the Ozark Biotic District or the Upland Ecoregion.

Drainage Affinities

The Neosho and Illinois Rivers, which drain the Ozark Biotic District, are tributaries of the Arkansas River. The Neosho enters the Arkansas at Muskogee, Oklahoma, about 25 miles (40 km) upstream from the mouth of the Illinois River. Robert S. Kerr Reservoir is on the Arkansas River downstream from both the Neosho and Illinois Rivers. Webbers Falls Reservoir is on the Arkansas between the mouths of the Neosho and the Illinois. Tenkiller Ferry Reservoir is on the Illinois River just upstream from the Arkansas, and Fort Gibson Reservoir is on the Neosho River just upstream from the Arkansas. Another similarity between Spring Creek and Tahlequah Creek is that both drain parts of the Cookson Hills and enter the two rivers just upstream from reservoirs.

Spring Creek begins about 18 miles (29 km) north and 10 miles (16 km) east of the origin of Tahlequah Creek. Ephemeral tributaries of the upstream end of Tahlequah Creek and the middle section of Spring Creek are 8.5 miles (13.6 km) apart and the perennial main streams are 13 miles (20.8 km) apart at the closest points, on a line due north and south. Tahlequah Creek begins 10 miles (16 km) farther west than Spring Creek but flows south and slightly east to the Illinois River. Therefore, Spring Creek begins farther east than Tahlequah Creek but is a member of the Neosho drainage which is west of Tahlequah Creek and the Illinois River. Fishes from prairie and savanna creeks have access to Spring Creek via the Neosho River while Tahlequah Creek is entirely under the influence of the Ozark Biotic District. Drainage affinities of Tahlequah Creek are of concern to ecology of Spring Creek when origins of fishes in either creek are considered and when the creeks are compared, as they may be by use of this paper and Jester et al. (1988).

Topography and Elevations

Topography. The Ozark Biotic District is characterized by presence of Boone chert, and the western boundary is formed by the Neosho River which flows southward along the western outcrop of the chert formation. Spring Creek flows westward across the formation and is located entirely within it.

The Boone chert formation consists of alternating layers of flint and limestone. It has been eroded to form steep hills, incised valleys, and prominent bluffs that make up the rugged topography of the Cookson Hills range. The chert has weathered into sharp, angular fragments which form a mantle 20 to 30 feet (6 to 10 m) deep on the slopes. Much of the drainage is underground and there is an abundance of caves and Karst depressions. This description of topography is taken in part from Blair and Hubbell (1938) and in part from Marcher and Bingham (1971), along with observations made in this study.

Elevations. Again, the maximum elevation of the Spring Creek watershed is 1,240 feet (378 m) MSL. The maximum elevation of recognizeable main channel is 1,150 feet (350.6 m), although a small, short, tributary channel begins slightly higher at 1,164 feet (354.9 m). The perennial portion of the creek begins from groundwater seepage at elevation 1,135 feet (346 m). The elevation of the creek bank is 554 feet (168.9 m) at Cedar Crest Dam. Top of the power pool or spillway elevation of Fort Gibson Reservoir is 582 feet (177.4 m), but does not encroach upstream in the creek because of the barrier formed by the dam. Therefore, the fall for the watershed is 686 feet (209.2 m) in 36 miles (57.6 km). The fall for the main channel is 596 feet (181.7 m) in 34 miles (55 km) and the fall for the perennial segment is 581 feet (177.1 m) in 33.5 miles (53.6 km). The total gradient for the watershed is 19.06 feet/mile (3.63 m/km).

Cultural Characteristics

Spring Creek is relatively large, has Ozark characteristics, and contains three stream orders, which combine to form a complex ecological system. Elevations, temperatures, gradients, and drainage affinities of Ozark creeks provide habitat, conditions, and species to support some of the most diverse fish communities and complex population equilibria in creeks in North America. Most of the fishes are "coolwater" forms which are steno-tolerant (narrow range) of numerous factors and several are sensitive to minor changes in water quality, habitat, or interspecific competition. It follows that they are intolerant of water quality and habitat degradation caused by human or "cultural" encroachment on the stream. This is demonstrated emphatically by the effects of an effluent from a sewage treatment plant on the fish community in Tahlequah Creek (Jester et al. 1988).

Spring Creek flows through Kansas (Okla.) where considerable amounts of paper and styrofoam trash are thrown into the creek at a small fast-food dispensary near Kansas High School. The creek forms a natural town boundary at Oaks but appears to receive little, if any, trash or other pollutants from that community. Oaks is an old Cherokee settlement occupied since the mid-1800's, and prehistoric Indian activity also occurred along the creek. However, here, as in Tahlequah Creek, there is no evidence that either historic or prehistoric human activity has caused significant modification of the aquatic community (Jester et al. 1988).

A major protective cultural aspect is rigorous water quality criteria mentioned above that are required by the state water quality standards (OWRB 1985).

While this may suggest that Spring Creek receives no pollutants, there are occasional incidents that reveal the hazards posed to creeks by the mere presence of man. During our investigation, we observed remains of a large gar and several large flathead catfishes, neither of which are endemic to the creek, in the water at our last station. Several days later the senior author counted the remains where at least 216 white bass and crappies had been dressed and the offal deposited in the creek at the same site. These fishes did not originate in the creek but apparently were caught in the Neosho River or Fort Gibson Reservoir about two miles (3.2 km) downstream and were dressed at the county road bridge in our station. These incidents, obviously, caused no permanent damage but, nevertheless, played aesthetic havoc for several days. At best, such activity is nasty and uncalled-for. At worst, it reveals malicious contempt for natural resources and the rights and sensitivities of other people.

Methods

Descriptions of the watershed, land use, cultural characteristics, riparian zone, and creek banks are taken from reports of several state and federal agencies and from observations made during an initial reconnaissance and repeated trips to sampling stations. Some information was gathered verbally from local sources. Topographic, geologic, soil, and climatological data are taken from official maps and serial publications of various agencies. All quantitative data were collected at stations which are described below.

Sampling Stations

Number and general locations of sampling stations were selected tentatively from the seven required USGS topographic maps, with consideration given to stream orders, progressive stream size, location of tributaries, and access. Two reconnaissance trips were made, first to judge tentatively-selected sites and identify potential station boundaries at each site, and then to review and confirm locations of stations as representative of each stream order and the entire creek. Stations for analyzing both water quality and the fish community were selected on the basis of criteria appropriate for each objective. However, the overall objective of measuring water quality was to determine its effects on the fish community. Therefore, eight stations were selected for collecting fishes, with six of them used to collect discrete water quality samples and three for continuous electronic monitoring of symptomatic water quality parameters. A major flood removed two of the electronic monitors but, otherwise, the stations served all of the functions for which they were selected. Sampling stations and their uses are shown in Figure 1.

Physical and Habitat Characteristics

Physical and habitat characteristics that are quantified -- such as lengths, widths, depths, velocities, and volumes of flow -- were measured by use of steel and fiberglass tapes and the graduated staff and mechanical unit of an Ott Meter. Transects, frequencies, depths, etc., were measured by use of standardized methods described by the USGS (1973) and Hammer and MacKichen (1981). Bottom materials and fish cover and concealment features of the habitat are classified and described after Roelofs (1944), Lagler (1956), and to some extent, Wentworth (1922) and common limnological terminology.

Water Quality

Temperature, dissolved oxygen, pH, and specific conductance were measured two ways. Discrete sampling was done by use of a digital electronic Hydrolab[4] which was calibrated in the laboratory and in the field before and after each use, according to the manufacturer's instructions.

Continuous monitoring of the symptomatic parameters was done

[4] 4000 Series, Digital 4041, Hydrolab Environmental Data Systems, Hydrolab Corporation, Austin, Texas.

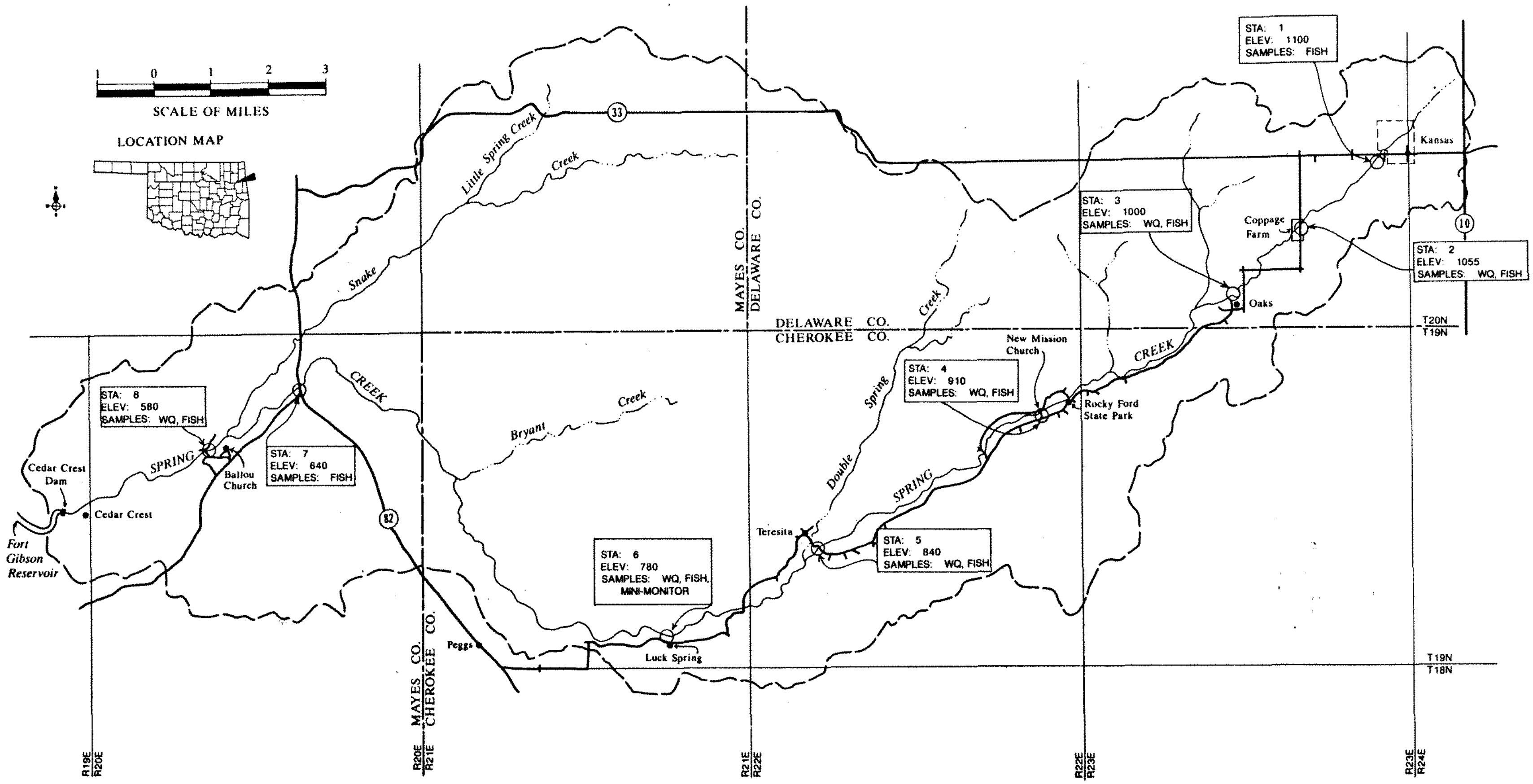

Figure 1. Locality, watershed, and stations where physical and chemical water quality data and biological samples were collected from Spring Creek in September, 1986. Stations 1-3 represent a First Order segment, Stations 4-5 represent a Second Order segment, and Stations 6-8 represent a Third Order segment (Stream orders after Horton 1945).

by use of an electronic system provided by the U.S. Geological Survey[5]. It also was calibrated in the laboratory according to the manufacturer's instructions. Final calibration was done in the field to coincide with Hydrolab readings. Periodic checks, with "fine-tuning" adjustments and corroboration of final readings with a Hydrolab, were used to insure accuracy and provide bracketing-data for quality control. Machines at Stations 2 and 8 were inundated and moved by a record flood, but data for 12 consecutive [24-hour] diel cycles were recovered from a machine at Station 6.

Discrete samples of water were collected in clean, sterile plastic jugs at two stations in each stream order for laboratory analysis of oxygen demands, macronutrient cycles, toxic gases, turbidity, and dissolved solids. These samples were stored in crushed ice in closed chests and delivered to the laboratory[6] within six hours after collection was started. The laboratory was required by certification to analyze samples promptly, use EPA-approved methods (EPA 1979, APHA 1980, 1985), and maintain EPA-required quality control. Additional data required for these purposes were collected by use of the Hydrolab and four field kits which conform with APHA (1985) standard methods. These analyses were free carbon dioxide, ABS + LAS detergents, total and free chlorine, and hydrogen sulfide[7].

Biological

Several biological investigations which were done on Tahlequah Creek were not required on Spring Creek because no point sources and no known nonpoint sources of pollution exist. Others were done recently by other investigators in greater detail than would have been required by our objectives, and repetition was not necessary. Therefore, our efforts were limited to intensive sampling of fishes for analysis of the fish community.

Fish community. Fishes were collected by electrofishing in long runs of diverse habitats at eight stations (Fig. 1). Power was supplied by a 120-240V, 60-cycle, AC, gasoline-powered generator which was mounted in a 12-foot, flat-bottom [Jon] boat. Copper probes were built by forming ¾-inch (19-mm) solid ground rod into 15-inch (38-cm)-diameter loops for maximum electrical-field efficiency (Vibert 1967).

The loops were modified to a rhombic or diamond shape to

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[5]USGS Water Quality Mini-Monitor, Yellow Springs Instrument Company, Yellow Springs, Ohio.

[6]Analyzed by Oklahoma City-County Health Department Laboratory, which is certified by Oklahoma Water Resources Board.

[7]Our purposes are ecological, not enforcement. Therefore, EPA approval was not required. Results indicate precision and accuracy adequate for ecological implications.

optimize electrical efficiency of the loops with ability to probe into brush, log jams, and undercuts along with efficient disruption of gravel and rubble on riffles. Specifications for the probes are shown in Jester et al. (1988). Electrofishing with this apparatus vs. seining was tested in Tahlequah Creek. It was found to be superior to seining, and acceptable as the only fish sampling method. Water quality, fish cover, bottom types, pool depths, and other factors are similar to the Third Order segment in Tahlequah Creek and results of sampling, mostly with 240V, indicate that efficiency was very similar in both creeks. Also, a blocking seine was used, as it was in Tahlequah Creek, to use the water current as an advantage.

Twelve qualitative and quantitative analyses were used to determine population structure and equilibria of the fish community. These methods are shown in context with their results.

Results and Discussion

Investigations reported here were coordinated with similar investigations on Tahlequah Creek (Jester et al. 1988) so that no major seasonal or climatic events could intervene to decrease comparability of findings and conclusions for the two creeks. Collections of various data were made during all of the month of September, 1986. Climatological data show that highest temperatures, least rainfall, and most evaporation occur in July and August, which would be expected to constitute the most critical period for the fish community. Therefore, investigations done in September follow the critical period too closely for the fish community to recover from any effects critical conditions may have had (although none are suspected).

Area and Land Use

Watershed. Spring Creek and its tributaries drain an area of 232.2 mi.^{2} (601.4 km^2) shown in Figure 1. Converted to common units of land ownership and use, area of the watershed is 148,598 acres (60,652.3 ha). A Conservation Needs Inventory done by the U.S. Soil Conservation Service, compiled by the Oklahoma Conservation Commission, and recorded by Grimshaw et al. (1980), shows areas of the watershed in four agricultural uses. We estimated the areas in urban use by the towns of Kansas and Oaks, and modified the agricultural areas to account for the urban areas (Table 1).

Almost half (49.30%) of the watershed supports [mostly regrowth] native hardwood forest and slightly less (48.51%) is in cultivated pasture. Pasture encroaches across the riparian zone to the banks at various sites along the creek but most of the pasture is limited to floodplain and upland areas, with forest in riparian zones and on banks. Urban, crop, and range uses combined occupy only 2.19 percent of the watershed.

Riparian zone. Narrow, elongated, and steep watersheds

Table 1. Area of the Spring Creek watershed and areas in urban and agricultural uses. Adapted from Grimshaw et al. (1980).

Use	Mi.²	km²	Acres	Hectares	Percent of total
Total	232.2	601.4	148,598	60,652.3	100.00
Urban[a]	0.36	0.9	228	93.0	0.15
Forest	114.5	296.4	73,252	29,898.8	49.30
Pasture	112.6	291.7	72,089	29,424.1	48.51
Crop	3.5	9.1	2,257	921.2	1.52
Range	1.2	3.1	772	315.1	0.52

[a]Urbanized area of Kansas, Oklahoma, estimated by planimetry to be 185.9 acres and area of Oaks, Oklahoma, estimated to be 46.3 acres. We subtracted 116.1 acres each from forest and pasture shown in the source literature to account for urban area which was not shown in the Conservation Needs Inventory.

produce geologically-young "cutting stream" systems which have characteristically-narrow riparian zones. Along Spring Creek, the riparian zone varies from a narrow terrace and a narrow, steep slope approximately 35 feet (11 m) wide to a flat, marshy area approximately 300 feet (92 m) wide. It, typically, is a combination of terrace and slope which varies from 75 to 100 feet (23 to 31 m) wide. Also, frequently, most of the zone is on one side of the creek. Except where cultivated pasture crosses the riparian zone, it is covered by thick, brushy shrubs and moderately-dense stands of trees.

Climate and Weather

Climate. The Kansas, Oklahoma, weather station is located at elevation 1,180 feet (359.8 m) MSL, one mile (1.6 km) from the beginning of perennial flow of Spring Creek. Therefore, data collected there are representative of conditions in the headwaters area. The second-closest station is at Tahlequah about 16 miles (26 km) south of the middle portion of Spring Creek but in similar terrain and at approximately the same elevation (780-840 ft. or 238-256 m). Weather data collected there probably are more representative of the middle and lower segments of the creek than data from the Kansas station, or each station represents approximately one-half of the creek.

Regardless of locations of stations, the creek is located in the Warm Temperate Zone of the Northern Hemisphere. By nature of its location in an interior state in the south-central area of the United States, the climate is continental modified by cooling effects of elevation, warming effects of air masses from the Gulf Coastal Plain, and humidity from the Gulf of Mexico.

Annual mean air temperature is approximately 58F (14.4C) at Kansas (27-year record) and 60F (15.6C) at Tahlequah (87-year record) (NWS 1986). Annual mean precipitation is approximately 40.1 inches (101.9 cm) at Kansas and 42.34 inches (107.5 cm) at Tahlequah. Annual mean total wind, measured as a stream that passes the weather station regardless of direction, is estimated to be approximately 12,000 miles (19,200 km) at Tahlequah (Jester et al. 1988) and can be estimated at Kansas only as approximately the same length from the same regional data. Annual mean evaporation of 58 inches (147 cm) also may be estimated for both stations from the same regional data. Mean lengths of the [frost-free] growing seasons are 203 days at Kansas and 209 days at Tahlequah. Therefore, the climate is slightly cooler and drier for the upstream half than it is for the downstream half of Spring Creek.

Overall, with relatively-high elevations, moderate mean temperatures, and high rainfall, the area must be considered as part of the cooler portion of the Warm-Temperate Zone.

Weather. Climate is a long-term summation of weather, and it is corollary that weather is a short-term measurement of climate. Quantities used to describe climate are mostly long-term ranges and means, and quantities which describe weather are mostly daily, monthly, and annual totals, ranges, and means.

Ranges and distributions of species frequently are described as coincident with climatic characteristics, which Jarman (1984) and others have used with clusters of species in attempts to establish their ecoregions. However, it also is known that occurrence or distribution of species within their ranges and, therefore, composition of communities may be modified or controlled by effects of weather or other characteristics which violate the limits of tolerance of the species (Shelford 1913). Therefore, in an investigation of structure and population equilibria in a fish community, effects of weather are as important as effects of climate.

Extremes or persistence of near-extremes of factors are the values which approach the limits of tolerance of each species and, therefore, become part of or make up the critical conditions which control occurrence and, to some extent, size of populations. In the temperate zones, most aquatic species are tolerant of winter conditions if depth or velocity of water is adequate to prevent the water from freezing solid or allowing oxygen depletion in darkness under snow-covered ice.

Monthly mean air temperatures during December-February are approximately 38.2F (3.4C), 41.6F (5.3C), and 43.6F (6.4C) at Kansas and 40.8F (4.9C), 37.0F (2.8C), and 42.1F (5.6C) at Tahlequah. Winter grand means are 41.1F (5.0C) and 40.0F (4.4C) respectively, and 40.6F (4.7C) for both stations. These temperatures are relatively mild and, typically, thin ice occurs only on pools and rarely exceeds one-inch (2.5 cm) thick or persists for more than four days on Spring Creek. Snow cover also is rare and obviously cannot persist longer than the ice.

Winter is the driest period of the year with mean precipitation of approximately 6.0 inches (15.2 cm) at Kansas and 6.66 inches (16.9 cm) at Tahlequah, but also is the only prolonged period when evaporation is less than precipitation (est. 5.25 inches or 13.3 cm (Jester et al. 1988)). The result is that the creek increases in volume after decreasing during summer and autumn when more precipitation occurs but evaporation is relatively and actually much greater. Therefore, there is no evidence that direct or indirect effects of winter weather may limit Ozark fishes in Spring Creek or its tributaries.

The most critical period for the biotic communities occurs during late summer because of temperatures, precipitation, and evaporation. The hottest period, with reduced precipitation and high rates of evaporation, consists of June-August (Table 2[8]). However, the creek is fed by springs and groundwater return, with a delay between changes in precipitation and changes in volume of flow in the creek. Therefore, the critical period consists of July, August, and part of September. Mean temperatures are approximately 78.3F (25.7C) at Kansas and 80.3F (26.8C) at Tahlequah for July and August. Precipitation is approximately 5.5 inches (14.0 cm) at Kansas and 6.45 inches (16.4 cm) at Tahlequah, and evaporation is 18.84 inches (47.9 cm) or 3.2-times precipitation. Volume of flow decreases and temperature of water increases considerably under these conditions.

Most of the indigenous Ozark fishes are coolwater forms, which live precariously when water temperature exceeds 80F (26.7C) by a few degrees for prolonged periods. Therefore, mean air temperatures of 80F (26.7C) and maximum temperatures as high as 110F (43.3C) (Table 2) appear to constitute a threat to the fishes in the creek. However, the preponderance of cool spring and ground water along with rapid flushing caused by steep gradients maintain maximum water temperatures in the range of 75-80F (24-27C) and sustain the fish community despite relatively-high air temperatures and rates of evaporation.

Most critical period. According to data in Table 2, July is the hottest month and August is the driest month of the critical period, although mean temperatures and precipitation for the two months are too similar for the differences to have ecological significance. However, on a year-to-year basis, one month or a shorter period may include departures from means which define that period as the most critical period during that year. Such a period occurred in 1986.

A hot, dry period occurred in July which caused the monthly mean air temperature to exceed the long-term mean by 4F (2.2C) and precipitation to fall below the long-term mean by 2.2 inches (5.6 cm) at Tahlequah (Table 2). Specifically, beginning on July 19, maximum air temperature reached or exceeded 100F (37.8C) during seven of 14 days at Kansas (Fig. 2) and 11 of 14 days at Tahlequah (Fig. 3). The seven days at Kansas were consecutive

[8]A comparable table of data from the Kansas weather station would show mean temperatures about 2F (1.2C) cooler, about one-inch (2.5 cm) less mean total precipitation, and the same values for wind and evaporation for June-August.

Table 2. Eighty-seven year means, 1986 means, and 1986 departures from the means of temperature and precipitation, total wind, and evaporation at Tahlequah, Oklahoma (from NWS 1986).

Month	Temperature (F) Mean	Temperature (F) 1986	Temperature (F) Departure	Precipitation (inches) Mean	Precipitation (inches) 1986	Precipitation (inches) Departure	Wind (miles)	Evaporation (inches)
January	37.0	42.1	+5.1	1.78	0.09	-1.69	e333	e1.50
February (min. 2F 2/11)	42.1	44.8	+2.7	2.42	3.45	+1.03	e500	e2.00
March (last frost 3/21)	50.0	54.5	+4.5	3.64	2.42	-1.22	e2000	5.68
April	61.1	62.4	+1.3	4.56	5.66	+1.10	1549	5.44
May	68.2	68.7	+0.5	5.47	10.30	+4.83	1257	5.84
June	76.1	77.8	+1.7	4.63	5.23	+0.60	762	7.02
July (max. 110F 7/29-30)	80.7	84.7	+4.0	3.39	1.19	-2.20	1374	11.08
August	79.9	77.6	-2.3	3.06	6.08	+3.02	802	7.76
September	72.9	74.4	+1.5	4.34	9.31	+4.97	1004	4.47
October	61.9	61.5	-0.4	3.39	10.07	+6.68	1107	3.26
November (first frost 11/11)	49.3	46.6	-2.7	3.20	3.27	+0.07	1312	e2.00
December	40.8	40.4	-0.4	2.46	0.88	-1.58	e1000	e1.75
Annual	60.0	61.3	+1.3	42.34	57.95	+15.61	12000	57.80

e = estimated by extrapolation of proportions from other areas from which year-round data are available.

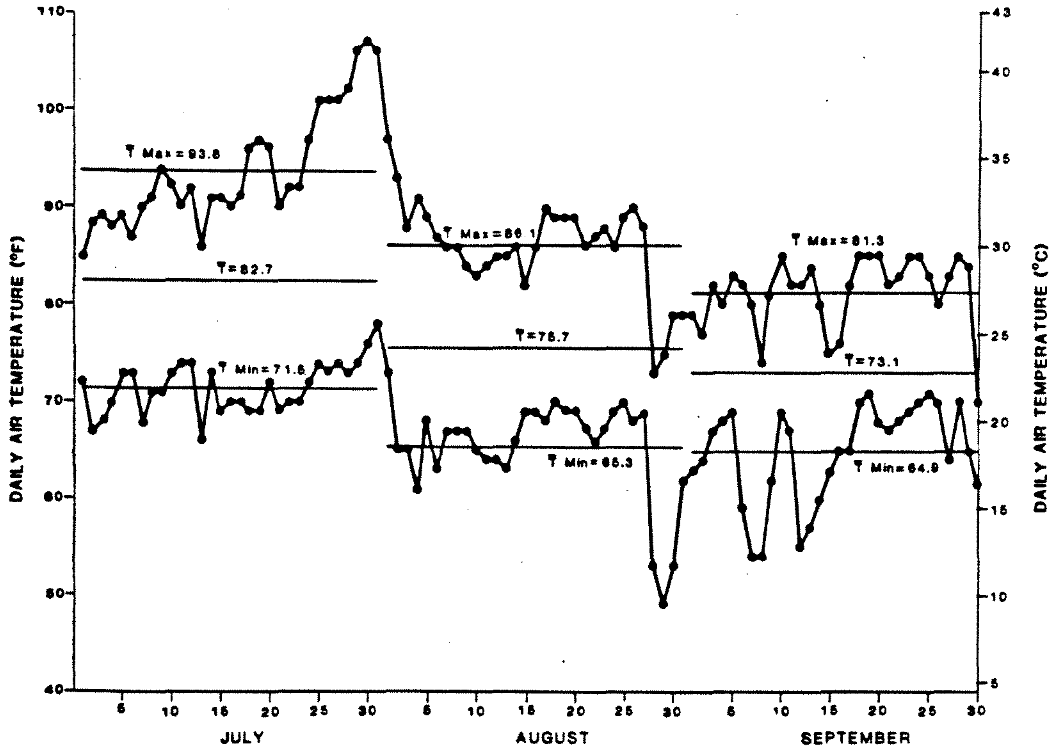


Figure 2. Daily maximum and minimum air temperatures at Kansas, Delaware County, Oklahoma, July through September, 1986 (NWS 1986), and computed monthly maxima, minima,and means.

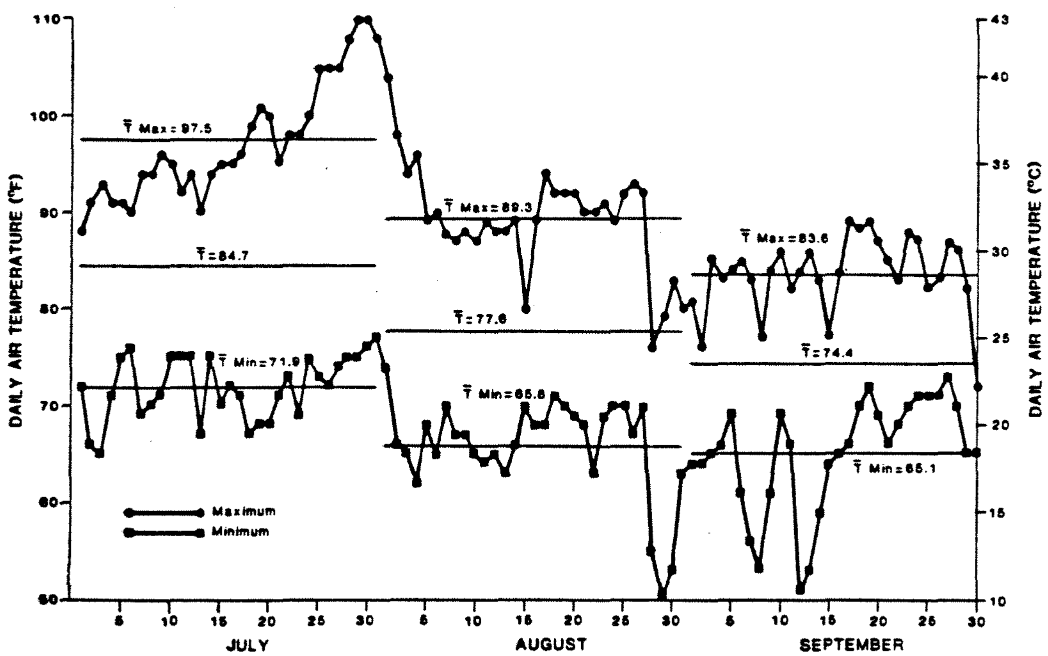


Figure 3. Daily maximum and minimum air temperatures at Tahlequah, Cherokee County, Oklahoma, July through September, 1986 (NWS 1986), and computed monthly maxima, minima, and means.

from July 26 through August 1 and nine of the 11 days at Tahlequah were consecutive from July 24 through August 1. Although temperature usually exceeds 100F (37.8C) on a few days each year, these were rather large numbers of days but were more unique because of high temperatures. Maxima ≥105F (40.6C) are rare. Yet, during this period, 107 and 108F (41.7 and 42.2C) occurred on three days at Kansas and 105 to 110F (40.6 to 43.3C) occurred on seven days at Tahlequah.

Although precipitation was almost five inches (12.7 cm) above normal through June, July was a very dry month. Only 1.5 inches (3.8 cm) of rain fell at Kansas (Fig. 4) and 1.19 inches (3.0 cm) fell at Tahlequah (Fig. 5), all before July 15. Also, the hot, dry period which spanned the last one-half of July was characterized by unusual hot winds so that the wind column for the month was 500 to 600 miles (800 to 960 km) longer than it was in June and August (Table 2). The wind increased evaporation by about four inches (10 cm), most of which probably occurred during the last one-half of the month. Heavy rains ended the drought in early-August (Figs. 4 and 5), and temperature and precipitation were favorable through August and September (Figs. 2-5). The unusually-high temperatures, low rainfall, and high evaporation during the last one-half of July, 1986, is an example of a Most Critical Period that can occur.

Vegetation

Surface soils are thin on top of the relatively-deep chert and limestone mantle on the watershed and slopes above the floodplain of the creek. Thus, the upland and slopes drain rapidly because of gradient and porous nature of the substrate. The typical forest type is a dry, oak-hickory hardwood association. Understory and ground cover are sparse. The principal trees are blackjack oak, *Quercus marilandica*; post oak, *Quercus stellata*; black hickory, *Carya buckleyi*; and winged elm, *Ulmus alata*. Understory consists of a few redbud, *Cercis canadensis*, and dogwood, *Cornus florida*, trees. Sassafras, *Sassafras variifolium*, is a prominent shrub. Most of the ground cover consists of huckleberry, *Vaccinium vacillans*, and coral berry, *Symphori-carpos orbiculatus*.

Deep, shaded ravines, north slopes, and slopes with seepage areas support sugar maple, *Acer saccharum*; white oak, *Quercus alba*; chinquapin oak, *Quercus muhlenbergi*; redbud, and dogwood. They also support shrubs including spice bush, *Benzoin aestivale*; wild hydrangea, *Hydrangea arborescens*; pawpaw, *Asiminia triloba*; sassafras, and coral berry. Mesophytic plants such as dogtooth violet, *Erythronium americanum*; May apple, *Podophyllum peltatum*; ginger, *Asarum canadense*; bloodroot, *Sanguinaria canadensis*; ferns, mosses, and liverworts occur on the forest floor.

The riparian zone is vegetated by cottonwood, *Populus deltoides*; sycamore, *Platanus occidentalis*; American and winged elm, *Ulmus americanus* and *U. alata*; birch, *Betula nigra*; willow, *Salix sp.*; maple, and various oaks. Stream banks have sparse to dense cover including mixed riparian herbs and forbs, grasses,

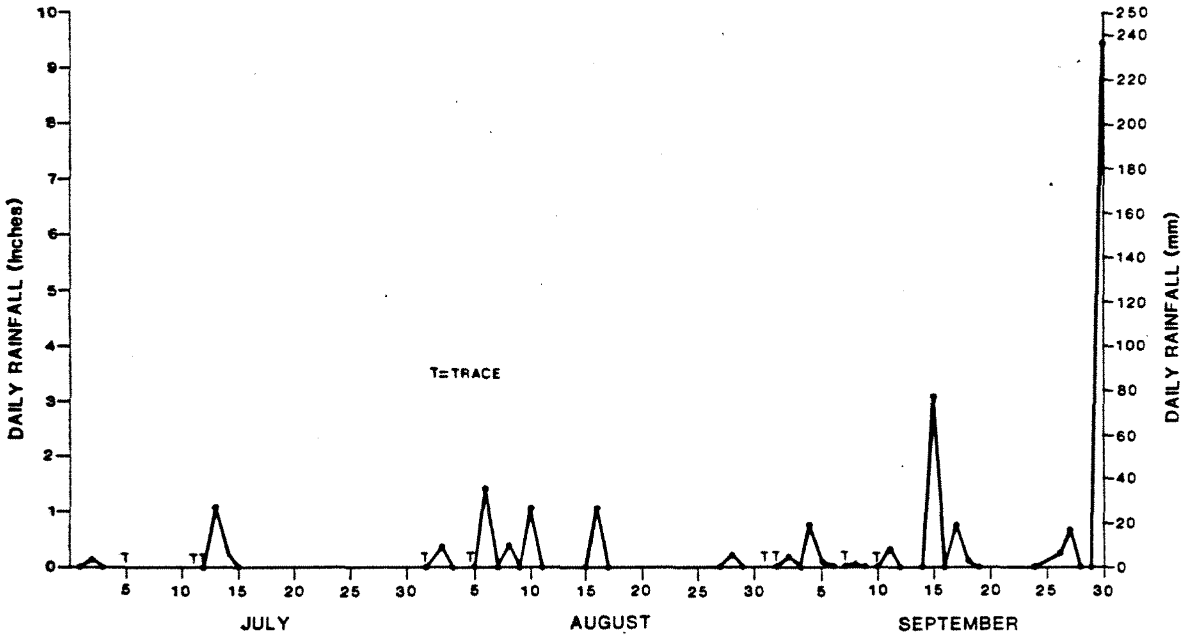


Figure 4. Daily precipitation (all rainfall) at Kansas, Delaware County, Oklahoma, July through September, 1986 (NWS 1986).

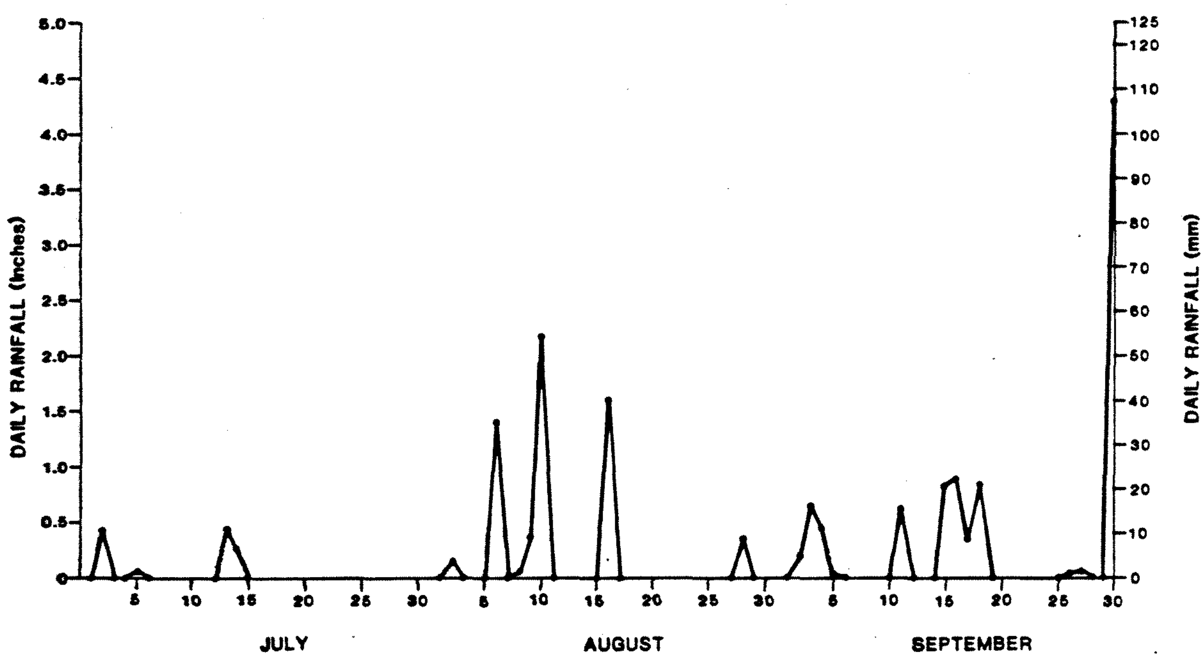


Figure 5. Daily precipitation (all rainfall) at Tahlequah, Cherokee County, Oklahoma, July through September, 1986 (NWS 1986).

brush, and trees such as willow, cottonwood, and sycamore. Very little erosion is evident, indicating that plants and their root systems are stabilizing banks regardless of their density.

Geology and Soils

Geology. The Ozarks are old mountains which owe their existence to several distinct uplifts that occurred over a period of 20 to 30-million years during the Permian Period about 225 to 255-million B.P.. Deposits laid down during the last 100-million years before the uplift have eroded away, down to the middle of the Mississippian Period which occurred about 325 to 340-million B.P..

The Boone chert formation consists of marine sediments of alternating layers of chert and limestone. It is a complex of Keokuk and Reeds Spring formations and St. Joe group limestone. Although undisturbed or lightly-fractured chert produces little water, the Boone chert formation (Fig. 6) consists of a mantle of badly eroded and broken chert and limestone gravel and rubble 20 to 30 feet (6 to 9 m) deep, Karst depressions, and bluff outcrops of limestone and underlying fractured shale (Marcher and Bingham 1971). It has a large capacity to store water and a high rate of transmissivity. Although fishes had existed for about 100-million years and had diversified into all of the classes and subclasses when the formations were laid down, vertebrate fossils are not found in the Boone chert limestone. The author has observed large numbers of crinoids, scallops and other bivalves, and a few snails but little if any evidence of major diversity of species or higher taxa.

Soils. Eroded and broken chert and limestone gravel and rubble allow considerable percolation of water through the 20 to 30-foot (6 to 9-m) Boone chert mantle. However, the amount of water that reaches the mantle is dependent upon the characteristics of the overlying soils.

Spring Creek drains uplands and slopes which are made up mostly of Baxter-Locust, Clarksville-Baxter-Locust, and Clarksville-Nixa soil associations (Cole 1970, Polone et al. 1975).

The narrow floodplain and stream bed consist of alluvia which make up the Sallisaw-Elsah-Staser association (Fig. 6) and a small amount of Sallisaw-Cannon association (not shown) in which Cannon soils replace Elsah and Staser soils along and under the creek.

Spring Creek begins in the Baxter-Locust association and flows through the Clarksville-Baxter-Locust association through Kansas toward Oaks. Floodplain development just northeast of Oaks gives rise to the Sallisaw-Elsah-Staser association which persists to the eastern Mayes County line. Upland and floodplain soils change abruptly near the county line to the Clarksville-Nixa and Sallisaw-Cannon associations which persist almost to the mouth of the creek.

The Baxter-Locust and Clarksville-Baxter-Locust associations consist of relatively deep, stony and cherty, very-gently-sloping

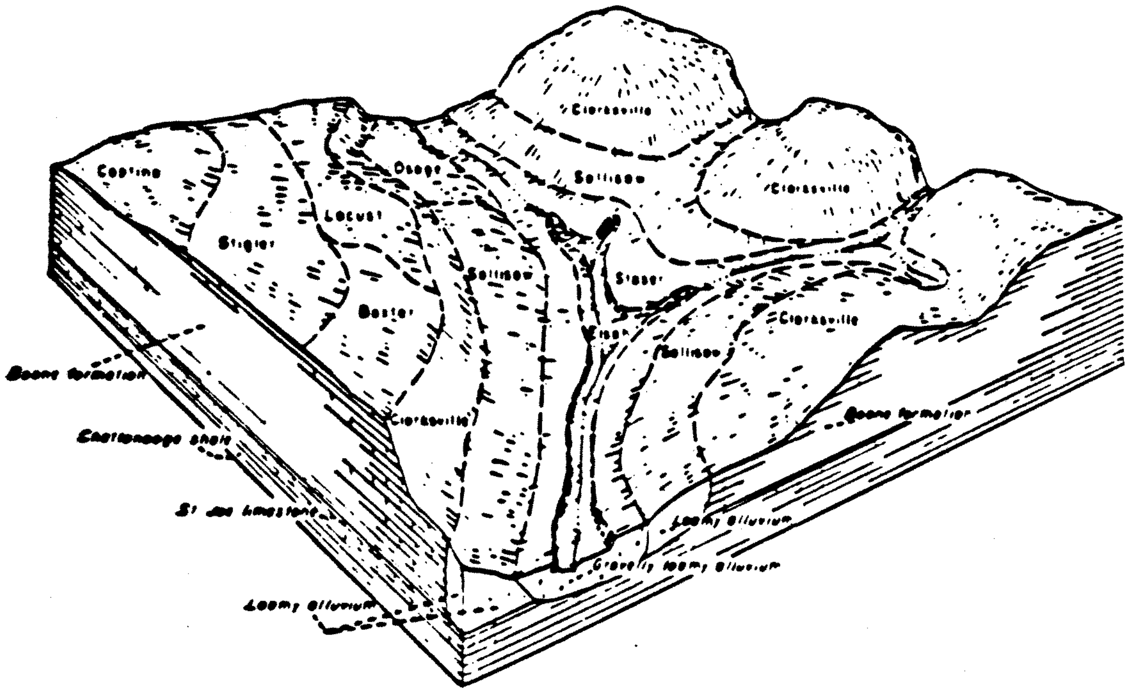


Figure 6. Major soils in the Clarksville-Baxter-Locust Association and their relationship to the landscape which is drained by Spring Creek. From Cole 1970 and Polone et al. 1975).

to steep soils on timbered uplands. These soils form under trees in cherty limestone areas between streams. Baxter and Locust soils occur in higher positions than Clarksville soils (Fig. 6). Baxter and Locust soils make up more than 90 percent of the soils in the headwaters but give way considerably to Clarksville soils in the Clarksville-Baxter-Locust association. These soils make up 41 percent of Cherokee County where most of the creek occurs and Clarksville soils make up about 91 percent of the association.

Each of the four series of upland soils is described below (after Cole 1970 and Polone et al. 1975).

<u>Clarksville series</u>. The Clarksville series consists of deep, very-gently-sloping to steep soils that have a stony and cherty, medium-textured surface layer and moderately-fine-textured or fine-textured subsoil.

In a typical profile, the upper part of the surface layer is dark grayish-brown, stony, silt loam about two inches (5 cm) thick. The lower part is a lighter-colored mixture of the same materials about eight inches (20 cm) thick. This layer varies from slightly acid near the surface to strongly acid in the lower part. The subsoil extends to a depth of 60 inches (1.5 m). It is strong-brown, strongly acid, very stony, silt-clay loam to a depth of 40 inches (1.0 m). At this depth, the subsoil grades to chert beds and interlayers of brownish-yellow, strongly acid, stony and cherty, silty-clay loam that is mottled with brownish, reddish, and grayish colors.

These soils are well-drained to excessively drained and are rapidly permeable.

Baxter series. The Baxter series consists of deep, very-gently-sloping to gently-sloping soils that have a cherty or a medium-textured surface layer and a cherty subsoil.

In a typical profile, the surface layer is a dark grayish-brown, strongly-acid, cherty, silt loam about nine inches (23 cm) thick. The subsoil extends to a depth of 60 inches (1.5 m) and is strongly acid. It is a reddish-brown and yellowish-red, cherty, silty-clay loam to a depth of 22 inches (0.6-m) and is red, firm-cherty and very-cherty clay below that depth. Below 34 inches (0.9-m), the subsoil is mottled with yellowish red and gray and is 50 percent chert fragments.

These soils are well-drained and moderately slow in permeability.

Locust series. The Locust series consists of deep, very-gently to gently-sloping soils that develop in materials weathered from cherty limestone on upland slopes. These soils have a cherty, medium-textured surface layer and a cherty subsoil that is mostly moderately-fine textured. A fragipan occurs at about 22 inches (0.6-m).

In a typical profile, the surface layer, about 10 inches (25 cm) thick, is strongly-acid, cherty, silt loam that is about 15 percent chert by volume. It is dark grayish-brown in the upper six inches (15 cm) and is brown in the lower part. The subsoil extends to a depth of 42 inches (1.1 m). It is yellowish-brown, strongly-acid, cherty, silt loam in the upper six inches (15 cm) and yellowish-brown, cherty, silt-clay loam in the next layer. Below 22 inches (0.6-m), the subsoil grades to a very-strong acid fragipan of mottled yellowish-brown, gray and strong-brown, cherty, silt-clay loam. This layer is about 30 percent chert by volume.

These soils are well-drained. Permeability is moderate above the fragipan and slow within it.

Nixa series. The Nixa series consists of deep, nearly-level and gently-sloping soils on uplands, occupying somewhat the same position as Baxter and Locust soils in relation to Clarksville soils (Fig. 6). They form under pine, oak, and understory of native grasses in material weathered from cherty limestone.

In a typical profile, the upper four inches (10 cm) is dark, grayish-brown, cherty, silt loam which becomes brown to a depth of about 12 inches (30.5 cm). It is yellowish-brown, very-cherty, silt-clay loam down to 19 inches (0.5-m) and pale brown to strong-brown, brittle, very-cherty, silt loam down to 42 inches (1.1 m). The last layer, down to 60 inches (1.5 m), is red, very-cherty, clay loam.

These soils are moderately-well drained, have slow permeability, and available-water capacity is moderate.

In summary, the Clarksville, Baxter, Locust and Nixa soils vary from 42 to 60 inches (1.1 to 1.5 m) thick. They are acid to strongly acid and range from 15 percent chert and limestone fragments in the upper layer to 50 percent chert by volume in the subsoil. They are well-drained and moderately-slow to rapidly permeable. The Clarksville soils which make up 91 percent of the association are rapidly permeable. Therefore, these soils absorb rainfall rapidly and allow it to flow readily both horizontally in the soil and vertically into the Boone chert mantle.

The narrow floodplain and stream bed cause the characteristics of soils in the Sallisaw-Elsah-Staser and Sallisaw-Cannon associations to be more important in terms of groundwater return to the creek than for the amount of rainwater that they absorb. Also, they determine the composition of the creek banks and bottom, which are major factors in the habitats of aquatic organisms. The four series of soils are described briefly (after Cole 1970 and Polone et al. 1975).

Sallisaw series. The Sallisaw series consists of deep, very-gently-sloping to sloping soils that have a gravelly or medium-textured surface layer and a gravelly or moderately-fine-textured subsoil. These soils develop in loamy alluvium on benches along major streams (Fig. 6).

In a typical profile, the surface layer is dark-brown silt loam about nine inches (23 cm) thick. It is slightly acid and about 15 percent gravel. The subsoil is strong-brown and strongly acid. It has an upper layer of silt loam or silty-clay loam that is about 20 percent gravel. At a depth of 32 inches (0.8-m), it is about 75 percent gravel.

Sallisaw soils are well-drained and moderately permeable.

Staser series. The Staser series consists of nearly-level to very-gently-sloping soils that have a gravelly and medium-textured surface layer and subsoil. These soils develop in gravelly and loamy alluvium on flood plains bordering the creek (Fig. 6).

In a typical profile, the surface layer is about 12 inches (0.3-m) thick. It is very-dark, grayish-brown, slightly-acid, gravelly loam that is about 20 percent gravel to a depth of 43 inches (1.1 m). The substratum is dark-brown and about 70 percent gravel.

These soils are well-drained and have moderately-rapid permeability.

Elsah series. The Elsah series consists of nearly-level to slightly-undulating soils that have a very-gravelly, medium-textured surface layer and subsoil. These soils develop in gravelly alluvium on stream beds that are flooded frequently.

In a typical profile, the surface layer is dark-brown, medium-acid, very-gravelly loam about 15 inches (0.4-m) thick. It is about 70 percent gravel. The subsoil is dark grayish-brown, medium-acid loam which is 70 to 90 percent gravel.

Elsah soils are excessively-drained and have rapid permeability.

Cannon series. The Cannon series consists of deep, nearly-level soils on flood plains. They form in loamy sediment under hardwood forest. They are slightly to medium acid.

In a typical profile, the surface layer is about 12 inches (0.3-m) thick. It is very-dark, grayish-brown, gravelly loam, underlain by 12 inches (0.3-m) of a gravelly, silt loam with the same descriptive characteristics. From 24 to 60 inches (0.6 to 1.5 m), the soil is dark, yellowish-brown, gravelly, silty-clay loam.

Cannon soils are well-drained, rapidly permeable, and available-water capacity is high.

The floodplain and streambed soils which make up the Sallisaw, Elsah, Staser, and Cannon series are all dark, acid loams which range from 15 to 70 percent gravel in the surface layer and 70 to 90 percent gravel in the deeper subsoils. They are moderately to rapidly permeable. Therefore, they transmit water readily into the stream and provide gravel of various sizes which make up most of the creek bottom. Some of the gravel has been ground to course chert sand which underlies the gravel.

Stream Orders

Horton (1945) devised the stream order concept as part of his analysis of erosional development of streams and drainage basins. He defined First Order streams as small headwaters without tributaries. Two First Order streams converge to form a Second Order stream, two Second Order streams converge to form a Third Order stream, etc.. For purposes of stream ecology, the ultimate end of this bifurcation, such as two erosion rills converging in a cornfield on a hilltop, is of no concern. Therefore, for our purposes, First Order streams begin at the point where they become perennial or at least are intermittent with refuge pools to sustain aquatic life.

Classification. First Order streams in the Ozarks characteristically have the shortest length, steepest gradients, greatest velocities, and smallest volumes of flow in the system. Gradient and velocity usually decrease and length and volume usually increase in each succeeding or increasing stream order, so that the stream becomes larger and macro and micro habitats become more abundant and more diverse downstream. Ecological implications are that the number and size of species tend to be small in First Order segments and to increase substantially as size and diversity of habitats increase in each succeeding order. This trend occurred very markedly in Tahlequah Creek (Jester et al. 1988), which demonstrates correlation between diversity of habitat and diversity of species. However, data which are discussed under other topics show that size of Spring Creek increases with stream orders but that other characteristics which make up habitat diversity vary less throughout the creek and as much within as between orders. The result is that habitat diversity is as great in the First Order segment as it is anywhere in the creek, and the number and diversity of species of fishes are as great because of it. Correlation between habitat and species diversity is still demonstrated, while it is shown that habitat diversity is not always dependent upon stream order. Therefore, upstream ranges of species are dependent upon habitat, but not necessarily stream order.

In Spring Creek, habitat and species diversity vary among stream orders so that orders are valid units for analysis, although classical increases in diversity downstream do not occur.

First Order. Two First Order segments of Spring Creek begin northeast and west-northwest of the town of Kansas (Fig. 1). The longest or main-stem segment is 9.5 miles (15.2 km) long and the short segment is 3.8 miles (6.1 km) long. Therefore, combined length of First Order segments is 13.3 miles (21.3 km).

Second Order. Two First Order streams or segments converge to form a Second Order stream which usually is longer, has a lower gradient, and larger volume of flow (Horton 1945). The headwaters segments converge to form a Second Order stream in Spring Creek at elevation 975 feet (297.3 m) MSL three miles (4.8 km) west of Oaks. This segment is 9.3 miles (14.9 km) long before its confluence with another Second Order stream, Double Spring Creek, 0.38-mile (0.67-km) south of the community of Teresita. Although the gradient is variable in this segment and the length of the segment is approximately the same as the length of the First Order segment, it conforms otherwise with expectations for size.

Third Order. The Third Order segment begins at elevation 835 feet (254.6 m) MSL and continues 14.7 miles (23.5 km) down to elevation 554 feet (168.9 m) at Cedar Crest Dam. Gradient increases in this segment while size, velocity, and volume fluctuate unpredictably. One large Second Order tributary, Snake Creek, enters the Third Order segment at elevation 615 feet (187.5 m) approximately one mile (1.6 km) upstream from Station 8, but the volume of flow at Station 8 is less than it is at Station 7 despite the tributary. Overall, the Third Order segment is both longer and larger than the Second Order segment but is characterized by erratic changes within the segment.

A Third Order stream in a long, lowland system might provide conditions for bottom materials to stabilize and build a flatter, wider channel, or become a "building stream" (Welch 1952, Cole 1983). However, the Spring Creek system is steep, cool, and "cutting" throughout so that habitat does not exist for many species of fishes which occur in the Neosho River and Fort Gibson Reservoir. Therefore, fish communities which occur typically in the three orders of streams are unique to coolwater creeks of the Ozark highland and the Ozark Biotic District (Hall 1952, Blair 1959, Branson 1967).

Gradient. The gradient of a stream is defined as change of elevation as a function of distance. In normal stream development, First Order streams are the shortest and have the steepest gradients. Each order thereafter usually is longer and flatter so that a gradient profile approaches a concave exponential curve on which the rate of fall decreases with distance. Gradient affects incidence and size of pools and riffles, pool-to-riffle ratios, rates of flow, and scouring or deposition of bottom materials, and, thus, is quite significant ecologically.

In Spring Creek, the First and the Second Order segments of the main stem are approximately the same length and the Third Order segment is longer, but only the Second Order segment is flatter before gradients increase again in the Third Order segment (Fig. 7). Although this deviation does not appear to be great, its ecological effects are obvious in the analysis of the fish community in each stream order.

An effective gradient was used for ecological analysis of Tahlequah Creek because the creek contains numerous low falls and abrupt drops which have only limited local effects while conditions in most of the segments are determined by longer, flatter gradients (Jester et al. 1988). Abrupt drops are too few and too small in Spring Creek for the effective gradient to serve any useful purpose. Therefore, true gradients and effective gradients are the same values in this creek. Gradients for significant segments of the creek are described below.

Entire creek. The highest elevation on the channel is 1,164 feet (354.9 m), and perennial flow starts 0.5-mile (0.8-km) downstream at 1,135 feet (346.0 m) (Fig. 7). Therefore, the gradient for the ephemeral upstream end of the creek is 58 feet/mile (11.1 m/km).

Elevation 554 feet (168.9 m), or the mouth of the creek, is 610 feet (186.0 m) below and 34 miles (55.4 km) downstream from the highest elevation on the channel. Therefore, the gradient for the entire channel is 17.9 feet/mile (3.4 m/km). The mouth of the creek is 581 feet (177.1 m) below and 33.5 miles (53.6 km) downstream from the beginning of perennial flow, and the gradient is 17.3 feet/mile (3.3 m/km).

First Order. The longest First Order segment is 9.5 miles (15.2 km) long from elevation 1,135 feet (346.0 m) to elevation 975 feet (297.3 m), three miles (4.8 km) west of Oaks. Therefore, the gradient for the First Order segment of the main stem of the creek is 16.8 feet/mile (3.2 m/km).

The other First Order segment begins at elevation 1,038 feet (316.5 m) and flows 3.8 miles (6.1 km) to the confluence to produce a gradient of 16.6 feet/mile (3.2 m/km).

Second Order. The Second Order segment begins at elevation 975 feet (297.3 m) three miles west of Oaks and ends 9.3 miles (14.9 km) downstream at elevation 835 feet (254.6 m) at the mouth of Double Spring Creek, 0.38-mile (0.6-km) south of Teresita. The gradient is 15.1 feet/mile (2.9 m/km).

Third Order. The distance from the mouth of Double Spring Creek to the mouth of Spring Creek is 14.7 miles (23.5 km) in which the elevation declines from 835 feet (254.6 m) to 554 feet (168.9 m). Therefore, the gradient for the Third Order segment is 19.1 feet/mile (3.6 m/km).

Summary. The two First Order segments of Spring Creek fall 160 feet (48.8 m) in 9.5 miles (15.2 km) and 63 feet (19.2 m) in 3.8 miles (6.1 km), respectively, to produce gradients of 16.6 feet/mile (3.2 m/km) and 16.8 feet/mile (3.2 m/km), the latter representing the main stem of the creek. The Second Order segment is slightly flatter, falling 140 feet (42.7 m) in 9.3 miles (14.9 km) to produce a gradient of 15.1 feet/mile (2.9 m/km). The Third Order segment is the steepest in the creek, falling 281 feet (85.7 m) in 14.7 miles (23.5 km) to produce a gradient of 19.1 feet/mile (3.6 m/km). The entire creek falls 581 feet (177.1 m) in 33.5 miles (53.6 km) to produce a mean gradient of 17.3 feet/mile (3.3 m/km).

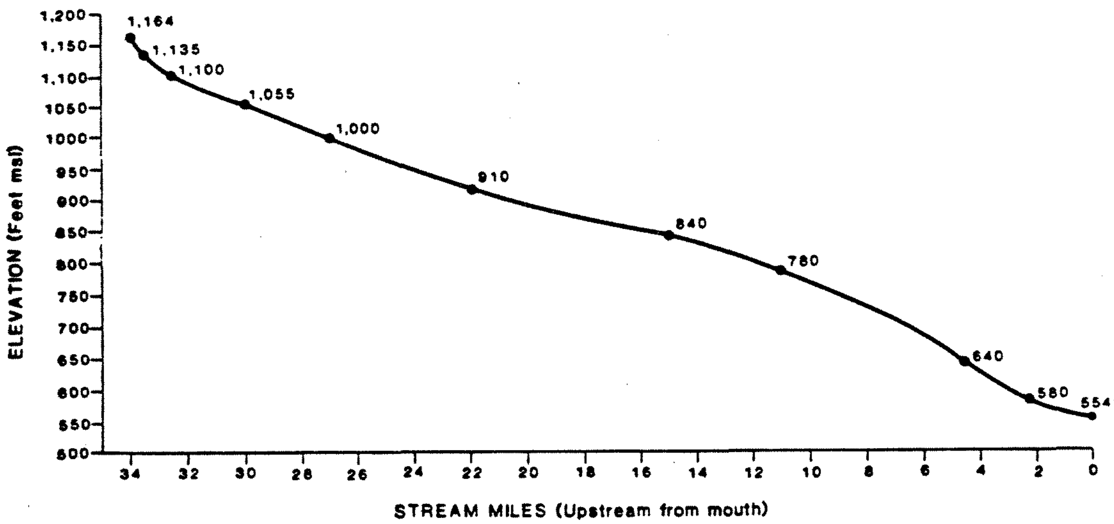


Figure 7. Gradients of Spring Creek. Stream order boundaries are between elevations 1,000 and 910 and between elevations 840 and 780.

Overall, the gradients of the First Order segments are most similar to the mean for the creek, varying by only 0.5 and 0.7 feet/mile (9 and 13 cm/km) less than the mean. The gradient of the Second Order segment is least similar, varying by 2.2 feet/mile (0.4-m/km) less than the mean. The gradient of the Third Order segment exceeds the mean by 1.8 feet/mile (0.3-m/km). However, the gradients for all of the segments are within the range of four to 25 feet/mile (0.8 to 4.8 m/km) and the more-ideal range of 7 to 20 feet/mile (1.3 to 3.8 m/km) which Trautman (1942) described as the range of gradients (and associated habitat characteristics) required by the smallmouth bass, which is a prominent and probably the most abundant top carnivore in most Ozark creeks.

Hydrology. An annual mean of 40.1 inches (101.9 cm) of precipitation, moderately-permeable to rapidly-permeable soils, and the broken and fragmented Boone chert mantle allow penetration, storage, and vertical and horizontal subsurface movement of large quantities of relatively-shallow groundwater in the Spring Creek watershed of the Cookson Hills. The nature of the mantle and floodplain soils produces many small, relatively-permanent springs on lower slopes and in the channel of the creek. Also, the gravel bottom and gravelly soils of the flood plain allow considerable ground storage of water during high flows and release back into the creek during periods of normal and low flows. These storage and flow characteristics tend to stabilize the creek so that the head of permanent flow does not vary greatly upstream and downstream, and intermittent pools and dry areas are rare. The result is greater hydraulic stability than might be expected of a creek in steep terrain and a relatively-small watershed.

McNeely (1986) described the creek as alternating pools separated by 2,300 to 2,600-foot (700 to 800-m) stretches of dry stream bed where flow is subterranean by percolating through chert-gravel-cobble [rubble] substrate. His study was done in 1980 during an extremely hot, dry period. This description of the creek has not applied in eight years since his study and, therefore, represents atypical conditions. However, it does describe the extreme occurrence and one segment where the water goes underground for approximately one-half mile (0.8-km) in the Second Order segment during normal and even wet years. The same phenomenon occurs in the mouth of Double Spring Creek so that it appears to be an ephemeral tributary rather than a Second Order creek at the confluence (Fig. 1).

Station and Segment Characteristics

Characteristics discussed above describe Spring Creek and each stream order rather well and lay a foundation for general understanding of the coolwater Ozark fish community that occurs in the creek. However, variations within and between stream orders combine to produce considerable variation in habitats and structure of the community throughout the creek. These characteristics were measured at each station where fishes were collected (Table 3).

Physical characteristics. At Station 1, where the gradient is 18 feet/mile (3.4 m/km), the volume of flow was 0.6 cfs (0.02 cms) on September 24 (Table 3).

Width, depth, and velocity shown in Table 3 are characteristics of the transect where volume of flow was estimated at each station rather than means for the station, except that an effort was made to place transects where width of the creek is typical or average for the station. This was done to facilitate estimation of areas of runs, riffles, and pools from the estimated percentages of each at the station. For example, if 1,000 linear feet (304.9 m) of the creek at each station is used for comparison among stations, the surface area of 1,000 feet (304.9 m) at Station 1 is [6.7 feet x 1,000 feet =] 6,700 feet^2 (2.04 m x 304.88 m = 622 m^2), of which approximately 2,680 feet^2 (248.8 m^2) consist of flat runs, 1,340 feet^2 (124.4 m^2) consist of riffles, and 2,680 feet^2 (248.8 m^2) consist of pools. Similar computations may be made to compare areas of each type of macrohabitat in order to compare fish population samples from each station.

The gradient decreases to 17 feet/mile (3.2 m/km), mean width of the creek increased to 9.0 feet (2.7 m), and volume of flow increased to 2.2 cfs (0.06 cms) at Station 2. Proportions of runs, riffles, and pools are the same as Station 1; 40 percent, 20 percent, and 40 percent, respectively.

At Station 3, the gradient is 16 feet/mile (3.1 m/km), mean width was 11.0 feet (3.4 m), and volume of flow was 5.6 cfs (0.16 cms). Flat runs decrease to 20 percent of the surface area, riffles remain at 20 percent, and pools increase to 60 percent;

Table 3. Geographical, physical, macrohabitat, and discrete symptomatic water quality characteristics of Spring Creek, Oklahoma, September 24, 1986. All depths are means except in pools for which ranges are shown. Gradient, volume of flow, and percent saturation of dissolved oxygen are computed values.

Characteristics	Stations							
Parameters	1	2	3	4	5	6	7	8
Geographical								
Elevation (ft. MSL)	1100	1055	1000	910	840	780	640	580
Gradient (ft./mi.)	18	17	16	15	15	18	22	17
Physical								
Width (ft.)	6.7	9.0	11.0	75.0	54.0	36.0	35.0	86.0
Depth (ft.)	0.1	0.2	0.75	0.25	1.25	1.0	3.0	2.75
Velocity (f/s)	1.15	1.5	0.75	2.0	1.5	2.0	2.1	0.7
Volume of flow (cfs)	0.6	2.2	5.6	30.0	91.1	64.8	198.5	149.0
Macrohabitat								
Flat runs								
Percent (area)	40	40	20	40	50	40	40	20
Depth (ft.)	0.3	1.0	0.5	0.6	1.0	1.0	1.4	1.2
Riffles								
Percent (area)	20	20	20	20	25	25	20	50
Depth (ft.)	0.1	0.3	0.3	0.3	0.3	0.2	0.4	0.4
Pools								
Percent (area)	40	40	60	40	25	35	40	30
Depth (ft.)	2-5	2.5	5	3->10	4-5	3-6	3-6	4
Water quality								
Temperature (C)	21.4	20.2	21.4	22.1	21.8	22.0	22.7	22.8
Dissolved oxygen (mg/l)	5.1	6.1	6.5	6.7	5.6	6.1	7.0	8.0
Saturation (mg/l)[1]	8.5	8.8	8.5	8.5	8.5	8.5	8.5	8.5
Percent saturation[2]	60.3	69.1	76.1	79.3	66.3	71.5	82.1	93.8
pH	7.2	7.3	7.4	7.6	7.3	7.3	7.2	7.4
Specific conductance (µmhos/cm)	275	206	236	230	210	193	179	181

[1] Saturation values were rounded-off from thousandths to tenths after Percent saturation was computed. Therefore, (Dissolved oxygen/Saturation)(100)≠ Percent saturation precisely as shown here.

[2] Saturation was computed from tabular values for the ambient temperatures at sea level corrected for elevation. Percent saturation was computed from ambient dissolved oxygen divided by computed saturation, quantity x 100, or $\%S = (O_2/S)(100)$.

the largest proportion of pools at any station on the creek.

In summary, Stations 1-3 represent the First Order segment of the creek. The mean gradient is 16.8 feet/mile (3.2 m/km), mean width was 8.8 feet (2.7 m), and mean volume of flow was 2.8 cfs (0.08 cms). The area of the segment is approximately 33.3 percent flat runs, 20 percent riffles, and 46.7 percent pools. Depths of these habitats are variable (Table 3) but are deep enough to provide suitable habitat for most of the species of fishes in the creek. Pools, which are sparse and shallow or absent in First Order segments of small, steep-gradient Ozark creeks such as Tahlequah Creek (Jester et al. 1988), are relatively numerous and relatively deep here. They apparently are scoured during flood flows where the terrain is suitable, while the normal velocities and volumes of flow are too small to move gravel to fill them in. Thus, habitat diversity allows high species richness and diversity in the First Order segment of Spring Creek.

The Second Order Stations, 4 and 5, have the flattest gradients in the creek at 15 feet/mile (2.9 m/km) (Table 3). Otherwise, they are physically dissimilar in most respects. The creek was approximately 75 feet (22.9 m) wide at Station 4, and 54 feet (16.5 m) wide at Station 5. At the same time, the volume of flow was only 30.0 cfs (0.9 cms) at Station 4 while it was 91.9 cfs (2.6 cms) at Station 5. This apparently was a function of a large volume of subsurface flow in a large bed of gravel at Station 4 and a smaller, shallower bed of gravel with less subsurface flow at Station 5. A one-half-mile (0.8-km) segment with no surface flow occurred between the stations. Macrohabitats also vary considerably among the stations. Sixty percent of Station 4 is shallow flat runs and riffles and 40 percent is pools. Seventy-five percent of Station 5 is runs and riffles, and only 25 percent is pools. Also, some pools are deeper at Station 4 but mean depths of runs and pools are greater at Station 5 to accomodate three-times the volume of flow.

Overall, the gradient of the Second Order segment is 15.1 feet/mile (2.9 m/km), mean width was 64.5 feet (19.7 m), and mean volume of flow was 60.6 cfs (1.7 cms). The area of the segment is approximately 45 percent flat runs, 22.5 percent riffles, and 32.5 percent pools.

The gradient increases again to 18 feet/mile (3.4 m/km) while mean width of the creek decreased to 36 feet (11.0 m) at Station 6. The creek bed appears to cross a large, wide gravel deposit which is overlain by a wide, flat, forested floodplain of Sallisaw soils where considerable subsurface flow may occur. The volume of flow decreased accordingly from 91.1 cfs (2.6 cms) at Station 5 to 64.8 cfs (1.8 cms) at this station. Flat runs make up 40 percent, riffles 25 percent, and pools 35 percent of the surface area of the creek.

Mean width of the creek was 35 feet (10.6 m) or almost unchanged at Station 7 while the gradient of 22 feet/mile (4.2 m/km) is the steepest among the eight stations. Also, there appears to be no major gravel deposits associated with the station, and the volume of flow of 198.5 cfs (5.6 cms) was the largest in the creek. Macrohabitats consist of 40 percent runs, 20 percent riffles, and 40 percent pools, which is characteristic of half of the stations and typical for the creek.

The gradient flattens to 17 feet/mile (3.2 m/km) and the width of the creek increased to 86 feet (26.2 m) at Station 8. This station also is located in a large gravel deposit where subsurface flow reduced the volume of flow in the creek from 198.5 cfs (5.6 cms) at Station 7 to 149.0 cfs (4.2 cms) at this station. This subsurface flow included both the 49.5 cfs (1.4 cms) difference between the stations and the unmeasured full volume of Snake Creek, a Second Order stream which enters Spring Creek just upstream from Station 8. The gravel deposit extends as a sandy-gravel floodplain for about 300 yards (275 m) on both sides and five feet (1.5 m) higher than the cut bank of the creek channel for a distance of approximately 0.5-mile (0.8-km) along the creek. Volume of subsurface flow obviously is dependent upon depth of the gravel, which is not known. However, the loss of water from Station 7, groundwater return and spring water entering downstream from Station 7, and the volume of water entering from Snake Creek indicate that subsurface flow may be as great or greater than surface flow at Station 8. Depth and diversity of habitat also decrease, with 70 percent of the surface area composed of runs and riffles and 30 percent composed of pools. The pools have a maximum depth of four feet (1.2 m), which is the shallowest maximum depths at any station except for Station 2 (Table 3).

The mean gradient for the Third Order segment is 19.1 feet/mile (3.6 m/km), mean width of the segment was 51.3 feet (15.6 m), and mean volume of flow was 137.4 cfs (3.9 cms). The area of the segment is approximately 33.3 percent runs, 31.7 percent riffles, and 35.0 percent pools.

The mean gradient for the entire creek is 17.3 feet/mile (3.3 m/km), which occurs at two stations, is exceeded at three stations, and is not achieved at three stations. Mean width of the creek was 39.1 feet (11.9 m) and mean volume of flow was 67.8 cfs (1.9 cms) on September 24. Widths were less than the mean at three stations, approximately equal to the mean at two stations, and greater than the mean at three stations. Volume of flow was approximately equal to the mean at only one station, less than the mean at four stations, and greater than the mean at three stations. Area of the creek is approximately 36.25 percent flat runs, 25.00 percent riffles, and 38.75 percent pools. These types of macrohabitats do not follow sequential trends correlated with gradient and stream order in Spring Creek as they do in Tahlequah Creek (Jester et al. 1988) and other creeks, which will be discussed in an ecological context. Conversely, they show that while downstream sequences may be the rule, there are exceptions in which distribution of fishes may vary by as much as two stream orders, as they do in similar communities in this and Tahlequah Creek.

Symptomatic water quality. Several physical and chemical parameters which may be measured in discrete or sequential samples are influenced by other parameters to the extent that they may be used as indicators or symptoms of water quality in addition to whatever direct effects they may have on the biota.

They may be symptoms of either natural or anthropogenic conditions, but only indicate, not identify, the conditions. For example, dissolved oxygen has a rather narrow range of concentrations under natural conditions at any given temperature and elevation (atmospheric pressure) but may deviate from this range by large amounts because of excess organic production and organic and inorganic consumption. Also, in some instances, subsaturation of oxygen indicates that natural aeration of anoxic ground water is incomplete. Symptomatic data collected in discrete samples on September 24 indicates that Spring Creek is a relatively-clean, cool stream but is subject to subsaturation of dissolved oxygen (Table 3).

Temperature. Temperature of water was erratic at Stations 1-4 where volume of flow was relatively small. The range of temperatures was 20.2 to 22.1C (68.4 to 71.6F), or a maximum difference of 1.9C (3.2F) between Stations 2 and 4 (Table 3). Erratic temperatures are attributed to variations in volume of groundwater return and springs entering the creek and to length of flow between these erratic influxes where warming can occur. At Stations 5 to 8, the water was slightly warmer at each consecutive station but varied by only 1C (1.8F) from 21.8 to 22.8C (71.2 to 73.0F) among all stations.

Apparently, a large and continuous inflow of cool subsurface water and rapid rate of exchange of water in the creek combine to prevent temperature of the water from warming to the mean temperature of the air during the warm seasons. The mean water temperature at Stations 1-4 was 21.3C (70.3F) while the mean air temperature was 22.8C (73.1F) for the month of September at Kansas, Oklahoma (Fig. 2). Therefore, the mean water temperature was approximately 1.5C (2.8F) less than the mean air temperature in the upstream half of the creek. Concurrently, mean water temperature was 22.3C (72.1F) at Stations 5-8 while the mean air temperature was 23.6C (74.4F) for September at Tahlequah, Oklahoma (Fig. 3). Therefore, the mean water temperature was approximately 1.3C (2.3F) less than the mean air temperature in the downstream half of the creek. For the entire creek, mean water temperature at Stations 1-8 was 21.8C (71.2F), compared with a mean air temperature of 23.3C (73.9F) at Kansas and Tahlequah. Therefore, the mean water temperature was approximately 1.5C (2.7F) less than the mean air temperature for the entire creek.

If these differences also are accepted as approximations for July, the mean maximum temperatures for the year are approximately [82.7 - 2.8 =] 79.9F (26.6C) at Stations 1-4, [84.7 - 2.3 =] 82.4F (28.0C) at Stations 5-8, and [83.7 - 2.7 =] 81.0F (27.2C) for the entire creek.

Dissolved oxygen. Dissolved oxygen ranged from 5.1 mg/l at 9:00 a.m. at Station 1 to 8.0 mg/l at 11:00 a.m. at Station 8. These concentrations represent a range of 60.3 to 93.8 percent of saturation (Table 3). Obviously, the low concentration at Station 1 could be residual from a natural pre-dawn diel minimum, but departure from saturation is much greater than expected to occur in a clean, cool, high-gradient creek, where departures of ±5 percent to ±10 percent are probable. This phenomenon continued through Station 7 until almost 11:00 a.m. before the concentration of oxygen occurred within the range of saturation ±10 percent at Station 8. Although none of the observed concentrations are critical for a typical Ozark-creek fish community, they represent major departures from saturation and indicate that the state minimum criterion of 5.0 mg/l for smallmouth bass streams (OWRB 1985) may be violated by natural conditions during the normal pre-dawn diel-minimum period. There are no point or nonpoint sources of oxygen-demanding materials entering the creek to account for large and consistent subsaturation of oxygen. Therefore, subsaturation must be attributed to the same cause as it was in Tahlequah Creek; anoxic water from subsurface sources enters the creek faster than oxygen can dissolve, so that oxygenated water is diluted by unoxygenated water and the oxygen concentration in the mixture is less than saturation. This would be a rather tenuous conclusion if it were based entirely upon data shown in Table 3. However, it will be supported by a more-complete ecological chemical analysis and continuous-monitoring data in subsequent sections of this paper.

pH. pH values were mildly-alkaline at all stations on September 24, ranging from 7.2 to 7.6 (Table 3). Recalling that all of the soils on the watershed are described as being acid and that carbon dioxide from plant roots and bacteria dissolve in water as it percolates through the soil, pH of water in the creek represents loss of CO_2 to the atmosphere and ionization of $Ca(HCO_3)_2$ in solution which resulted from reaction of water in the form of carbonic acid, H_2CO_3, with $CaCO_3$ in the Boone chert formation. Further discussion of these data is more appropriate for the carbon dioxide nutrient cycle under the topic of **Ecological Chemistry.**

Specific conductance. Specific conductance varied erratically at several stations but decreased overall from 275 µmhos/cm at Station 1 to approximately 180 µmhos/cm at Stations 7 and 8 (Table 3). Because conductance is a function of electrolytic salts in solution, downstream decreases in conductance indicate downstream decreases in concentrations of dissolved salts in the creek. This can only be a function of the salts available or of the volume of water to which a given amount of salts is exposed for a given period of time. This parameter, along with temperature, dissolved oxygen, and pH, indicate that water quality is suitable for a typical Ozark-creek fish community.

Ecological Chemistry

The temperature and chemical parameters discussed above are described as symptomatic because they cannot vary outside of very narrow ranges of their own volition. They are dependent upon other factors which constitute water quality, and their concentrations are symptoms of those factors and, therefore, of water quality. However, aquatic organisms have ranges of tolerance (Shelford 1913) specifically for temperature, dissolved oxygen, pH, and combinations thereof, so that values of these factors may be as important ecologically as the factors for which they function as symptoms. Single discrete samples such as those described above may have ecological implications but not ecological ramifications that may be revealed by continuous monitoring to analyze a series of diel cycles. Such analysis becomes ecological chemistry rather than merely checking for symptoms. Discrete samples for analysis of nutrient cycles, anthropogenic pollutants, salts, and gases also are ecological chemistry and are discussed below.

Continuous monitoring. Destruction of continuous-monitoring equipment at Stations 3 and 8 by a flood was mitigated to some extent by survival of a Mini-monitor at Station 6 in the middle segment of the creek where symptomatic parameters were relatively close to the means for the creek (Table 3). Therefore, it appears that the ranges of values in cycles in First and Third Order segments vary by approximately the same differences that occur between these segments and Station 6 in Table 3, allowing estimation of ranges and magnitudes of cycles upstream and downstream from Station 6.

Data were recorded hourly from 3:00 p.m., September 17, until 1:00 p.m., September 29, or two hours less than 12 diel [24-hour-day] cycles. The monitor apparently was deactivated by effects of weather at the beginning of a storm which produced a major flood on the creek. However, it was compared with a Hydrolab the previous day and was recording data accurately at that time.

Temperature. Temperature of the water at Station 6 varied only from 20.5C (68.9F) to 22.8C (73.0F) or through a total range of 2.3C (4.1F) during the 12-day period that the Mini-monitor recorded data. Mean temperature was 21.5C (70.7F). The maximum and minimum temperatures occurred 32 hours apart on September 18 and 19 (Table 4) when there were no extremes of air temperature (Fig. 3) to cause extremes of water temperature. In fact, maximum, minimum, and mean water temperatures were almost identical on the first and last days (Table 4), despite differences in air temperature (Fig. 3), indicating that temperature of water in the creek is controlled mostly by temperature of water returning from subsurface storage, with only a small diel range caused by air temperature. Some variation may have occurred during the first three or four days, including the maximum and minimum temperatures, because of runoff from approximately 3.5 to 4.5 inches (8.9 to 13.7 cm) of rain which fell during September 15-18 (Figs. 4, 5).

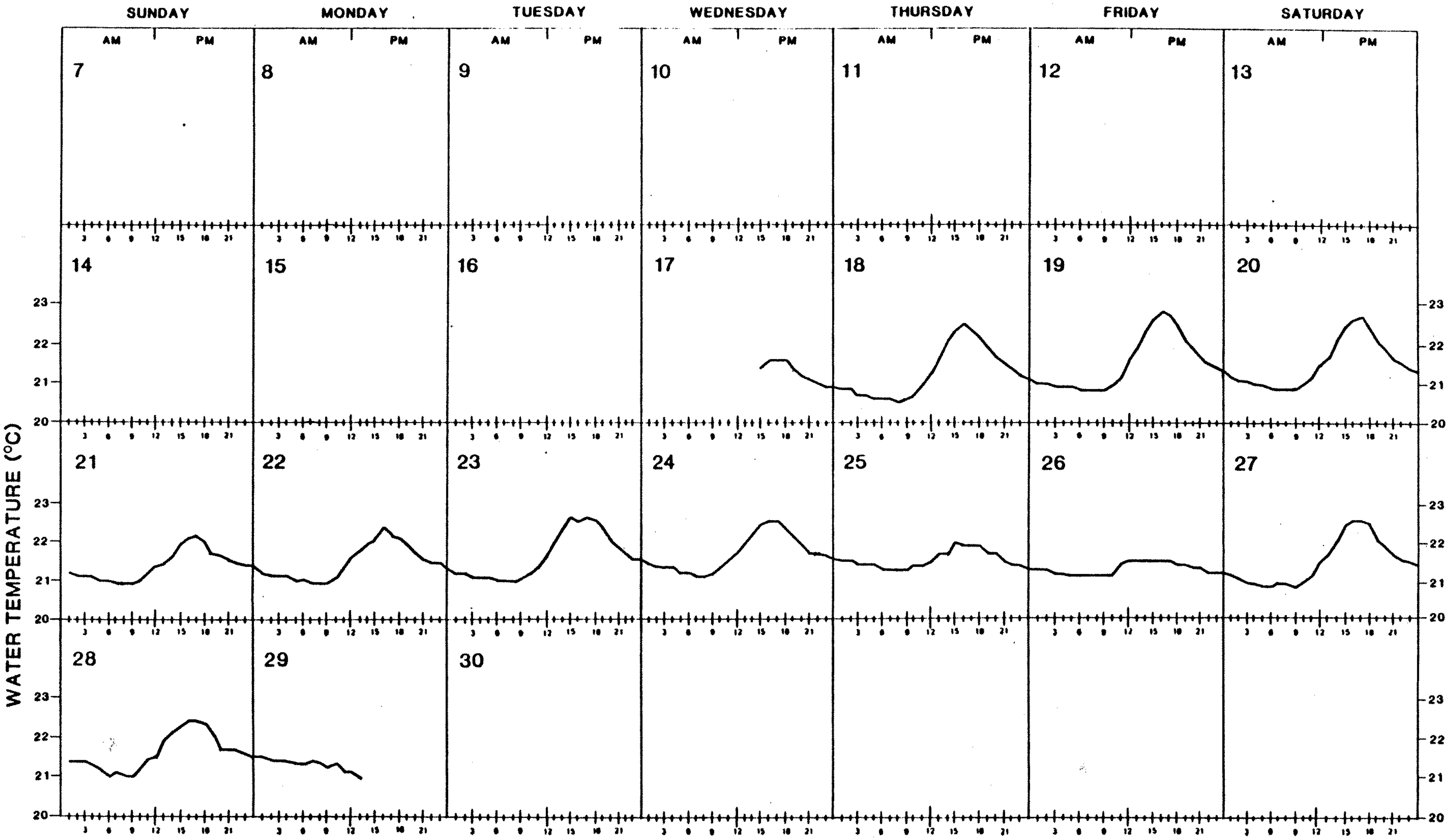
The diel temperature cycle was fairly regular, with an early-morning minimum and a late afternoon maximum, both with approximately the same amplitude except that maxima appeared to be suppressed by weather on September 25 and 26 (Fig. 8). Disregarding the two aberrant days, the minimum temperature occurred first at 6:00 a.m. twice, 7:00 a.m. one time, 8:00 a.m. twice, 9:00 a.m. four times, and bimodally at 6:00 and 9:00 a.m. one time. Therefore, the mean time of first occurrence was 7:54 a.m.. It persisted for four hours one time, three hours one time, two hours one time, and one hour six times, for a mean of 1.67 hours or 1 hour and 40 minutes.

Table 4. Maximum, minimum, and mean values of symptomatic water quality parameters recorded by a USGS Mini-Monitor at Station 6 on Spring Creek, Oklahoma, September 17-29, 1986.

Date	Temperature (C)			Dissolved oxygen (O_2 as mg/l)			pH			Specific conductance (μmhos/cm)		
September	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
17[a]	21.6	20.9	21.3	7.4	6.1	6.7	7.20	7.00	7.08	194	190	193
18	22.5	20.5	21.3	7.5	5.9	6.6	7.11	7.00	7.09	227	194	197
19	22.8	20.8	21.5	7.4	5.9	6.5	7.11	7.00	7.06	210	194	195
20	22.7	20.9	21.5	7.3	5.8	6.4	7.11	7.00	7.05	195	194	195
21	22.2	20.9	21.4	7.6	5.8	6.4	7.10	7.00	7.04	195	194	195
22	22.3	20.9	21.4	7.5	5.8	6.4	7.11	7.00	7.04	198	194	196
23	22.6	21.0	21.6	7.1	5.6	6.2	7.05	7.00	7.02	199	190	197
24	22.5	21.1	21.7	7.2	5.4	6.1	7.05	7.00	7.01	199	190	197
25	22.0	21.3	21.5	7.0	5.3	6.0	7.11	7.00	7.03	198	190	197
26	21.5	21.2	21.3	6.7	5.3	5.7	7.10	7.00	7.02	199	190	196
27	22.6	20.9	21.5	6.9	5.2	5.9	7.05	7.00	7.01	200	191	196
28	22.4	21.0	21.6	7.1	5.3	6.0	7.01	6.99	7.00	200	191	196
29[b]	21.5	20.9	21.3	6.7	5.2	5.6	7.15	7.00	7.04	200	179	192
Period	22.8	20.5	21.5	7.6	5.2	6.2	7.20	6.99	7.04	227	179	196

[a]Nine hours, 3:00 p.m. until 12:00 m..

[b]Thirteen hours, 12:00 m. until 1:00 p.m..



SPRING CREEK, STATION 6
SEPTEMBER 1986
WATER TEMPERATURE

Figure 8. Water temperatures recorded hourly at Station 6 near the middle of Spring Creek, September, 1986.

The maximum temperature occurred first at 3:00 p.m. one time, 4:00 p.m. seven times, 5:00 p.m. twice, and bimodally at 3:00 and 5:00 p.m. one time. Therefore, the mean time of first occurrence was 4:06 p.m.. It persisted for three hours one time, two hours three times, and one hour six times, for a mean of 1.5 hours.

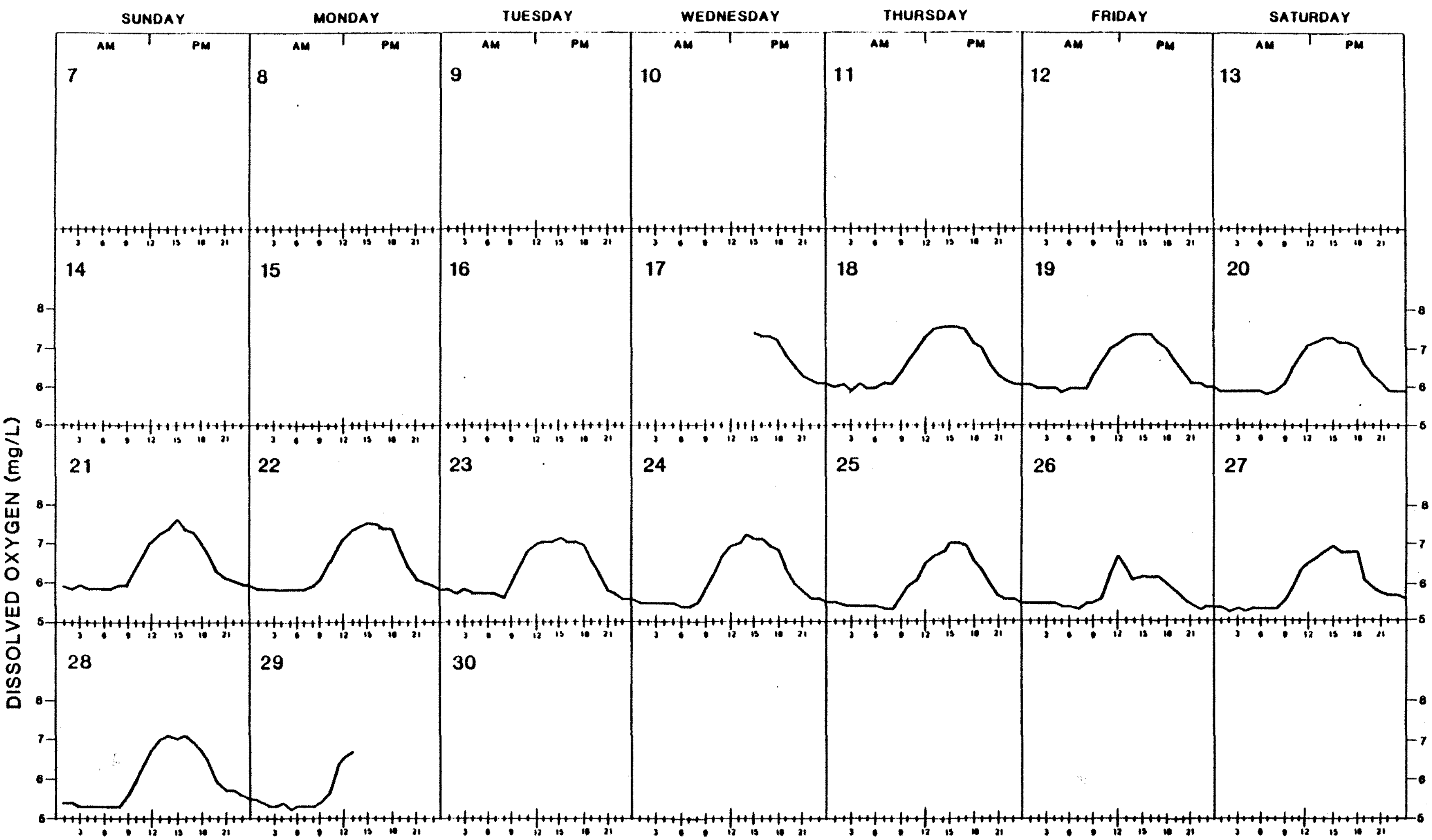
Dissolved oxygen. Dissolved oxygen ranged from 5.2 to 7.6 mg/l with a mean concentration of 6.2 mg/l for the 12 diel cycles (Table 4). The maximum concentration is 90.1 percent of saturation at the maximum temperature and the minimum concentration is 58.3 percent of saturation at the minimum temperature. The mean concentration is only 71.8 percent of saturation at the mean temperature. Therefore, ambient dissolved oxygen concentrations are consistently low at a point in the creek that is far-removed from any potential anthropogenic impact.

The explanation for this phenomenon is the same as it was for lightly-impacted and unimpacted stations on Tahlequah Creek (Jester et al. 1988) and appears to represent common conditions in Ozark creeks. The inflow of anoxic springs and subsurface seepage is consistent enough to maintain a mixture of aerated and unaerated water in which the concentration of oxygen remains below the extant saturation value. However, cool water has high saturation values, and the subsaturated concentrations are high enough to support coolwater fishes which have relatively-high oxygen requirements.

Diel cycles from which the data in Table 4 were taken are shown in Figure 9. The diel cycles are not sinusoidal, which would be expected if the normal production-consumption curves of approximately saturation ±10 percent occurred. Instead, the diel cycle consists of a diurnal normal-distribution curve and a relatively-flat nocturnal curve which approaches a line, each persisting for approximately 12 hours beginning and ending at approximately 9:00 a.m. and 9:00 p.m.. The diurnal curve appears to represent normal production while the nocturnal curve is flattened because it starts at a low value and reaches maximum consumption rapidly and remains there until production becomes dominant at 9:00 a.m., or respiration and turbulent reaeration are in equilibrium.

State water quality standards (OWRB 1985) require a minimum dissolved oxygen concentration of 6.0 mg/l but allow an excursion to not less than 5.0 mg/l for not more than eight hours during each 24-hour period in smallmouth bass streams from June 1 to October 15, except for naturally-occurring conditions. Because these oxygen concentrations occur naturally, the state criterion is not violated. However, it would be violated seriously if the low concentrations were anthropogenic.

Concentrations of less than 6.0 mg/l occurred during each diel cycle and persisted for more than eight hours during nine of the 12 cycles. Beginning at 10:00 p.m. on September 20, the excursion persisted for 10 hours twice, 12 hours one time, 13 hours one time, 14 hours twice, 15 hours twice, and 16 hours one time (Fig. 9). Mean persistence of these excursions was 13.2 hours during the nine cycles in which they exceeded eight hours and 10.75 hours for the 12 cycles. These data and double natural



SPRING CREEK, STATION 6
SEPTEMBER 1986
DISSOLVED OXYGEN

Figure 9. Dissolved oxygen recorded hourly at Station 6 near the middle of Spring Creek, September, 1986.

violations by excursions for more than eight hours and concentrations of less than 5.0 mg/l in Tahlequah Creek (Jester et al. 1988) indicate that state criteria for dissolved oxygen in smallmouth bass streams [= coolwater fish communities] are too stringent and should be reviewed with a view toward reasonable reduction (e.g., possibly 0.5 mg/l).

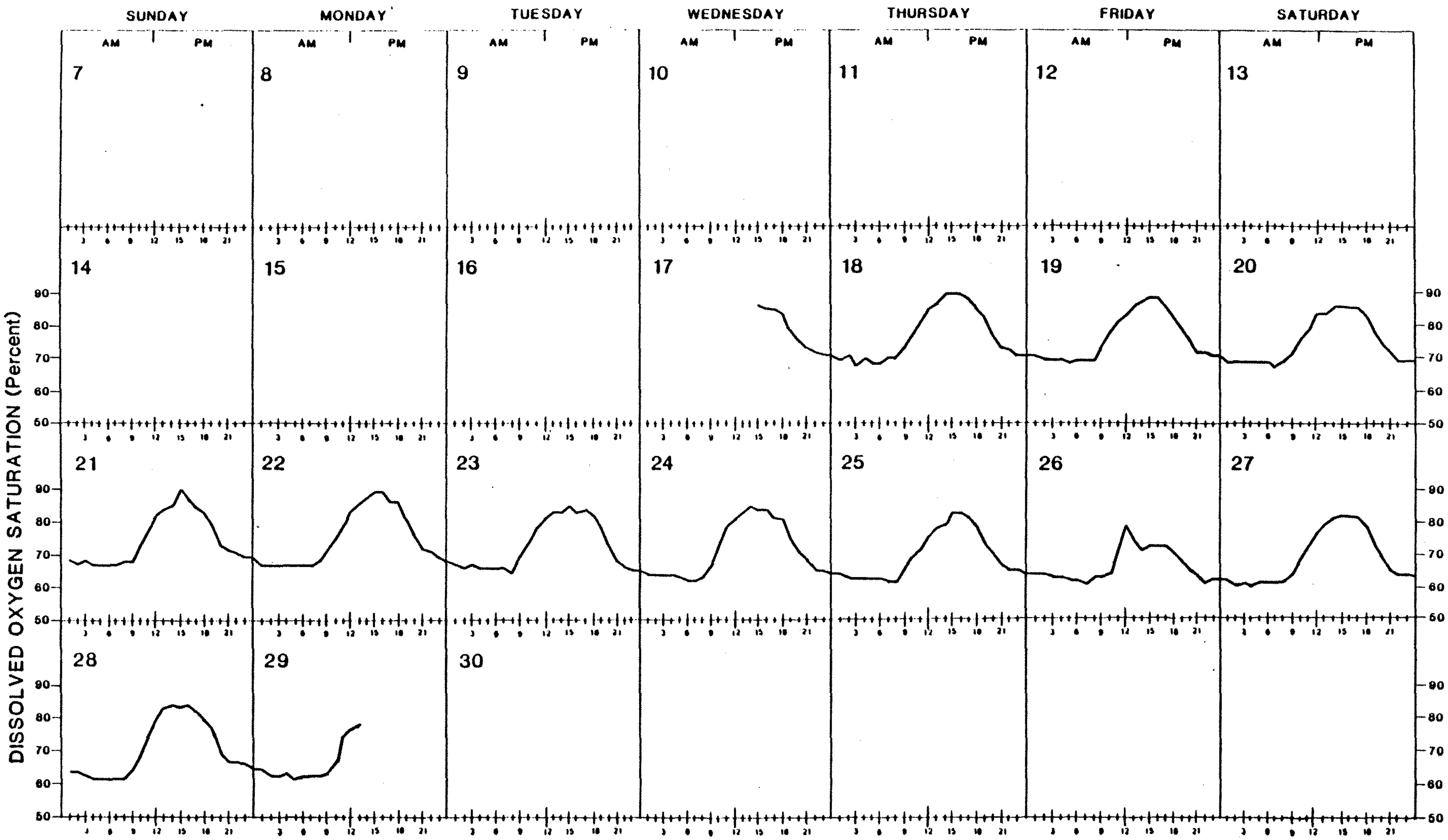
The diel cycles of percent saturation of dissolved oxygen (Fig. 10) show that 90 percent of saturation was the maximum and occurred only one time, from 2:00 to 4:00 p.m. on September 18. Otherwise, the maximum value exceeded 80 percent during 10 days and was slightly less than 80 percent on September 26 and 29. The minimum percent saturation was more than 60 percent but less than 70 percent during the entire period.

pH. The entire range of pH was only 6.99 to 7.20, with a very-mildly-alkaline mean of 7.04 (Table 4). The most alkaline values, 7.20 and 7.15, occurred during the first hour and last two hours that data were recorded (Fig. 11). Otherwise, mildly-alkaline values ranging from 7.01 to 7.11 occurred daily and the minimum value was 7.0 or neutral every day except for one hour when 6.99 was recorded at 9:00 a.m. on September 28. In fact, 164 or 57.1 percent of the 287 pH values plotted are 7.00 and 7.01, or essentially neutral. The values recorded at this station are within the ranges of pH that usually are expressed as "ideal" or "best" for most coolwater and many warmwater fishes in North America.

pH will be discussed as a factor in the Carbon Dioxide Cycle under **Discrete samples.**

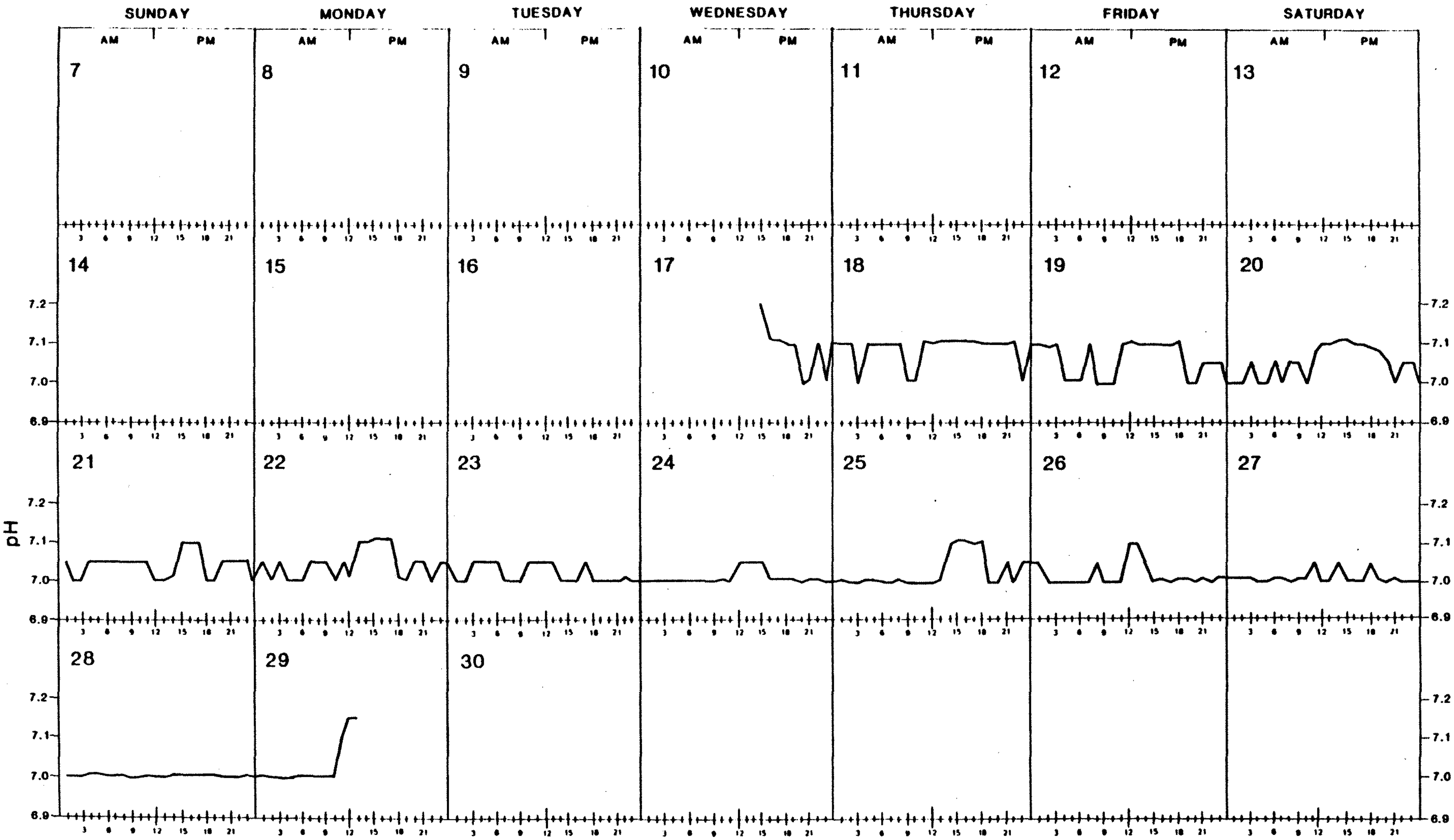
Specific conductance. Specific conductance was extremely stable, ranging from 190 to 200 µmhos/cm, usually less than 200, during 10 of 13 days that data were recorded (Table 4). Four one-hour excursions up to 227, 205, 217, and 210 µmhos/cm occurred during an 11-hour period on September 18 and 19 (Fig. 12). They apparently represent surges of runoff from rainfall in which surface materials from the watershed increase conductance briefly. The other excursion was a decrease to 180 µmhos/cm for two hours and 179 µmhos/cm for one hour when the last data were recorded on September 29. Although the rain which started a flood on September 30 was not recorded at either weather station on September 29 (Figs. 4, 5), the storm was visible over the middle section of Spring Creek from Tahlequah on that date and apparently provided enough rain to dilute conductive salts in the creek. None of the excursion values were large or persistent enough to cause ecological perturbations in the creek.

A diel cycle of specific conductance occurred at two stations in Tahlequah Creek, at which conductance is approximately 30 µmhos/cm less and 60 µmhos/cm more, respectively, than it is at Station 6 on Spring Creek. A diel cycle occurred at both stations in Tahlequah Creek that was described as primary producers removing enough salts by metabolic activity to reduce conductance slightly during the daylight hours (Jester et al. 1988). Most primary production occurs in sparse standing crops of aufwuchs in both creeks. Spring Creek is considerably deeper than Tahlequah Creek and has a greater volume to bottom-area ratio, apparently enough greater that utilization



SPRING CREEK, STATION 6
SEPTEMBER 1986
DISSOLVED OXYGEN SATURATION

Figure 10. Percent saturation of dissolved oxygen at Station 6 near the middle of Spring Creek, September, 1986. Computed for water temperatures and dissolved oxygen shown in Figures 8 and 9.



SPRING CREEK, STATION 6
SEPTEMBER 1986
pH

Figure 11. pH recorded hourly at Station 6 near the middle of Spring Creek, September, 1986.

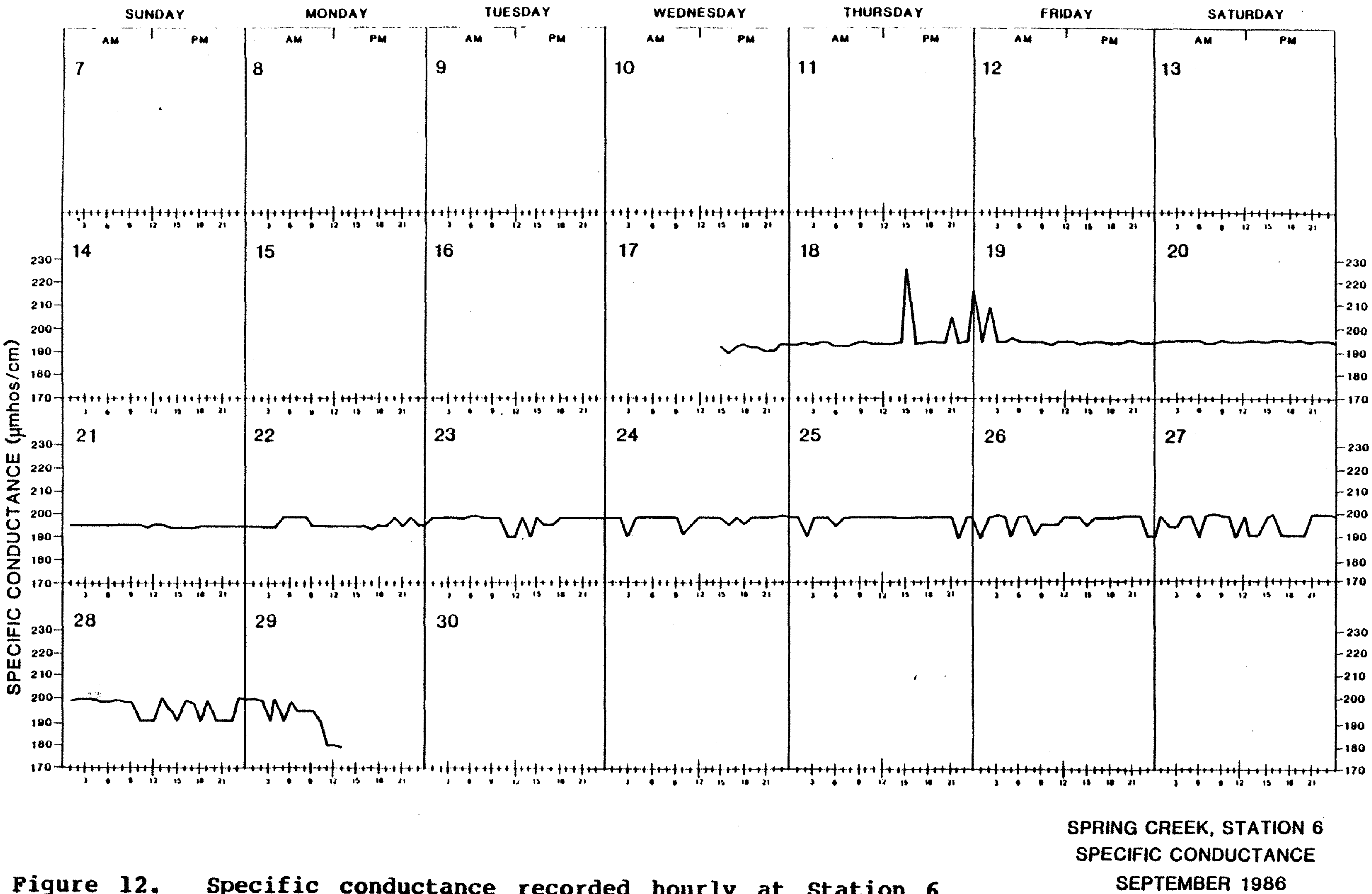


Figure 12. Specific conductance recorded hourly at Station 6 near the middle of Spring Creek, September, 1986.

by producers is not enough to remove detectable quantities of salts from the water. Therefore, a detectable cycle of specific conductance does not occur in the Third Order segment of Spring Creek (Fig. 12).

Discrete samples. Dissolved gases, oxygen demands, nutrient cycles, several anthropogenic toxicants, and indicator materials that are deemed important to ecology of the creek were analyzed from a series of discrete samples collected at two stations in each stream order on September 24, 1986. These samples were collected six days after the most recent rain (Figs. 4, 5), and no indications of effects of rainwater or runoff were detected. Also, stability of symptomatic parameters indicates rather uniform water quality and suggests that these data probably are representative of late summer and early autumn conditions.

Volumes of flow and temperatures measured when these samples were collected are shown in Table 3 and their interactions were discussed under **Symptomatic water quality.**

Oxygen. Biochemical and chemical oxygen demands were less than the detection limits of 5.0 mg/l at all stations (Table 5) and, therefore, were incapable of reducing the concentrations of dissolved oxygen to less than saturation. Yet, oxygen was subsaturated at all stations because of continuous influx of anoxic water from springs and seepage. During the time that samples were collected from upstream to downstream and from 7:00 to 9:30 a.m. on September 24, the concentration of oxygen increased from the diel minimum of 5.4 mg/l to 6.1 mg/l, or only 0.7 mg/l at Station 6 (Fig. 9). Therefore, all of the increase from 6.1 mg/l to 6.7 mg/l and 69.1 to 79.3 percent saturation from Station 2 to Station 4 during half of the sampling period (Table 5) is not likely to have occurred because of the onset of duirnal production. Rather, it appears that the differences in oxygen among these stations result from slightly greater dissolution at each station, with saturation not achievable because of [nearly-] continuous inflow of anoxic ground water.

A large decrease to 5.6 mg/l and 65.6 percent saturation at Station 5 coincides with a large increase in volume of flow from 30.0 cfs at Station 4 to 91.1 cfs at Station 5 which obviously represents a large influx of ground water. Then, at Station 6, approximately 30 percent of the water had returned to subsurface flow and oxygen had increased to 6.1 mg/l and 71.5 percent of saturation.

Although the volume of flow of 149.0 cfs at Station 8 is more than twice the volume at Station 6 (Table 5), it actually represents a large loss from 198.5 cfs at Station 7 (Table 3) and the water had absorbed oxygen up to 8.0 mg/l and 93.8 percent saturation at 9:30 a.m. (Table 5). Saturation probably occurred later in the morning and probably only in the segment of the creek at and downstream from this station. There were no visual indications that production could drive the concentration to supersaturation, and any supersaturation that may have occurred probably was only a small percentage that could have occurred in the most turbulent areas.

Carbon dioxide. The carbon dioxide cycle is one of the most important and potentially complex nutrient cycles in terms of

Table 5. Discrete physical and chemical data from Spring Creek, Oklahoma, September 24, 1986. Stations are located near the middle and downstream ends of stream order segments. Units are mg/l except as noted.

Parameter	First Order Stations 2	First Order Stations 3	Second Order Stations 4	Second Order Stations 5	Third Order Stations 6	Third Order Stations 8
Volume of flow (cfs)	2.2	5.6	30.0	91.1	64.8	149.0
Temperature (c)	20.2	21.4	22.1	21.8	22.0	22.8
Dissolved oxygen	6.1	6.5	6.7	5.6	6.1	8.0
Percent saturation	69.1	76.1	79.3	65.6	71.5	93.8
BOD_5	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Carbonaceous BOD	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Nitrogenous BOD	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
COD	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Carbon dioxide	0.4	0.6	0.4	0.4	1.1	1.4
Phenolphthalein alkalinity	0	0	0	0	0	0
Total alkalinity[1]	72	80	88	80	74	76
Bicarbonates	72	80	88	80	74	76
Carbonates	0	0	0	0	0	0
Hydroxides	0	0	0	0	0	0
pH (H^+-ions)	7.3	7.4	7.6	7.3	7.3	7.4
Ammonia	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Nitrites	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrates	0.78	0.71	0.36	0.36	0.24	0.36
Orthophosphate	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total phosphorous	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Detergents (ABS+LAS)	0.01	0.01	0.04	0.01	0.05	0.03
Chlorine						
Free	0	0	0	0	0	0
Total	0	0	0	0	0	0
Chlorides	9.9	14.9	13.9	9.9	9.9	7.9
Hydrogen sulfide	0.0	0.0	0.0	0.0	0.0	0.0
Sulfates	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Specific conductance (µmhos/cm)	206	236	230	210	193	181
Total suspended solids	<2	2	4	2	4	4
Total dissolved solids @ 103-105C	110	136	132	120	110	104
Turbidity (NTU)	1.3	1.0	2.1	1.4	1.2	1.1

[1]Bicarbonates, carbonates, and hydroxides are computed from Phenolphthalein and Total alkalinity. The Phenolphthalein Method measures one-half of the normal carbonates. If $(0.5)(CO_3) = 0$, then $CO_3 = 0$. OH^--ions form by hydrolysis of carbonates, and if no carbonates have precipitated to hydrolyze, $OH^- = 0$. Therefore, Total alkalinity = [consists entirely of] Bicarbonates.

ecological implications. It includes gaseous CO_2, carbonic acid, alkaline earth metal compounds, and pH, shown as a group of parameters in Table 5.

Carbon dioxide dissolves in water vapor and droplets so that raindrops in equilibrium with atmospheric carbon dioxide contain approximately 0.6 mg/l of dissolved CO_2 when they reach the surface. Carbon dioxide and water combine to form carbonic acid which dissociates weakly to produce a mild acid reaction:

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightleftharpoons H^+ + HCO_3^-.$$

pH of rainwater caused by dissociation of H_2CO_3 is approximately 5.6 (Cole 1983).

Rainwater flows on the surface and percolates through the soil where it absorbs more CO_2 which is produced by respiration of soil and decay bacteria, plant roots, and burrowing animals. A representative reaction for all of these organisms is $C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$. This CO_2 combines with water to increase the concentration of H_2CO_3 and H^+-ions.

This ground water or carbonic acid solution contacts alkaline earth metals which, in this drainage, consist mostly of Mississippian limestone, $CaCO_3$, in the soil and Boone chert mantle. The acid-carbonate reaction forms calcium bicarbonate:

$$CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2.$$

The concentration of $Ca(HCO_3)_2$ in ground water entering the creek depends upon: (1) CO_2 content of the water, (2) $CaCO_3$ content of the earth, and (3) exposure time allowed by underground flow. Some of the H_2CO_3, part of which may be detectable as free CO_2, may remain in solution because it is excessive over low content of $CaCO_3$ or because of rapid percolation. Also, some of it remains in solution because it is a buffer for its alkaline salt:

$$Ca(HCO_3)_2 \,||\, CO_2.$$

The buffer requirement is approximately 0.6 mg/l of CO_2/100 mg/l of $Ca(HCO_3)_2$. Greater concentrations of CO_2 represent supersaturation but lower concentrations, including 0.0 mg/l, may not represent subsaturation. If pH is in a range of 4.3 to 8.3 and alkalinity consists entirely of bicarbonates, the $Ca(HCO_3)_2$ is buffered partly or totally by H_2CO_3 which contains available CO_2.

Bicarbonates in solution dissociate; e.g.,

$$Ca(HCO_3)_2 \rightleftharpoons Ca^{++} + 2HCO_3^-,$$

then hydrolysis of the weak carbonic acid occurs:

$$HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^- \rightleftharpoons H^+ + HCO_3^- + OH^-.$$

OH^--ions are partially offset by H^+-ions from dissociation of buffer carbonic acid, resulting in a small excess of OH^--ions over H^+-ions and a buffered $Ca(HCO_3)_2$ solution that is mildly alkaline, pH $\leq$8.3.

Presence of carbonates and hydroxides represent a disruption of the normal cycle described above. Massive photosynthesis, caused by excessive nutrients, may deplete buffer CO_2 and its product H_2CO_3 by a reaction such as $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$, triggering an equilibrium reaction which precipitates carbonates,

$$Ca(HCO_3)_2 \rightleftharpoons CaCO_3 + H_2O + CO_2,$$

which, in turn, allows hydrolysis,

$$CaCO_3 + H_2O \rightleftharpoons Ca^{++} + HCO_3^- + OH^- ,$$

and produces carbonates, hydroxides, and alkaline pH values as high as 11.0 if the reaction continues until the $Ca(HCO_3)_2$ is exhausted.

pH values in Table 4 and Figure 11 and all of the analysis of the cycle at six stations shown in Table 5 reveal the normal cycle described above. Buffer CO_2 at Stations 2-5 (Table 5) is very close to the equilibrium ratio of 0.6 mg/l:100 mg/l $Ca(HCO_3)_2$ and exceeds equilibrium concentrations at Stations 6 and 8. Therefore, bicarbonates are more than adequately buffered to prevent precipitation of carbonates and hydrolysis of hydroxides, allowing pH to remain in an ideal mildly-alkaline range (Swingle 1950, Welch 1952, Lagler 1956, Cole 1983). Timing of this investigation and observation of the creek during all seasons of the year indicate that production-consumption equilibrium is too stable to allow surplus production to deplete buffer CO_2 and disrupt the cycle. Therefore, the carbon dioxide cycle probably does not vary significantly from parameters shown in Table 5.

Nitrogen. Atmospheric nitrogen may be fixed by several bacteria and blue-green algaes, none of which are known or appear to occur in Spring Creek. Therefore, sources of nitrogen in the creek are decay of allochthonous organic detritus and an autochthonous nitrogen cycle.

Inorganic nitrates are among the macronutrients used in the largest quantities by plants to synthesize amino acids and proteins:

$$NO_3 + C_x + H_x \rightarrow C_xH_xO_xN_x,$$

part of which are incorporated into tissues of animals which eat the plants and, in turn, into tissues of predaceous animals. Decay of amino acids and proteins in dead plants, dead animals, and animal wastes releases un-ionized ammonia, of which a large portion ionizes in the presence of various combinations of temperature and pH. Using Potassium nitrate as a demonstration to avoid protein formulas,

$$K_2NO_3 + 2H_2O \rightarrow NH_3 + 2KO_2 + OH^-.$$

When un-ionized ammonia, NH_3, dissolves in water, some of it reacts with water to form ammonium ions, and an equilibrium is established among un-ionized ammonia (NH_3), ionized ammonia (NH_4^+), and hydroxyl ions (OH^-):

$$NH_3 + H_2O \rightarrow NH_3 \cdot H_2O \rightleftharpoons NH_4^+ + OH^-.$$

Ammonia is measured as total ammonia, $NH_4^+ + NH_3$, which is shown in Table 5. The un-ionized fraction, NH_3, is acutely toxic to several forms of aquatic life at concentrations ≥ 0.2 mg/l and chronically toxic at concentrations as low as 0.02 mg/l, according to EPA (1975) water quality criteria.

Most of the ammonia is NH_4^+ in the natural ranges of temperature and pH, and NH_3 varies in equilibrium with NH_4^+. Therefore, only NH_4^+ is required to describe the nitrogen cycle. Accordingly, the next step in the cycle is oxidation of NH_4^+ by Nitrosomonas bacteria, which produces the nitrite radical:

$$NH_4^+ + 2O_2 \rightarrow NO_2 + 2H_2O.$$

Nitrites also are toxic to fishes but rarely, if at all, in concentrations <5.0 mg/l and then as a stress factor which allows lethal success of pathogenic bacteria (Hanson and Grizzle 1985).

Nitrites are oxidized by Nitrobacter to produce inorganic nitrates:

$$2NO_2 + O_2 \rightarrow 2NO_3,$$

which completes the cycle and makes the nitrogen available for reuse by primary producers.

In an unpolluted system in which the nitrogen cycle is in equilibrium, ammonia and nitrites rarely reach detection limits and most of the nitrogen that is not contained in living tissue is detectable as NO_3-N or nitrates. Analysis of the nitrogen cycle in Table 5 reflects the foregoing conditions throughout the creek.

Sulfur. Sulfur is a macronutrient which enters water primarily in the sulfate radical, SO_4, as part of a dissolved salt such as $CaSO_4$. These salts are the source of sulfur for the natural sulfur cycle. Sulfates, like bicarbonates, are mildly alkaline. Photosynthesis splits sulfur out of sulfates and incorporates it into several amino acids and proteins.

When organisms and their wastes decay in water, sulfur is released as gaseous hydrogen sulfide, H_2S, which dissolves as it forms. In the presence of oxygen,

$$H_2S + 2O_2 \rightarrow H_2SO_4,$$

which reacts instantaneously (no effect on pH) with (1) bicarbonates, (2) carbonates, and (3) phosphates (see Phosphorous below);

(1) Bicarbonates:

$$H_2SO_4 + Ca(HCO_3)_2 \rightarrow CaSO_4 + 2H_2O + 2CO_2.$$

(2) Carbonates:

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2.$$

Reaction (1) may occur with bicarbonates in solution in the creek (Table 5). Reaction (2) also may occur to a very limited extent by acid forming in contact with limestone gravel and exposed bedrock. Obviously, Reaction 1 is the most common. Both reactions convert a potentially-toxic gas to a potentially-toxic acid, then to SO_4-salts and CO_2 which are useable inorganic nutrients.

Concentrations of sulfates were below the detection limit or <5.0 mg/l at all stations on Spring Creek (Table 5) despite concentrations ranging from 10.5 to 22.8 mg/l in Tahlequah Creek nearby. Although H_2S is a stage in the sulfur cycle, the low concentrations of sulfates indicate that H_2S produced in the cycle would be too sparse and react too rapidly to be detected. Therefore, any H_2S in solution would indicate specific sources of pollution. As expected, no H_2S was found in the creek.

Phosphorous. Phosphorous is a major macronutrient required in quantities second only to nitrogen. It is recycled in several ways, one of which is by reacting with the H_2SO_4 ($H_2S + 2O_2 \rightarrow H_2SO_4$) in the sulfur cycle (see Sulfur above).

Tricalcium phosphate is an organic product of decay and is too complex for a plant nutrient. It reacts with H_2SO_4 to produce inorganic monocalcium phosphate which plants can use, and also makes more of the sulfur from H_2S available for reuse. The representative reaction is

$$Ca_3(PO_4)_2 + 2H_2SO_4 \rightarrow Ca(H_2PO_4)_2 + 2CaSO_4.$$

Therefore, phosphate and hydrogen sulfide released by decay react with dissolved oxygen to produce inorganic phosphate. Monocalcium phosphate is the nutrient in superphosphate commercial fertilizer and is one of the major nutrients used in algae production.

These phosphates may be called polyphosphates, which are not useable by plants, and orthophosphates, which are useable by plants. However, the issue of useability of tricalcium- or polyphosphates is trivial because their occurrence in solution is temporary until they are converted by some bacteria or react with some acid to yield monocalcium- or orthophosphate.

In an unpolluted system in which the phosphorous cycle is in equilibrium, orthophosphate is utilized rapidly by algae and rarely exceeds the detection limit of 0.01 mg/l. Total phosphorous, which is a practical estimate of phosphorous present in ortho- and polyphosphates also is rarely detectable. Neither parameter was detected at any of the six stations on the creek (Table 5).

A major concern of water quality and stream managers with regard to phosphorous is the N:P ratio because of its effect on quality of primary production. N:P <5.0 is favorable for Cyanophyta which are unfavorable to intolerant benthos and forage and game fishes. N:P >7.0 is favorable for Chlorophyta and Chrysophyta and, in turn, the intolerant animals. N:P ratios in

Spring Creek are not known because phosphorous was below the detection limit. However, it was at least 7:1 at Stations 2 and 3 where nitrates were 0.78 and 0.71 mg/l and phosphorous was <0.01 mg/l. Dominance of Chlorophyta and Chrysophyta at the other stations indicate that the N:P ratio probably was also at least 7:1 at those stations.

Detergents. Poly- and metaphosphates are constituents of many surfactants including anionic alkyl butyl sulfonate (ABS) and linear alkylbenzene sulfonate (LAS) detergents. They are common in domestic and many industrial wastes, and frequently become a major source of phosphorous pollution in surface waters.

Detergents were analyzed to indicate the extent of household and industrial waste (if any) and its contribution to the phosphorous load in the creek. Low concentrations ranging from 0.01 to 0.05 mg/l were found at all stations (Table 5) indicating that small amounts, probably of non-biodegradable ABS, reach the creek from Kansas, Oaks, and a few rural septic tanks along the creek. The concentrations found are trivial both as pollution indicators and sources of phosphorous.

Chlorides. Chlorides vary from almost none to thousands of mg/l from natural sources in various places but usually are sparse in waters where rainfall is abundant and causes considerable leaching of soluble salts. Therefore, low concentrations would be expected in Spring Creek, and a large increase at any station would indicate an anthropogenic point source.

Chlorides conformed with expectations, varying from 7.9 to 14.9 mg/l at the six stations (Table 5). No concentrations were high enough or increased enough to indicate an anthropogenic source or to affect occurrence or distribution of any organism in the creek.

Chlorine. Chlorine does not occur naturally and, thus, its presence in a natural water always indicates anthropogenic sources. No free or total chlorine was found in the creek (Table 5).

Specific conductance, solids, and turbidity. It was noted under Continuous monitoring that specific conductance was extremely conservative or stable at Station 6, ranging from 190 to 200 μmhos/cm, and that no diel cycle occurred. The instantaneous range throughout the creek was slightly greater, from 181 μmhos/cm at Station 8 to 236 μmhos/cm at Station 3. The highest rates of conductivity, indicating the greatest concentrations of salts, tended to occur upstream and the lowest rates downstream correlated inversely with the volume of flow (Table 5).

Most of the solids which support conductance were dissolved salts (Table 5). In a series of somewhat oversimplified estimates, bicarbonates and chlorides made up approximately 39 to 46 percent of the dissolved solids.

Turbidity, in keeping with low concentrations of suspended solids, was very low, ranging from 1.0 to 2.1 NTU (Table 5). Therefore, the water in Spring Creek is both clean and clear, conforming with the widely-held perception of pristine Ozark creeks.

Biological Characteristics

Sparse standing crops of aufwuchs, moderately-abundant benthos, and relatively-high values of abundance and diversity of fishes indicate that most of Spring Creek is quite productive. Producers and consumers are in equilibrium so that surplus primary production or conspicuous standing crop of aufwuchs does not occur as it would in a stream where pollutants limit diversity and biomass of consumers while either feeding or at least not limiting producers.

High rates of biomass production are expected in clean Ozark creeks whose basins contain significant deposits of limestone. Available nitrogen and phosphorous are utilized and stored as organic material in living organisms to the extent that inorganic concentrations of these nutrients in solution are very low in equilibrium systems. Phosphorous, especially, may be relatively abundant in the system but may be consumed at luxury rates (⟹ stored) by some primary producers so that it is undetectable in solution. Bicarbonates, nitrates, and phosphates conform with these conditions at all stations on Spring Creek (Table 5).

This rationale was used to describe Tahlequah Creek upstream from a sewage-plant outfall (Jester et al. 1988) in an effort to show that a creek which contains clear, clean water, little or no visible aufwuchs, and at least moderately-abundant benthos and fishes represents a productive producer-consumer equilibrium. These conditions were contrasted with aufwuchs, benthos, and fishes downstream from the outfall where water quality was poor, aufwuchs consisted of a relatively-abundant standing crop, and benthos and fishes were sparse. Measured production of chlorophyll was 20-times as great where no aufwuchs were visible as it was where aufwuchs were relatively abundant and benthos and fishes were sparse. We feel that these conditions in Tahlequah Creek, with the clean-water conditions repeated in Spring Creek, tend to corroborate our hypothesis or support our theory, as the case may be, that lack of visible standing crops of aufwuchs represent producer-consumer equilibrium in a productive system while abundant standing crops of aufwuchs represent sparse, inhibited communities of benthos and fishes.

Emphasis of these investigations is on composition and ecology of fish communities in an Ozark creek. The foregoing describes physical and chemical characteristics of the various segments of the creek in which fish communities occur. It also is necessary to have some knowledge of other biological characteristics which affect the communities. Accordingly, limited descriptions of aufwuchs, vascular plants, benthos, and occurrence of tolerant and intolerant fishes in each stream order are reported here to complete the context in which the communities occur.

Aufwuchs. Visible accumulations of aufwuchs or periphyta occur only in small quantities on the surfaces of flat rocks in very-shallow water and on inundated woody debris for a few weeks in late summer. Otherwise, benthos and grazing minnows, both herbivores and omnivores, appear to be in equilibrium with primary production, and the bottom and the water remain clean and clear.

Confirmation of the theoretical concept that sparse aufwuchs, low concentrations of nutrients, and abundant fishes represent equilibrium in a productive system depends upon evidence that significant production of aufwuchs occurs while a standing crop does not. Estimates of production and distribution of aufwuchs were beyond the scope of this study except to record the general observations described above. However, growth of aufwuchs on replicated periphytometers was used as part of a comparative toxicity test in Tahlequah Creek (J. J. Black, OWRB, personal communication) and at two stations in Spring Creek to determine if production was greater than indicated by observed standing crops.

Two periphytometers were maintained at Station 2 and two at Station 5 for 14 days in September, 1986. Two weeks of growth contained the quantities of chlorophyll shown in Table 6. Assuming that the climax community had not occurred or at least had not been present for a prolonged period, production of Chlorophyll a was in the range of 36.4 to 40.0 mg/m^2 and production of total chlorophyll was approximately 51.6 mg/m^2 at Station 2. These values are equivalent to production of 2.60 to 2.86 $mg/m^2/day$ of Chlorophyll a and 3.69 $mg/m^2/day$ of total chlorophyll.

Station 5 was less productive, with Chlorophyll a in the range of 29.6 to 32.5 mg/m^2. Production of total chlorophyll was approximately 46.8 mg/m^2. These values are equivalent to production of 2.11 to 2.32 $mg/m^2/day$ of Chlorophyll a and 3.34 $mg/m^2/day$ of total chlorophyll.

Compared with other creeks, production of total chlorophyll is approximately an order of magnitude greater than production of chlorophyll under similar conditions except for indications of chronic toxicity in Taloka Creek about 65 miles (104 km) south of Spring Creek (Simpson and Jester 1987). It also is an order of magnitude greater than production under similar conditions in a toxic segment of Tahlequah Creek (Jester et al. 1988). Conversely, chlorophyll production at the two stations in Spring Creek was approximately 65 to 80 percent of production in an unpolluted segment of Tahlequah Creek.

Production at different stations in chronically-toxic and non-toxic segments of the three creeks appears to be correlated with availability of nitrates. Consequently, we assumed that nitrates account for the different rates of production at Stations 2 and 5. Nitrate concentrations were 0.78 and 0.71 mg/l at Stations 2 and 3 and 0.24 and 0.36 mg/l at Stations 4, 5, 6, and 8 (Table 5). Therefore, we weighted mean chlorophyll production at 2-times the Station 5 values to one Station 2 value. Results shown in Table 6 indicate that production of Chlorophyll a ranged from 31.9 to 35.0 mg/m^2 and production of total chlorophyll was approximately 45.2 mg/m^2 in the creek. These values are equivalent to production of 2.28 to 2.50 $mg/m^2/day$ of Chlorophyll a and 3.23 $mg/m^2/day$ of total chlorophyll. These values tend to confirm the hypothesis that significant production of aufwuch occurs while a standing crop

Table 6. Mean chlorophyll content of aufwuchs on replicated periphytometers colonized for 14 days, September 10-24, 1986, at Stations 2 and 5 on Spring Creek, Oklahoma.

Analytical Method Type of Chlorophyll	Chlorophyll in µg/cm²		
	Station 2	Station 5	Weighted $\bar{x}$
Trichromatic Method			
Chl-a	4.001	3.254	3.503
Chl-b	0.339	0.270	0.293
Chl-c	0.824	0.673	0.723
Mean total chlorophyll	5.164	4.197	4.519
Monochromatic Method			
Chl-a	3.644	2.961	3.189
Phe-a	0.568	0.673	0.638

does not, indicating that conditions in Spring [and Tahlequah] Creek represent equilibrium among producers and consumers.

Algaes which grew on periphytometers were not identified or divided into various taxa. However, McNeely (1987) sorted algae from digestive tracts of five species of cyprinids; three herbivores, an omnivore, and a carnivore, into filamentous and non-filamentous forms. He defined non-filamentous algae as mostly diatoms (Chrysophyta) and a few green algaes (Chlorophyta). Filamentous algaes are mostly green algaes (Chlorophyta) and a few diatoms (Chrysophyta). He stated that the algaes in the fishes, approximately 69 percent non-filamentous and 31 percent filamentous, reflected their presence in the creek. Therefore, approximately 69-70 percent of the algaes are solitary and colonial Chrysophyta and 30-31 percent are filamentous Chlorophyta. Presumably, production could be allocated to these percentages.

Vascular plants. McNeely (1987) also listed vascular plant parts (leaves, stems, and flowers) as food items in cyprinids and mentioned vegetation as a constituent of habitat (McNeely 1986) but did not identify or quantify species of plants or their localities. He reported little or no vegetation in the middle section and scattered beds of vegetation in the upstream and downstream sections of the creek. Gore and Lindsay (1985) described habitat of a darter as macrophyte beds, mostly *Myriophyllum*, at their stations in the vicinity of our Stations 7 and 8 (Fig. 1). We found the greatest abundance and variety of vegetation in the middle section where McNeely found the least, and no *Myriophyllum* (or the darter) where Gore and Lindsay collected 57 of the darters which inhabited it. We attribute these differences to a severe drought during McNeely's study in

1980 followed by six years of average and above-average rainfall when we carried out our investigation in 1986. At the same time, Gore and Lindsay's description of their study area in 1982-83 is similar to our description except for the vegetation. Because the loose-gravel bottom is very unstable, we believe that pools, riffles, etc., were relocated and submerged vegetation was obliterated in a major flood in 1985. Observations made while we were searching for Mini-Monitors after the flood which began on September 30, 1986, confirmed mass movement of gravel. We would have written a description of the creek similar to our field notes of a month earlier but locations of pools, riffles, runs, vegetation beds, and debris were drastically different. Another factor that would affect incidence and distribution of rooted vegetation over time is McNeely's description of the creek as 80 percent pools and 20 percent riffles in 1980, while we found only 25 to 60 percent pools with a mean of 39 percent at eight stations in 1986.

Although none of the investigators found large, extensive stands of vascular plants, Gore and Lindsay (1985) found that plants were important as a habitat requirement for two species of darters, one of which was sparse and the other absent in our collections after incidence and abundance of vegetation were reduced. Therefore, stands of aquatic vegetation are transient and ephemeral, apparently because of an exaggerated function of a "cutting stream", but, nevertheless, are an important factor in composition and equilibrium of the fish community at any given time.

Three species of vascular aquatic plants were found during the investigation in 1986. All are members of Phylum Spermatophyta, Class Angiospermae, and Order Dicotyledonae. American Water Willow and Water Cress occur in all of the three stream orders, and Coon-tail or Hornwort was observed only in a short continuous segment in Second and Third Orders.

Water Cress, <u>Rorippa</u> <u>nasturtium-aquaticum</u> (Syn. <u>Nasturtium officinale</u>), Family Brassicaceae (Mustard), occurs in small scattered patches at all stations where investigations were done. Its habitat is primarily shallow stream-margins where current is visible but slow and the bottom is fine gravel mixed with sand or soil. It is locally abundant in a few shallow streamside pools which are served by undergravel flow and in small backwaters which, themselves, are sparse. Its greatest density was observed along gravelly and silty margins of small spring-run tributary brooks located mostly in the Second Order segment of the creek.

Three invertebrate forms; Planaria, Hydracarina, and a small snail in Genus <u>Amnicola</u>, appeared to be associated with Water Cress only, and did not occur among food items of seven species of cyprinids enumerated by McNeely (1987) or four <u>Etheostoma</u> darters enumerated by Gore and Lindsay (1985). No fishes were collected from Water Cress either by electrofishing or by hand-sorting.

Ecological significance of Water Cress is great for a community of algae and the invertebrates listed above, but is minor with regard to fishes or to the creek overall.

American Water Willow, <u>Justicia</u> <u>americana</u> (Syn. <u>Dianthera</u>

americana), Family Acanthaceae (Water Willow), is the most abundant vascular aquatic plant on Spring Creek. Light to moderate stands occur at all stations and many other sites observed during the investigation. Typical habitat is gravel bars with undergravel flow and adjacent shallow water where the current is slow. The largest beds observed are along the backwater or eddy side of large, especially-wide riffles. A few of these extend as much as 10 to 25 feet (3.1 to 6.1 m) but less than halfway across the creek. Maximum depth where plants occur is 12 to 15 inches (0.3 to 0.4-m). Other common locations are outside of the thalweg on gradients where current is slow at inlets and outlets of pools.

McClendon and Rabeni (1987) attributed considerable importance to Water Willow as a positive factor in habitat of smallmouth bass and rock bass in a small Ozark river in Missouri. However, we are unable to support their contention with our samples. We collected smallmouth bass among Water Willow on pool-to-riffle gradients but never without observing as many or more than we caught moving from deeper portions of the pool as we moved the electrical field downstream. Our deliberate observations to determine their evasive behavior revealed that they moved downstream to the gradient approaching the riffle, darted rapidly at random but would not enter the riffle, moved into any brush or vegetation as the sampling crew approached, and then were collected either in the cover or attempting to escape back into the deeper water of the pool. Thus, we found smallmouth bass using Water Willow as escape cover but not as feeding or resting habitat. Neither did we find smallmouth bass, and only one immature largemouth bass, among Water Willow in Tahlequah Creek (Jester et al. 1988). We collected rock bass in and near Water Willow but also in pools where no vegetation occurred. Both fishes appear to prefer depth $\geqq$2.5 feet (0.8-m) over presence of vegetation in selecting their habitat.

Coon-tail or Hornwort, Ceratophyllum demersum, Family Ceratophyllaceae (Hornwort), was found only in the downstream portion of the Second Order and upstream portion of the Third Order segments of the creek. It is limited to a few spring-run brooks and short segments of the creek downstream from the mouths of the brooks. One site was included in Station 6 where Luck Spring forms a brook about 0.25-mile (0.4-km) long (Fig. 1). Bottom of the spring-run or brook is deep, soft silt and supports a dense and almost-continuous stand of Coon-tail through much of its length. Downstream from the mouth of the brook, scattered patches of Coon-tail occur on gravel-silt bottom and large quantities and long filaments are attached to a downed-tree and other woody debris in a long, deep pool. Only a few filaments occur on woody debris in one pool after the creek crosses a riffle.

Intensive sampling of vegetation beds in the brook and the creek yielded only crawfishes and sculpins. Therefore, Ceratophyllum apparently does not replace Myriophyllum as darter habitat, presumably because of silt vs. gravel substrate.

The sites where Ceratophyllum demersum was found are in Cherokee County, which represents a new distribution record according to Nelson and Couch (1985). However, it was known previously in Delaware and Mayes Counties, and a new record within five miles (8 km) of both counties, especially in a creek that occurs in both counties, is a very minor and unsurprising extension of the range of the species in the state.

Nekton and benthos. Forty-one taxa of nektonic and benthic invertebrates from Spring Creek have been observed and identified by Gore and Lindsay (1985), Gore (1983), McNeely (1987), and in this investigation. Two of the investigations were directed primarily toward food habits of fishes, apparently including reference collections with which organisms and parts from fish digestive tracts were compared. One was a habitat-preference study and the other was general observation of presence and distribution of organisms. None of the investigations were designed specifically to quantify the invertebrata but, nevertheless, may be combined to yield relative abundance of the organisms and food grade classification of the creek. While differences occur among stations and habitats, all encompassing reaches of the creek are similar enough to be included in a general description of the creek.

Relative abundance is reported as:

Abundant - numerous in several collections, occurs at 3/4 or more of collection sites, occurs in digestive tracts of 3/4 or more of the species of carnivorous and omnivorous darters and minnows, and constitutes more than 40 percent of the food in at least one species and 20 to 40 percent of the food in at least one additional species of these fishes.

Moderate - numerous to sparse in several collections, occurs at 1/4 to 3/4 of collection sites, occurs in digestive tracts of 1/2 to 3/4 of the species of darters and minnows, and constitutes 20 to 40 percent of the food in at least one species and 10 to 20 percent of the food in at least one additional species.

Sparse - usually sparse in collections, occurs at less than 1/4 of collection sites, occurs in digestive tracts of less than 1/2 of the species of darters and minnows, and constitutes 10 to 20 percent of the food in at least one species and 1.0 to 10 percent of the food in at least one additional species.

Rare - a few specimens in collections, and a few specimens, mostly less than 1.0 percent of food, in digestive tracts of darters and minnows. Less than sparse.

Five taxa which were observed during our investigations did not occur in digestive tracts of seven species of minnows (three herbivores) and four species of darters examined by McNeely (1987) and Gore and Lindsay (1985). Three of these; Planaria, Hydracarina, and the snail Amnicola (Table 7), are found only in clumps of Water Cress in water less than two inches (5.1 cm) deep. Thus, they are rarely, or perhaps never, available for fish predation. The other two, lumbricid earthworms and mosquito larvae are rare, probably because of predation by fishes.

Among the 36 taxa that were found in fish digestive tracts, six forms are abundant. Four are Entomostraca (small or lower Crustacea), the largest being the amphipod genus Gammarus. One is the chironomid subfamily Orthocladinae, also small, and one is a prosobranch snail, Elimia potosiensis (Table 7). E. potosiensis was reported as a synonym, Goniobasis sp., by McNeely (1987). Gore (1983) indicated that the largest specimens are approximately 14 mm (0.55-in.) long (slender spiral shell).

Eight taxa conform with the criteria for the Moderate category in terms of relative abundance (Table 7). Seven are insects, including three Mayflies, a dragonfly, a Caddisfly, the water penny or riffle beetle, and Subfamily Tanypodinae of the Chironomidae. The midge is small while the other insects are intermediate sizes. The eighth taxon which is moderate in relative abundance is the lone representative of Malacostraca in the creek, a crawfish in Genus Orconectes, probably O. palmeri longimanus (Reimer, R. D., personal communication). This is an intermediate size crawfish, maximum length approximately three inches (7.6 cm), but is the largest invertebrate in Spring Creek. Because of its size, it provides the greatest invertebrate biomass despite moderate abundance.

Nine taxa which are eaten by minnows and darters are classified as Sparse and 12 are Rare (Table 7).

All of the nekton and benthos found in Spring Creek except Planaria and Hydracarina are regarded as widely-used and high quality fish food by consensus of all fish food and feeding literature. Therefore, variety and quality of fish food are excellent. Food Grade or Richness of a stream is based upon volume (or weight) and number of invertebrates (mostly benthos) per unit area of bottom. A scale established by Lagler (1956) is converted here from organisms/ft.^{2} to organisms/m^2. Volume and weight data are interchangeable because Specific Gravity of organisms $\simeq 1.0$. Therefore, 1.0 ml of organisms (determined by volume displacement) $\simeq 1$ g.

Food Grade 1. Exceptional Richness.
Volume or weight: >21.5 ml or g/m^2
Number: >538/m^2.

Food Grade 2. Average Richness.
Volume or weight: 10.8 to 21.5 ml or g/m^2
Number: >538/m^2.

Food Grade 3. Poor in Food.
Volume or weight: <10.8 ml or g/m^2
Number: <538/m^2.

Both volume and number are required. The smallest determines the Food Grade.

The snail, Elimia potosiensis, occurs in a wide variety of

Table 7. Relative abundance of nekton and benthos in Spring Creek, Oklahoma, observed in field samples in this investigation and in fish food habits studies by McNeely (1987) and Gore and Lindsay (1985). Abundance terms defined in text.

Taxon	Common Name	Relative Abundance
TURBELLARIA	Flatworms	
Planariidae	Planaria	Sparse
ANNELIDA		
Lumbricidae	Aquatic Earthworms	Rare
Tubificidae	Tubifex worms	Sparse
CRUSTACEA		
Cladocera	Water fleas	
Chydorus		Abundant
Copepoda	Copepods	
Cyclops		Sparse
Ostracoda	Seed shrimp	Abundant
Isopoda	Sowbugs	
Lirceus fontinalis		Abundant
Amphipoda	Scuds or "shrimp"	
Gammarus		Abundant
Hyallela		Sparse
Decapoda	Crawfish	
Orconectes		Moderate
HYDRACARINA	Water mites	Sparse
INSECTA		
Plecoptera	Stone flies	Rare
Nemoura		
Ephemeroptera	Mayflies	
Baetis		Moderate
Ephemerella		Sparse
Isonychia sicca		Rare
Leptophlebia		Moderate
Pseudocloeon		Sparse
Stenonema scitulum		Moderate
Odonata	Damsel flies and Dragon flies	
Calopteryx		Rare
Ischnura		Rare
Lanthus		Moderate
Hemiptera	True bugs	
Gerridae		Rare
Corixidae		Rare
Trichoptera	Caddisflies	
Brachycentrus		Rare
Chimarra		Rare
Helicopsyche borealis		Sparse
Hydroptila		Rare
Marilia		Moderate
Oxythira		Rare
Triaenodes		Rare
Coleoptera	Beetles	
Oreodytes		Sparse
Psephenus		Moderate
Diptera	Flies	
Chironomidae	Midges	
Tanypodinae		Moderate
Orthocladinae		Abundant
Culcidae	Mosquitos	Rare
GASTROPODA	Snails	
Pulmonata	Lung-snails	
Ferrisia		Rare
Heliosoma		Sparse
Physella		Sparse
Prosobranchia	Gill-snails	
Amnicola		Moderate
Elimia potosiensis		Abundant
PELECYPODA	Mussels	
Pisidium	Fingernail clam	Sparse

flows, depths, and substrates; and densities in Spring Creek were approximately 800/m² (74.4/ft²) according to Gore (1983). Large densities were observed at all stations, and these numbers with expected average weight alone would place the entire creek in Food Grade 1. Moderate abundance and typical sizes of crawfishes also were observed at all stations, and add relatively large numbers and weight, especially the latter, to the food supply. These and 36 other taxa of organisms which are used as fish food constitute Food Grade 1, or Exceptional Richness, throughout the creek.

Fishes. Fishes were collected at eight stations; three in the First Order segment, two in the Second Order segment, and three in the Third Order segment of Spring Creek (Fig. 1). Eight families are represented in the creek, with seven families in each stream order (Table 8). The blackspotted topminnow, representing Cyprinodontidae, is present while the mosquitofish, representing Poeciliidae, is absent in First and Second Order segments and vice versa in the Third Order segment. The other six families are represented in all stream orders.

The composite sample from all stations consists of 2,089 fishes in 29 species, all of which apparently are indigenous to the creek. Twenty species, or 69 percent, are listed by EPA (1983) or recognized locally as intolerant of water quality or habitat degradation, primarily the former. Although size of the creek varied from a mean volume of flow of 2.8 cfs (0.08-m³/sec.) in the First Order segment to 60.6 cfs (1.72 m³/sec.) in the Second Order segment and 137.4 cfs (3.89 m³/sec.) in the Third Order segment during the investigation, diversity of habitat is similar in all stream orders (Table 3) and the numbers of species varies only from 20 to 22 among the orders (Table 8).

The First Order segment yielded 22 species in a sample of 632 fishes from three stations. Four species; black bullhead, bluegill, spotted bass, and slenderhead darter, were collected only in this segment. Seven species which were collected from the other stream orders were absent from this sample (Table 8). The greatest difference from the other segments is presence of only one of five species of suckers, compared with three and four species in the Second and Third Order segments. The northern hog sucker inhabits shallower pools than the other suckers here and in Tahlequah Creek (Jester et al. 1988), and the others apparently are absent because of lack of deeper pools.

Sixteen or 72.7 percent of the 22 species are relatively intolerant of water quality or habitat degradation. Except for the redspot chub, creek chub, and white sucker, which are uniquely-tolerant coolwater species, the tolerant forms are ubiquitous warmwater species which have wide ranges of tolerance for many factors (Shelford 1913). The black bullhead and green sunfish are among the most tolerant species in North America. Therefore, their presence represents their tolerance of coolwater conditions rather than any degradation of the creek.

The Second Order segment yielded 20 species in a sample of 538 fishes from two stations. This sample contains two fewer species and 94 fewer fishes than the sample from the First Order segment. However, the mean number of fishes per station is 269

Table 8. A check-list of fishes collected by electrofishing at eight stations on Spring Creek, Oklahoma in September, 1986, and stream orders where each species was collected. Common names after AFS (1980). I = intolerant and T = tolerant species (EPA 1983).

Family Species	Common Name	Stream Order 1	 2	 3
Cyprinidae - carps and minnows				
Campostoma anomalum	Central stoneroller	I	I	I
Nocomis asper	Redspot chub	T	T	T
Notropis boops	Bigeye shiner	I	I	
Notropis pilsbryi	Duskystripe shiner	I	I	I
Notropis rubellus	Rosyface shiner			I
Phoxinus erythrogaster	Southern redbelly dace	I	I	I
Semotilus atromaculatus	Creek chub	T	T	T
Catostomidae - suckers				
Catostomus commersoni	White sucker		T	T
Hypentelium nigricans	Northern hog sucker	I		I
Minytrema melanops	Spotted sucker		I	I
Moxostoma duquesnei	Black redhorse		I	
Moxostoma erythrurum	Golden redhorse		I	
Cyprinodontidae - topminnows and killifishes				
Fundulus olivaceus	Blackspotted topminnow	T	T	
Ictaluridae - catfishes				
Ictalurus melas	Black bullhead	T		
Noturus exilis	Slender madtom	I	I	I
Poeciliidae - livebearers				
Gambusia affinis	Mosquitofish			T
Cottidae - sculpins				
Cottus carolinae	Banded sculpin	I	I	I
Centrarchidae - sunfishes				
Ambloplites rupestris	Rock bass	I	I	I
Lepomis cyanellus	Green sunfish	T	T	T
Lepomis macrochirus	Bluegill	T		
Lepomis megalotis	Longear sunfish	I	I	
Lepomis cyanellus x *L. macrochirus*	Hybrid sunfish			T
Micropterus dolomieui	Smallmouth bass	I	I	I
Micropterus punctulatus	Spotted bass	I		
Micropterus salmoides	Largemouth bass	I		I
Pomoxis annularis	White crappie			T
Percidae - perches [darters]				
Etheostoma flabellare	Fantail darter	I	I	I
Etheostoma punctulatum	Stippled darter	I	I	I
Etheostoma spectabile	Orangethroat darter	I	I	I
Percina phoxocephala	Slenderhead darter	I		
Intolerant species		16	15	14
Tolerant species		6	5	6
Total species		22	20	20

in the Second Order segment and 210.67 in the First Order segment, reflecting the larger size of the creek in the Second Order segment (Table 3). Six species occur in the First Order segment that do not occur in the Second Order segment; northern hog sucker, black bullhead, bluegill, spotted bass, largemouth bass, and slenderhead darter (Table 8). Loss of four of these species is offset by addition of four species of suckers which inhabit deeper pools than the northern hog sucker.

Fifteen intolerant species make up 75 percent of the species of fishes in the segment. This is the largest percentage of intolerant species among the stream orders, indicating that a decrease of two species downstream from the First Order segment represents a minor decrease in habitat diversity, with no decrease in water quality.

The Third Order segment yielded 20 species and a hybrid in a sample of 919 fishes from three stations. The number of species is the same as the number found in the Second Order segment. However, the mean number of fishes per station is 306.33, or 37.33 and 95.67 more than mean numbers per station in the First and Second Order segments. These data also indicate habitat diversity similar to the other two segments but greater carrying capacity [$\Longrightarrow$ production] because of larger size of the creek.

Although the degree of habitat diversity changes very little, there appears to be several differences in species composition of the fish community in succeeding stream orders. As mentioned above, the poecilid mosquitofish replaces the cyprinodontid blackspotted topminnow (Table 8) because of depth and bottom materials in backwaters. Other changes include replacement of the bigeye shiner by the rosyface shiner among the minnows, replacement of the longear sunfish by the white crappie and return of the largemouth bass among the sunfishes, and, again, the greatest change is among the suckers. The northern hog sucker returned after being absent from the Second Order and the black and golden redhorses are absent after being present in the Second Order.

Fourteen intolerant species make up 70 percent of the species of fishes in the Third Order segment. This is a net decrease of one intolerant species and a net increase of one tolerant species from the Second Order segment. The change in intolerant species resulted from absence of the bigeye shiner, black and golden redhorses, and longear sunfish which occur in the Second Order segment and addition of the rosyface shiner and return of the northern hog sucker and largemouth bass which occur in the First Order segment. The change in tolerant species consists of replacement of the blackspotted topminnow by the mosquitofish in backwater habitat and addition of the white crappie in a large Third Order pool.

Consistency is as important as difference among stream orders in a qualitative description of the fish community in a creek. Accordingly, nine species occur only in one stream order each; four in First Order, two in Second Order, and three in Third Order. Seven species occur in two stream orders each; three in First and Second Orders, two in First and Third Orders, and two in Second and Third Orders. Therefore, 16, or 55 percent, of the species in the creek are absent from one or more stream orders, and 13 species, or the remaining 45 percent, occur throughout the creek.

Eight of the species which occur in all stream orders -- central stoneroller, duskystripe shiner, southern redbelly dace, slender madtom, banded sculpin, and three Etheostoma darters -- are found almost exclusively on riffles. Five species -- redspot chub, creek chub, rock bass, green sunfish, and smallmouth bass -- are limited to pools, with rock bass and smallmouth bass rarely found in pools where maximum depth is less than three feet (1 m). These habitat limitations were observed for the same species (except rock bass which do not occur) in Tahlequah Creek where only the central stoneroller, southern redbelly dace, and green sunfish are found in all stream orders (Jester et al. 1988). Comparison of fish distribution in the two creeks underscores our contention that regionally-indigenous species occur in a given stream and stream orders within it on the basis of occurrence and distribution of suitable habitat; habitat requirements being the basis of our disagreement with Hughes et al. (1986) that watershed area and mean annual discharge are more important than stream order for determining regional control streams and stations.

Blair (1959) collected fishes at five stations on Spring Creek and three stations on tributaries but reported only darters. His stations on Spring Creek included all stream orders. Branson (1967) collected from only two stations on the Third Order segment and one station on a tributary. McNeely's (1986) sampling scheme was similar to ours, with 13 stations, five of which apparently were identical or very close to ours. However, he worked during an extreme drought with low and intermittent flows, and his first station was his only station in the First Order compared with three of ours. Therefore, most of his samples were collected from Second and Third Order segments.

Collectively, Blair, Branson, and McNeely reported 31 species of fishes from Spring Creek, or two more species than we collected in 1986. However, the difference was not simply presence or absence of two species. They reported seven species and a hybrid that we did not collect, and we collected five species and a hybrid that they did not report (Table 9). Given the taxonomic distinctness of the species and the competence of the authors it is highly unlikely that any of the differences are due to misidentification. Therefore, historical and new data indicate that the fish community in Spring Creek has consisted or does consist of 36 species. Also, small samples of all except two species suggests that failure to occur in all investigations is caused by small populations. However, our failure to collect the Ozark minnow and the least darter must be explained by factors other than abundance in samples.

Gore and Lindsay (1985) reported 57 specimens of the least darter from beds of the macrophyte Myriophyllum in the Third Order segment of the creek. It was shown in a discussion of macrophytes above that Myriophyllum beds were almost or completely destroyed in a flood during 1985. Therefore, it is concluded that the darter was extremely sparse in 1986 because

Table 9. Fishes reported previously from Spring Creek which were not collected during this study and fishes collected during this study that had not been reported previously.

Family Species Common name	Specimens (N)	Reported by
Cyprinidae - carps and minnows		
Hybopsis amblops Bigeye chub	11	McNeely (1986)
Notropis nubilus (=*Dionda nubila*) Ozark minnow	805[a]	Branson (1967) McNeely (1986)
Campostoma anomalum x *Phoxinus erythrogaster* Hybrid minnow	1	Hubbs and Bailey (1952)
Cyprinodontidae - topminnows and killifishes		
Fundulus sciadicus Plains topminnow	2 small samples	Branson (1967)
Percidae - perches [darters]		
Etheostoma blennioides Greenside darter	2 samples[b] 1 sample 1	Blair (1959) Branson (1967) McNeely (1986)
Etheostoma cragini Arkansas darter	1 sample[c] 1[c] 1	Blair (1959) McNeely (1986) Gore and Lindsay (1985)
Etheostoma microperca Least darter	2 samples 57 4 abundant[d]	Blair (1959), Branson (1967), Gore and Lindsay (1985), McNeely (1986) Blair and Windle (1961)
Percina caprodes Logperch	1 sample[e] 1	Blair (1959) McNeely (1986)
Cyprinidae - carps and minnows		
Notropis boops Bigeye shiner	8	new record
Ictaluridae - catfishes		
Ictalurus melas Black bullhead	2	new record
Centrarchidae - sunfishes		
Lepomis cyanellus x *Lepomis macrochirus* Hybrid sunfish	1	new record
Micropterus punctulatus Spotted bass	2	new record
Pomoxis annularis White crappie	1	new record
Percidae - perches [darters]		
Percina phoxocephala Slenderhead darter	1	new record

[a] Branson found 5-12 specimens at each of two stations; McNeely reported it from 11 of 13 stations and as one of the largest populations.

[b] mouth of Snake Creek and Spring Creek at mouth of Snake Creek.

[c] mouth of Snake Creek.

[d] Little Spring Creek, Hwy. 82 bridge, Mayes County, Jan. 25 and April 14, 1961.

[e] mouth of Snake Creek.

habitat was sparse. It probably persists in small numbers and the population expands when Myriophyllum or other vascular plants are available in otherwise-suitable habitat.

Failure to collect the Ozark minnow in 1986 defies explanation on the basis of available information. McNeely (1986) collected 805 specimens from 11 of his 13 stations in 1980, with only the duskystripe shiner more numerous. Yet, Branson (1967) reported only 5 to 12 specimens from each of three stations on Spring Creek and a tributary, and we did not collect the species from Spring Creek in 1986, although we found 28 specimens in similar habitat in Second and Third Order segments of Tahlequah Creek (Jester et al. 1988). Therefore, reason suggests that abundance of the Ozark minnow fluctuates in response to some habitat or community characteristic which was extremely favorable during hot, low-flow conditions in 1980. Then, the same or some other characteristic was extremely unfavorable under normal cooler, wetter conditions in the mid-1980's. Miller and Robison (1973) state that the Ozark minnow ".....seems most common in pools of small to medium sized streams with gravel or rubble bottom." And while Spring Creek is generally a relatively-large stream, the First Order segments and the upstream portion of the Second Order segment are "small to medium sized with gravel and rubble bottom", and McNeely collected 293 specimens at two stations there in 1980. Thus, overall increase in size of the creek does not account for disappearance of the species from all segments of the creek. While we stated with some conviction that the least darter probably persists and the population expands when habitat is available, there appears to be no straightforward reason to make a similar statement concerning the Ozark minnow. It may persist in small numbers awaiting favorable conditions or it may have, for some reason unknown to us, become extinct in the creek between 1980 and 1986.

One other species listed in Table 9 has a unique status which is worthy of comment. The slenderhead darter is described by Miller and Robison (1973) as "an inhabitant of the larger streams and rivers of Oklahoma." Therefore, its occurrence in the Third Order segment of Spring Creek would not be unexpected, although neither would it necessarily be expected. However, this specimen was collected in small-creek conditions in the First Order segment (Table 8) where required habitat described by Miller and Robison is sparse. Thus, finding the slenderhead darter in Spring Creek is only a minor event with regard to fish distribution but the site where it was collected suggests a broader acceptance of habitat than has been reported.

Although the origins of all fishes in Spring Creek and Tahlequah Creek appear to be identical (Jester et al. 1988 and **Origins and Distribution of Fishes** this paper, based upon Branson 1967), there are differences in species composition of the communities in addition to a difference of two species between the creeks. Physical characteristics, water quality, and macrohabitats are similar and 25 species of fishes are common to both creeks. At the same time, nine species occur only in Tahlequah Creek and 11 species occur only in Spring Creek, apparently because of differences in microhabitats based primarily upon sizes of the creeks. Tahlequah Creek contains 16 species of minnows while only nine species, which are common to both creeks, have been reported from Spring Creek. Two of the seven species unique to Tahlequah Creek, the fathead minnow and golden shiner, apparently resulted from human introduction, and the others -- gravel chub, common shiner, ribbon shiner, suckermouth minnow, and bluntnose minnow -- are present in smaller and shallower pools than most of the pools in Spring Creek.

The yellow bullhead catfish also occurs in Tahlequah Creek but not in Spring Creek. It is found in a few deep, sluggish pools on and adjacent to the floodplain of the Illinois River, conforming with Branson's (1967) notation that it seems to prefer the quieter parts of streams and deep ponds and lakes. Spring Creek has larger and deeper pools than Tahlequah Creek but they lack the sluggish characteristics and woody debris that occur where the fishes were collected.

One of five darters in Tahlequah Creek does not occur in Spring Creek. According to Miller and Robison (1973), the banded darter occurs most abundantly in Ozark streams of moderate size, with moderate to high gradients, and with an abundance of algae on larger stones in fairly deep riffle areas. Segments of both creeks meet the requirements for size, gradient, and riffles. However, the algae apparently is required for spawning habitat and possibly other uses. Such habitat does not occur in Spring Creek and is limited to a small segment downstream from the sewage plant in Tahlequah Creek where algae is abundant and water quality has recovered adequately to support darters. This segment is the only site in either creek where the banded darter was collected.

The 11 species which occur in Spring Creek but not in Tahlequah Creek are distributed among four families; suckers, killifishes, sunfishes, and perches. Presence of all of them is attributed to addition of microhabitats within common macrohabitats because Spring Creek is larger. Three catostomids -- white sucker, black redhorse, and spotted sucker -- and two centrarchids -- rock bass and white crappie -- occur in pools that are larger (especially deeper) than most of the pools in Tahlequah Creek. Three of four percids -- greenside, Arkansas, and least darters -- apparently are present because more and larger riffles offer a greater variety of combinations of bottom materials and depths. Presence of the other perch, the slenderhead darter, is attributed by Gore and Lindsay (1985) and above in this paper to presence of the macrophyte Myriophyllum in Spring Creek. Two killifishes, blackspotted and plains topminnows, inhabit silty- and sandy-bottom backwaters which are rare in both creeks but are more numerous and larger in Spring Creek than they are in Tahlequah Creek where the mosquitofish was the only backwater form collected.

According to these data, fish communities are similar in both creeks, with 25 species in common. However, they also differ with nine species which occur in Tahlequah Creek, mostly because of microhabitats attributable to a small Ozark creek, and

11 species which occur in Spring Creek, mostly because of microhabitats which are attributable to a large Ozark creek. The greatest differences are that seven more species of minnows occur in Tahlequah Creek while two species of killifishes, three more species of suckers, and three more species of darters occur in Spring Creek. It appears from descriptions of habitat in the literature, such as Branson (1967), Miller and Robison (1973), Gore and Lindsay (1985), and McNeely (1986), that these communities are typical of small and large creeks in the Ozark Biotic District or Upland Ecoregion.

Community Ecology of Fishes

These introductory remarks are similar to a discussion by Jester et al. (1988) because, in both papers, they are intended to contrast community composition among stream orders in Spring and Tahlequah Creeks. However, they are expanded to compare a community in Big Creek, Arkansas (Jackson and Harp 1973), an Ozark creek intermediate in size between the two Oklahoma creeks.

Abell (1961) proposed that Horton's (1945) stream orders might be used as a classification for stream communities and Kuehne (1962) found species of fishes distributed by stream order. Harrell et al. (1967) found a correlation between quantified species diversity of fishes and stream orders, and Harrell and Dorris (1968) reported differences in species diversity of invertebrates in Third through Sixth Order streams. Hynes (1970) generalized that stream-fish communities increase in species richness and diversity, mainly by addition of species, in a downstream gradient. Lotrich (1973) found positive relationships between distribution (community composition), production, and growth of fishes in First through Third Orders of a creek. He concluded that stream order may be [⟹ probably is] a valid biological unit.

Correlations between biotic diversity and environmental variables have been shown by several authors. Smith and Powell (1971) correlated species diversity with stream size, Horwitz (1978) correlated diversity with discharge, and habitat "quality" was correlated with diversity by Gorman and Karr (1978), Evans and Noble (1979), and Guillory (1982). Trautman (1942) showed that gradient affects distribution and abundance of certain fishes, and Hocutt and Stauffer (1975) found a negative correlation between gradient and diversity. Typically, gradient decreases while stream size, discharge, and "quality", or diversity of habitat increase downstream with major changes occurring among consecutive stream orders. Therefore, stream order may serve as a classification for stream communities when "stream order" is a comprehensive term which encompasses typical changes in stream size, gradient, and diversity of habitat. Vannote et al. (1980) suggested using stream order as a basis for biological classification of streams; in effect, confirming Abell's (1961) proposal and Lotrich's (1973) conclusion.

Hughes and Omernik (1983) advocated stream order as an analytical unit, but Hughes et al. (1986) wavered to suggest substituting watershed area and mean annual discharge for stream order, although they showed no data and cited no literature to justify the substitution.

McNeely (1986) found different fish community structure in different stream orders but did not find downstream sequences of increasing species richness and diversity in his investigations of Spring Creek during drought conditions in 1980. Despite several major and minor changes in species composition since McNeely's study, discussed under **Biological Characteristics, Fishes,** we found the same pattern six years later during prolonged normal temperatures and average to above-average precipitation. Absence of sequentially-increasing community parameters is attributed to absence of sequential increases in habitat diversity (McNeely 1986 and this paper, with similar conditions found in Big Creek, Arkansas, by Jackson and Harp 1973). This is in sharp contrast with Tahlequah Creek where both habitat and species diversities increase with each stream order.

Big Creek is a tributary of the North Fork River or, more precisely, Norfork Reservoir on the North Fork of the White River in the Ozarks in north central Arkansas. The White River is a tributary of the Arkansas River near the confluence of the Arkansas and the Mississippi Rivers in southeastern Arkansas. Thus, Big Creek is distantly-related by drainage affinity to Spring and Tahlequah Creeks. So, for that matter, are they all distantly-related to Rocky Mountain trout streams west of Denver, Colorado. Therefore, fish communities may differ considerably without indicating major ecological differences if different species occupy similar habitats or niches. Jackson and Harp (1973) described Big Creek as a relatively small, clear, coolwater stream. The stream channel averages 3.7 m (12 ft.) in width. Elevation drops from 283 to 198 m (928 to 649 ft.) and mean gradient is 8.1 m/km (42.5 ft./mi.). The creek is 35.4 km (22.1 mi.) long. Predominant bottom materials are coarse gravel on riffles and small rubble in pools. They assigned fishes to riffle and pool habitat but did not specify proportions of each habitat in the creek.

Whereas Spring and Tahlequah Creeks have 25 species of fishes in common, Branson (1967) and Jester et al. (1988) attributed 28 species in Spring Creek and 21 species in Tahlequah Creek to possible origin from the White River drainage by stream capture. Therefore, six of 10 families and 14 species in five of the families are, not surprisingly, common to the three creeks. Additionally, one family represented by one species occurs in Spring and Big Creeks but not in Tahlequah Creek and two species occur in Tahlequah and Big Creeks but not in Spring Creek, or 17 species occur in two or more of the three creeks. Ten species occur in Spring Creek only, seven species occur in Tahlequah Creek only, and 12 species occur in Big Creek only. Five of the species in Big Creek, four Notropis sp. from pools and one Etheostoma sp. from riffles, are not known to occur in Oklahoma but are very similar ecologically to species which do.

Similarities of fish communities in the three creeks but differences among stream orders are shown in Tables 10 and 11. Two of the differences among families (Table 10) are trivial in

Table 10. Families of fishes and number of species in each family in Tahlequah and Spring Creeks, Oklahoma, and Big Creek, Arkansas. Numbers in parentheses represent fishes reported from Spring Creek by other authors.

	Number of Species in Samples		
Family	Tahlequah	Big	Spring
Esocidae	--	1	-- --
Cyprinidae	16	9	7 (+2)
Catostomidae	2	3	5
Ictaluridae	3	2	2
Cyprinodontidae	--	2	1 (+1)
Poeciliidae	1	--	1
Atherinidae	--	1	-- --
Cottidae	1	1	1
Centrarchidae	6	6	8
Percidae	5	4	4 (+4)
Total species	34	29	29 (36)
Total families	7	9	8

that Esocidae in Big Creek is represented by only one specimen of northern pike, probably introduced into Norfork Reservoir, and Poeciliidae is represented by only one specimen of mosquitofish from Tahlequah Creek and one from Spring Creek. The other differences are major in that Atherinidae is represented by 522 specimens of brook silverside from all orders of Big Creek only and Cyprinodontidae are represented by 907 specimens of two species from all orders and all stations of Big Creek and only six specimens of one species from one station each in First and Second Orders of Spring Creek. Overall, if there were minor plausible differences of one less northern pike, one more topminnow, one more mosquitofish, and two more brook silversides in the samples, the communities in the three creeks would consist of the same eight families along with the similarities in species composition discussed above.

Along with similarities of family and species composition of the communities, major differences occur in distribution of taxa among stream orders in the three creeks. Tahlequah Creek is classical in all respects according to the literature summarized above in the introduction to **Community Ecology of Fishes.** The fish community begins with six (apparently only four indigenous) species in two families in First Order segments (Table 11) where habitat consists of 95 percent shallow riffles. Two Second Order

Table 11. **Mean number of fishes per sample per station and numbers of families and species in samples from each stream order in Tahlequah and Spring Creeks, Oklahoma, and Big Creek, Arkansas.**

Creek	Order	Stations	$\bar{N}$/Station	Families	Species
Tahlequah Creek OK	1	2	54.0	2	6
	2	5	105.0	5	18
	3	4	502.5	7	32
		11	240.3	7	34
Big Creek AR	1	2	270.7	7	19
	2	3	139.8	7	19
	3	3	189.1	8	23
		8	191.0	9	29
Spring Creek OK	1	3	210.7	7	22
	2	2	269.0	7	20
	3	3	306.3	7	20
		8	261.1	8	29

segments contain seven species in four families and 17 species in five families respectively, varying with habitat diversity, for a total of 18 species in five families. The Third Order segment, with maximum habitat diversity, contains 32 of 34 species in all of seven families in the creek.

Spring Creek is analyzed only in terms of 29 species collected in this investigation because of uncertainty about numbers of specimens and where some species were collected in other investigations. Of eight families of fishes in the creek, seven were collected in each stream order (Table 11). Although each consecutive stream order increases in size, 47 percent of the First Order segment consists of pools, several of which are at least five feet (1.5 m) deep. Riffles and runs also vary to depths of four to six inches (10 to 15 cm). These diverse habitats support 22 species, or the greatest diversity of fishes in the creek. The Second and Third Order segments are much wider and have much larger volumes of flow but probably slightly less habitat diversity than the First Order segments. Maximum depths of riffles are similar throughout the creek and flat runs are only slightly deeper in these segments. Except for one station in the Second Order segment where two pools are deeper than 10 feet (3.1 m), most of the pools are approximately the same depths as First Order pools but make up only 32.5 and 35 percent respectively of the two orders. Each stream order contains 20 species.

Distribution of fish taxa in Big Creek is similar to Spring Creek except that habitat diversity appears to be slightly greater in the Third Order segment of Big Creek. This segment contains 23 species in eight families compared with 19 species in seven families in First and Second Order segments (Table 11). Therefore, our contention that stream order is a valid unit for biological classification but habitat diversity is the primary determinant of which species and families occur in each stream order appears to be corroborated.

Another set of data in Table 11 also appears to conflict with conventional wisdom. That is, as a creek becomes larger with each stream order, standardized samples of fishes from each order should become larger to reflect larger populations or production. This was the case in Tahlequah and Spring Creeks and in Second and Third Orders of Big Creek. However, the mean number of fishes per sample per station in the First Order segment of Big Creek was almost twice the number from the Second Order and 143 percent of the number from the Third Order. Unfortunately, no data or discussion was provided to explain the apparent incongruity of the size of the First Order samples.

If stream orders are biological as well as physiographic units, characteristics of biotic communities should differ among orders. Communities have unique structural and functional characteristics, and investigations may involve either or both. Structure and interactions resulting from it are emphasized here because they serve the objectives of the study.

Community Structure

A spring-fed, coolwater creek in the Ozarks region is expected to support a combination coolwater-warmwater fish community, with species composition dependent upon suitable habitat. Most of the indigenous coolwater species are characterized by rather narrow ranges of tolerance (Shelford's Law, Odum 1971, 1983) and require cool, clean water, rocky bottom, and moderate to steep gradients, and may be limited to riffles, runs, or pools. Narrow ranges of tolerance imply that these species are sensitive to degradation of water quality or habitat. They may be classified as intolerant (EPA 1983) and used as indicators of quality or degradation. Usually the more or greater percentage of intolerant species, the better the quality.

The warmwater species are those which have wide ranges of tolerance so that they are adapted to typical conditions in coolwater creeks in addition to the warm, sluggish, mud-bottom, low-gradient streams of the prairies and coastal plains. They are tolerant of coolwater creeks but are not in or near optimum conditions where they would be inherently dominant. They may be relatively abundant in favorable habitat but abundance at the expense of intolerant coolwater species is definitive evidence of degradation in a coolwater creek.

A large creek which contains the three major types of macrohabitat will support fish communities which are quite diverse in terms of microhabitat requirements and numbers of families and species. Spring Creek is an example of a large and diverse, spring-fed, coolwater creek in the Ozark Biotic District. Fish communities in each stream order are discussed separately below.

First Order. Physiography, volume of flow, and symptomatic water chemistry are shown in Table 3 for Stations 1 through 3 or the First Order segment of Spring Creek.

Twelve species of fishes were collected at Station 1 (Table 12). This is the fewest species collected at a First Order

Table 12. Fishes collected by electrofishing at Stations 1-3 (Fig. 1) on the First Order segment of Spring Creek, Oklahoma, in September, 1986. Weights in grams.

Family Common Name	Intolerant (*)	Station 1 N	Station 1 W	Station 2 N	Station 2 W	Station 3 N	Station 3 W	First Order N	First Order %N	First Order W	First Order %W
Cyprinidae - carps and minnows											
Central stoneroller	*	69	220.8	16	59.4	76	574.3	161	25.5	854.5	7.10
Redspot chub		1	3.2	13	195.9	38	876.9	52	8.2	1076.0	8.93
Bigeye shiner	*					2	3.0	2	0.3	3.0	0.03
Duskystripe shiner	*	18	88.0	28	42.0	8	22.0	54	8.5	152.0	1.26
Southern redbelly dace	*			16	42.4	6	9.6	22	3.5	52.0	0.43
Creek chub		11	167.1	23	1034.0	19	926.1	53	8.4	2127.2	17.66
Catostomidae - suckers											
Northern hog sucker	*					3	1031.9	3	0.5	1031.9	8.57
Cyprinodontidae - topminnows and killifishes											
Blackspotted topminnow		5	8.9					5	0.8	8.9	0.07
Ictaluridae - catfishes											
Black bullhead				2	291.4			2	0.3	291.4	2.42
Slender madtom	*			12	46.2			12	1.9	46.2	0.38
Cottidae - sculpins											
Banded sculpin	*			12	91.9	24	76.8	36	5.7	168.7	1.40
Centrarchidae - sunfishes											
Rock bass	*			1	69.2	7	118.1	8	1.3	187.3	1.56
Green sunfish		31	572.9	31	801.2	14	721.5	76	12.0	2095.6	17.40
Bluegill				1	11.9	19	584.7	20	3.2	596.6	4.95
Longear sunfish	*	3	25.7	1	28.0			4	0.6	53.7	0.45
Smallmouth bass	*	3	1162.4			8	1546.3	11	1.7	2708.7	22.49
Spotted bass	*	1	7.2			1	8.3	2	0.3	15.5	0.13
Largemouth bass	*					1	332.4	1	0.2	332.4	2.76
Percidae - perches [darters]											
Fantail darter	*	6	6.6	28	39.1	2	3.5	36	5.7	49.2	0.41
Stippled darter	*	23	94.0	1	9.4	3	18.4	27	4.3	121.8	1.01
Orangethroat darter	*	32	43.3	7	16.0	5	11.3	44	7.0	70.6	0.59
Slenderhead darter	*					1	1.4	1	0.2	1.4	0.01
Total fishes:											
N and W		203	2400.1	192	2778.0	237	6866.5	632		12044.6	
Families		4		5		5		7			
Species		12		15		18		22			
Intolerant species		8(66.7%)		10(66.7%)		14(77.8%)		16(72.7%)			
Species Richness Index		0.41		0.52		0.62		0.76			
Shannon Index		1.72	1.53	2.13	1.81	2.23	2.15	2.47		2.26	

station but not the fewest at any station on the creek. Twelve species also were collected at one station each in the Second and Third Order segments. Five species which inhabit riffles -- central stoneroller, duskystripe shiner, and three Etheostoma darters -- constitute 72.9 percent of the number and 18.9 percent of the weight of fishes in the sample. Five specimens of the blackspotted topminnow which weigh 8.9 g (0.3-oz.) were collected in small, gravel-bottom backwaters. The remaining six species, two large minnows and four sunfishes, inhabit pools. Fifty specimens make up 24.6 percent of the number and 80.8 percent of the weight of the sample. Therefore, riffle forms contribute most of the number and pool forms contribute most of the weight of fishes at the station.

Depth of riffles increased from 0.1-foot (1.2 in. or 3.1 cm) to 0.3-foot (3.6 in. or 9.1 cm) and maximum depths of pools decreased from five feet (1.5 m) to 2.5 feet (0.8-m) from Station 1 to Station 2, although proportions of each habitat are unchanged (Table 3). Fifteen species of fishes were collected at Station 2 (Table 12), with the increase from 12 species at Station 1 attributable to relatively—large numbers of three riffle-dwelling forms. However, there also are changes in species composition in pools, and one additional pool-inhabiting species is included in the sample. At the same time, the blackspotted topminnow did not occur in the sample, presumably because its backwater habitat does not occur at the station.

The southern redbelly dace, slender madtom catfish, and banded sculpin are the additional riffle inhabitants, contributing 40 specimens and 425.5 g (0.94-lb.) to the sample. Depth of riffles also appears to have caused reversal of relative abundance of darters at the two stations.

Two black bullheads, which require pools, cover, and soft bottom, were collected among the roots of a large stump in a shallow, silt-bottom pool (Table 9). These are a new record for the creek and were the only bullheads collected. Four species of sunfishes occur in pools at both Stations 1 and 2. However, those at Station 2 are the smaller forms, rock bass and Lepomis sp., which tolerate shallow pools, and even the rock bass is limited by depths of less than approximately 2.5 feet (0.8-m). Smallmouth bass and spotted bass older than one year were collected only from pools at least three feet (0.9-m) deep in both Tahlequah and Spring Creeks.

Overall, eight species inhabit riffles and contribute 120 specimens or 62.5 percent of the number of fishes in the sample. Seven species inhabit pools and contribute 2,431.6 g (5.4 lbs.) or 87.5 percent of the weight.

Pools increase from 40 percent of the area of the creek at Station 2 to 60 percent at Station 3, all at the expense of flat runs (Table 3). Therefore, riffles are larger only because the creek is larger. Conversely, pools are relatively larger and more abundant, and maximum depths are approximately five feet (1.5 m). Increase in pools accounts for an increase from 15 to 18 species from Station 2 to Station 3 (Table 12). Actually, five additional pool species occur but two species from Station 2 are not in the sample from Station 3. Also, one additional riffle species, the only slenderhead darter collected, occurs at Station 3 but is offset by failure to collect the slender madtom. Five families of fishes also occur at each station but the catfishes are absent from Station 3 and are offset by a sucker which did not occur at either previous station. The number of fishes in the sample at Station 3 is only 45 or 23.4 percent more than the number at Station 2 but the weight at Station 3 is 247.2 percent of the weight at Station 2, an increase from 2,778.0 g (6.1 lbs.) to 6,866.5 g (15.1 lbs.).

Riffle species are more numerous than pool species at Station 3, as they are at Stations 1 and 2, but only by 125, or 52.7 percent, of 237 specimens. Weight of pool species is dominant, with 6,149.2 g (13.6 lbs.) making up 89.6 percent of 6,866.5 g (15.1 lbs.).

The composite sample from Stations 1 through 3 consists of 632 fishes which weigh 12,044.6 g (26.5 lbs.) from the First Order segment of Spring Creek (Table 12). These fishes include 22 species in seven families.

Macrohabitats consist of 20 percent riffles, 0.1 to 0.3-foot (1.2 to 3.6 in. or 3.1 to 9.1 cm) deep; 33.3 percent flat runs, 0.3 to 1.0 foot (3.6 to 12 in. or 9.1 to 30.5 cm) deep; and 46.7 percent pools, two to five feet (0.6 to 1.5 m) deep. Bottom materials are mostly fine and course gravel with scattered small to intermediate rubble, with small areas of exposed bedrock and a few small backwater pools where the bottom is a thin ephemeral layer of silt. Riffles and runs combined result in 53.3 percent of the area of the creek consisting of "shallow-water" habitat. Fishes conform to a shallow-water vs. pool division moreso than they do to the three habitats. In fact, in Spring and Tahlequah Creeks, no species are limited to or appear to prefer flat runs, although some species appear to be tolerant of the slower, deeper runs and occupy both riffle and run habitats. Abundance is less in the runs than in the riffles and the fishes which occur there tend to retreat to riffles rather than *vice versa*, which indicates that they are primarily riffle fishes.

Nine species in four families of fishes occur in riffle or shallow-water habitat. Two families, Cyprinidae and Ictaluridae, are represented in both shallow water and pools, and two families, Cottidae and Percidae, are limited to shallow water. The nine species -- central stoneroller, duskystripe shiner, southern redbelly dace, slender madtom, banded sculpin, fantail darter, stippled darter, orangethroat darter, and slenderhead darter -- consist of 393 individuals or 62.18 percent of the number of fishes collected from the First Order segment.

Twelve species of fishes in four families occur in pools. Catostomidae and Centrarchidae are represented along with minnows and catfishes. No species were found in both shallow water and pools. The 12 species -- redspot chub, bigeye shiner, creek chub, northern hog sucker, black bullhead, and seven sunfishes -- consist of 234 individuals or 37.03 percent of the number of fishes but weigh 10,519.3 g (23.2 lbs.) which is 87.34 percent of the weight of the sample. Therefore, the number of fishes is disproportionately greater than the percentage of shallow water and the weight or biomass of fishes is disproportionately greater than the percentage of pools. These relationships also were noted in Tahlequah Creek except at stations where portions of the community are disrupted by anthropogenic factors (Jester et al. 1988).

One remaining family and species in the First Order segment consists of five specimens of a cyprinodontid, the blackspotted topminnow, which weigh 8.9 g (0.3-oz.) and make up 0.79 percent of the number and 0.07 percent of the weight of fishes in the sample.

Intolerant species range from 8 to 14 in number and from 66.7 to 77.8 percent of the total number of species at the three stations. Overall, 16 species or 72.7 percent of 22 species in the First Order segment are intolerant of water quality or habitat degradation or both. Also, Shannon Indices of general diversity (Shannon and Weaver 1963) are the highest values reported for a First Order stream and among the highest reported for any stream in Oklahoma (Jester et al. 1988).

Second Order. Physiography, volume of flow, and symptomatic water chemistry are shown in Table 3 for Stations 4 and 5 or the Second Order segment of Spring Creek. The Second Order segment is much larger than the First Order segment, increasing by a factor of 7.3 in mean width and a factor of 21.6 in mean volume of flow. However, habitat diversity decreases by a major increase from 33.3 percent to 45 percent flat runs, the least diverse and least productive type of habitat, and a major decrease from 46.7 percent to 32.5 percent pools, the most diverse and most productive type of habitat.

Station 4 consists of approximately 40 percent pools and 20 percent riffles, and, thus, is relatively productive. The sample of fishes consists of 411 specimens which weigh 5,799.2 g (12.8 lbs.) (Table 13). Seventeen species represent seven families. These values are equal to the largest number of families and the second largest number of species collected at any station. The sample sizes also are the second largest number and weight.

Four families -- Cyprinidae, Ictaluridae, Cottidae, and Percidae -- occur on riffles. Seven species; including the central stoneroller, duskystripe shiner, southern redbelly dace, slender madtom, banded sculpin, stippled darter, and orangethroat darter, are represented by 318 specimens and 1,347.4 g (3.0 lbs.) or 77.3 percent of the number and 23.2 percent of the weight of the sample.

Nine species but only three families occur in pools. Cyprinidae is the only family and no species is common to both pools and shallow-water habitats. The pool species are the redspot chub, bigeye shiner, creek chub, rock bass, green sunfish, longear sunfish, and smallmouth bass which also occur in the First Order segment and white and spotted suckers which occur here and at one station each in the Third Order segment. Pool species are represented by 92 specimens and 4,446.2 g (9.8 lbs.) or 22.4 percent of the number and 76.7 percent of the weight of the sample.

The seventh family is represented by one blackspotted topminnow which weighs 5.6 g (0.2-oz.) and makes up 0.3 percent of the number and 0.1 percent of the weight of the sample. This

Table 13. Fishes collected by electrofishing at Stations 4 and 5 (Fig. 1) on the Second Order segment of Spring Creek, Oklahoma, in September, 1986. Weights in grams.

Family Common Name	Intolerant (*)	Station 4 N	 W	Station 5 N	 W	Second Order N	 %N	 W	 %W
Cyprinidae - carps and minnows									
Central stoneroller	*	66	627.8			66	12.3	627.8	9.87
Redspot chub		49	242.0	2	7.9	51	9.5	249.9	3.93
Bigeye shiner	*	6	13.4			6	1.1	13.4	0.21
Duskystripe shiner	*	194	536.6	70	161.8	264	49.1	698.4	10.98
Southern redbelly dace	*	23	69.5	4	4.2	27	5.0	73.7	1.16
Creek chub		4	43.2	6	56.6	10	1.9	99.8	1.57
Catostomidae - suckers									
White sucker		2	1360.8			2	0.4	1360.8	21.39
Spotted sucker	*	1	4.9			1	0.2	4.9	0.08
Black redhorse	*			1	4.6	1	0.2	4.6	0.07
Golden redhorse	*			1	70.4	1	0.2	70.4	1.11
Cyprinodontidae - topminnows and killifishes									
Blackspotted topminnow		1	5.6			1	0.2	5.6	0.09
Ictaluridae - catfishes									
Slender madtom	*	1	3.2			1	0.2	3.2	0.05
Cottidae - sculpins									
Banded sculpin		26	80.3	28	156.8	54	10.0	237.1	3.73
Centrarchidae - sunfishes									
Rock bass	*	1	22.1			1	0.2	22.1	0.35
Green sunfish		3	349.1	1	75.9	4	0.7	425.0	6.68
Longear sunfish	*	23	823.0			23	2.8	823.0	12.94
Smallmouth bass	*	3	1587.7	1	3.8	4	0.7	1591.5	25.02
Percidae - perches [darters]									
Fantail darter	*			10	10.2	10	1.9	10.2	0.16
Stippled darter	*	2	14.2	1	6.3	3	0.6	20.5	0.32
Orangethroat darter	*	6	15.8	2	3.4	8	1.5	19.2	0.30
Total fishes:									
N and W		411	5799.2	127	561.9	538		6361.1	
Families		7		5		7			
Species		17		12		20			
Intolerant species		12(70.6%)		9(75.0%)		15(75.0%)			
Species Richness Index		0.59		0.41		0.69			
Shannon Index		1.79	1.97	1.44	1.80	1.79		2.11	

specimen, like the First Order sample, was collected from a small, shallow, gravel-bottom backwater.

Station 5 contains the largest proportion of flat runs (50 percent) and the smallest proportion of pools (25 percent) of any station that was measured (Table 3). Therefore, it has the least habitat diversity. Families of fishes decrease to five and species decrease to 12 (Table 13) to equal the smallest number of families except for Station 1 and the smallest number of species at any station. The sample of fishes consists of only 127 specimens and 561.9 g (1.2 lbs.).

Three families and six species occur in both riffles and pools, with only Family Cyprinidae and no species in common. The duskystripe shiner, southern redbelly dace, banded sculpin, and three Etheostoma darters occur only on riffles where 115 specimens and 342.7 g (0.8-lb.) make up 90.6 percent of the number and 61.0 percent of the weight of the sample.

The redspot chub, creek chub, green sunfish, and smallmouth bass occur in pools throughout the creek but two suckers, black redhorse and golden redhorse, were collected only at this station. Twelve pool fishes which weigh 219.2 g (0.5-lb.) make up 9.4 percent of the number and 39.0 percent of the weight of fishes in the sample. Again, this station has the smallest proportion of pools, and it is the only station at which shallow-water fishes make up more than half of the weight of fishes in the sample.

The composite sample of fishes collected from the Second Order segment of the creek consists of 538 specimens which weigh 6,361.1 g (14.0 lbs.) from Stations 4 and 5. Twenty species represent seven families (Table 13). Six species in four families that occur in the First Order segment were not collected here but are replaced (numerically, not ecologically) by four species in one family. Species lost between stream orders are northern hog sucker, black bullhead, bluegill, spotted bass, largemouth bass, and slenderhead darter. Species gained are all catostomids, consisting of the white sucker, spotted sucker, black redhorse, and golden redhorse. White and spotted suckers were collected from one large pool where depth was approximately four feet (1.2 m) and bottom of the creek was entirely exposed bedrock. The redhorses were collected from eddy currents at the sides of gravel-bottom pools where depth was approximately three feet (0.9-m).

Eight species represent four families of fishes in riffles and runs (Table 13). Three minnows, one madtom, one sculpin, and three darters contribute 433 specimens and 1,690.1 g (3.7 lbs.) or 80.5 percent of the number and 26.6 percent of the biomass. Three families and 11 species occur in pools, with only Cyprinidae and no species in common. Three minnows, four suckers, and four sunfishes contribute 104 specimens and 4,665.4 g (10.3 lbs.) or 19.3 percent of the number and 73.3 percent of the biomass. The blackspotted topminnow, from a small backwater, represents Cyprinodontidae with one specimen which weighs 5.6 g (0.2-oz.). This fish makes up 0.2 percent of the number and 0.1 percent of the biomass of fishes in the sample from the Second Order segment of the creek. Overall, riffle or shallow-water species contribute 80.5 percent of the number of fishes in 67.5 percent of the habitat, and pool species contribute 73.3 percent of the biomass in 32.5 percent of the habitat.

Incidence and percentages of intolerant species remain high at the two stations and in the composite sample from the Second Order segment. Twelve of 17 species at Station 4 make up 70.6 percent of the species at the station. Station 5 has only 12 species because of less habitat diversity but nine of the 12 or 75 percent of the species are intolerant. The Shannon Index also shows effects of reduced habitat diversity. Four species; central stoneroller, redspot chub, duskystripe shiner, and banded sculpin, make up 80.9 percent of the number of fishes in the sample. Five species; central stoneroller, duskystripe shiner, white sucker, longear sunfish, and smallmouth bass, make up 80.2 percent of the biomass. The resultant indices are 1.79 for numerical diversity and 2.11 for biomass diversity, compared with 2.47 and 2.26 respectively for the First Order segment.

Third Order. Physiography, volume of flow, and symptomatic water chemistry are shown in Table 3 for Stations 6 through 8 or the Third Order segment of Spring Creek. Mean width of the Third Order segment is 52.3 feet (16.0 m) compared with 64.5 feet (19.7 m) for the Second Order segment. However, mean volume of flow increases by a factor of 2.25, implying greater depth and velocity although depths of individual pools are similar. Habitat diversity increases slightly by an increase from 32.5 to 35.0 percent pools and 22.5 to 31.7 percent riffles.

Approximately 35 percent of Station 6 consists of pools and 25 percent consists of riffles, and, thus, is moderately productive. The sample of fishes consists of 245 specimens which weigh 3,043.9 g (6.7 lbs.) (Table 14). Fifteen species and a hybrid represent six families. Two stations have more families (7 each) and three stations have more species (16, 17, and 18).

Four families and eight species occur on riffles. The families are Cyprinidae, Ictaluridae, Cottidae, and Percidae. The species -- central stoneroller, duskystripe shiner, southern redbelly dace, slender madtom, banded sculpin, and three Etheostoma darters -- are represented by 212 specimens which weigh 1,006.8 g (2.2 lbs.). These fishes make up 86.5 percent of the number and 33.1 percent of the weight of the sample from the station.

Three families, seven species, and a hybrid occur in pools. The families are Cyprinidae, two species; Catostomidae, two species; and Centrarchidae, three species and a cross between green sunfish and bluegill. The redspot chub, creek chub, white sucker, northern hog sucker, rock bass, green sunfish, white crappie, and the hybrid are represented by 33 specimens or 13.5 percent of the number and 2,037.1 g (4.5 lbs.) or 66.9 percent of the weight of fishes in the sample.

Riffles make up only 20 percent of the area of the creek at Station 7. However, pools make up 40 percent, which is the greatest incidence in the Third Order segment (Table 3). Therefore, the station should be at least moderately productive, with pool species especially dominant. Three other stations consist of 20 percent riffles and 40 percent pools, and one

Table 14. Fishes collected by electrofishing at Stations 6-8 (Fig. 1) on the Third Order segment of Spring Creek, Oklahoma, in September, 1986. Weights in grams.

Family Common Name	Intolerant (*)	Station 6 N	 W	Station 7 N	 W	Station 8 N	 W	Third Order N	 %N	 W	 %W
Cyprinidae - carps and minnows											
Central stoneroller	*	9	265.8	4	29.2	68	424.6	81	8.8	719.6	6.11
Redspot chub		21	318.5	4	41.6	41	1100.9	66	7.2	1461.0	12.41
Duskystripe shiner	*	46	217.4	21	92.4	249	554.6	316	34.4	864.4	7.34
Rosyface shiner	*					3	3.6	3	0.3	3.6	0.03
Southern redbelly dace	*	1	2.3			1	1.0	2	0.2	3.3	0.03
Creek chub		1	6.9	5	70.5	17	259.2	23	2.5	336.6	2.86
Catostomidae - suckers											
White sucker		1	907.2					1	0.1	907.2	7.71
Northern hog sucker	*	1	114.5	2	248.1	2	1079.4	5	0.5	1442.0	12.25
Spotted sucker	*			2	8.5			2	0.2	8.5	0.07
Ictaluridae - catfishes											
Slender madtom	*	9	182.2	2	6.0	46	156.1	57	6.2	344.3	2.92
Poeciliidae - livebearers											
Mosquitofish						1	0.2	1	0.1	0.2	0.002
Cottidae - sculpins											
Banded sculpin	*	102	284.7	2	23.0	77	503.9	181	19.7	811.6	6.89
Centrarchidae - sunfishes											
Rock bass	*	5	137.6	16	835.1	16	673.7	37	4.0	1646.4	13.98
Green sunfish		2	184.4			2	63.5	4	0.4	247.9	2.11
Lepomis cyanellus x L. macrochirus		1	64.3					1	0.1	64.3	0.55
Smallmouth bass	*			6	1902.4	4	370.4	10	1.1	2272.8	19.30
Largemouth bass	*			2	201.2			2	0.2	201.2	1.71
White crappie		1	303.7					1	0.1	303.7	2.58
Percidae - perches [darters]											
Fantail darter	*	27	26.0			68	50.9	95	10.3	76.9	0.65
Stippled darter	*	4	17.3	1	5.1	3	18.4	8	0.9	40.8	0.35
Orangethroat darter	*	14	11.1			9	7.3	23	2.5	18.4	0.16
Total fishes:											
N and W		245	3043.9	67	3463.1	607	5267.7	919		11774.7	
Families		6		6		7		7			
Species		15		12		16		20			
Intolerant species		10(66.7%)		10(83.3%)		12(75.0%)		14(70.0%)			
Species Richness Index		0.52		0.41		0.55		0.69			
Shannon Index		1.86	2.24	2.04	1.36	1.90	1.89	2.04		2.40	

station consists of 20 percent riffles and 60 percent pools.

The sample of fishes from Station 7 consists of 67 individuals which weigh 3,463.1 g (7.6 lbs.) (Table 14). This is the smallest numerical sample by approximately 50 percent but weight is fourth among the eight stations. Twelve species represent six families.

Four families and only five species occur on riffles. The central stoneroller, duskystripe shiner, slender madtom, banded sculpin, and stippled darter are represented by 30 specimens which weigh 155.7 g (0.3-lb.). These values are 44.8 percent of the number and 4.5 percent of the weight of the sample. Three families and seven species occur in pools. The redspot chub, creek chub, northern hog sucker, spotted sucker, rock bass, smallmouth bass, and largemouth bass are represented by 37 specimens which weigh 3,307.4 g (7.3 lbs.). These values are 55.2 percent of the number and 95.5 percent of the weight of the sample.

This is the only station on either Spring Creek or Tahlequah Creek (Jester et al. 1988) where less than 50 percent of the number of fishes occurs on riffles. More than half of the weight occurs in pools as expected but 95.5 percent is an unexpectedly large proportion. In either case, it appears that numbers of fishes are small in both types of habitat, although no reason for reduced numbers is known.

An increase to 50 percent riffles at Station 8 from 20 percent at Station 7 and a maximum of 25 percent at other stations is reflected by the largest numerical sample of fishes collected during the study. At the same time, the second largest weight of fishes was collected at Station 8 despite a decrease to 30 percent pools from 40 percent at Station 7 and 40 to 60 percent at four other stations. Also, maximum depth of pools is approximately four feet (1.2 m), compared with approximately six feet (1.8 m) at the other stations in the Third Order segment of the creek.

The sample consists of 607 fishes in seven families and 16 species. Weight of the sample is 5,267.7 g (11.6 lbs.) (Table 14). One family, Poeciliidae, and two species, mosquitofish and rosyface shiner, were collected only at this station.

Eight species in four families occur on riffles. They are the central stoneroller, duskystripe shiner, southern redbelly dace, slender madtom, banded sculpin, and three Etheostoma darters. Their total number, 521 specimens, makes up 85.8 percent and their weight, 1,716.8 g (3.8 lbs.), makes up 32.6 percent, respectively, of the sample. Seven species in three families occur in pools. They are the redspot chub, rosyface shiner, creek chub, northern hog sucker, rock bass, green sunfish, and smallmouth bass. There are only 85 specimens which make up 14 percent of the number of fishes in the sample, but 3,550.7 g (7.8 lbs.) make up 67.4 percent of the weight. Therefore, despite the large proportion of riffles and the usual numerical dominance of riffle species, pool species maintain their dominance in terms of biomass. The mosquitofish consists of one specimen which weighs 0.2 g (0.007-oz.) and makes up 0.2 percent of the number and 0.004 percent of the weight of fishes in the sample. It was collected in a small, silt-bottom, apparently-ephemeral backwater.

The Third Order segment of the creek contains 2.5 percent less shallow-water habitat and 2.5 percent more pools than the Second Order segment. Within shallow-water habitat, flat runs decrease from 45 percent to 33.3 percent and riffles increase from 22.5 percent to 31.7 percent. Overall, these changes represent habitat improvement, and the segment of the creek should be more productive.

Fishes were collected at two stations in the Second Order segment and at three stations in the Third Order segment. Comparison of the segments requires equal sampling, which is estimated by expanding Second Order number and weight data by 50 percent. It is assumed that the results yield a reasonable estimate despite major differences in the two stations because each station appears to be representative of approximately half of the segment. Assuming validity of the projected sample, approximately 807 fishes which weighed approximately 9,541.7 g (21 lbs.) would have been collected at three stations in the Second Order segment. The sample from the Third Order segment consists of 919 fishes which weigh 11,774.7 g (25.9 lbs.) (Table 14). Therefore, assumptions of habitat improvement and greater production, shown by larger standing crop, appear to be valid.

Twenty species represent seven families of fishes in the Third Order segment just as they do in the Second Order segment. Sixteen species and six families occur in both segments. Four species in three families that occur in the Second Order segment do not occur in the Third Order segment and four species in four families that occur in the Third Order segment do not occur in the Second Order segment. Species lost between stream orders are the bigeye shiner, black redhorse, golden redhorse, and blackspotted topminnow. Species gained are the rosyface shiner, northern hog sucker, mosquitofish, and white crappie.

Eight species represent four families in riffles and runs. Three minnows, one madtom, one sculpin, and three darters contribute 763 specimens and 2,879.3 g (6.3 lbs.) or 83 percent of the number and 24.5 percent of the biomass of fishes in the segment. Three families, 11 species, and a hybrid occur in pools, with only Cyprinidae and no species in common. Three minnows, three suckers, five sunfishes, and a hybrid sunfish contribute 155 specimens and 8,895.2 g (19.6 lbs.) or 16.9 percent of the number and 75.5 percent of the biomass. The mosquitofish represents Poeciliidae with one specimen which weighs 0.2 g (0.007-oz.) from a small backwater. This fish makes up 0.1 percent of the number and 0.002 percent of the biomass. Overall, riffle or shallow-water species contribute 83 percent of the number of fishes in 65 percent of the habitat and pool species contribute 75.5 percent of the biomass in 35 percent of the habitat.

Incidence and percentages of intolerant species are high at all stations in the Third Order segment. Ten of 15 species at Station 6 make up 66.7 percent of the species at the station. Station 7 has only 12 species but 10 of the 12 or 83.3 percent are intolerant. Twelve or 75 percent of 16 species at Station 8 are intolerant. The composite sample for the Third Order segment consists of 20 species of which 14, or 70 percent, are intolerant.

The Shannon Indices of general diversity for species are relatively large for the Third Order segment. Both Second and Third Order segments contain 20 species but the numerical diversity values are 1.79 for the Second Order and 2.04 for the Third Order. Biomass diversity is 2.11 for the Second Order and 2.40 for the Third Order, or second largest and largest respectively for the three stream orders.

Entire creek. Overall, Spring Creek consists of approximately 38.8 percent pools, 25 percent riffles, and 36.2 percent flat runs, or approximately 40 percent pools and 60 percent shallow-stream habitat. Volume of flow ranged from 0.6 cfs (0.017 m^3/sec.) to 198.5 cfs (5.63 m^3/sec.) on September 24, 1986 (Table 3). Mean volume of flow was 67.825 cfs (1.92 m^3/sec.). Assuming that the estimated length of the creek is accurate enough for reasonable conversion to feet and meters, there were 176,880 linear feet (53,600 m = 33.5 miles = 53.6 km) of water in the creek. Therefore, instantaneous storage or volume was [(176,880)(67.825) $\simeq$] 11,996,886 $ft.^3$ (275.4 acre-feet) or [(53,600)(1.92)$\simeq$] 102,912 m^3.

The composite sample from the entire creek consists of 2,089 fishes which weigh 30,180.4 g (66.5 lbs.). They include 29 species which represent eight families. Twenty, or 69 percent, of the species are moderately to strongly intolerant of degraded water quality, habitat, or both (Table 15).

Nine species, or 31 percent of the species of fishes in the creek, inhabit riffles and, to a lesser extent, flat runs primarily or exclusively. They are the central stoneroller, duskystripe shiner, southern redbelly dace, slender madtom, banded sculpin, fantail darter, stippled darter, orangethroat darter, and slenderhead darter. These are the same riffle species which occur in Tahlequah Creek (Jester et al. 1988) except for one darter. One specimen of the banded darter, *Etheostoma zonale*, was collected from Tahlequah Creek but not from Spring Creek and one specimen of the slenderhead darter was collected from Spring Creek but not from Tahlequah Creek.

Total number of specimens of riffle species is 1,589 and total weight is 6,085.8 g (13.4 lbs.). These values represent 76.1 percent of the number and 20.2 percent of the weight of fishes in the sample. Two other shallow-water species, or seven percent of the species in the creek, were collected only in backwaters. They are the blackspotted topminnow collected over gravel bottom and the mosquitofish collected over silt bottom. Six blackspotted topminnows weigh 14.5 g (0.5-oz.) and one mosquitofish weighs 0.2 g (0.007-oz.). Collectively, they make up 0.35 percent of the number and 0.0507 percent of the weight of the sample.

The remaining 18 species, which is 62 percent of the species of fishes in the creek, inhabit pools primarily or exclusively. Also, one hybrid, green sunfish x bluegill, occurs in pools. Total number of specimens is 493 and total weight is 24,079.9 g (53.0 lbs.). These values represent 23.6 percent of the number

Table 15. Fishes collected by electrofishing at eight stations on Spring Creek, Oklahoma, in September, 1986. Weights in grams.

Family Common Name	Intolerant (*)	N	%N	W	%W
Cyprinidae - carps and minnows					
Central stoneroller	*	308	14.7	2201.9	7.30
Redspot chub		169	8.1	2786.9	9.23
Bigeye shiner	*	8	0.4	16.4	0.05
Duskystripe shiner	*	634	30.4	1714.8	5.68
Rosyface shiner	*	3	0.1	3.6	0.01
Southern redbelly dace	*	51	2.4	129.0	0.43
Creek chub		86	4.1	2563.6	8.49
Catostomidae - suckers					
White sucker		3	0.1	2268.0	7.52
Northern hog sucker	*	8	0.4	2473.9	8.20
Spotted sucker	*	3	0.1	13.4	0.04
Black redhorse	*	1	0.05	4.6	0.02
Golden redhorse	*	1	0.05	70.4	0.23
Cyprinodontidae - topminnows and killifishes					
Blackspotted topminnow		6	0.3	14.5	0.05
Ictaluridae - catfishes					
Black bullhead		2	0.1	291.4	0.97
Slender madtom	*	70	3.4	393.7	1.31
Poeciliidae - livebearers					
Mosquitofish		1	0.05	0.2	0.0007
Cottidae - sculpins					
Banded sculpin	*	271	13.0	1217.4	4.03
Centrarchidae - sunfishes					
Rock bass	*	46	2.2	1855.8	6.15
Green sunfish		84	4.0	2768.5	9.17
Bluegill		20	1.0	596.6	1.98
Longear sunfish	*	27	1.3	876.7	2.91
Smallmouth bass	*	25	1.2	6573.0	21.78
Spotted bass	*	2	0.1	15.5	0.49
Largemouth bass	*	3	0.1	533.6	1.77
White crappie		1	0.05	303.7	1.01
Lepomis hybrid		1	0.05	64.3	0.21
Percidae - perches [darters]					
Fantail darter	*	141	6.8	136.3	0.45
Stippled darter	*	38	1.8	183.1	0.61
Orangethroat darter	*	75	3.6	108.2	0.36
Slenderhead darter	*	1	0.05	1.4	0.005
Total fishes:					
N and W		2089		30180.4	
Families		8			
Species		29			
Intolerant species		20(69.0%)			
Shannon Index		2.32		2.58	

and 79.8 percent of the weight of fishes in the sample.

In summary, approximately 60 percent of the macrohabitat in the creek is shallow water. It contains six families and 11 species of fishes. Two of the families and species are limited to small backwaters. The 11 species make up 38 percent of the species, 1,596 specimens or 76.4 percent of the number, and 6,100.5 g (13.4 lbs.) or 20.2 percent of the weight of fishes in the sample.

Approximately 40 percent of the macrohabitat is pools. They contains four families, 18 species, and one hybrid. Two of the families also have species in shallow water. The 18 species and the hybrid make up 62 percent of the species, 493 specimens or 23.6 percent of the number, and 24,079.9 g (53.0 lbs.) or 79.8 percent of the weight of fishes in the sample.

Shannon Indices of Diversity for the entire creek are relatively high values. Higher values for either index occur at one station or stream order in several creeks and, in fact, the index for numerical diversity is greater for the First Order segment than it is for all of Spring Creek (2.47 vs. 2.32) (Tables 12, 15). However, the values of 2.32 for numerical diversity and 2.58 for biomass diversity are the third highest reported for entire creeks among 15 creeks where diversity has been reported in eastern Oklahoma (Black et al. 1986). Tahlequah Creek is nearby and has a similar fish community. Shannon Indices of 2.26 and 2.46 in that creek (Jester et al. 1988) suggest that values in this range are normal for Ozark coolwater creeks in Oklahoma.

Community Analysis

Quantitative analysis of the structure of a biotic community or any of its subdivisions, such as a fish community, depends upon complexity of the community and the type of habitat in which it occurs. Certain analyses are common to all communities and others may apply individually or in various combinations. Therefore, most of the analysis methods are selected after samples have been collected in order to determine which methods are most appropriate. Even then, choices among similar methods may be made in order to minimize effort required to gain a given amount of information. After-the-fact selection of analysis methods requires the most representative samples that may be collected.

Considered to be obvious and essential are data such as number of families and species; family affinities; number, weight, and percentages of each species; and total number and weight of fishes in each sample. In addition to these, for which formulas or models are shown for two, seven more methods (some with two parts) were selected because the authors believe that they provide an excellent description of fish communities for each stream order and the entire creek. The methods and models are shown and attributed to their various authors in Table 16.

Similarity and dissimilarity. Sorenson's (1948) Index of Similarity is designed to compare the number of species that are

Table 16. Methods and models used to compute characteristics of the fish community shown in Tables 17-19.

Parameter
Author
Method or Model

1. N - total number of individuals in sample

   $N = \sum_{i=1}^{n} n_i$, when

   n_i = no. of each species

2. W - total weight (biomass) of fishes in sample

   $W = \sum_{i=1}^{n} w_i$, when

   w_i = wt. of each species

3. Intolerant species

   Number - n of species, not individuals

   Percent = (n/N)(100), when

   n = intolerant species
   N = total number of species

4. Indices of Richness
   (for instream comparison)

   Family Richness Index

   FRI = f/F, when

   f = number of families in sample
   F = number of families in stream

   Species Richness Index

   SRI = s/S, when

   s = number of species in sample
   S = number of species in stream

5. Indicies of Dominance
   (Simpson (1949)

   $c_n = \sum_{i=1}^{n}(n_i/N)^2$, or

   $c_w = \sum_{i=1}^{n}(w_i/W)^2$, when

   n_i or w_i = importance value for each species

   N or W $= \Sigma n_i$ or Σw_i

6. Index of Similarity
   (compare two samples)
   Sorenson (1948)

   Similarity (S):

   $S = \frac{2C}{A + B}$, when

   A = number of species in Sample A
   B = number of species in Sample B
   C = number of species common to both samples

   Dissimilarity (D):

   D = 1 - S

7. Indices of Variety (or richness. Differ from our SRI because they may be compared among streams.)

   Margalef (1958)
   $d_1 = (S-1)/\log N$

   Menhinick (1964)
   $d_2 = S/\sqrt{N}$, when

   S = number of species
   N = number of individuals

8. Indicies of Evenness
   Pielou (1966)
   $e = \bar{H}/S$, when

   $\bar{H}$ = Shannon Index
   S = number of species
   (e_n or e_w depends upon use of $\bar{H}_n$ or $\bar{H}_w$)

9. Shannon Index
   Shannon and Weaver (1963)

   $\bar{H} = -\Sigma(n_i/N)\ln(n_i/N)$, when
   n_i = importance value for each species
   N = total of importance values

common to two samples with the total number of species in both samples (Method 6, Table 16). The index is a ratio or proportion with a maximum value of 1.0 which indicates maximum similarity. The reciprocal of similarity is the Index of Dissimilarity which also is 1.0 or less, with higher values indicating greater dissimilarity or simply difference in species composition. Similarity and dissimilarity of the fish community at stations within a stream reflect the combined effects of stream size and order, habitat, water quality, and any other factors that may affect population size and distribution of species.

Similarity and dissimilarity in the fish community among sampling stations and stream orders are shown in Table 17. Again, Stations 1-3 represent the First Order segment, Stations 4 and 5 represent the Second Order segment, and Stations 6-8 represent the Third Order segment.

Similarity of fishes is greater than dissimilarity among all First Order stations. Similarity between Stations 1 and 2 and Stations 1 and 3 are the same (0.667) but the greatest similarity is between Stations 2 and 3 (0.727) which share 12 of 21 species that occur at the two stations (Table 12).

Similarity also is greater than dissimilarity at Stations 4 and 5 (Second Order segment) but the S-value of 0.621 is the smallest between two consecutive stations on the creek. Physical and macrohabitat differences are greater between these stations than any others on the creek (Table 3) and the stations share only nine of 20 species that occur in the segment (Table 13). Actually, similarity is greater between transitional stations entering and leaving the Second Order segment than it is within the segment. The Indices of Similarity are 0.686 between Stations 3 and 4 and 0.643 between Stations 5 and 6. In fact, the greatest similarity among stations is an index of 0.813 between Stations 2 and 4 which share 12 of 20 species that occur at the two stations (Tables 12, 13).

Similarity of fishes also is greater than dissimilarity in the Third Order segment of the creek. However, the index for Stations 6 and 7 is 0.643 which is the least similar between consecutive stations within the same stream order except for Stations 4 and 5 in the Second Order. Then Stations 7 and 8 are the second-most-similar among consecutive stations (0.714 _vs._ 0.727 between Stations 2 and 3). The greatest similarity in the Third Order segment is shown by an index of 0.813 for Stations 6 and 8 equal to the index for Stations 2 and 4 mentioned above. Stations 6 and 8 share 13 of 19 species which occur at the two stations.

The least similar or most dissimilar assemblages of fishes are at Stations 1 and 7 and Stations 5 and 7 where both Indices of Similarity and Dissimilarity are 0.500.

When data from stations are combined and similarity is computed for stream orders, First and Second Orders are most similar, Second and Third Orders are second-most-similar, and First and Third Orders are least similar (Table 17).

Population interactions. The structure of a community is the end-product of interactions of all populations present in the community. Structure and interactions are implied or described

Table 17. Indices of Similarity (S) and Dissimilarity (D) of the fish community among sampling stations and stream orders on Spring Creek, Oklahoma, in September, 1986.

Station		Station 2	3	4	5	6	7	8
1	S	0.667	0.667	0.690	0.667	0.571	0.500	0.643
	D	0.333	0.333	0.310	0.333	0.429	0.500	0.357
2	S		0.727	0.813	0.667	0.774	0.592	0.774
	D		0.273	0.187	0.333	0.226	0.408	0.226
3	S			0.686	0.600	0.647	0.667	0.765
	D			0.314	0.400	0.353	0.333	0.235
4	S				0.621	0.727	0.690	0.727
	D				0.379	0.273	0.310	0.273
5	S					0.643	0.500	0.714
	D					0.351	0.500	0.286
6	S						0.643	0.813
	D						0.357	0.187
7	S							0.714
	D							0.286

Stream Order		Stream Order II	III
I	S	0.762	0.698
	D	0.238	0.302
II	S		0.732
	D		0.268

by the methods and models listed in Table 16. Results of several methods are listed in Tables 12 through 15 to describe changing structure of the fish community as habitat varies. Similarity and dissimilarity are shown in Table 17 and discussed above to reveal the amount of change as it occurs along the length of the creek. The other parameters are discussed here to describe interactions and characteristics which constitute a large portion of the ecology of the community.

<u>Interactions among stations</u>. Several parameters shown in Table 18 are discussed under **Community Structure** in relation to each sample of fishes. They are not discussed here but must be retained in the table for discussion of various indices for which they serve as the basis for computation. Thus, all quantitative characteristics of the fish community are shown in context with the stations at which they occur.

Indices of Richness (Method 4, Table 16) compare the number of families and species at each station with the total number of each taxon in the creek. These indicate the sum of effects of macrohabitats, water quality, and diversity within macrohabitats on distribution of fishes [Conditions are suitable or the fishes would not be present!]. Any sequential analysis that may be appropriate may be used to describe changes in family and species composition with size of the creek, diversity of habitat, stream orders, etc...

Family Richness Index or FRI in Table 18 is based upon occurrence of eight families of fishes. The smallest FRI value of 0.50 at Stations 1 and 5 represents four families or 50 percent and the largest FRI value of 0.88 at Stations 4 and 8 represents seven families or 88 percent of the families of fishes

Table 18. Characteristics of the fish community at each sampling station on Spring Creek, Oklahoma, in September, 1986. Authors and computation models are shown in Table 16.

Sample and Community Parameters	Station 1	2	3	4	5	6	7	8
N	203	192	237	411	127	245	67	607
W(g)	2400.1	2778.0	6866.5	5799.2	561.9	3043.9	3463.1	5267.7
Families (N)	4	5	5	7	4	6	6	7
Species (N)	12	15	18	17	12	16	12	16
Intolerant species:								
Number	8	10	14	12	9	10	10	12
Percent	66.7	66.7	77.8	70.6	75.0	62.5	83.3	75.0
Indices of Richness:								
Family (FRI)	0.50	0.63	0.63	0.88	0.50	0.75	0.75	0.88
Species (SRI)	0.41	0.52	0.62	0.59	0.41	0.55	0.41	0.55
Indices of Dominance:								
Abundance (c_n)	0.182	0.111	0.160	0.274	0.363	0.235	0.181	0.222
Biomass (c_w)	0.308	0.335	0.136	0.176	0.206	0.143	0.370	0.137
Indices of Similarity and Dissimilarity - see Table 17.								
Indices of Variety:								
Margalef (d_1)	4.77	6.13	7.16	6.12	5.23	6.28	6.02	5.39
Menhinick (d_2)	0.84	1.08	1.17	0.84	1.07	1.02	1.47	0.65
Indices of Evenness:								
Abundance (e_n)	1.59	1.81	1.78	1.46	1.33	1.55	1.89	1.58
Biomass (e_w)	1.42	1.54	1.71	1.60	1.67	1.86	1.26	1.57
Shannon Index:								
Abundance ($\bar{H}_n$)	1.72	2.13	2.23	1.79	1.44	1.86	2.04	1.90
Biomass ($\bar{H}_w$)	1.53	1.81	2.15	1.97	1.80	2.24	1.36	1.89

in the creek. No station has an FRI value of 1.00 or all families present, which indicates that no small segment of the creek contains all of the habitat requirements or potential niches that occur in the entire creek. Failure of Stations 4 and 8 to have all eight families is caused by presence of Cyprinodontidae (blackspotted topminnow) and absence of Poeciliidae (mosquitofish) at Station 4 and vice versa at Station 8.

The Species Richness Index or SRI in Table 18 is based upon occurrence of 29 species of fishes in the creek. The smallest SRI value of 0.41 at Stations 1, 5, and 7 represents 12 species and the largest SRI value of 0.62 at Station 3 represents 18 species. Again, as with FRI, no small segment of the creek contains all of the habitat requirements or potential niches for all of the fishes. There are no indications that water quality is limiting at any stations, which leaves the implication that habitat is least diverse at Stations 1, 5, and 7 and most diverse at Station 4. Small volume of flow at Station 1, sparse pools and abundant flat runs at Station 5, and a greater variety of depths at Station 4 (Table 3) account for low and high SRI values at these stations. However, none of these characteristics account for the low SRI value at Station 7, suggesting that differences in microhabitat may be responsible for low species diversity at that station.

Indices of Dominance (Method 5, Table 16) are based upon a maximum value of 1.000 or 100 percent of the number or weight of fishes in a sample consisting of one species. High values of less than 1.000 indicate dominance by one or a few species and lower values represent greater distribution of numbers or weight among more species, or less dominance. Indices of Dominance for both abundance (c_n) and biomass (c_w) are shown because numerical dominance may consist of small fishes while either small or large fishes may be dominant in terms of weight. Thus, the two indices are not correlated and both must be considered in order to evaluate dominance.

The largest index of numerical dominance, c_n, is 0.363 at Station 5 (Table 18). This station consists of 75 percent riffles and runs (Table 3), and three shallow-water species -- duskystripe shiner (70), banded sculpin (28), and fantail darter (10) -- make up 85 percent or 108 of 127 specimens in the sample. However, nine other species, six from pools and three from riffles, also contribute (Table 13) and, overall, the index of dominance is low. The largest index of biomass dominance, c_w, is 0.370 at Station 7 (Table 18). The station consists of 20 percent riffles and 40 percent pools (Table 3), and four pool species -- northern hog sucker (248.1 g), rock bass (835.1 g), smallmouth bass (1,902.4 g), and largemouth bass (201.2 g) [0.55-lb., 1.84 lbs., 4.19 lbs., and 0.44-lb.] -- make up 92.2 percent or 3,186.8 g (7.02 lbs.) of 3,463.1 g (7.63 lbs.) in the sample. Eight other species contribute 7.8 percent (Table 14) and the index of dominance is low.

Two different Indices of Variety, or species richness, are based upon the same general theory of computation of the number of species per number of individuals in a sample but vary in results because one (Margalef 1958) is based upon log N while the other (Menhinick 1964) is based upon $\sqrt{N}$ (Method 7, Table 16). Therefore, they may or may not differ by an order of magnitude and in some instances both may increase or decrease from station-to-station, while in other instances one may become larger while the other becomes smaller. Thus, neither is predictive of the other and each must be compared only with itself. They differ from our SRI both mathematically and by being comparable among streams while SRI is comparable only among stations within a stream. Potential values are "open-ended", or may be greater than 1.00, in both methods, with larger values representing greater variety in terms of the number of species and more-even distribution of individuals among species.

The least variety (d_1 = 4.77) occurs at Station 1 according to the Margalef Index (Table 18), where 203 individuals are distributed among 12 species and the greatest variety (d_1 = 7.16) occurs at Station 3 where 237 individuals are distributed among 18 species. According to Menhinick (1964), who places greater emphasis on the number of species by using $\sqrt{N}$ as a divisor, the least variety (d_2 = 0.65) occurs at Station 8 where 607 individuals are distributed among 16 species and the greatest variety (d_2 = 1.47) occurs at Station 7 where 67 individuals are distributed among 12 species. The minimum values of both indices are much larger in Spring Creek than they are in Tahlequah Creek (4.77 vs. 1.51 and 0.65 vs. 0.38) (Jester et al. 1988) but maximum values are similar in both creeks (7.16 vs. 7.91 and 1.47 vs. 1.40).

Indices of Evenness (Pielou 1966), e_n and e_w, are based upon distribution of Shannon Indices (Shannon and Weaver 1963) over the number or weight of species in a sample (Method 8, Table 16). Greater diversity (higher value of $\bar{H}$) for a given number or weight of species indicates more-even distribution of number or weight among the species. Therefore, larger values of e represent greater evenness and *vice versa*. This method also standardizes the computation so that values of e are comparable among stations or streams. Although the basis and objectives for computing evenness and diversity appear to be very similar, their difference is demonstrated by minima and maxima of each occurring sometimes at the same stations and sometimes at different stations. Neither are the least and greatest evenness values necessarily correlated with smallest and largest numbers or weights of species.

The lowest value of numerical evenness (e_n = 1.33) occurs at Station 5 where the lowest $\bar{H}_n$ occurs along with the second smallest numerical sample and the smallest biomass sample of fishes (Table 18). The lowest value of evenness of biomass (e_w = 1.26) occurs at Station 7 where the lowest $\bar{H}_w$ occurs along with the smallest numerical sample but the fifth largest biomass sample of fishes.

Maximum numerical evenness (e_n = 1.89) occurs at Station 7 and maximum evenness of biomass (e_w = 1.86) occurs at Station 6 along with maximum $\bar{H}_w$.

Interactions among stream orders. It has been shown that volume of flow is erratic among stations while it increases with stream orders. Sizes of fish habitats increase downstream but quality and diversity are greater upstream. Water quality is good to excellent for an Ozarks coolwater fish community.

When a large segment such as a stream order is analyzed, effects of small segments such as stations are minimized so that parameters represent the entire community including both prevailing and aberrant conditions. Community parameters for composite samples show cumulative effects of size and habitat diversity modified by water quality on the fish community in each stream order in the creek (Table 19).

If the number and weight of fishes from the Second Order segment are expanded to the equivalent of three samples, the number would be 807, which is intermediate between First and Third Orders. However, the weight would be 9,541.7 g (21.0 lbs.) or third among the three orders. The number of families of fishes is the same in each order while species and species richness indices decrease from First to Second Order and remain the same from the Second to the Third Order segment. Intolerant species decrease by one in each segment but range from 70 to 75 percent of the total number of species.

Dominance, variety, and evenness all reflect that habitat and species diversity are slightly greater in the First Order segment followed in order by the Third and Second Order segments.

Interactions in the entire creek. Detailed discussion of parameters shown for the entire creek (**Total** column, Table 19) would be repetitive except for mention of a few specific values. Therefore, data are shown but not discussed. Instead, graphic representations of changes in several parameters through the sequence of stations and stream orders is more descriptive of the dynamics of the community as it responds to changes in habitat and interactions among species from-station-to-station and from one stream order to the next.

Selection of characteristics for graphing was based upon the following rationale. The number of species or species richness varies with habitat diversity even though no single station may contain all habitat requirements for all species in the creek. The stations with fewer species should have proportionally larger populations of the best adapted species and vice versa so that dominance by one or a few species increases as the community becomes less complex. Conversely, as the community becomes more complex [more species], each population constitutes a smaller proportion of the community, and numerical expression of diversity increases accordingly. As diversity increases, dominance by one or a few species decreases as a dependent variable of diversity. Therefore, the Species Richness Index (SRI), Indices of Dominance (c_n and c_w), and Shannon Indices of general diversity ($\bar{H}_n$ and $\bar{H}_w$) were selected for graphing and for regression analysis as appropriate, and the Indices of Dominance are regressed over the Indices of Diversity to show the interactions of the two characteristics.

Twelve species of fishes occur at Station 1, 15 species at Station 2, 18 species at Station 3, and 22 species at the three stations or in the First Order segment of the creek. Species Richness Indices for these numbers are 0.41, 0.52, and 0.62 for

Table 19. Characteristics of the fish community in each stream order and all of Spring Creek, Oklahoma, in September, 1986. Authors and computation models are shown in Table 16.

Sample and Community Parameters	Stream Order I	II	III	Total
N	632	538	919	2089
W(g)	12044.6	6361.1	11774.7	30180.4
Families (N)	7	7	7	8
Species (N)	22	20	20	29
Intolerant species:				
Number	16	15	14	20
Percent	72.7	75.0	70.0	69.0
Indices of Richness:				
Family (FRI)	0.88	0.88	0.88	1.00
Species (SRI)	0.76	0.69	0.69	1.00
Indices of Dominance:				
Abundance (c_n)	0.117	0.281	0.188	0.149
Biomass (c_w)	0.137	0.155	0.110	0.100
Indices of Similarity and Dissimilarity - see Table 17.				
Indices of Variety:				
Margalef (d_1)	7.50	6.96	6.75	8.43
Menhinick (d_2)	0.88	0.86	0.69	0.64
Indices of Evenness:				
Abundance (e_n)	1.84	1.38	1.54	1.59
Biomass (e_w)	1.68	1.62	1.82	1.76
Shannon Index:				
Abundance ($\bar{H}_n$)	2.47	1.79	2.04	2.32
Biomass ($\bar{H}_w$)	2.26	2.11	2.40	2.58

the stations and 0.76 for the segment (Fig. 13). The indices for Station 3 and the First Order segment are the highest values in the creek. In the Second Order segment, 17 species occur at Station 4, 12 species at Station 5, and 20 species at the two stations. SRI values are 0.59 and 0.41 for the stations and 0.69 for the segment. The indices at Stations 3 and 4 are the highest in the creek, reflecting the greatest habitat diversity.

Fifteen species occur at Station 6, 12 species at Station 7, 16 species at Station 8, and 20 species in the Third Order segment. SRI values are 0.52, 0.41, and 0.55 for the stations and 0.69 for the segment (Fig. 13). Whereas, size of the creek, habitat diversity, and Species Richness Indices increase downstream in Tahlequah Creek (Jester et al. 1988), habitat

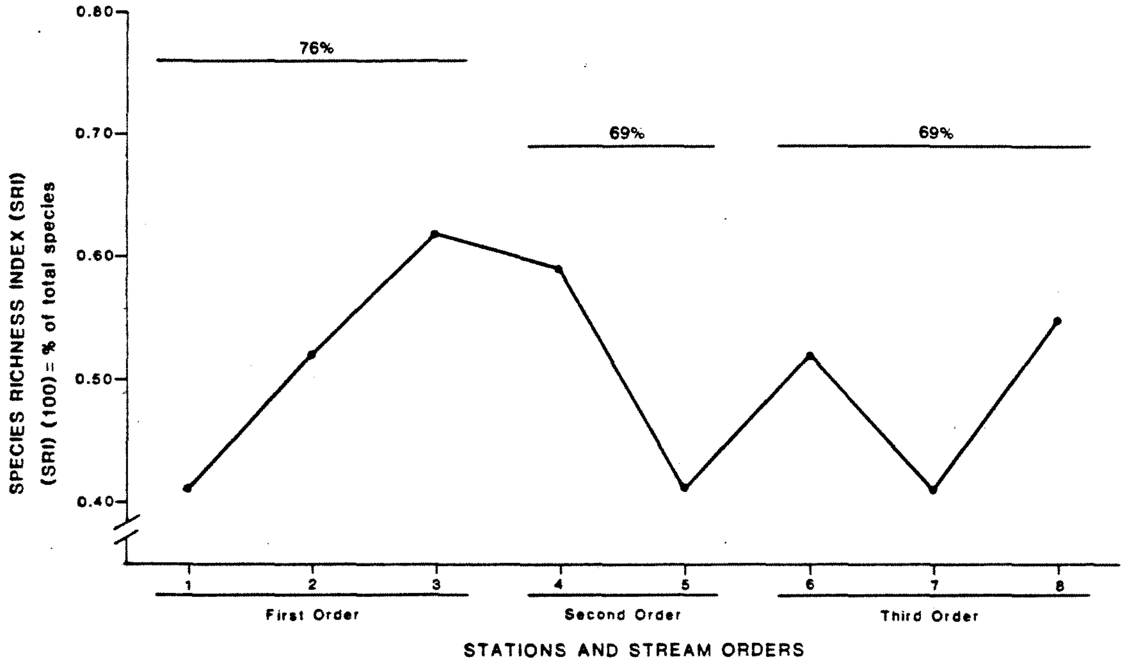


Figure 13. Species Richness Indices or fraction of all species that occur at each station and in each stream order in Spring Creek. Fishes collected in September, 1986.

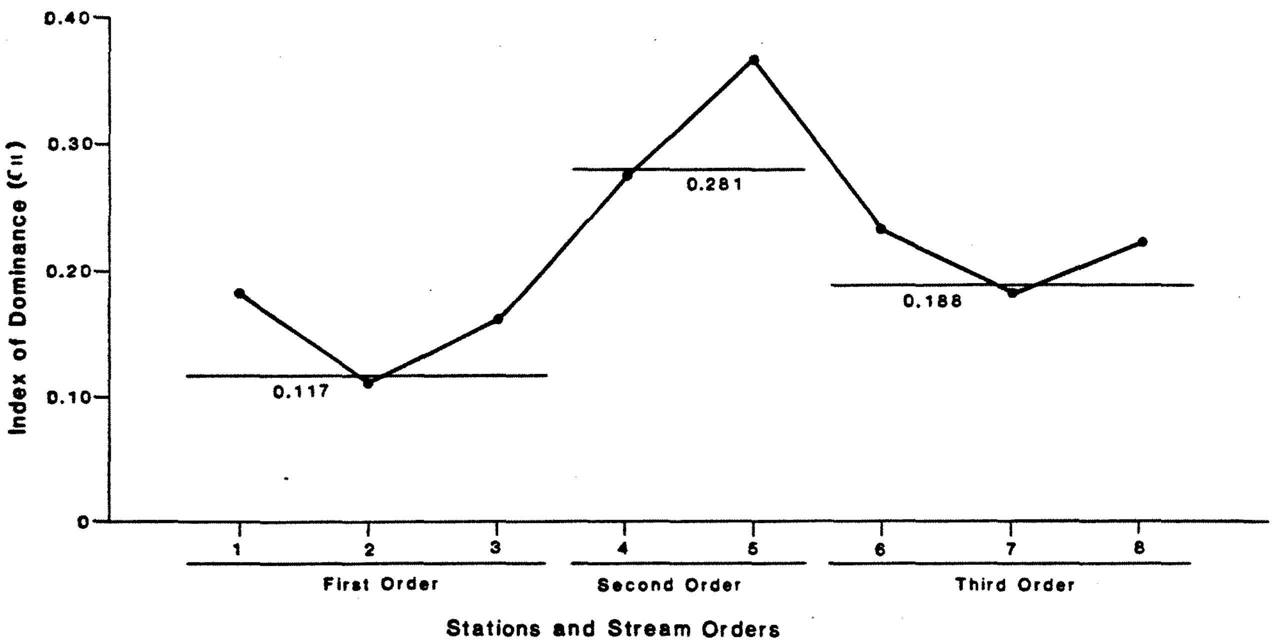


Figure 14. Indices of numerical dominance (Simpson 1949) of fishes at stations and in stream orders in Spring Creek. Fishes collected in September, 1986.

diversity is erratic in Spring Creek and appears to control the Species Richness Index.

Dominance by abundance of one or a few species (c_n) is erratic among stream orders but relatively consistent among stations within each order (Fig. 14). Also, largest dominance values caused by one or a few species are expected at First Order stations where the smallest number of species and the least habitat diversity usually occur (Jester et al. 1988). These conditions are not met and three of the four smallest dominance indices for stations and the smallest for a stream order occur in the First Order segment.

Station 4 has a unique combination of large uniform riffle habitat along with smaller amounts but great diversity of pool conditions. The result is that 17 species occur at the station but 260 or 63.3 percent of 411 fishes collected were the duskystripe shiner (194) and central stoneroller (66). The Index of Dominance is 0.274 or the second highest value despite the second largest number of species in the creek.

Habitat diversity is low at Station 5 where flat runs and riffles make up 75 percent of the area of the creek. Twelve species were collected, of which the duskystripe shiner and banded sculpin make up 70 and 28 respectively or a total of 98 which is 77.2 percent of 127 fishes in the sample. The Index of Dominance at the station is 0.363 and the index for the segment is 0.281, both representing the highest values in the creek.

Habitat diversity is much greater in the Third Order segment but still less than it is in the First Order. Consequently, Indices of Dominance are intermediate between the indices for First and Second Order segments and the groups of stations within each order.

Dominance by biomass appears to be scarcely related to numerical dominance (Fig. 15). The second- and third-most-dominant values occur at Stations 1 and 2 but are offset by the lowest value in the creek at Station 3 so that the First Order segment has an intermediate value, compared with the lowest numerical index. Stations 4 and 5 have low indices of biomass compared with numerical indices but are consistent enough for the Second Order segment to have the highest value of dominance by biomass. The largest index occurs at Station 7 but is offset by the second- and third-lowest values at Stations 6 and 8. Therefore, the index for the Third Order segment is the lowest in the creek, which is the only one of the six indices of abundance and biomass to conform with theoretical expectations. By comparison, Indices of Dominance for both abundance and biomass decrease linearly from First to Third Order in Tahlequah Creek (Jester et al. 1988).

Shannon Indices of general diversity apparently also are controlled more by effects of habitat diversity on community composition than by any other factor. In Tahlequah Creek, numerical and biomass diversity increase linearly with both stations and stream orders along with size of the creek, number of species, and habitat diversity (Jester et al. 1988). In Spring Creek, habitat diversity is greatest overall in the First Order segment, least in the Second Order segment, and

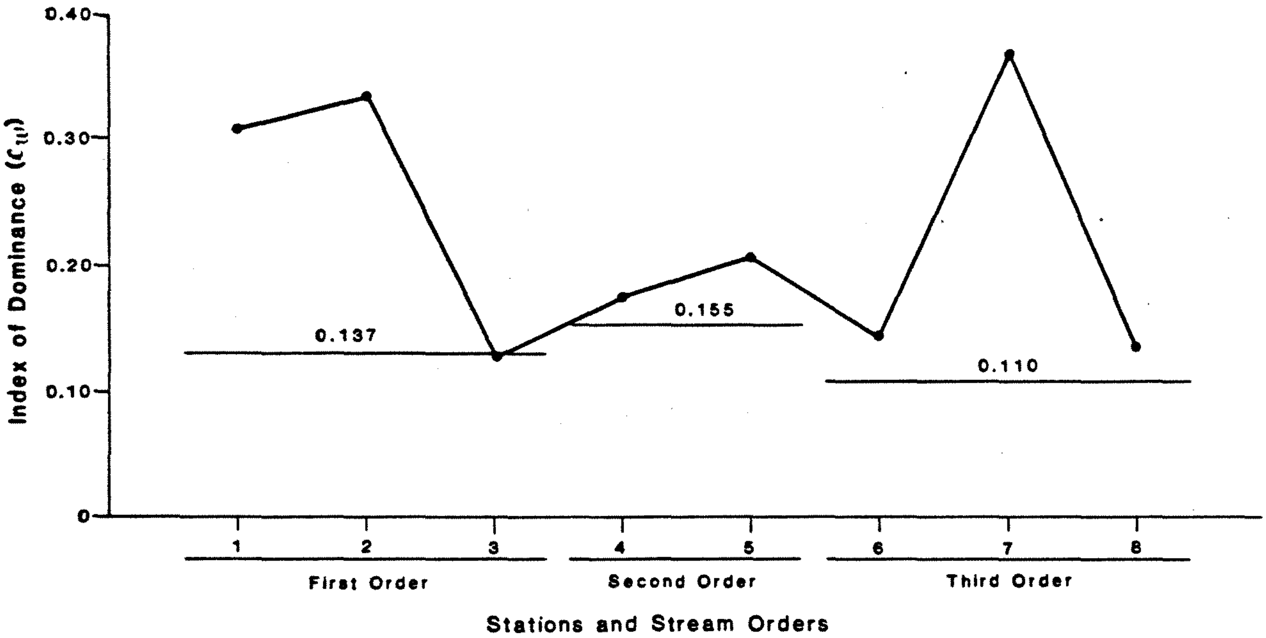


Figure 15. Indices of dominance by biomass (Simpson 1949) of fishes at stations and in stream orders in Spring Creek. Fishes collected in September, 1986.

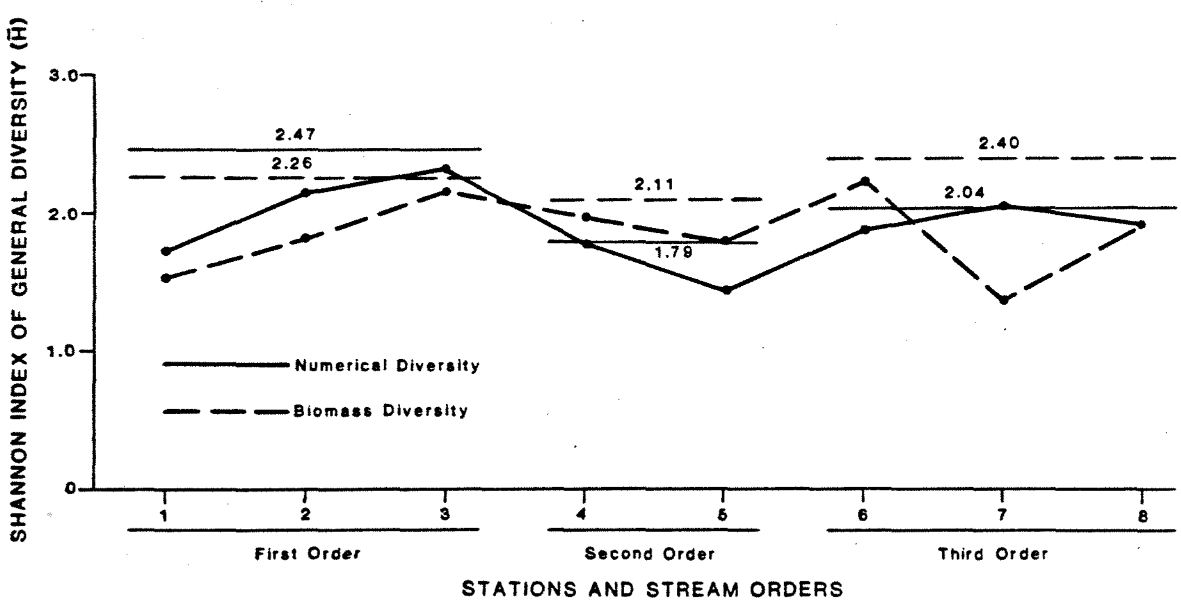


Figure 16. Shannon Indices of general diversity (Shannon and Weaver 1963) of abundance and biomass of species of fishes at each station and in each stream order in Spring Creek. Fishes collected in September, 1986.

intermediate in the Third Order segment. The Shannon Indices conform with habitat diversity regardless of size of the creek and number of species (Fig. 16).

If dominance is a dependent variable which decreases as diversity increases or *vice versa*, indices of dominance graphed over indices of diversity should yield lines which have negative slopes and close correlations. Numerical dominance by one or a few species decreases linearly as diversity, or more-even distribution of individuals among species, increases. The slope is $-0.2652\bar{H}_n$ (Fig. 17). Close correlation is demonstrated by observed r = -0.857 exceeding required r = -0.834 @ 1%. Dominance of biomass also decreases linearly as diversity increases, with a slope of $-0.2797\bar{H}_w$ and a close correlation of r = -0.852 (req. r = -0.834 @ 1%) (Fig. 18). Therefore, it appears that dominance and diversity constitute an interaction with diversity functioning as the independent variable and dominance functioning as the dependent variable. The change is linear here and in Tahlequah Creek (Jester et al. 1988).

Partitioning Resources

Closely-related species may partition habitat, food, and time of use (diel, seasonal) in order to occur and thrive in a given environment or community (Ricklefs 1973, Schoener 1974). Habitat partitioning is most common among terrestrial communities (Schoener 1974). Schoener suggested, however, that investigation of fish communities, especially in lotic ecosystems, would demonstrate that other factors may be more important than habitat.

Until recently, most studies of fish assemblages have emphasized food utilization and dietary overlap (Starrett 1950, Maitland 1965, Keast 1966, Moyle 1973, Wynes and Wissing 1982, McNeely 1987). However, Adamson and Wissing (1977), Werner (1977), Werner et al. (1977), and Harrell (1978) have shown that partitioning of habitat and feeding time or periodicity by fishes also are important.

Competition has been noted to vary with local factors (Wiens 1977, Sale 1977, 1979, Lister 1981, Grossman et al. 1982, Schlosser 1982), and was discussed for cyprinids in Spring Creek by McNeely (1987). Mendelson (1975) suggested that distinct food niches of four species of *Notropis* resulted from morphological adaptation to microhabitats where distinct food types occur. Werner (1977) and Werner et al. (1977) studied functional morphology and spatial segregation of species to explain species composition of sunfishes and distribution of sunfishes and other groups of fishes (species packing and niche complementarity) in small Michigan lakes.

McNeely (1987) studied niche relations of the cyprinids in Spring Creek during an extreme drought in 1980. He described the creek as a series of long springlike pools (surfacing of subterranean flow) isolated by dry channels up to several hundred meters long in the headwaters. Some pools remained connected by riffles. Downstream, stretches of flowing water were much longer

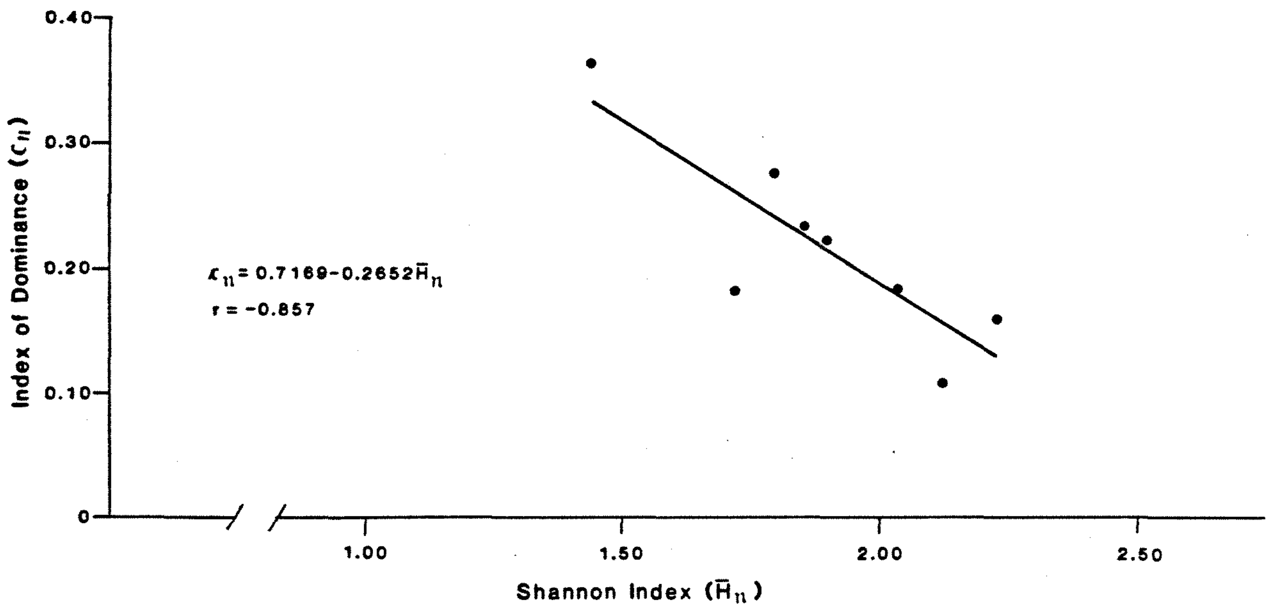


Figure 17. Linear relationship between numerical dominance and diversity of species of fishes in Spring Creek, September, 1986.

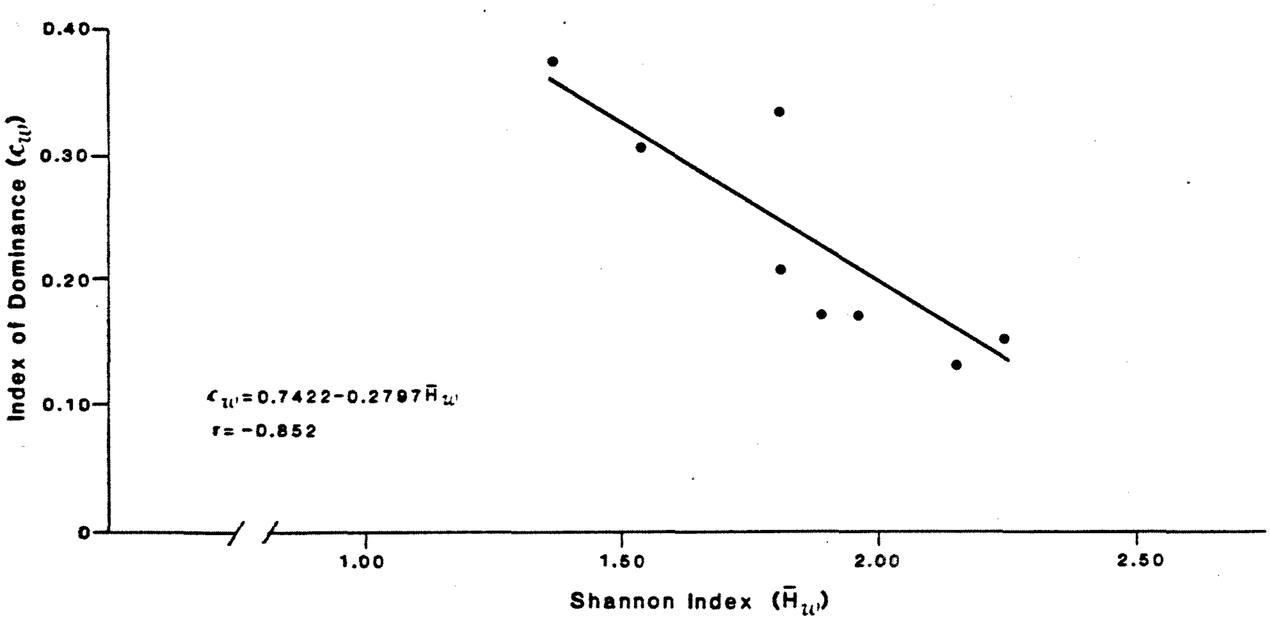


Figure 18. Linear relationships between biomass dominance and diversity of species of fishes in Spring Creek, September, 1986.

and most of the channel contained water continuously. He described the result of these conditions as 80 percent pools alternating with 20 percent riffles. He analyzed food habitats and performed a complex evaluation of habitats, and concluded that seven species of cyprinids were more specialized by diets than by microhabitats. Interspecific niche overlap was greatest upstream which McNeely described as less stable environmentally, and certainly was less stable at the time of his investigation.

At the time of our investigation in 1986, after topography and hydrology had varied about conditions shown in Table 3 for six years, both habitat and distribution of fishes in the creek were quite different from 1980. Flow was continuous except for one segment 0.5-mile (0.8-km) long between Stations 4 and 5 where surface flow occurs only during floods. Approximately 25 percent of the creek was riffles and 36.25 percent was flat runs, or approximately 61 percent was shallow, rapidly-flowing water and 39 percent was pools.

Several species of minnows were collected only from riffles and runs and several were collected only from pools. We used observed characteristics of collection sites to determine microhabitats occupied by each species, and computed Schoener (1968) Indices of dietary overlap[8] to determine if species were dependent upon or competing for the same food items.

Food habits of the central stoneroller, southern redbelly dace, and duskystripe shiner -- found only on riffles and runs -- are shown in Table 20. The central stoneroller and southern redbelly dace are primarily herbivores, and a Schoener Index value of 0.775 (Table 21) reflects considerable use of the same broad categories of plant materials. However, it is suspected that identification of food to lower taxonomic levels would reduce the Schoener Index value substantially. Regardless of similarity in food habits, southern redbelly dace were concentrated in shallow riffles ≤3.0 inches (7.6 cm) deep and central stonerollers were concentrated in riffles 4.0 to 6.0 inches (10 to 15 cm) deep, overlapping mostly in depths of 3.0 to 4.0 inches (7.5 to 10 cm), therefore partially separating the two species by partitioning habitat.

The duskystripe shiner is an omnivore which inhabits the deeper riffles and adjacent flat runs up to approximately one foot (30 cm) and sometimes as much as 18 inches (0.5-m) deep. Its habitat and diet overlap slightly with the central

[8]Index of dietary overlap (Shoener 1968):

$$D = 1 - 0.5 \sum_{i=1}^{n} | P_{x,i} - P_{y,i} |$$

When: $P_{x,i}$ = proportion of food item i in the gut content of species x.

$P_{y,i}$ = proportion of food item i in the gut content of species y.

n = number of available food items in combined gut contents of species x and y.

Table 20. Proportions or relative importance[1] of food items in the diets of riffle-dwelling Cyprinidae in Spring Creek, Oklahoma.

Food Item	Central stoneroller	Southern redbelly dace	Duskystripe shiner
Non-filamentous algae	0.541	0.357	0.071
Filamentous algae	0.092	0.116	0.187
Vascular plants	0.037	0.082	0.203
Detritus	0.302	0.289	0.091
Benthos			
Chironomidae	0.028		
Hyallela		0.054	0.030
Baetis		0.039	
Caenidae		0.034	
Marilia			0.060
Psephenus			0.156
Elimia potosiensis			0.078
Adult or terrestrial animals			
Chironomidae		0.029	0.028
Terrestrial flies			0.048
Terrestrial beetles			0.048
Summary			
Plant material	0.972	0.844	0.552
Benthos	0.028	0.127	0.324
Terrestrial animals	0.000	0.029	0.124

[1]Proportions or importance values x 100 = percent of food in gut consisting of the listed item or category.

Table 21. Schoener (1968) Indices of dietary overlap among riffle-dwelling Cyprinidae in Spring Creek, Oklahoma.

	Southern redbelly dace	Duskystripe shiner
Central stoneroller	0.7750	0.2895
Southern redbelly dace		0.4175

stoneroller, indicating separation primarily by habitat and secondarily by diet. The Schoener Index indicates a dietary overlap with the southern redbelly dace, or use of some of the same food items, but no competition occurs because of specialization by microhabitats. Especially if it is accepted that Schoener Index values must equal or exceed 0.60 to indicate significant competition (Zaret and Rand 1971), the riffle-dwelling minnows in Spring Creek are much more specialized by microhabitat than by diet, a reversal of McNeely's (1987) conclusion from data collected in 1980.

Food habits of the redspot chub, creek chub, Ozark minnow, and rosyface shiner -- found only in pools -- are shown in Table 22. The Ozark minnow was the second- or third-most-numerous fish in the creek during McNeely's study but did not occur in our samples. Also, the bigeye shiner consisted of only eight specimens in our samples and was not collected by McNeely. We retained the Ozark minnow here because data are available, and excluded the bigeye shiner because of the small sample.

The Ozark minnow is the only pure herbivore (100% plant food) and the redspot and creek chubs are the only pure carnivores (100% animal food) (Table 22) known among the cyprinids in the creek. Food habits of the bigeye shiner are unknown, but a short intestine (Miller and Robison 1973) indicates carnivory which may be modified slightly by inclusion of plant material similar to the diet of the rosyface shiner. Food habits and Shoener Indices reveal that very little dietary overlap occurs among any of the pool-dwelling species, indicating that the species are specialized by diet (Tables 22, 23). However, microhabitats also must be considered to be a factor in partitioning of resources among these minnows.

The redspot chub inhabits large, gravel-bottom pools, usually 2.5 to 4 feet (0.8 to 1.2 m) deep, and may or may not utilize cover. It mingles with schools of rosyface shiners and probably Ozark minnows (when present), partitioning resources with these species by specialized diets. In fact, the three species appear to be specialized by diets more than by microhabitats.

The creek chub is a large minnow, often exceeding six inches (15 cm) total length, but inhabits small, or at least shallow, pools, usually less than two feet (0.6-m) deep. Smaller individuals mingle in schools with the rosyface shiner and probably the Ozark minnow, partitioning resources by specialized diets. The larger individuals feed and appear to function, in terms of Micropterus-like behavior, as top carnivores. They feed on small fishes, crawfishes, and a few other large invertebrates along with approximately 65 percent terrestrial forms taken by striking at the surface. Specimens were collected over gravel and stable silt but were always associated with cover. When several individuals were collected at the same site, congregation appeared to result from use of cover and not from a tendency to school. The redspot and creek chubs, and large creek chubs and other top carnivores, partition resources by habitat specialization regardless of diet.

According to interpretation of habitat and food

Table 22. Proportions or relative importance[1] of food items in the diets of pool-dwelling Cyprinidae in Spring Creek, Oklahoma.

Food Item	Redspot chub	Creek chub	Ozark minnow	Rosyface shiner
Non-filamentous algae			0.267	0.024
Filamentous algae			0.111	0.058
Vascular plants			0.082	0.028
Detritus			0.540	
Elimia potosiensis	0.523	0.210		
Marilia	0.152			
Orconectes	0.138	0.039		
Helicopsyche	0.070			
Psephenus	0.051	0.028		0.044
Chironomidae	0.041			
Lanthus	0.026			
Adult aquatic beetles		0.065		
Baetis				0.049
Caenidae				0.042
Hyallela				0.048
Terrestrial beetles		0.185		0.085
Terrestrial flies		0.178		0.093
Ants		0.114		0.287
Adult caddisflies		0.053		0.083
Bees and wasps		0.048		
Hemiptera		0.039		
Orthoptera		0.031		
Adult Chironomidae				0.064
Adult Mayflies				0.050
Spiders				0.029
Adult Odonata				0.028
Summary				
Plant material	--	--	1.000	0.110
Benthos	1.000	0.342	--	0.183
Terrestrial animals	--	0.658	--	0.707

[1]Proportions or importance values x 100 = percent of food in gut consisting of the listed item or category.

specialization above, both factors contribute to partitioning of resources among cyprinids in Spring Creek, while McNeely (1987) recognized only dietary specialization in 1980. Also, the creek did not appear to be less stable nor interspecific niche overlap greater upstream than downstream as described by McNeely. Recognizing the instability of habitats that occurred during the drought in 1980, it appears that the cyprinids are versatile or tolerant enough to coexist and minimize competition by diet specialization during temporary loss of microhabitats, then redistribute themselves when their preferred microhabitats are reestablished. McNeely touched upon this phenomenon by stating "Perhaps stream minnows in unstable habitats are opportunists whose niches vary in size and structure in response to environmental change,...".

Table 23. Schoener (1968) Indices of dietary overlap among pool-dwelling Cyprinidae in Spring Creek, Oklahoma.

	Creek chub	Ozark minnow	Rosyface shiner
Redspot chub	0.282	0.000	0.025
Creek chub		0.000	0.377
Ozark minnow			0.109

Table 24. Schoener (1968) Indices of dietary overlap among darters in Spring Creek, Oklahoma. From Gore and Lindsay (1985). Arkansas darter added as per discussion in text.

	Orangethroat darter	Stippled darter	Least darter	Arkansas darter
Fantail darter	0.460	0.370	0.310	0.000
Orangethroat darter		0.470	0.330	0.049
Stippled darter			0.150	0.059
Least darter				0.000

Gore and Lindsay (1985) investigated partitioning of resources among four species of darters in Spring Creek in 1982 and 1983. They noted that Wynes and Wissing (1982) and other investigators have demonstrated that partitioning of food is most important among some assemblages of darters, and Adamson and Wissing (1977) and others found that some partitioning of food among darters is accomplished by utilizing the same habitat and sources of food at different times. Gore and Lindsay (op. cit.) determined habitat preferences of the darters by use of the methods of Gore and Judy (1981). Dietary overlap was computed by use of the Schoener (1968) Index that we used for cyprinids. We use Gore and Lindsay's results from their as-yet-unpublished paper with verbal permission of the senior author, Dr. James A. Gore of the University of Tulsa, Tulsa, Oklahoma.

Schoener Indices of dietary overlap computed by Gore and Lindsay are shown in Table 24. We added the computations for the Arkansas darter, Etheostoma cragini, computed from the food of one specimen which was 100 percent snails in the genus _Physella_. Certainly no statistical validity can be claimed for one specimen, but one specimen containing only snails suggests that snails are a major food item and that low overlap values with the other darters may be expected.

Analysis of habitat preference supported Page's (1983) suggestion that most darters have strict habitat requirements, with substrate being the most critical physical requirement. The fantail and orangethroat darters appear to prefer depths of 13.8 to 21.3 inches (35 to 45 cm) and the stippled and least darters appear to prefer 21.3 to 29.5 inches (45 to 75 cm) but without enough separation among any of them to specify a depth requirement other than 13.8 to 29.5 inches (35 to 75 cm) for all of them. Also, three species displayed a preference for a velocity of flow of approximately 25 cm (9.8 inches)/second, with only the least darter preferring a different velocity of <10 cm (3.9 inches)/second (mean velocity of water column).

Other than the least darter preferring low velocity, habitat specilization appears to be sharply defined only by substrate preference. The fantail darter, which contributed 95 specimens or 39.1 percent of the sample, has the least specific substrate requirement, inhabiting coarse gravel and small rubble (described as "medium cobble" by Gore and Lindsay (op. cit.)). The orangethroat darter, which contributed 56 specimens or 23.0 percent of the sample, inhabits fine gravel and course sand, which is the second-most-generalized substrate requirement.

The least darter is found almost exclusively in dense macrophyte beds, mostly _Myriophyllum_, in slack water (low velocity) with undergravel flow. Importance of macrophytes appears to be demonstrated, as discussed under **Vascular plants**, by Gore and Lindsay collecting 57 specimens of the least darter from _Myriophyllum_ beds in 1982 and 1983 while we collected none in 1986 after _Myriophyllum_ was destroyed by movement of gravel during a flood in 1985.

The stippled darter also was collected from macrophyte beds but was found along the edges generally away from least darters which inhabited the central body of plant beds. Most stippled darters were collected in leaf litter along edges of pools and riffles (Gore and Lindsay op. cit.). We found very little leaf litter but collected 38 stippled darters which made up 15 percent of our sample while Gore and Lindsay collected 25 specimens which made up only 10 percent of their sample. Our specimens were collected at the downstream edge of riffles in and near sparse stands of water willow and woody debris, which suggests, because _Myriophyllum_ and leaves were sparse, that the riffles and sparse water willow provide a secondary or alternate microhabitat.

We collected one slenderhead darter and Gore and Lindsay collected a total of 10 logperch, greenside darters, and Arkansas darters. Therefore, they, and we, must classify these species as transient, and no conclusions may be drawn concerning partitioning of habitat or food. However, the four species studied are separated by specialization of microhabitats, but diet specialization probably is adequate for all of them to coexist during periods of major environmental instability as the cyprinids did during McNeely's investigation.

Gore and Lindsay also noted coexistence of the banded sculpin with the darters and cited literature to conclude that the sculpin may be a competitor (Daiber 1956), predator (Howell and Dingerkus 1978), or both. They were uncertain of this relationship other than coexistance in Spring Creek because food of the sculpin was finely-ground and unrecognizeable. However, in our samples, we collected sculpins and slender madtoms in closer proximity than sculpins and darters.

Food of the slender madtom is described in literature as insect larvae and other small animals while food of the banded sculpin is described as insect larvae, small crustacea, and small fishes (Miller and Robison 1973). This implies that the greatest difference in food habits of the two species is fishes, which obviously may be mostly or all darters. Also, microhabitat is similar, consisting, in literature (Miller and Robison op. cit.) and in the creek, of shallow, fine-to-medium-gravel riffles for the slender madtom and medium to course gravel for the banded sculpin. Most of the very-shallow riffles consist of fine gravel and only the madtom is present while most of the deep riffles consist of coarse gravel and only the sculpin is present. However, most of the riffles are intermediate in depth and consist of mixed (thus, medium) gravel, and support both sculpins and madtoms. This coexistence of the two species in most of their habitats suggest strongly that partitioning of food must be fairly pronounced at lower taxonomic levels and habitat is only slightly-partitioned by slightly different ranges of tolerance of gravel size.

The mosquitofish and blackspotted topminnow which we collected, and the plains topminnow reported by Branson (1967), all inhabit shallow backwater pools and have very similar food habits described generally by Miller and Robison (op. cit.) as terrestrial and surface-feeding aquatic insects and surfacing aquatic larvae (midges and mosquitoes). The only apparently-significant difference among the three species for resource-partitioning purposes is the habitat in and substrate over which they occur. The blackspotted topminnow occurs over open gravel bottom and the plains topminnow occurs over sand or gravel among vegetation. The mosquitofish utilizes vegetation or other cover if it is available but appears to be more dependent upon silt or soil bottom, which apparently accounts for its sparsity in Ozark creeks. Therefore, these species apparently partition resources which occur in backwaters entirely on the basis of combinations of bottom type and vegetation, or microhabitat.

Collection sites and general descriptions of habitat requirements and food habits in literature (Miller and Robison op. cit.) also indicate the relative importance of habitat and food habits for partitioning resources among five species of Catostomidae found in Spring Creek. The northern hog sucker inhabits moderately-deep riffles and riffle-pool transitions where it feeds on small organisms on and under stones. We found the hog sucker consistently in the transition zone at the upstream end of pools at a depth of approximately two feet (0.6-m) in both Spring and Tahlequah Creeks (Jester et al. 1988).

The black and golden redhorses are described as inhabitants of medium and moderate-size streams (Miller and Robison op. cit.), which appears to translate to medium-size pools in both Spring and Tahlequah Creeks. We found the black redhorse on coarse gravel and bedrock in slow current at depths of about three feet (1 m) and the golden redhorse on coarse gravel and thin silt (one instance of the latter in Tahlequah Creek) in slow current at depths of three to four feet (0.9 to 1.2 m). Gravel appears to be the preferred substrate and, therefore, microhabitat requirements are similar, varying in range of substrate and perhaps minor differences in depth. Food habits are similar in that both species feed on insect larvae but differ by the black redhorse feeding on crustacea and aquatic worms and the golden redhorse feeding on small mollusks such as snails and fingernail clams (Miller and Robison op. cit.). Therefore, the two redhorses appear to partition resources by a combination of microhabit preference and food habits, with emphasis on food. However, none were collected together despite an appearance that they could coexist in the same pools, indicating subtle or undetected differences in microhabitat requirements.

Macrohabitat preference of white and spotted suckers is described by Miller and Robison (op. cit.) as gravel or hard bottom but tolerant of some silt in slow pools of large creeks and [usually] small rivers. Apparently only the larger pools in Spring Creek are large enough for these species probably because of slow-flow requirements, and none were found in the smaller-maximum-size pools in Tahlequah Creek. In Spring Creek, both species were collected from one pool and each species was collected separately from one additional pool. They were taken at Stations 4, 6, and 7, which contain the deepest pools in the creek (Table 3). Because they coexisted in one pool and sampling was too difficult in the other large pools for us to say that they did not coexist there, we must conclude that these suckers do not partition resources by habitat specialization. Food habits are more specialized, with the white sucker consuming a variety of small benthos and the spotted sucker feeding on mollusks and other benthic invertebrates. Lips of the white sucker are large, fleshy, and papillose as compared to thin, plicate lips of the spotted sucker, suggesting consumption of larger benthic organisms by the spotted sucker.

These data, although somewhat sparse and general, indicate that the five species of suckers partition resources partly by specializing in three categories of macrohabitat; the northern hog sucker in riffle-pool transition zones, black and golden redhorses in pools of medium sizes and depths, and white and spotted suckers in large, deep pools. Then, the redhorses partition resources within the pools primarily by diet specialization and apparently secondarily by microhabitat requirements. The white and spotted suckers may coexist in the same macro and microhabitats but partition resources by diet specialization. All of these inhabit pools which probably persist through drought conditions, and it does not become necessary for them to coexist to any greater extent than they do under normal conditions.

Careful consideration of Werner's (1977) paper on species packing and niche complementarity, based upon MacArthur and Levins' (1967) functional morphology concept, appears to explain why the sunfishes which occur in Spring Creek are present and others are not. Then, partitioning of resources among the species present is explained by consideration of food and habitat specialization as was done above for other families and ecologically-similar groups.

Four small, relatively-short, laterally-compressed, deep-bodied forms -- rock bass, green sunfish, bluegill, and longear sunfish -- feed upon various sizes and combinations of insects, crustaceans, mollusks, and small fishes. They also all inhabit pools and utilize cover and concealment. Therefore, they are ecologically-similar and must coexist by partitioning food, microhabitat, or both.

Werner et al. (1977) found eight species of sunfishes in two small Michigan lakes as we did in Spring Creek. Five of the species were the same, two were distinctly different, and the white crappie in Spring Creek is ecologically very similar to the black crappie in the lakes. They found only the largemouth bass and bluegill segregated by food size and the other centrarchids segregated predominantly by habitat.

We found similar partitioning of resources by the sunfishes in Spring Creek but did not, in some instances, find species in habitats where they would be expected in the transition from lakes to creeks. For example, green and longear sunfishes inhabit shallow littoral benches in the lake, partitioning habitat by the longear sunfish being closely-associated with bottom and the green sunfish concentrated higher in the water column. In Spring Creek, green sunfishes are found mostly in small, shallow pools, undercuts, vegetation, and tree roots over almost any bottom material. Conversely, the longear sunfish inhabits moderately-deep to deep pools. Most of them are found in the upper portion of the water column under or near overhanging terrestrial vegetation or dead brush where a major portion of their food is terrestrial insects. They also inhabit deeper pools with bluegills but remain somewhat separated by closer affinity of the longear sunfish with vegetation, large rubble, boulders, and inundated bluffs.

The bluegill inhabits the larger, deeper pools which have little or no vegetation. However, it uses woody brush, logs, and sometimes boulders for cover and concealment when these materials are present. It tolerates a variety of bottom materials but occurs mostly over gravel because of availability in Spring Creek.

The rock bass inhabits moderately-deep pools, usually three to four feet (0.9 to 1.2 m) deep. It requires cover which usually is rubble or boulders but frequently occurs under woody debris or over bedrock where it utilizes large cracks and "stepoffs". Thus, it partitions habitat with the other small sunfishes but frequently coexists with the smallmouth bass. One experience with the rock bass which appears to indicate some tendency in selecting habitat, although we have not interpreted the tendency, occurred when we sampled fishes at Station 7. We set a bag seine with a 6-foot by 4-foot (1.8 x 1.2-m) bag-opening as a blocking seine where the maximum depth of the creek was approximately 2½ feet (0.8-m) downstream from a pool about four feet (1.2 m) deep. We did not sample in the vicinity of the seine but left it in the creek overnight. When we removed it without seining or electrofishing the next morning, the bag contained 12, 4 to 6-inch (10 to 15 cm) rock bass and no other fishes, conveying the impression that they were attempting to colonize the bag.

Four of the larger sunfishes -- consisting of smallmouth, spotted, and largemouth basses and white crappie -- also were collected from Spring Creek. All have similar food habits in terms of broad categories of items but generally differ in terms of size of food organisms, order of preference, or both (Table 25) (Food habits interpreted from Miller and Robison (1973) except as noted in the table). Therefore, despite similarities in food shown in Table 25, most of these fishes probably could coexist in the same habitat on the basis of partitioning food resources by size or order of preference.

An example of potential partitioning of food by size is the utilization of the same categories of items by the smallmouth and largemouth basses. Apparently some partitioning would result from reversed order of preference for the two most-preferred categories of food. In fact, first preference for crawfish by the smallmouth bass consists of year-round feeding on that item while the second preference for crawfish by the largemouth bass consists of heavy use in late winter and early spring (ca. February to mid-April) with only occasional use at other times (Jester 1962). In terms of size, Stein (1977) found that the smallmouth bass tended to take the smallest crawfishes available, apparently to minimize effects of the ability of the active, armed prey to defend itself. In Spring Creek, they take mostly medium size crawfishes because small individuals are less available on gravel bottom. However, there are no indications that fishes and insects which do not have defensive mechanisms are selected for small size, but, rather, they are selected by Ivlev's (1945) Principle of the predator taking the largest prey that it can capture and swallow without difficulty. Conversely, the largemouth bass apparently does not honor the defensive ability of the crawfishes because of the destructive ability of the bass in its "striking" behavior to stun or kill its prey. Its size selection of crawfishes and other prey appear to conform entirely with Ivlev's Principle, and its larger mouth results in a largemouth bass feeding upon much larger items than a smallmouth bass of the same size. Timmons and Pawaputanon (1980) found that more than 90 percent of the fishes in stomachs of largemouth bass were in the range of 25 to 50 percent of the length of the bass while prey of these sizes made up much smaller percentages of the prey populations. Although we do not know of a similar study of the sizes of prey taken by the smallmouth bass, the senior author, in many years of experience, cannot recall finding a food item that was any larger than 25 percent of the length of the bass in which it was contained. This difference is explained by the relative size of the mouths of the two predators; the length and gape of the mouth of the smallmouth

Table 25. Broad categories and orders of preference for food eaten by the four large species of sunfishes in Spring Creek, Oklahoma.

Species	Categories of Food and (Order of Preference)		
Smallmouth bass	Large insects(3)	Small to medium crawfish(1)	Small fish(2)
Spotted bass	Insects (2)	Small to medium crawfish(1)	Small fish(3)
Largemouth bass	Large insects(3)	Medium to large crawfish(2)	Fish[a] (1)
White crappie[b]			
Subadult (<8 in. or 20 cm)	Insects (1)	Small crustacea (2)	Small fish(3)
Adult (>8 in. or 20 cm)	Insects (3)	Small crustacea (2) (mostly Cladocera)	Small fish(1)

[a]Most fishes eaten by largemouth bass are 25 to 50% of the length of the bass (Timmons and Pawaputanon 1980). All sizes of crawfishes found by Jester (1962).

[b]Orders of preference from Jester (1962).

bass being approximately 2/3 to 3/4 of the size of the mouth of the largemouth bass, with sizes of prey other than crawfishes reduced accordingly.

Another example of the ability of some of these species to coexist by partitioning food is the largemouth bass and white crappie, which coexist in the same habitat in many waters, although they were not collected together in Spring Creek. Subadult crappies partition food with adult crappies and largemouth bass by order of preference (Table 25) and also feed on smaller species and individuals in each category of food. However, the coexisting largemouth bass and adult crappies use the categories of food in the same order of preference. Thus, they must partition food by size in order to coexist. This is reflected in Table 25, and is based upon effect of relative mouth size on Ivlev's Principle; the mouth of the white crappie and the sizes of its prey being considerably smaller than those of the largemouth bass (e.g., Cladocera vs. crawfish).

Two species which probably could not coexist by partitioning food are the smallmouth and spotted basses. The mouth of the spotted bass is slightly larger relative to size of the fish than the mouth of the smallmouth bass, but potential, and usually actual, size of the spotted bass is smaller. Therefore, mouth sizes of both species are similar. Also, the spotted bass eats mostly crawfish while crawfishes consistently constitute more than 50 percent of the food of the smallmouth bass. Because of comparable mouth sizes of the fishes and availability of the sizes of crawfishes, both fishes are dependent upon medium-size crawfishes in Spring Creek, and probably would be competitive to the point of the law of competitive exclusion, or Gause's Principle (Hardin 1960), eliminating one of the populations if they occupied the same habitat. Therefore, most of the large sunfishes could coexist on the basis of partitioning food but others could not if instability under stress conditions forced all of the species into the same habitat.

These sunfishes, in fact, occupy different habitats in Spring Creek, therefore partitioning resources by habitat specialization regardless of their ability to partition food. All of the larger species of sunfishes inhabit pools but vary considerably in their preferences for gradients, depths, and cover and concealment, or microhabitat.

According to Trautman (1942), the smallmouth bass prefers a gradient of 4 to 25 feet/mile (0.8 to 4.8 m/km) but has a greater preference for 7 to 20 feet/mile (1.3 to 3.8 m/km), the spotted bass prefers 3 to 7 feet/mile (0.6 to 1.3 m/km), and the largemouth bass prefers 0 to 7 feet (0 to 1.3 m/km) but has a greater preference of 0 to 3 feet/mile (0 to 0.6 m/km). Effects of these preferences (requirements, except for the most tolerant individuals) are reflected by the numbers of each species in samples. Twenty-five smallmouth bass were collected from the three stream orders, two spotted bass were collected from First Order stations, three largemouth bass were collected from First and Third Order stations, and one white crappie was collected from a Third Order station. Therefore, 80.7 percent of the large sunfishes consisted of the smallmouth bass, at least partly because of tolerance or preference for conditions caused by steep gradients.

The spotted bass prefers small, shallow pools two to three feet (0.6 to 0.9-m) deep in small, spring-fed streams with gravel or silt bottom. It appears to prefer undercut banks or overhanging rock for cover but will remain near bottom in the deepest area of the pool in the absence of such cover. It was collected only from pools where maximum depths were approximately 2.5 feet (0.8-m) in Spring Creek.

The smallmouth bass was collected from pools which appear to remain ≥3.0 feet (0.9-m) deep during critical conditions and was collected from depths as great as five to six feet (1.5 to 1.8 m) in Spring Creek. Bottom materials at collection sites consist of gravel, rubble, boulders, and bedrock. The most-used cover is rocky overhangs and along the uneven faces of inundated bluffs. Despite some recent literature, the smallmouth bass in both Spring and Tahlequah Creeks appear to prefer depth and rocky cover, and not vegetation. The large sample is attributed to oligothermal, stenothermal tendencies along with gradient and habitat requirements, which probably accounts for the smallmouth bass being the dominant piscivorous Micropterus in Ozark creeks. It was noted above that the rock bass and the smallmouth bass coexist in several pools. Although their preferred food categories are similar, their coexistence is attributed to selection of smaller species and individuals by the smaller rock bass which has a smaller mouth, similar to the coexistence of crappies and largemouth bass described above.

The largemouth bass was collected from large, deep, quiet pools at First and Third Order stations in Spring Creek as expected from habitat requirements described by Miller and Robison (1973). It uses cover and concealment such as aquatic vegetation, logs, stumps, and boulders, and may be collected over gravelly, rocky, or silt bottom. Also, despite occurring in deep pools, it usually is found in or near cover at depths of two to three feet (0.6 to 0.9-m) in warm weather, occupying the depths only when it is relatively inactive or "hibernating" during cold weather. Therefore, the three species of Micropterus partition resources in Spring Creek by habitat specialization. They may partition food if necessary except that smallmouth and spotted bass apparently would be very competitive and could coexist only temporarily. The white crappie coexists with the largemouth bass and the rock bass coexists with the smallmouth bass, partitioning resources by dietary specialization in both instances. Therefore, the sunfish community partitions resources in Spring Creek mostly by habitat specialization, with presence of several (at least two) species allowed by dietary specialization.

Origins and Distribution of Fishes

Branson (1967) collected and compiled data to determine presence and distribution of fishes in the Neosho River system in Oklahoma. He considered geological and recent drainage affinities and distribution of species in adjacent drainages to determine probable origin of each species.

Branson listed 22 species known to be present in Spring Creek. Other investigators cited previously in this paper expanded the list to 31 species and the samples reported here include an additional five species. Therefore, 36 species have been reported from Spring Creek. All are listed by Branson as occurring in the Neosho drainage but several are reported from a single specimen and origins of some are not attributed.

We have extracted the data from other authors, combined the species known from the creek, and determined the origins of those not reported previously to show the origins and relative distribution of fishes in Spring Creek (Table 26).

The Neosho River is the western boundary of the Ozark Biotic District (Blair 1959). Tributaries which enter the Neosho from the west are prairie and savanna creeks. Branson (1967) called the Neosho an ecotone and Hill et al. (1981) provided additional agreeable data. It is notable in Table 26 that the species in Spring Creek are reported generally from eastern tributaries of the Neosho, only 19 of the 36 species occur in the Neosho, and only 12 species from Spring Creek extend across the Neosho into the prairie and savanna creeks. None of the species are western or prairie forms which have crossed the Neosho into the Ozark creeks. Therefore, all species in Spring Creek originated in the Ozark drainages east of the Neosho River.

Two potential sources are indicated. The Neosho is a tributary of the Arkansas River, and other tributaries of the Arkansas bound the Ozark creeks that flow into the Neosho. Therefore, the Arkansas River drainage obviously is the major contributor of species to Spring Creek. However, several species in Spring Creek and other eastern tributaries of the Neosho occur in the White River drainage in southwestern Missouri and north-central Arkansas but not in the intervening Arkansas tributaries. Tributary creeks of the Elk River are as close as four miles (6.4 km) to tributaries of the White River in southwestern Missouri where transfer of White River species by stream capture is likely to have occurred (Branson 1967). Therefore, fishes in Ozark tributaries of the Neosho apparently originated in the Arkansas and White River drainages.

Eight species in Spring Creek do not occur in the White River drainage and obviously were contributed by the Arkansas River or its tributaries (Table 26). Conversely, two species and one subspecies are abundant in the Elk and White Rivers but only a few specimens occur in the Arkansas drainage including the Neosho and its tributaries. These are the white sucker, Arkansas darter, and an undescribed subspecies of the longear sunfish. The remaining 25 species occur in both the Arkansas and White Rivers and, therefore, could have entered the Neosho system from either or both rivers. Obviously, because of direct connections, the Arkansas River is the most likely source but it also is likely that many or all of these species entered the Neosho system along with the other White River forms.

These origin and distribution data corroborate our original assertion that the fish community in Spring Creek is a mixture of intolerant coolwater species and a few wide-ranging tolerant

Table 26. Origin and relative distribution of fishes known from Spring Creek in the Neosho River system of Oklahoma. 1 - Arkansas River drainage, 2 - White River drainage by stream capture. After Branson (1967), with additions and revised nomenclature.

Common Name	Eastern Tributaries	Neosho River	Western Tributaries	Origin
Central stoneroller	x	rare	rare	1 2
Bigeye chub	x	-	-	1
Redspot chub[a]	x	-	-	1 2
Bigeye shiner	x	x	-	1
Ozark minnow[b]	x	-	-	1 2
Duskystripe shiner	x	-	-	1
Rosyface shiner	x	-	-	1 2
Southern redbelly dace[c]	x	-	-	1 2
Creek chub	x	-	-	1 2
White sucker	rare	-	-	2
Northern hog sucker	x	rare	-	1 2
Spotted sucker	x	rare	rare	1
Black redhorse	x	rare	-	1 2
Golden redhorse	x	rare	-	1
Blackspotted topminnow	rare	-	-	1
Plains topminnow	rare	-	-	1 2
Black bullhead	rare	x	x	1
Slender madtom	x	rare	-	1 2
Mosquitofish	x	x	x	1 2
Banded sculpin	x	-	-	1 2
Rock bass	x	-	-	1 2
Green sunfish	x	x	x	1 2
Bluegill	x	x	x	1 2
Longear sunfish	x	x	x	2[d]
Smallmouth bass	x	-	-	1 2
Spotted bass	x	x	x	1 2
Largemouth bass	x	x	x	1 2
White crappie	x	x	x	1 2
Greenside darter	x	x	-	1 2
Arkansas darter	x	-	-	2
Fantail darter	x	-	-	1 2
Least darter	x	-	-	1 2
Stippled darter	x	-	-	1 2
Orangethroat darter	x	x	x	1 2
Logperch	x	x	x	1 2
Slenderhead darter	x	x	-	1

[a]Reported as _Hybopsis biguttata_, hornyhead chub, by Branson.

[b]Reported as _Dionda nubila_ by Branson.

[c]Reported as _Chrosomus erythrogaster_ by Branson.

[d]Branson requires White River origin because of distinctive characteristics which appear to represent an undescribed subspecies.

warmwater species that is unique to spring-fed, coolwater creeks of the Ozarks. The same conclusion was drawn for the same reasons for a similar fish community in Tahlequah Creek on the Illinois River (Arkansas) drainage about eight miles (12.8 km) south of Spring Creek (Jester et al. 1988).

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