presented in Table 17.2. Mean movement distances did not differ between groups of individuals released in heated areas compared to transitional areas ($t=0.25$, $P>0.50$), but a significantly greater average displacement from heated release sites was detected in comparison with ambient release sites ($t=3.40$, $P<0.01$). The fluctuating and occasionally extreme temperature cycle which is characteristic of the heated location may in part contribute to a greater between-season displacement among bass since power plant operation practices could contribute to considerable between-season variability in water temperatures, a factor which would demand relocation of fishes in extreme cases. The temperature cycle of the ambient area of Coffeen Lake would be expected to be more stable and predictable in the sense that only atmospheric events contribute to the temperature variability; that area thus represents the type of thermal regime that northern largemouth bass have adapted to.

Distances traveled by marked fishes were not related to either size at release or to number of days at liberty as judged by a lack of correlation between those variables and respective displacement distances (Table 17.3). Among those fishes recaptured during the fall or spring seasons following their release (long-term movements), a tendency to remain within a restricted areas was suggested by the high frequency of recaptures which occurred at or near original release sites. Approximately 60% of long-term recaptures were found within 1,000 meters of their original release sites and over half of that number were found within 200 meters of that location (Fig. 17.1). Displacement distances progressively decreased in frequency up to a maximum of 6,246 meters which was the greatest displacement observed by an individual after a long-term period of liberation.

Crossing of the main lake channel by largemouth bass was commonly observed among both short-term and long-term groups; those crossings were detected in 29% and 36%, respectively, of the total number of observations. Passages through the railroad causeway culverts were 5% and 9% for the short-term and long-term groups, respectively, with north to south and south to north movements about evenly distributed. The majority of those movements were observed among individuals originally captured and released near the structure.

Table 17.2. Means and ranges of distances traveled by tagged largemouth bass in Coffeen Lake. Release sites, sample size (N), and days elapsed between release and recapture (means and ranges) are given. All observations represent long-term movements (see text).

Release Site	N	Days elapsed		Distance traveled (meters)	
		mean	range	mean	range
Heated	53	310	141-703	1574	0-6246
Transitional	26	319	153-705	1474	0-5179
Ambient	46	297	148-690	671	0-3275
Lake-wide	125	307	141-705	1221	0-6246

Table 17.3. Correlations between distanced traveled (Log [meters+1]) by tagged largemouth bass and selected independent variables. Separate correlations for short-term and long-term movements were made. Sample size (N), correlation coefficient (r), Students t-value, and significance probability (P) are given.

Independent variable	N	r	t	P
Short term				
A) Days elapsed	154	-0.17	0.01	>0.50
B) Days elapsed	125	-0.01	0.07	>0.50
Long term				
A) TL at release	154	-0.00	0.01	>0.50
B) TL at release	125	0.03	0.32	>0.50

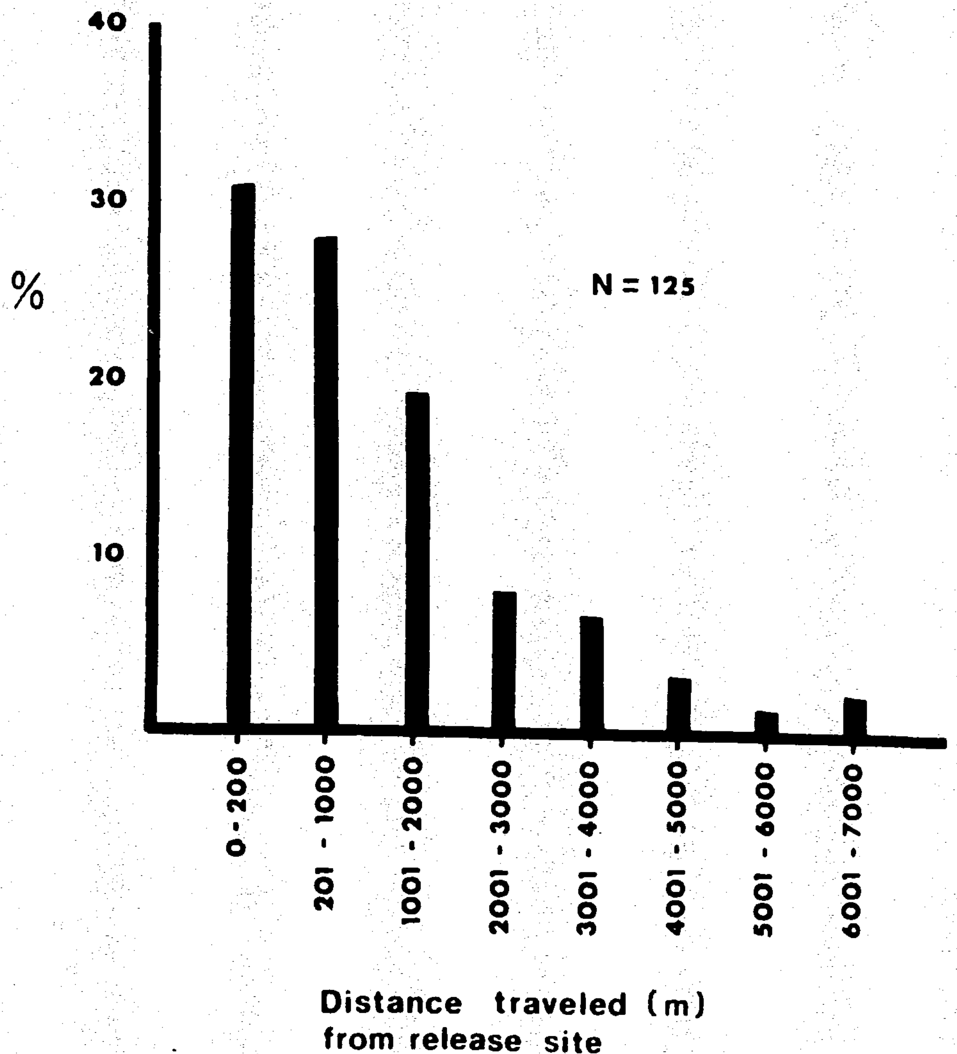

Fig. 17.1. Frequency of displacement (ranges in meters) from release sites exhibited by tagged largemouth bass in Coffeen Lake. All tagged fish were released in the spring and recaptured during the following fall or spring seasons.

Knowledge of the life history of largemouth bass is extensive as evidenced by a large body of literature (Robbins and MacCrimmon 1974, Stroud and Clepper 1975, Heidinger 1976) but, until recently, little was known of the daily or seasonal movement patterns of this species. Coutant (1975) maintained that water temperature was the most important factor governing bass movements, and, in nature, individuals adjust their position daily and seasonally in an effort to locate preferred temperatures. Beyond that basic behavioral response, two generalized patterns of movement emerge from the literature. Some investigators have noted that bass movements were concentrated within a well-defined area, an observation which led to the concept of "home range" (Lewis and Flickinger 1967, Warden and Lorio 1975). The location of such centers of activity were believed to change seasonally. Fetterolf (1952) offered the viewpoint that differing innate characteristics among individual bass may produce an extensive mobility in some and a more sedentary nature in others. Distances traveled by bass in Coffeen Lake (ranging up to 7 kilometers) were not exceptional compared to other studies reported in the literature since the magnitude of movement exhibited by this species appears to be limited only by the physical limits of its environment (Heidinger 1976, Tranquilli et al. 1979b, and others). Extensive displacement between seasons apparently was the exception rather than the rule in Coffeen Lake since most recaptured individuals were found within the same general area during spring and fall seasons. However, the frequency and magnitude of movements which occurred during the interim period could not be determined with certainty, and the broad range of displacement distances observed after only a short period of liberty suggests that those distances may have been extensive.

Cooling lakes provide a rather unique environment for evaluating fish movements since widely divergent temperatures generally persist. In unheated lakes, thermoselective movements are usually limited to vertical adjustments, whereas cooling lakes offer a mode of thermoselective movement in the horizontal direction as well. In Lake Sangchris, Tranquilli et al (1979a, 1979b) found that average daily movements and absolute distances traveled by largemouth bass were significantly greater among individuals originally captured and released in heated areas, a finding which was supported by the results of this study. The authors predicted a seasonal cycle of attraction and avoidance at thermally extreme locations, whereas fishes inhabiting thermal transition areas were believed to be most sedentary. In contrast, Quinn et al. (1978) concluded from their study, and earlier studies of bass movements in a southeastern cooling reservoir, that fishes in heated areas were generally most sedentary and exchange of individuals between heated and ambient areas was uncommon. The fishes observed were found to travel extensively within the lake even though their movements were apparently unrelated to the thermal gradient.

Population Estimates

A total of 1,124 largemouth bass were captured by electroshocking during the 1979 population census. Included were 271 individuals (≥350 mm TL) that comprised the recapture sample required for population estimation. Of that number, 54 had been previously marked. Therefore, the estimated population size as of May 1979 was 4,958 individuals for the size group considered (Table 17.4). The 95% confidence interval for that estimate ranged from 3,784 to 6,132 individuals. The 1980 census produced 1,124 individuals including 340 (≥360 mm TL) which were selected for inclusion in the recapture sample. Of that group, 65 had been previously marked yielding an estimate of 5,466 individuals and a 95% confidence interval from 4,285 to 6,647 (Table 17.4). The two estimates were in close agreement over the two years. Corresponding standing crop estimates, 9.3 and 10.8 kg/ha (Table 17.4) were similar to the 10 kg/ha figure cited by Jenkins (1975) as an average for mid-southern reservoirs, and to the Lake Sangchris and Lake Shelbyville estimates of 8.8 kg/ha and 12.6 kg/ha, respectively (Tranquilli et al. 1979b). Estimation of the biomass of largemouth bass by this method yielded slightly higher values than the 7.7 kg/ha estimate derived by cove rotenone sampling in Coffeen Lake (Section 14, herein). The latter technique generally yielded few individuals of large size compared to catches obtained by electrofishing. The mark and recapture estimates excluded individuals <200 mm total length and thus would have been somewhat higher had they been included.

Fisherman exploitation

From the spring of 1979 to the spring of 1981 sport fishermen reported 80 catches of tagged bass and 84 catches of untagged fish. Of the total, 90 fish were kept, 28 were released, and the fate of 46 was not reported. The shortest

Table 17.4. Mark and recapture population estimates (± 2 standard errors) of largemouth bass ≥200 mm total length as of May 1979 and May 1980 in Coffeen Lake. Estimates of number per hectare, average weight, and standing crop are given.

Parameter	Value
1979 Population Estimate	
Estimate	4958 ± 1174
Number/ha	11.1
Average weight	0.840 kg
Standing crop	9.3 kg/ha
1980 Population Estimate	
Estimate	5466 ± 1181
Number/ha	12.3
Average weight	0.882 kg
Standing crop	10.8 kg/ha

time interval between tagging and reported capture by a fisherman was 3 days, the longest 689 days. Sixty-two successful fishing days were reported, 1 in February, 5 in March, 6 in April, 28 in May, 15 in June, 4 in July, 2 in November, and 1 in December. Thirty-nine parties were reportedly fishing the south part of the lake (south of railroad) and seven were fishing the north part.

All of our catch records were obtained through voluntary reports, usually by telephone. Since reports were only received from fishermen who were successful in catching a tagged fish, we cannot quantify the rate or impact of fisherman exploitation on the bass population other than that which is implied by the above data. At most, exploitation of this species is moderate compared to public fishing lakes (Coffeen Lake is closed to the public) and the reader is reminded that population dynamics of the bass population, as reported herein and in other Sections of this report, may in part reflect a comparatively low rate of fishing mortality relative to other, more heavily fished lakes.

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SECTION 18

INCIDENCE AND INTENSITY OF BLUEGILL PARASITISM BY THE WHITE LIVER GRUB (*POSTHODIPLOSTOMUM MINIMUM*) IN COFFEEN LAKE

by

Lance G. Perry

ABSTRACT

The occurrence of *Posthodiplostomum minimum* cysts was 100% in liver tissues of bluegill collected from heated and ambient areas of Coffeen Lake. Mean numbers of cysts per individual were 309.7 and 779.0 from these locations, respectively, but the values did not differ significantly (P>0.05). A significant, positive correlation was found between number of liver cysts and total length of the host fish. The partial correlation between number of cysts and relative weight, an index of body condition, was not significant at the 5% probability level, but the calculated value was very close to significance and is discussed accordingly. Intensity of *P. minimum* infestations in Coffeen Lake bluegills were high enough to retard growth, as judged from the results of other studies reported in the literature, and may have contributed to the relatively low condition of adults. Common usage of littoral areas by bluegills and piscivorous aquatic birds probably perpetuates the life cycle of *P. minimum* in Coffeen Lake.

INTRODUCTION

Metacercaria of the digenetic trematode (*Posthodiplostomum minimum*), commonly known as the white liver grub, are endoparasitic cysts commonly found in the viscera of many species of freshwater fishes (Hoffman 1967). Aquatic birds serve as definitive hosts for the parasites while snails of the genus *Physa* and fishes serve as first and second intermediate hosts, respectively. Heavy infestations of white liver grubs have been observed in wild bluegill populations (Hunter 1942, Sinderman 1953, Lewis and Nickum 1964) and have been shown to exert a detrimental effect on growth and condition of this species in controlled experiments (Smithermann 1963). Since the bluegill population of Coffeen Lake is stunted, and adults occasionally exhibit poor body condition (Section 15, herein), an investigation of the occurrence and intensity of infestations was initiated in an attempt to determine the extent of impact of these parasites on bluegill condition.

MATERIALS AND METHODS

Ten bluegills were collected from heated and ambient locations at monthly intervals beginning in May and continuing through September 1980. Specimens were captured by electroshocking, weighed, measured, placed on ice in the field, and kept frozen until analyzed. Whole livers were excised after partial thawing and compressed in a tissue press (Bulow and Anderson 1978) for viewing under a dissecting stereomicroscope. Total numbers of metacercariae of *P. minimum* were enumerated. Relationships between number of parasites (transformed to square root) and total length of each fish were examined, and rates of infestations were compared between heated and ambient locations. A partial correlation procedure was used to examine the relationship betwen parasite number and body condition of the host.

RESULTS AND DISCUSSION

The occurrence of P. minimum was 100% in bluegills from heated and ambient locations. Mean number of parasitic cysts in liver tissues averaged [illegible] and 209.0 among specimens from heated and ambient areas, respectively (Table 18.1). The means were not significantly different according to t-test results (P>0.20). A positive correlation (r=0.59, P<0.01) was found between number of liver cysts and total length of individuals from heated and ambient areas combined (Table 18.2). Average total lengths of bluegills did not differ between heated and ambient samples (t=0.64, P>0.50) and thus was not considered a source of error in comparing the intensity of infestations between those locations. Highest numbers of liver cysts (>500) were found in individuals that ranged from 133 to 153 mm in length which represents the maximum length attained by this species in Coffeen Lake (Section 15, herein).

The partial correlation between the number of liver parasites and the relative weight (Wr of Anderson 1980) of the host fish was computed to examine the relationship between body condition and intensity of infestation directly, i.e., after removal of the influence of total length. That correlation was not significant (Table 18.3) but it was close to significance at the 5% level; that is, a tabulated r-value of 0.20, with 95 degrees of freedom, corresponded to significance probability of P<0.05. Since the calculated r-value was 0.19 (Table 18.3), a high correlation is suggested even though it was not significant. Thus, intensity of parasitic infestations in bluegills may in part contribute to a relatively low body condition in adults, but only 3.6% (r^2) of the observed variation in condition was accounted for in the correlation with parasite density.

Results of other studies suggest that the intensity of P. minimum infestations observed in Coffeen Lake bluegills may contribute to their slow growth rate. Smitherman (1968) tested three levels of infestations and found that an average total density of 103.3 metacercaria per fish (39.9 in the liver) did not reduce growth of infected bluegills compared to a control group, but averages of 353.1 (142.5 in liver tissues) and 546.9 (248.1 in livers) parasites significantly reduced growth of infected versus control groups. Although the levels of

Table 18.1. Mean number of *P. minimum* cysts found in livers of Coffeen Lake bluegills. Sampling location, sample size (N), range, Students t-value, and significance probability (P) are given. The t-test comparison was performed on transformed data.

Location	N	Number parasites		Comparison	
		mean	range	t	P
Heated	50	309.7	5 - 1974	0.88	>0.20
Ambient	48	209.0	4 - 1764		

Table 18.2 Correlation between number of *P. minimum* cysts in liver tissues of Coffeen Lake bluegills (dependent variable) and total length of the host fish. Sample size (N), correlation coefficient (r), Students t-value, and significance probability (P) are given.

Independent variable	N	r	t	P
Total length	93	0.59	7.16	0.01

Table 18.3. Partial correlation coefficient ($r_{AB \cdot C}$) between number of *P. minimum* cysts in livers of Coffeen Lake bluegills and relative weights of host fishes where A=number parasites, B= relative weight, and C=total length (held constant). Sample size (N), degrees of freedom (d.f.), and significance probability (P) are given.

Variable	N	d.f.	$r_{AB \cdot C}$	P
Relative weight	98	95	-0.19	>0.05

infestation in that study were artifically induced, they are not considered unusual in nature and comparable densities were frequently observed in this study. Lewis and Nickum (1964) observed natural infestations of *P. minimum* in bluegills ranging up to 1035 per fish, but they found no effect of those densities on condition of the host fishes. Occurrence of *P. minimum* infestations was 100% in bluegills from Lake Sangchris, a central Illinois cooling lake, but only 56%, and of a lesser severity, in Lake Shelbyville, a central Illinois flood control reservoir (Hagele and Tranquilli 1979). It is also noteworthy that growth of age I and older bluegills was more rapid in Lake Shelbyville than in Lake Sangchris, which has a stunted bluegill population similar to that of Coffeen Lake.

Reasons for the proliferation of white liver grubs in Coffeen Lake are only conjectural. Great blue herons, which serve as the principal definitive hosts in the life cycle of this species, were occasionally observed in littoral areas of the lake, but they were not common. The steeply sloping shoreline, which is characteristic of Coffeen Lake, limited vascular plant growth, primarily *Potomogeton* spp., to a narrow band paralleling the shoreline. Bluegills typically congregated in those areas throughout most of the growing season. Common usage of littoral areas by definitive hosts (herons) and second intermediate hosts (fishes) probably perpetuates the life cycle of *P. minimum* in Coffeen Lake since large numbers of bluegills concentrated in restricted shoreline areas would provide a readily-accessible forage base for piscivorous birds such as herons. As indicated above, intensity of infestations observed in Coffeen Lake are certainly extreme enough to retard growth of bluegills and may have contributed to the relatively low condition of larger individuals. However, isolation of one cause for the stunted nature of the population may lead to an erroneous conclusion. Other possible contributing factors, discussed elsewhere in this report (Sections 7 and 15), include a relatively low density of benthic (forage) organisms, lack of sufficient predation to prevent overcrowding of bluegills, and competition from other sunfish species utilizing the same forage base.

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PART II ECOLOGICAL INVESTIGATIONS OF SHOAL CREEK

PART II

SECTION 1

INTRODUCTION: SHOAL CREEK[1]

The East Fork of Shoal Creek lies immediately below the Coffeen Lake Dam. The stream receives overflow from the lake during periods of high water and in the past water was pumped from the creek into the lake to hasten lake filling. One-year studies of water chemistry, phytoplankton, benthos, and fish were implemented to assess the effect of lake overflow and/or pumping of water from the East fork of Shoal Creek upon the biota of this stream.

DESCRIPTION OF THE STUDY AREA

The study area established on the East Fork of Shoal Creek was directly south of Coffeen, Illinois (T7N, R3W, Section 23). With an average width of 35 feet and a gradient of 4.5 feet mile $^{-1}$, the creek flows in a southerly direction towards Shoal Creek and the Kaskaskia River (Lopinot 1970). The drainage primarily consists of pasture or farmland which periodically becomes inundated during periods of high discharge. Lopinot (1970) reported that the stream bottom consisted of 70 percent silt and 30 percent sand. Historically, this stream provided water for lake filling during a severe drought which coincided with the completion of the Coffeen Lake Dam (CIPS 1977). The auxiliary pumping facilities installed immediately below the Coffeen Lake Spillway were designed to maintain a reasonably constant lake level. However, pumping operations were apparently sporadic in the past and have not occurred at all during the course of this investigation of Coffeen Lake. Prior to the onset of this study, the last record of a spillway discharge into the East Fork of Shoal Creek was June 1975 (CIPS 1977).

Figure 1.1 illustrates sampling stations on the East fork of Shoal Creek. Stations 1, 2, and 4 were major sampling stations for water chemistry, periphyton, benthos, and fish. Each of these stations encompassed both a riffle and a pool of the stream. Stations 0, 1.5, and 3 served as ancillary stations for certain subprojects.

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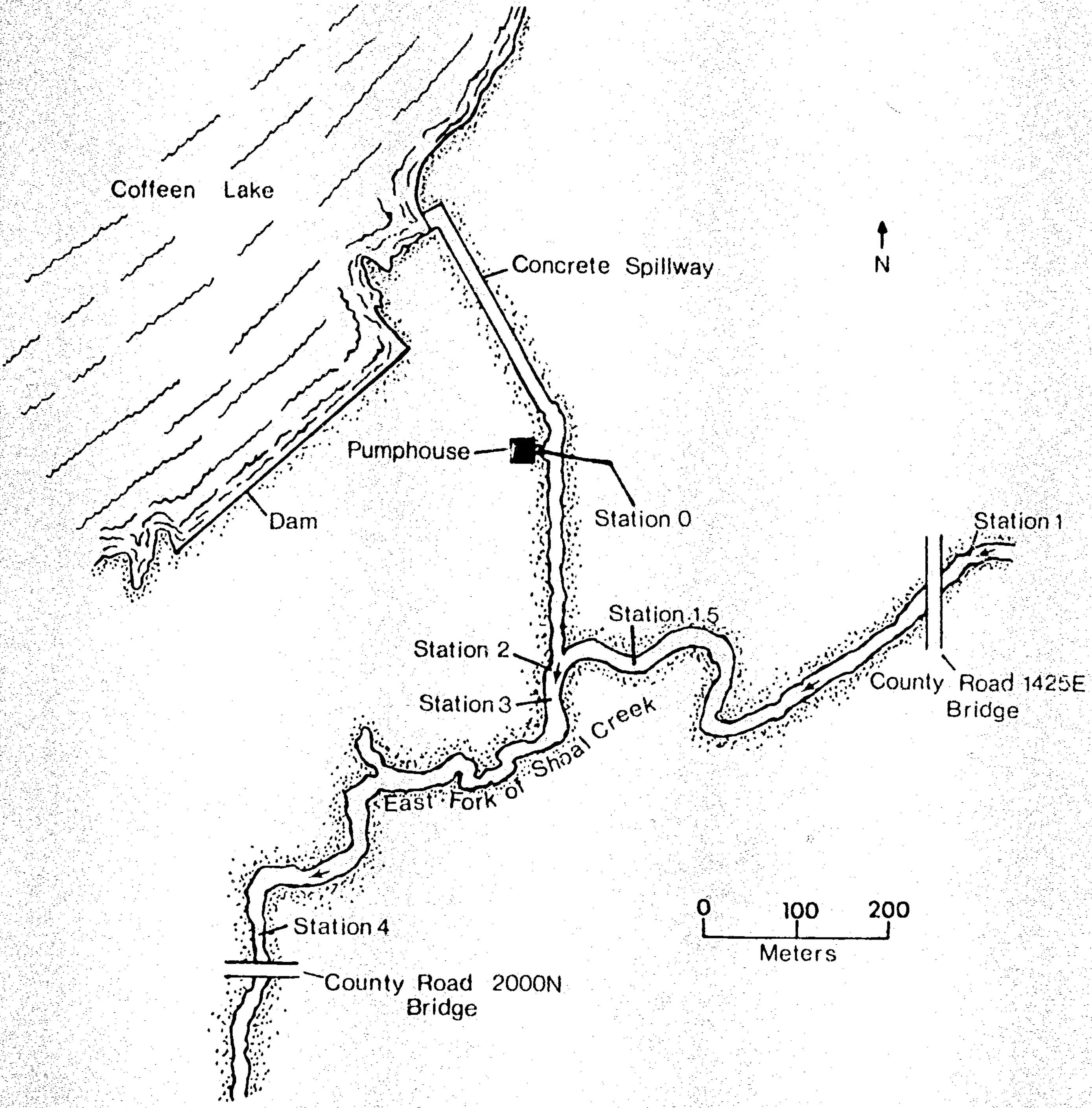

Figure 1.1. Sampling stations on the East Fork of Shoal Creek below the Coffeen Lake dam and spillway.

Stations 2 and 3 are in close proximity to one another because a rubble dam was once present between those two sites. However, in early February 1979 the dam was removed in preparation for the possible construction of a permanent low-head weir dam. Since then construction plans have been deferred. Stations 0, 1.5, and 2 thus consisted of an impounded pool during most of the 1 year baseline study period on this stream, while Station 3 represented the pool just below the rubble dam.

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SECTION 2

SHOAL CREEK WATER QUALITY

by

Sarah Liehr-Storck

ABSTRACT

An investigation of the East Fork of Shoal Creek was conducted from August 1978 through September 1979 for the purpose of studying the impact of Coffeen Lake overflow on Shoal Creek water quality. In the fall of 1978, the sampling station upstream of the Coffeen Lake discharge had very high concentrations of chloride, total alkalinity, soluble orthophosphate, and organic carbon and low concentration of dissolved oxygen relative to the other sampling stations. These concentrations indicated that the stream was impacted by an upstream sewage effluent during that period of low flow. In March 1979, the spring flood had more effect on the water quality than did the overflow from Coffeen Lake. Characteristics of Shoal Creek water quality at that time were extremely high turbidity, along with high levels of iron, phosphorus, and inorganic nitrogen, and relatively low concentrations of chloride, alkalinity, hardness, and sulfate. By April 1979, Coffeen Lake overflow altered water quality at Shoal Creek. The most noticeable effects were greater sulfate concentrations and lower alkalinity at the downstream stations. By June those effects were no longer evident. The summer flood in August 1979 had a slight diluting effect on Shoal Creek water quality, but there were only minor indications of impact by lake overflow.

INTRODUCTION

This investigation, conducted between August 1978 and September 1979, was begun with the following objectives: to determine (1) the impact of Coffeen Lake overflow on Shoal Creek water quality, (2) the impact of pumping water from Shoal Creek on the water quality of the lake, and (3) the impact of the pumping operation on the water quality of Shoal Creek. Since water was not pumped into the lake from Shoal Creek during the study period, only the impact of the lake overflow on the stream was investigated. This objective was accomplished by determining the relative impacts of lake water and climatological events such as temperature, floods, and low flow on water quality parameters in Shoal Creek.

MATERIALS AND METHODS

SAMPLING SCHEDULE

Water quality parameters were measured at Stations 1, 2, 3, 4, and directly south of Station 0 (Fig. 1.1). In February 1979 the rubble dam between Stations 2 and 3 was removed and thereafter Station [illegible] was no longer sampled.

The following parameters were measured at monthly intervals: turbidity, total alkalinity, carbon dioxide (CO_2), EDTA hardness, total phosphorus, soluble orthophosphate, ammonia, nitrate, nitrite, total iron, soluble iron, ferrous iron, sulfate, sulfite, total sulfide, dissolved hydrogen sulfide, unionized hydrogen sulfide, chloride, and fluoride. At quarterly intervals water samples were also analyzed for organic nitrogen, total organic carbon, particulate organic carbon, dissolved organic carbon, and chemical oxygen demand. Temperature, dissolved oxygen, pH, and total dissolved solids (TDS) were measured twice each month during the study period.

FIELD AND ANALYTICAL METHODS

Water samples were collected in plastic bottles approximately 0.3 meters below the surface. Samples analyzed for soluble iron were immediately filtered and fixed with hydruchloric acid, and samples for ferrous iron were fixed immediately with hydrochloric acid. Samples analyzed for sulfide forms were fixed immediately with 0.2 N zinc acetate, and analyses were run within 24 hours of collection. Sulfite and pH were measured in the field or in the laboratory immediately after collection. Temperature and dissolved oxygen were measured in the field with a YSI Model 57 dissolved oxygen meter. Conductivity was measured in the field with a YSI Model 33 S-C-T meter, and the results were corrected for temperature and used to calculate total dissolved solids. Chemical parameters were measured using the same analytical methods given in Section 3, Part I, herein.

RESULTS AND DISCUSSION

Climatological events had considerable effect on water quality in the stream. Floods occurring in the spring and in the summer impacted the stream, increasing the rate of flow, creating runoff from farmland, and causing water to go over the spillway from Coffeen Lake. The major flood occurred during the spring of 1979 and lasted from late February to early May (Fig. 2.1), with water from the lake going over the spillway from early March to mid-May (Fig. 2.2). Another shorter period of water overflow occurred in the summer from late July to early August. Periods of very low or zero flow also occurred, from August 1978 to mid-November, and in 1979 from late June to late July. Stations 1, 3, and 4 were ice covered in January 1979, and were open on various dates between late January to late February.

Most of the following discussion is about Stations 1, 3, and 4. Station 2 was not discussed since sampling at that site was discontinued in February. Station 0 was intended to evaluate the quality of water pumped into Coffeen Lake from Shoal Creek. Since water was not pumped from Shoal Creek into the lake, water quality at that station was discussed only when water was going over the spillway and thus impacting the stream. Data are listed in Appendices 2.1-2.3. Table 2.1 and Table 2.2 present station means and monthly means, respectively.

TURBIDITY

Turbidity was extremely high in Shoal Creek in March 1979 (Table 2.2), with levels of 1380 NTU, 1470 NTU, and 1530 NTU observed at Stations 1, 3, and 4, respectively, on 20 March. These high levels corresponded to the spring flood conditions. Prior to March, turbidity levels were in the range of 5 to 35 NTU. In April, turbidity returned to normal levels even though high flow conditions remained (Fig. 2.1). Turbidity levels were not unusually high after the July-August 1979 flood period. Overall, the highest turbidity levels were observed at Station 3 (Table 2.1). However, in December and January the highest levels were observed at Station 1, and in March the highest levels were observed at Station 4. High levels of turbidity were associated with high levels of iron and total phosphorus.

Table 2.1. Station means of water quality parameters measured at Shoal Creek from August 1978 through September 1979.

	Station 1		Station 3		Station 4		Station 0	
	mean	n	mean	n	mean	n	mean	n
Turbidity NTU	109	14	122	14	119	14	48	14
Temperature °C	12.7	27	13.5	27	13.0	27	14.6	27
Dissolved oxygen mg/l	6.3	27	7.8	27	7.7	27	7.3	27
% saturation D.O. mg/l	57.1	27	72.7	27	71.2	27	72.2	27
pH	7.48	25	7.66	25	7.42	25	7.67	25
Total dissolved solids mg/l as NaCl	571	26	516	25	493	26	570	25
Alkalinity mg/l $CaCO_3$	260	14	231	14	232	14	210	14
Hardness mg/l $CaCO_3$	193	14	202	14	208	14	214	14
Chloride mg/l	50.2	14	32.3	14	29.2	14	29.1	13
Sulfate mg/l	89	14	95	14	94	14	147	14
Total iron mg/l	1.79	14	1.67	14	1.37	14	1.59	14
Total phosphorous mg P/l	.252	9	.213	9	.204	9	[illegible]	9
Ortho-phosphate mg P/l	.065	13	.058	13	.030	13	[illegible]	13
Ammonia-N mg N/l	.173	14	.179	14	.153	14	[illegible]	14
Nitrate-N mg N/l	.444	14	.481	14	.462	14	[illegible]	14
Nitrite-N mg N/l	.019	14	.021	14	.016	14	[illegible]	14
Organic carbon mg c/l	36.8	3	32.3	3	34.3	3	[illegible]	3
Organic nitrogen mg N/l	.208	4	.185	4	.190	4	.220	4

Table 2.2. Monthly means of water quality parameters measured at Shoal Creek at Stations 0, 1, 3, and 4 from August 1978 through September 1979.

	August 1978		September 1978		October 1978		November 1978		December 1978		January 1979		February 1979	
	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n
Turbidity NTU	22	4	16	4	16	4	22	4	6.9	4	12	4	7.9	4
Temperature °C	23.2	4	18.5	8	12.1	8	10.9	8	2.4	8	0.1	12	6.2	4
Dissolved oxygen mg/l	7.0	4	3.5	8	5.1	8	3.8	8	9.5	8	9.8	12	9.4	4
% saturation D.O. mg/l	83	4	37	5	48	8	35	8	71	8	68	12	83	4
pH	7.63	4	7.45	8	7.95	8	7.76	8	7.25	4	7.58	12	7.55	4
Total dissolved solids mg/l as NaCl	599	2	548	8	590	8	669	8	462	8	435	4	718	4
Alkalinity mg/l CaCO$_3$	265	4	259	4	282	4	304	4	252	4	252	4	264	4
Hardness mg/l CaCO$_3$	126	4	134	4	184	4	240	4	127	4	[illegible]	4	[illegible]	4
Chloride mg/l	44.6	4	64.0	4	58.4	4	74.7	4	47.1	4	55.5	4	40.5	4
Sulfate mg/l	50	4	52	4	65	4	72	4	122	4	125	4	144	4

Table 2.2. Monthly means of water quality parameters measured at Shoal Creek at Stations 0, 1, 3, and 4 from August 1978 through September 1979. (continued)

	March 1979		April 1979		May 1979		June 1979		July 1979		August 1979		September 1979	
	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n
Turbidity NTU	1,180	4	15	4	10	4	33	4	20	4	14	4	20	4
Temperature °C	6.9	8	12.1	8	14.9	8	23.0	8	24.9	12	22.4	8	15.5	4
Dissolved oxygen mg/l	10.4	8	9.9	8	9.6	8	4.1	8	5.7	12	6.9	8	8.5	4
% saturation D.O. mg/l	85	8	92	8	95	8	49	8	71	12	81	8	92	4
pH	7.51	8	7.35	4	8.06	8	7.32	8	7.18	12	7.71	8	8.00	4
Total dissolved solids mg/l as NaCl	323	8	621	8	627	8	550	8	491	12	504	8	[illegible]	4
Alkalinity mg/l $CaCO_3$	68	4	128	4	170	4	232	4	209	4	233	4	256	4
Hardness mg/l $CaCO_3$	116	4	258	4	267	4	187	4	225	4	209	4	231	4
Chloride mg/l	12.1	4	19.4	3	24.1	4	21.5	4	32.0	4	[illegible]	4	37.4	4
Sulfate	148	4	242	4	201	4	8							

Table 2.2. Monthly means of water quality parameters measured at Shoal Creek at Stations 0, 1, 3, and 4 from August 1978 through September 1979. (continued)

	August 1978		September 1978		October 1978		November 1978		December 1978		January 1979		February 1979	
	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n
Total iron mg/l	1.42	4	1.01	4	1.17	4	1.83	4	1.41	4	1.00	4	1.17	4
Total phosphorus mg P/l	—	—	—	—	—	—	—	—	—	—	.118	4	.088	4
Ortho phosphate mg P/l	.010	4	.050	4	.050	4	.218	4	.010	4	.020	4	—	—
Ammonia mg N/l	.033	4	.063	4	.053	4	.103	4	.037	4	.445	4	.560	4
Nitrate mg N/l	.050	4	.048	4	.038	4	.010	4	.550	4	.985	4	.763	4
Nitrite mg N/l	.010	4	.013	4	.013	4	.010	4	.010	4	.013	4	[illegible]	4
Organic carbon mg C/l							62.0	4					[illegible]	4
Organic nitrogen mg N/l							.425	4					[illegible]	4

Table 2.2. Monthly means of water quality parameters measured at Shoal Creek at Stations 0, 1, 3, and 4 from August 1978 through September 1979. (continued)

	March 1979		April 1979		May 1979		June 1979		July 1979		August 1979		September 1979	
	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n
Total iron mg/l	7.98	4	.39	4	.28	4	.74	4	1.9	4	[illegible]	4	[illegible]	4
Total phosphorus mg P/l	.638	4	.058	4	.035	4	.119	4	.095	4	[illegible]	4	[illegible]	4
Ortho phosphate mg P/l	.145	4	.020	4	.010	4	.030	4	.028	4	[illegible]	4	[illegible]	4
Ammonia mg N/l	.315	4	.178	4	.075	4	.173	4	.190	4	[illegible]	4	[illegible]	4
Nitrate mg N/l	1.758	4	1.075	4	.215	4	.075	4	[illegible]	4	[illegible]	4	[illegible]	4
Nitrite mg N/l	.090	4	.040	4	.015	4	.015	4	.010	4	[illegible]	4	[illegible]	4
Organic carbon mg C/l					—	—					4.4	4		
Organic nitrogen mg N/l					.248	4					[illegible]	4		

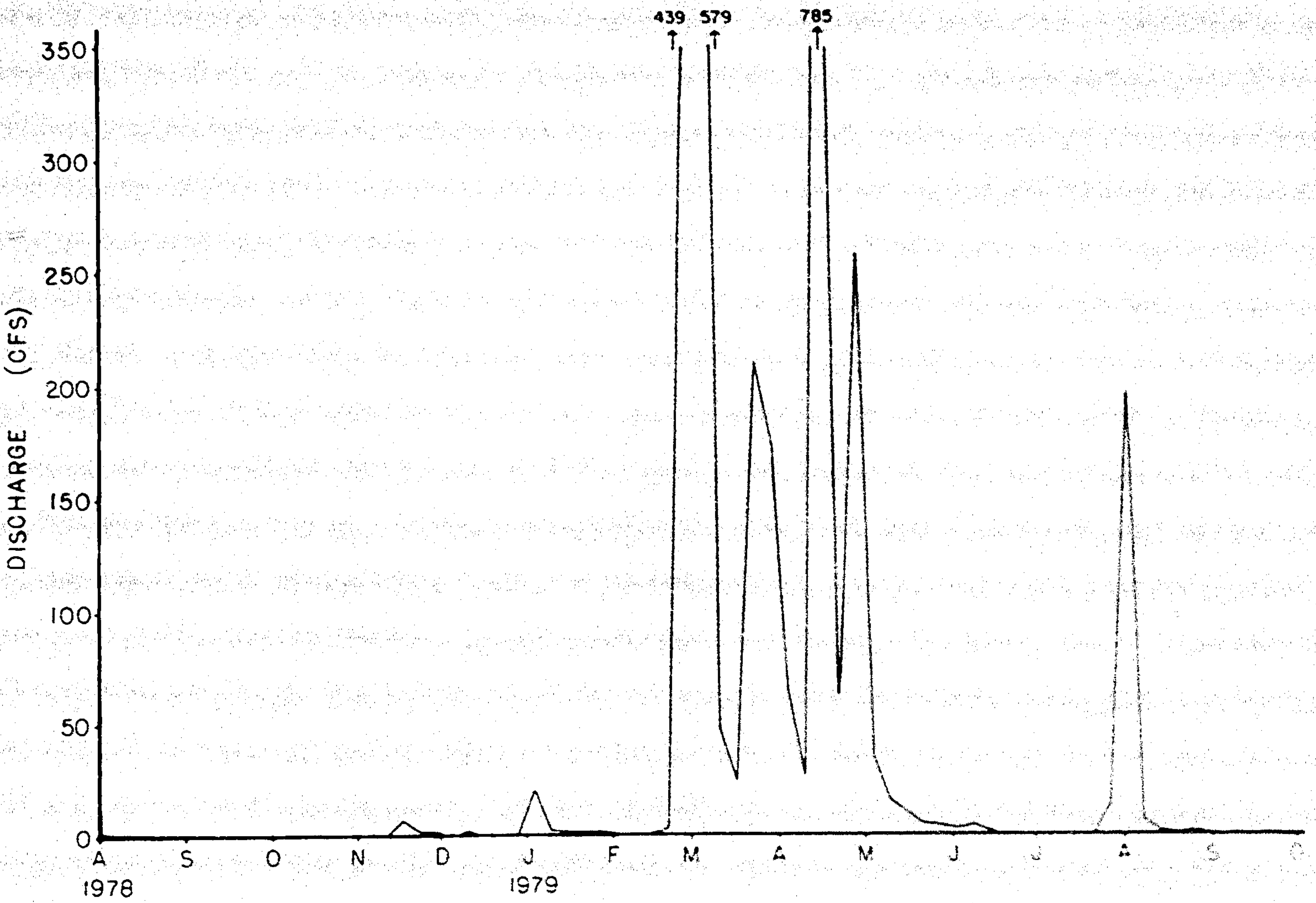

Figure 2.1. Six-day means of discharge in the East Fork of Shoal Creek near Coffeen, IL, from August 1978 through September 1979 (U.S. Geological Survey 1978-1979).

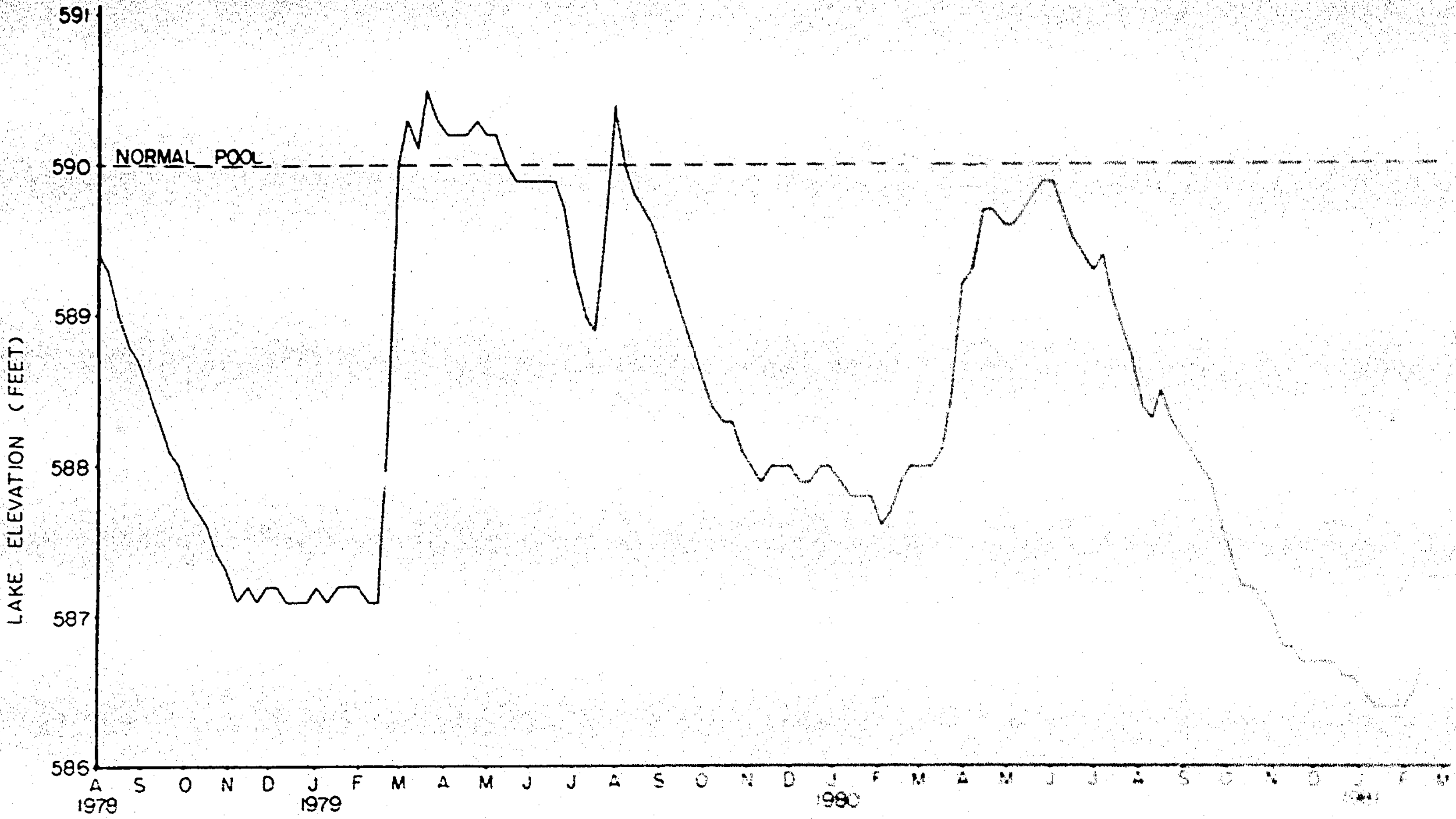

Figure 2.2. Weekly lake elevation means at Coffeen Lake from August 1978 through February 1981

TEMPERATURE AND DISSOLVED OXYGEN

Temperatures were very similar at Stations 1 and 2 at all times of the year, and discharge of water from the lake to the stream had little apparent effect on the temperature of the downstream station (Fig. 2.3). Station 3, directly below the discharge channel, had slightly higher temperatures overall (Table 2.1). Dissolved oxygen concentrations generally decreased with increased temperatures (Fig. 2.4). Concentrations were generally slightly lower at Station 3 than at the other stations (Table 2.1), however, from August through November 1978, concentrations were considerably lower at Station 1 where oxygen levels were generally below 3 mg/l. During that time, oxygen levels were also reduced at the other stations. Oxygen-demanding organic matter, measured quarterly as total organic carbon and organic nitrogen, was also greater in November 1978 (Table 2.2) with the highest levels of both parameters observed at Station 1 (Table 2.1). Dissolved oxygen levels also declined to low levels at all stations in June 1979, immediately after the spring flood had subsided.

pH

Data for pH were generally in the range of 7.0 to 8.0, with the overall highest pH occurring at Station 3 and lowest at Station 4 (Table 2.1). The highest pH at all stations occurred in May 1979, and the lowest occurred in July 1979 (Table 2.2). Water in Shoal Creek was well buffered because of high alkalinity levels, so sharp fluctuations in pH would not be expected.

DISSOLVED SOLIDS

Total dissolved solids (TDS) concentrations were much higher at Station 1, upstream of the lake discharge channel, in the fall of 1978 than at the other stations (Fig. 2.5). TDS levels increased through the winter at all stations, then decreased substantially in March 1979 with the spring flood (Table 2.2). In April, TDS levels rose at all stations, with the greatest increase occurring at stations downstream of the Coffeen Lake spillway. At that time, TDS concentrations were much greater at Station 0, the lake overflow channel, than at the Shoal Creek stations since TDS was typically greater in Coffeen Lake than

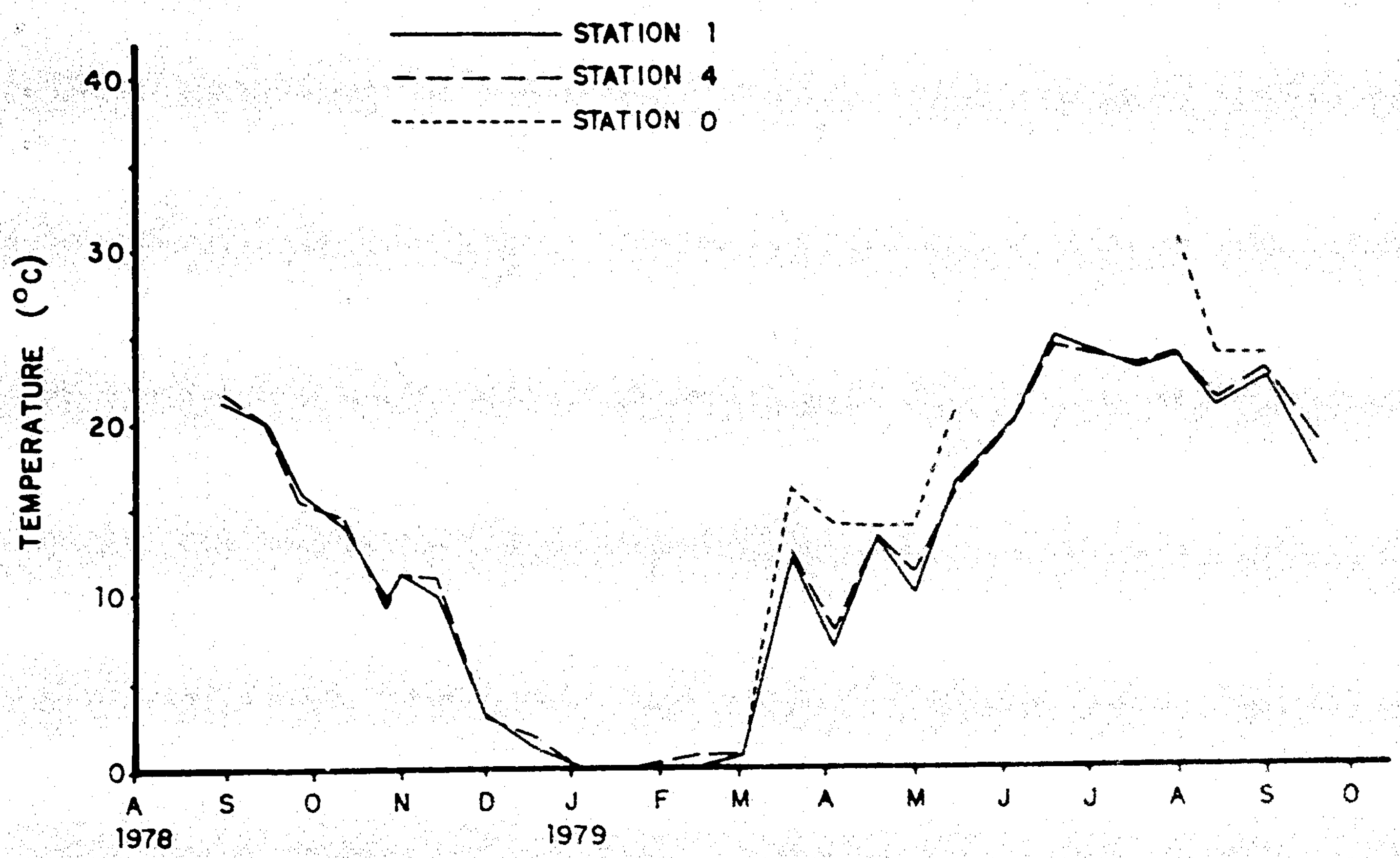

Figure 2.3. Temperatures at Shoal Creek sampling stations from August 1978 through September 1979.

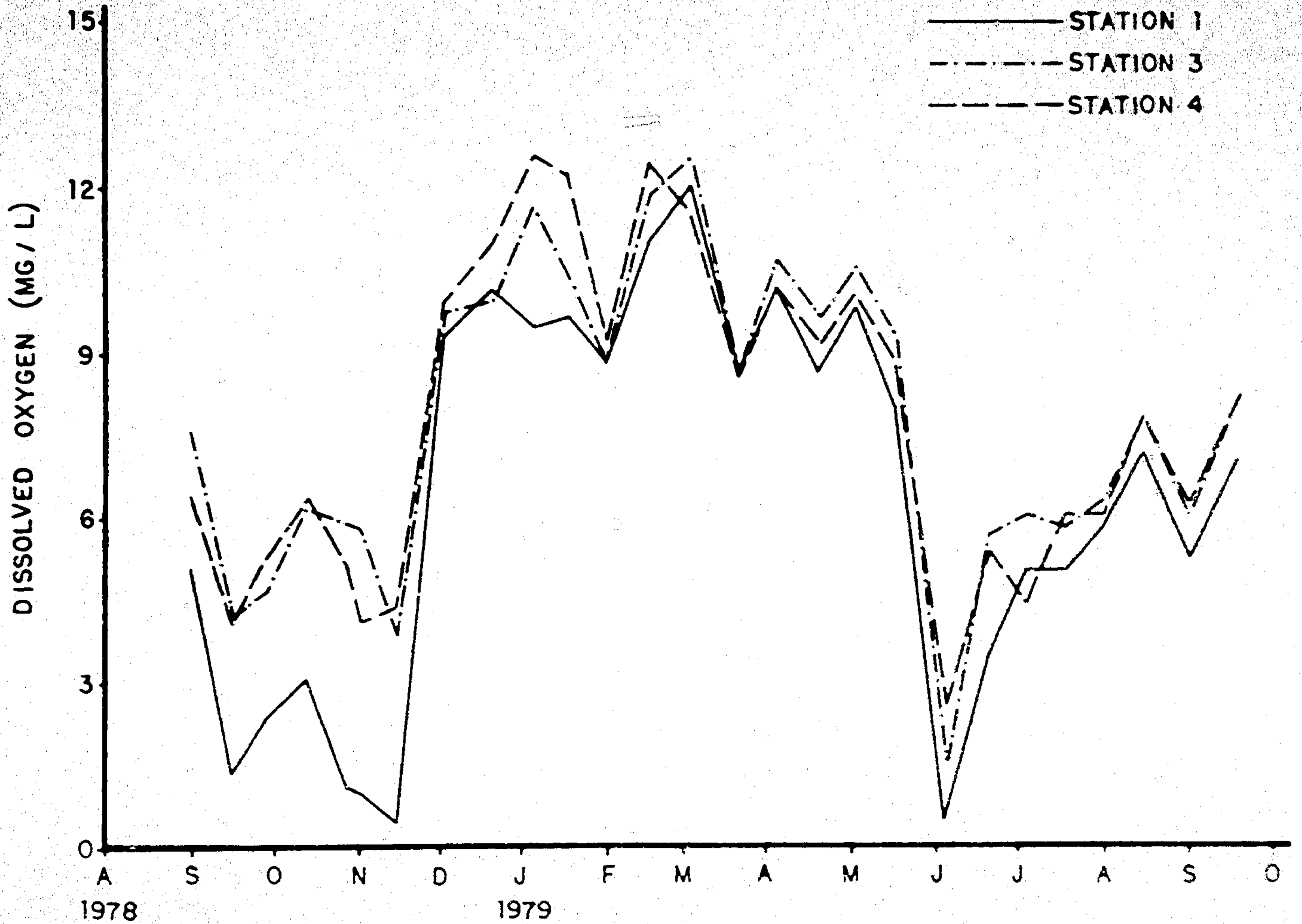

Figure 2.4. Dissolved oxygen concentrations at Shoal Creek sampling stations from August 1978 to September 1979.

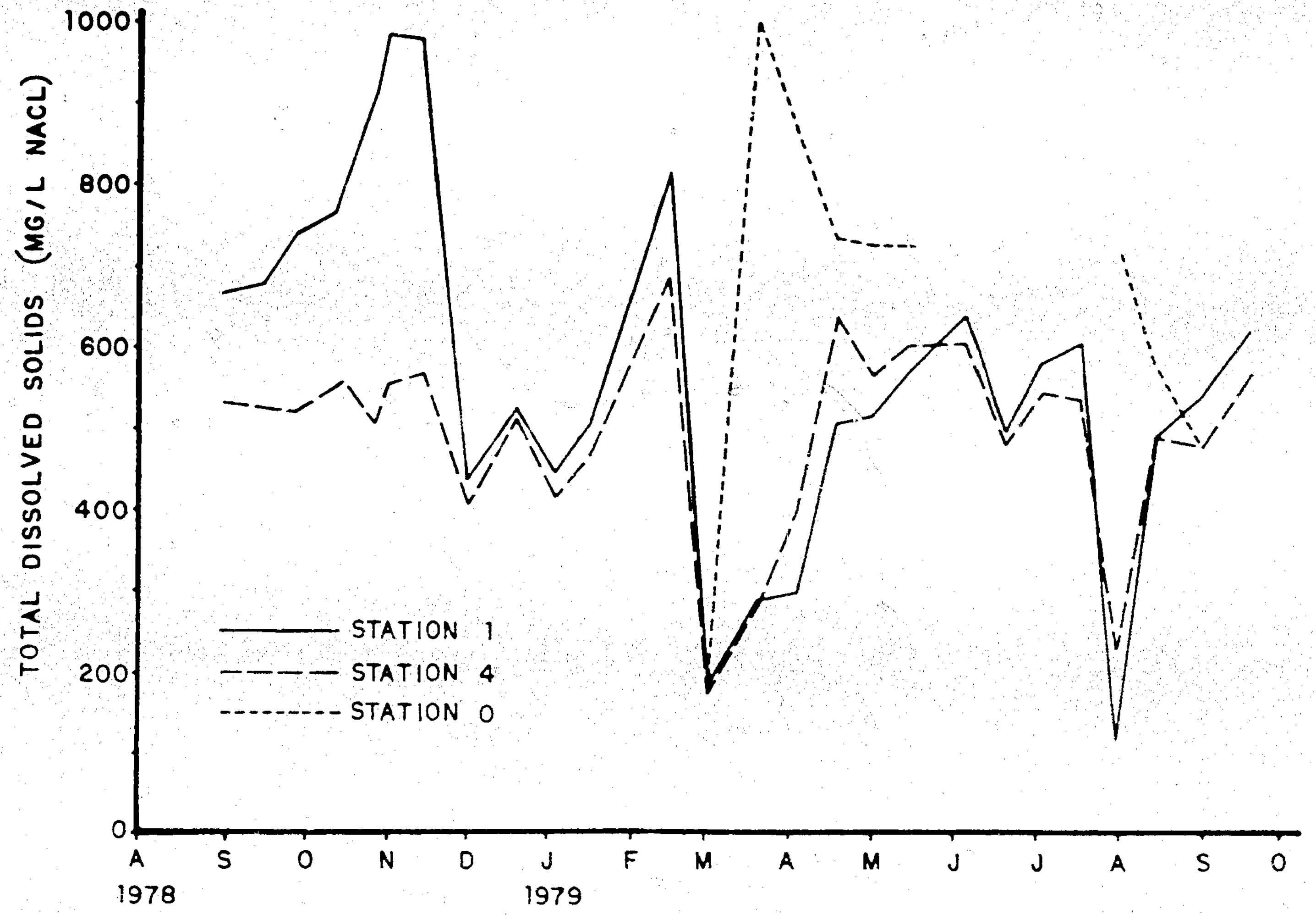

Figure 2.5. Total dissolved solids concentrations at Shoal Creek sampling stations from August 1978 to September 1979.

in Shoal Creek. By mid-May, however, the concentrations had again become fairly uniform among stations. Then in late July and early August, when another flood and overflow from the lake occurred, TDS levels in Shoal Creek again decreased substantially while levels at Station 0 increased. By mid-August, stream station levels of TDS were back to normal, with no apparent effect from the lake overflow.

Alkalinity concentrations were considerably greater in Shoal Creek than in Coffeen Lake at all times except March 1979, during the spring flood. Prior to March 1979, alkalinity was observed in the range of about 250 to 280 mg/l as $CaCO_3$ at Stations 3 and 4, however, from August through November 1978, levels were 30 to 90 mg/l higher at Station 1. These data correspond to high total dissolved solids levels at Station 1 during that time. In April 1979, alkalinity increased at all stations in spite of overflow from the lake, but the levels at stations downstream of the spillway increased at a slower rate than did concentrations at Station 1. Alkalinity levels continued to increase until July, and a small decrease was observed after the summer flood (Table 2.2). Hardness increased at all stations during the fall of 1978. As with other dissolved components, concentrations decreased dramatically in March 1979 during the spring flood, then started increasing to normal levels in April (Table 2.2).

Chloride concentrations in Shoal Creek were generally similar to concentrations in Coffeen Lake; therefore spillway discharges had little effect on the stream. All stations except Station 1 had similar chloride levels (Table 2.1). Chloride concentrations at Station 1 were extremely high relative to the other stations from the beginning of the study in August 1978 through November 1978, with the maximum concentration of 145 mg/l observed in September. Station concentrations were fairly consistent through the winter, then dropped to a minimum of about 12 mg/l at all stations in March 1979 (Table 2.2). From that time until the end of the study in September 1979, Station 1 again had the highest chloride concentrations with a maximum observed in September of about 55 mg/l.

Sulfate concentrations in Shoal Creek were considerably lower than in Coffeen Lake. In Shoal Creek, concentrations were slightly higher at Station 1 that at Stations 3 and 4 from August through November 1978. From December to March, concentrations at all three stream stations were nearly the same. A decrease was observed in March, corresponding to the spring flood (Table 2.2). In April and May, concentrations were much higher at Stations 3 and 4 than at Station 1 as water from Coffeen Lake had more influence on stream concentrations. Sulfate levels were again similar at all stations from June 1979 to the end of the study in September 1979 in spite of the lake overflowing during the summer flood.

These data for the components of dissolved solids suggest that Station 1 was especially adversely impacted by the low flow in Shoal Creek in the summer and fall of 1978. The high alkalinity and chloride levels, along with the higher organic carbon levels and low dissolved oxygen, indicate that a sewage effluent upstream of Station 1 probably caused the degradation of water quality.

PHOSPHORUS

Soluble orthophosphate concentrations were very high at all stations in November 1978, but especially at Stations 1 and 3 (0.32 and 0.27 mg P/l, respectively). Concentrations increased at all stations in March 1979 to about 0.15 mg P/l (Table 2.2). Total phosphorus also increased at that time (mean; 0.64 mg P/l), corresponding to extremely high turbidity. Total phosphorus levels increased after the summer flood in August 1979 (mean; 0.59 mg P/l), but orthophosphate levels remained low (Table 2.2). The phosphorus concentration was usually less than 0.10 mg P/l.

NITROGEN

Concentrations of inorganic nitrogen were similar among stream stations at all times (Table 2.1). Ammonia levels were greatest in January, February, and March 1979 and least during the summer and fall of 1978 (Table 2.2). Concentrations were slightly increased in August 1979 after the summer flood. Concentrations of nitrate were low in the summers and in the fall (0.1 to 0.6 mg N/l), but increased during the winter. Maximum concentrations were observed in March and April (Table 2.2). A slight increase in nitrate occurred at Stations 3 and 4 in August 1979 after the summer flood, apparently caused in part by overflow from Coffeen Lake. Nitrite concentrations were low (.01 to .03 mg N/l) at all times except during March and April when levels were 0.09 and 0.04 to .05 mg N/l, respectively. The total inorganic nitrogen concentration was greatest in March 1979 (2.97 mg N/l) and lowest in August 1978 (0.09 mg N/l).

The overall impact of Coffeen Lake overflow is difficult to assess since overflow from the lake only occurred during periods of high discharge in Shoal Creek. Parameters that were found in especially high or low concentrations in Coffeen Lake relative to Shoal Creek (total dissolved solids, sulfate, and alkalinity) had limited impact on the receiving stream because of the high discharge. Changes in the levels of these parameters at downstream stations due to lake overflow were of short duration. Temperature increase at the downstream station was very small. During most of the study period all stream stations had similar concentrations of most parameters, or the worst water quality was found at the upstream station.

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SECTION 3

PERIPHYTON ON ARTIFICIAL SUBSTRATES IN SHOAL CREEK[1]

by

Larry W. Coutant

ABSTRACT

Periphyton colonizing artificial substrates exposed quarterly for 28 day-periods from August 1978 through May 1979 were examined from four locations in Shoal creek to determine effects of overflow from Coffeen Lake, a cooling lake for a coal-fired power plant. The relative importance of the major divisions of algae was similar between most stations on most sampling dates but the dominant division was different between collections. The greatest diversities of algae occurred during August 1978 and the lowest ones occurred during November 1978; Station 4 generally had the highest diversity during the quarterly periods when samples from that station were collected. During the period when overflow did occur from Coffeen Lake, in April and May 1979, the periphyton community downstream from the confluence of the overflow from Coffeen Lake with Shoal Creek was not adversely affected by the entrance of water from Coffeen Lake.

INTRODUCTION

Attached algae, or periphyton, are an excellent means of assessing impacts of point sources of pollution on aquatic environments. Because of their sessile nature, the algae are confined to a specific area such that the algal community that develops is indicative of the environmental conditions in that area. To further limit the number of variables, artificial substrates such as glass slides can be used and placed in such a position in the water that variations in substrate composition and light penetration between locations can be minimized.

In this study, Shoal Creek periphyton colonizing artificial substrates were examined to determine the impacts of overflow from Coffeen Lake on Shoal Creek and to determine overall dynamics of the Shoal Creek periphyton community. Sampling stations were located upstream and downstream from that point at which water from Coffeen Lake entered Shoal Creek to allow comparisons of unaffected and potentially affected areas.

MATERIALS AND METHODS

Periphyton was collected quarterly on glass slides suspended in floating periphyton samplers at a depth of approximately 0.025 m for 28 days. Quarterly collections were made in August and November 1978, and February and May 1979. Two stations were selected on Shoal Creek; Station 1.5 was upstream from the junction of Shoal Creek with the pumphouse canal and Station 2 was located below that junction (see Fig. 1.1, Part II). Two additional stations were chosen for study from November 1978 through May 1979; Station 1 was 300 m upstream from Station 1.5 and Station 4 was located approximately one mile downstream from Station 2. At the time of collection, each of three slides was preserved intact in a bottle containing 2 ml of acidified Lugol's solution and 63 ml of water.

Scrapings from an entire slide were stirred in a Waring blender and diluted to a known volume (e.g., 50 ml). Duplicate samples were then counted by the same procedure outlined for phytoplankton samples (Section 5, Part I, herein) except that the appropriate multiplication factors were used to give densities in algal units per 10 cm^2.

RESULTS AND DISCUSSION

COMPOSITION

Seventy-five algal taxa were identified from collections of periphyton from artificial substrates in Shoal Creek (Table 3.1). As expected, many of those same taxa were found in the Coffeen Lake periphyton collections (Section 5, Part I, herein).

ABUNDANCE

Similar periphyton densities were present at Stations 1.5 and 2 during August 1978 (Table 3.2). The periphyton densities declined from roughly 2,500,000 units per 10 cm^2 in August to approximately 1,200,000 by November 1978 (Table 3.2) Stations 1 and 4 had algal densities of approximately 234,000 and 869,000, respectively, in February 1979; those densities were the lowest recorded for the study year and were most likely a result of reduced light availability and temperature which contributed to slower growth rates. The densities of periphyton in May 1979 were substantially greater than those recorded in November 1978 and February 1979 at all stations; Station 1 had densities of 2,326,200 and Stations 1.5, 2, and 4 had densities of 3,038,510, 4,744,400, and 6,148,360, respectively.

The relative importance of the major divisions of algae was similar between most stations on any given sampling date, but the most abundant algal division was different in nearly every collection (Table 3.3). The Bacillariophyta were the dominant group in the August 1978 and May 1979 collections, the Chlorophyta were

Table 3.1. Algal taxa identified from quarterly periphyton collections from artificial substrates at four sampling stations in Shoal Creek from August 1978 through May 1979.

Green coccoids
Green colonies
Characium sp. A. Braun
Closteriopsis sp. 1
Monoraphidium spp. Kom.-Legn.
Monoraphidium contortum (Thuret In Breb) Kom.-Legn.
Scenedesmus spp. Meyen
Scenedesmus bijuga (Turpin) Lagerh.
Scenedesmus dimorphus (Turpin) Kutz.
Scenedesmus quadricauda (Turpin) De Brebisson
Cosmarium spp. Corda
Unidentified euglenoids
Melosira granulata (Ehr.) Ralfs
Cyclotella glomerata Bachmann
Cyclotella meneghiniana Kutz.
Cyclotella pseudostelligera
Cyclotella stelligera Grun.
Stephanodiscus sp. 1
Stephanodiscus hantzschii Grun.
Skeletonema potamos (Weber) Hasle
Diatoma vulgare Bory
Fragilaria spp. Lyngbye
Fragilaria capucina v. *mesolepta* (Rabh.) Grun.
Fragilaria crotonensis v. *oregana* Sov.
Fragilaria vaucherie
Synedra spp. Ehr.
Synedra incisa Boyer
Synedra fasiculata v. *truncata* (Grev.) Pat.
Synedra rumpens Kutz.
Synedra ulna (Nitzsch) Ehr.
Achnanthes exigua Grun.
Achnanthes lanceolata De Brebisson
Achnanthes lanceolata v. *dubia* Grun.
Achnanthes minutissima (Kutz.) Cleve.
Navicula spp. Bory
Navicula sp. 19
Navicula capitata v. *hungarica* (Grun.) Ross
Navicula cryptocephala v. *veneta* (Kutz.) Grun.
Navicula minima Grun.
Navicula protracta Grun.
Navicula pupula Kutz.
Navicula pupula v. *rectangularis* (Greg.) Grun.
Navicula symmetrica Pat.
Pinnularia obscura Krasske
Caloneis bacillum (Grun.) Mereschkowsky

Scrapings from an entire slide were stirred in a Waring blender and diluted to a known volume (e.g., 50 ml). Duplicate samples were then counted by the same procedure outlined for phytoplankton samples (Section 5, Part I, herein) except that the appropriate multiplication factors were used to give densities in algal units per 10 cm^2.

RESULTS AND DISCUSSION

COMPOSITION

Seventy-five algal taxa were identified from collections of periphyton from artificial substrates in Shoal Creek (Table 3.1). As expected, many of those same taxa were found in the Coffeen Lake periphyton collections (Section 5, Part I, herein).

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Similar periphyton densities were present at Stations 1.5 and 2 during August 1978 (Table 3.2). The periphyton densities declined from roughly 2,500,000 units per 10 cm^2 in August to approximately 1,200,000 by November 1978 (Table 3.2) Stations 1 and 4 had algal densities of approximately 234,000 and 869,000, respectively, in February 1979; those densities were the lowest recorded for the study year and were most likely a result of reduced light availability and temperature which contributed to slower growth rates. The densities of periphyton in May 1979 were substantially greater than those recorded in November 1978 and February 1979 at all stations; Station 1 had densities of 2,326,200 and Stations 1.5, 2, and 4 had densities of 3,038,510, 4,744,400, and 6,148,360, respectively.

The relative importance of the major divisions of algae was similar between most stations on any given sampling date, but the most abundant algal division was different in nearly every collection (Table 3.3). The Bacillariophyta were the dominant group in the August 1978 and May 1979 collections, the Chlorophyta were

Table 3.1. Algal taxa identified from quarterly periphyton collections from artificial substrates at four sampling stations in Shoal Creek from August 1978 through May 1979 (continued).

Diploneis sp. 1
Amphipleura pellucida Kutz.
Gomphonema spp. Agardh
Gomphonema cf. *angustatum* (Kutz.) Rabh.
Gomphonema olivaceum (Lyngbye) Kutz.
Gomphonema parvulum Kutz.
Cymbella minuta Hilse & Rabh.
Amphora cf. *acutiusculus* (Kutz.) Hust.
Nitzschia spp.
Nitzschia spp. 1
Nitzschia sp. 2
Nitzschia sp. 4
Nitzschia amphibia Grun.
Nitzschia filiformis (W. Smith) Hust.
Nitzschia cf. *ignorata* Krasske
Nitzschia palea (Kutz.) W. Smith
Nitzschia rostellata Hust.
Surirella spp. Turpin
Surirella angustata Kutz.
Surirella ovata Kutz.
Bluegreen coccoid colonies
Chroococcus spp. Nageli
Chroococcus turgidus (Kutz.) Nageli
Merismopedia glauca (Ehr.) Nageli
Merismopedia tenuissima Lemm.
Oscillatoria sp. 1
Oscillatoria geminata Menegh.
Lyngbya sp. 1
Lyngbya sp. 3
Anabaena spp. Bory

Table 3.2. Total densities (algal units per 10 square centimeters) of periphyton collected quarterly from artificial substrates at four sampling stations in Shoal Creek from August 1978 through May 1979 (--indicates missing data).

Station	August 1978	November 1978	February 1979	May 1979
1	--	--	233,580	2,326,200
1.5	2,547,000	1,395,210	--	3,038,510
2	2,584,630	1,246,160	--	4,744,400
4	--	1,055,110	868,840	6,148,360

Table 3.3. Densities (algal units per 10 square centimeters) and percentage composition (in parentheses) of major algal divisions identified from periphyton collections made quarterly at four sampling stations in Shoal Creek from August 1978 through May 1979.

Station	Greens (Chlorophyta)	Diatoms (Bacillariophyta)	Bluegreens (Cyanophyta)	Cryptomonads (Cryptophyta)	Other
		August 1978			
1.5	279,420	2,212,760	35,940	0	19,280
	(11.0)	(86.9)	(1.4)	(0.0)	(1.0)
2	543,790	1,966,050	59,370	0	15,420
	(21.0)	(76.1)	(2.3)	(0.0)	(1.0)
		November 1978			
1.5	845,480	308,400	141,100	0	100,230
	(60.6)	(22.1)	(10.1)	(0.0)	(7.2)
2	730,830	347,030	52,650	0	115,659
	(58.6)	(27.8)	(4.2)	(0.0)	(9.3)
4	537,070	308,320	94,070	0	115,650
	(50.9)	(29.2)	(8.9)	(0.0)	(11.0)
		February 1979			
1	76,480	53,930	87,750	0	15,420
	(32.7)	(23.1)	(37.6)	(0.0)	(6.6)
4	239,470	408,630	182,190	0	38,550
	(27.6)	(47.0)	(21.0)	(0.0)	(4.4)
		May 1979			
1	751,730	1,441,780	40,170	15,420	77,100
	(32.3)	(62.0)	(1.7)	(1.0)	(3.3)
1.5	416,340	2,490,320	54,750	30,840	46,260
	(13.7)	(82.0)	(1.8)	(1.0)	(1.5)
2	422,130	4,194,290	27,750	46,260	53,970
	(8.9)	(88.4)	(1.0)	(1.0)	(1.1)
4	285,280	5,605,180	88,280	15,420	154,200
	(4.6)	(91.2)	(1.4)	(0.0)	(2.5)

dominant in November 1978, and the Cyanophyta and Bacillariophyta were the dominant algal groups in the February 1979 collection. There was spillway overflow from the lake during April and May 1978 but no major differences in algal divisions were noted on substrates located at the stations upstream and downstream from the junction of the pumphouse canal with Shoal Creek at that time.

DIVERSITY

Diversity indices were calculated according to the formulas of Shannon (1948) and are presented in Table 3.4. The diversity indices were highest in August 1978 (i.e., 4.46 at Station 1.5 and 4.21 at Station 2) and somewhat lower in November 1978 (i.e., 2.73 at Station 1.5 , 3.03 at Station 2 and 3.26 at Station 4) in Shoal Creek. The diversities calculated for the February 1979 collection were similar to and slightly higher than those in November 1978 (i.e., 3.03 at Station 1 and 3.45 at Station 4) but still lower than the values calculated for the August 1978 collection. In May 1979, Station 4 had a diversity index of 4.41 and Stations 1, 1.5, and 2 had values of 3.93, 3.61, and 3.15, respectively. Throughout the year Station 4 had the highest diversities during the year; the reasons for this trend were not clear but the location of Stations 1.5 and 2 in a pool formed near the junction of the pumphouse canal and Shoal Creek may have influenced colonization at those stations. During the April to May exposure period, the lowest index was calculated for Station 2. This period was of particular interest because overflow from the spillway occurred then and Station 2 was under the influence of water coming from Coffeen Lake. Although the diversity at Station 2 may have been reduced by the outflow of lake water, it was not low enough to indicate a stress situation and the much higher diversity index calculated for Station 4 during the same period indicated that a very diverse periphyton community existed only a short distance downstream.

Table 3.4. Diversity indices calculated for periphyton collected after quarterly 28-day exposure on glass slides at four stations in Shoal Creek from August 1978 through May 1979 (---- indicates missing data).

Stations	August 1978	November 1978	February 1979	May 1979
1	----	----	2.27	3.93
1.5	4.46	2.73	----	3.61
2	4.21	3.03	----	3.15
4	----	3.26	3.45	4.41

SECTION 4

BENTHIC INVESTIGATIONS AT SHOAL CREEK

by

Gary Warren and James Buckler

ABSTRACT

A study of the benthos of Shoal Creek was conducted in order to assess the effect of heated water overflow from Coffeen Lake upon the benthic fauna. Three stations (one control, two downstream from impact) were sampled over a one-year period. The taxonomic compositions of the three locations were similar, but differences were present in densities of the dominant organisms among the three stations. All collections were dominated by immature Oligochaeta and the midge genera *Chironomus* and *Polypedilum*. Analysis of temperature and dissolved oxygen data recorded concurrently with benthic collections indicated that levels of these two parameters were within the tolerance limits of most benthic taxa during the two lake overflow periods of 1979. Diversity values calculated for all stations were generally highest near the end of the spring lake overflow. All values for this period were well above 3.0, indicating little stress on benthic habitats.

INTRODUCTION

The release of epilimnetic water from Coffeen Lake into the East Fork of Shoal Creek has occurred infrequently as a means of controlling lake water elevation. A one year study of the benthos of the East Fork was conducted in order to assess the effect of heated water overflow upon the benthic fauna.

METHODS AND MATERIALS

Benthic collections were taken from Stations 1, 2, and 4 (Fig. 1.2) on the East Fork of Shoal Creek during November 1978 and January, March, May, July, and September 1979. Station 1 was considered the control location; Stations 2 and 4 were the areas of possible thermal impact. Each collection consisted of 21 samples; seven grabs were taken along a transect at each of the three stations. Samples were obtained with a Petermore dredge (Larimore 1970), washed in a U.S. Standard No. 30 mesh seive bucket, and preserved in quart jars. In the laboratory, each sample was examined separately under a stereodissecting microscope with magnification to 40X. Benthic animals were removed from detritus and inorganic material, identified to the lowest possible taxonomic level utilizing the literature cited in Appendix A7.1, counted, and weighed. Raw data were converted to number or milligrams of organisms per square meter.

Organisms that required slide-mounting for identification, such as Chironomidae and Oligochaeta, were cleared in 10% KOH solution or Amman's lactophenol and mounted in Polyvinyl Lactophenol or Hydramount. Identifications were then made using a compound microscope with magnification to 1000X.

Ancillary measurements recorded concurrently with benthic collections included water temperature and dissolved oxygen.

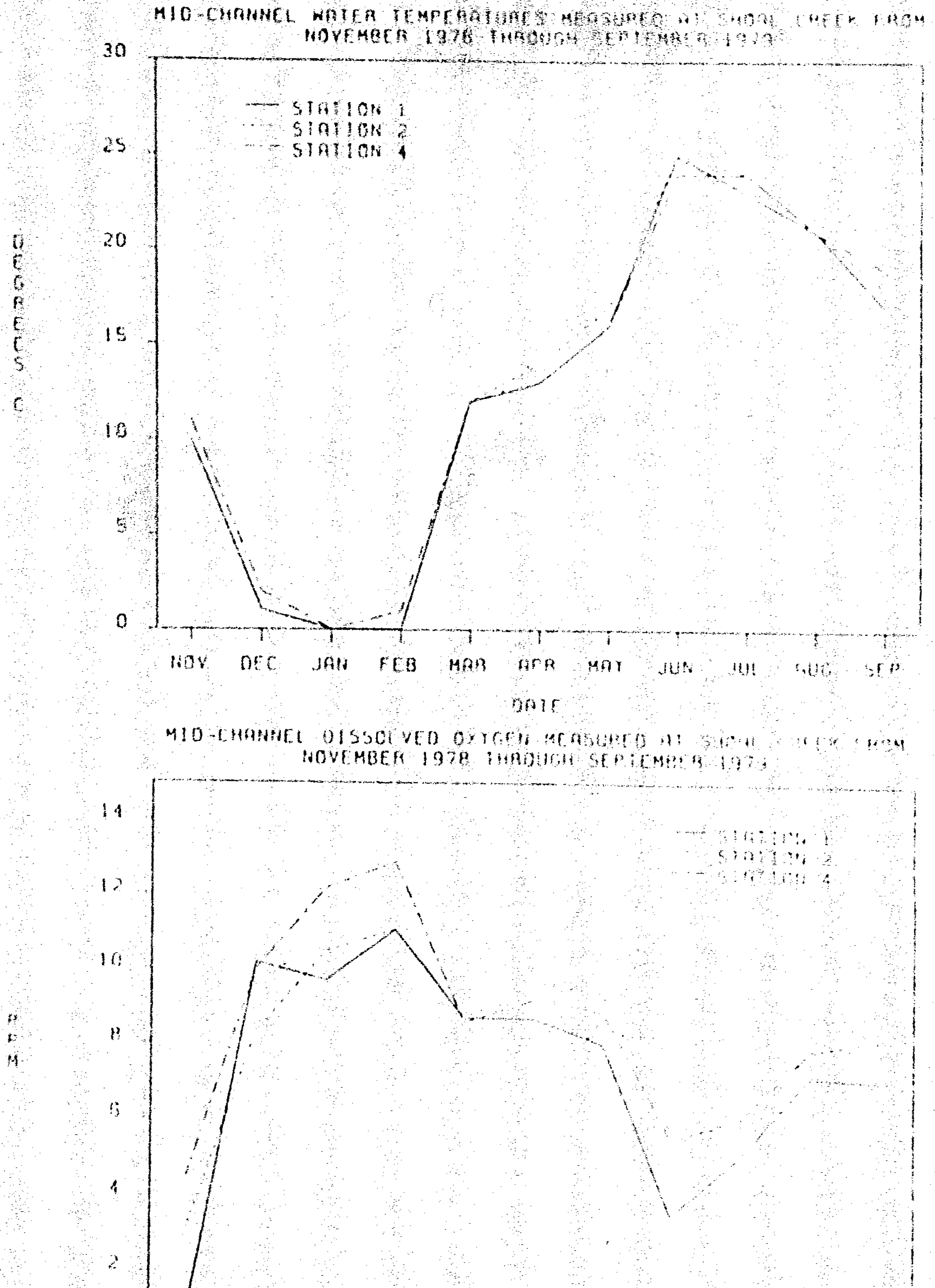
RESULTS AND DISCUSSION

Overflow of water from Coffeen Lake into Shoal Creek occurred from early March to mid-May 1979 and for a short period from late July to early August 1979 (Fig. 2.2). The March to May overflow coincided with a period of spring-rain-caused high discharge in Shoal Creek; the July to August lake overflow occurred during a period of low discharge (Fig. 2.1). Water temperature measured in Shoal Creek during the periods of lake-water overflow (Fig. 4.1) were very similar at the control and downstream stations and were well within the tolerance levels of most benthic insect taxa (Curry 1965, Nebeker and Lemke 1968, Gaufin and Hern 1971, Hubbard and Peters 1978). Dissolved oxygen levels at stations downstream from the spillway were critically low only during November 1978 and exhibited a normal seasonal pattern during the remainder of the study period (Fig. 4.1). Dissolved oxygen at the control station (1) was consistently lower than at the downstream stations (2 and 4).

COMPOSITION AND ABUNDANCE

A total of 115 taxa were collected from Shoal Creek during the study period; 73 taxa were collected at Stations 1 and 4, while 62 taxa occurred at Station 2. Figure 4.2 illustrates the seasonal fluctuations in number of taxa at each station. These data exhibit no real trend toward dominance of total taxa by any one station. Higher numbers of taxa occurred at Stations 2 and 4 for one-half of the study. However, during the period of lake-water overflow in March and May 1979 the number of taxa present at the stations downstream from the spillway fell below the number of taxa collected at the control station.

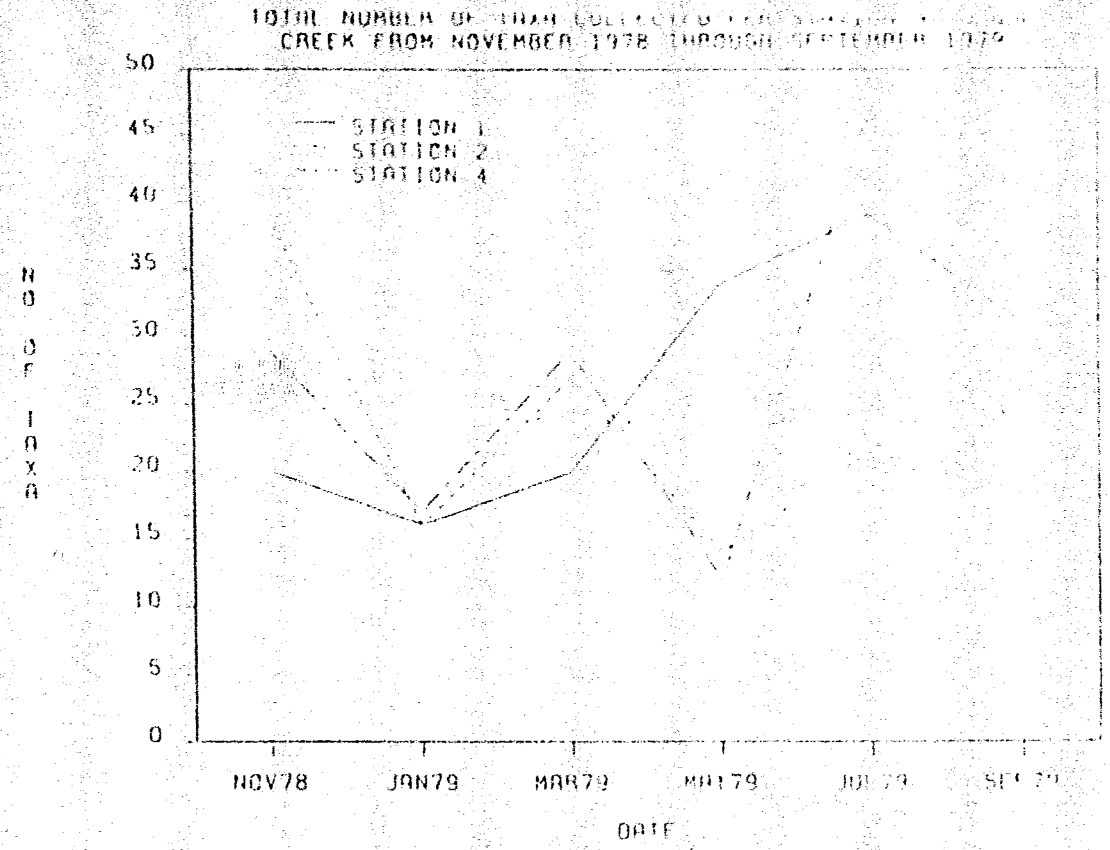
Mean relative abundance for the entire Shoal Creek benthic study equalled 2,009 organisms/m^2. Mean total density for individual stations was highest at Station 4 (3,139 organisms/m^2) and lowest at Station 2 (1,197 organisms/m^2). Mean total density at Station 1 equalled 1,796 organims/m^2. Seasonal fluctuations in density at each station are illustrated in Figure 4.2. As was the case with total taxa, no station was clearly different from any other in terms of mean density, but the densities at Stations 2 and 4 fell below the density at Station 1 during the lake overflow period from March to May 1979. The depression in total taxa and mean total densities at Stations 2 and 4 during this spring overflow were not dissolved oxygen or temperature related, and may have had physical (scouring) or chemical causes.



MID-CHANNEL WATER TEMPERATURES MEASURED AT SHOAL CREEK FROM NOVEMBER 1978 THROUGH SEPTEMBER 1979

MID-CHANNEL DISSOLVED OXYGEN MEASURED AT SHOAL CREEK FROM NOVEMBER 1978 THROUGH SEPTEMBER 1979

Figure 4.1. Mid-channel temperature and dissolved oxygen measured monthly at Shoal Creek Stations 1, 2, and 4 from November 1978 through September 1979.


TOTAL NUMBER OF TAXA COLLECTED FROM SHOAL CREEK FROM NOVEMBER 1978 THROUGH SEPTEMBER 1979

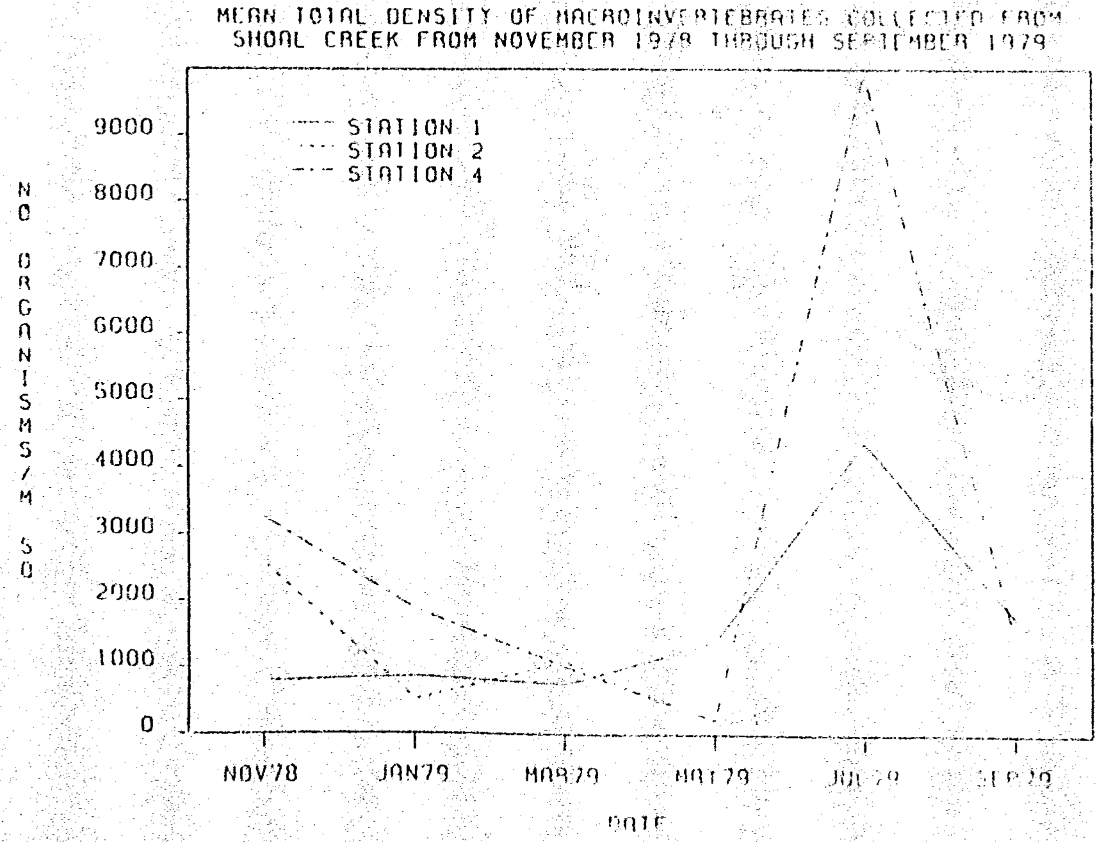

MEAN TOTAL DENSITY OF MACROINVERTEBRATES COLLECTED FROM SHOAL CREEK FROM NOVEMBER 1978 THROUGH SEPTEMBER 1979

Figure 4.2. Total number of taxa and mean density of total organisms collected from Shoal Creek Stations 1, 2, and 4 from November 1978 through September 1979.

Figure 4.3 illustrates the seasonal fluctuations in density of the five most abundant taxa occurring at each station. Immature oligochaetes and two genera of Chironomidae (*Chironomus* and *Polypedilum*) dominated the benthic collections at all stations and accounted for 50% of the total organisms collected. The Oligochaeta and *Chironomus* prefer organically enriched habitats where the oligochaetes derive their nutrition from bacteria and *Chironomus* are tube-building detritivores. *Polypedilum* have been found in a variety of habitats and have feeding habits ranging from predatory to detritivorous. Other important taxa occurring in Shoal Creek were the midges *Tanytarsus*, *Dicrotendipes*, and *Procladius*, and the mayfly *Caenis*. These genera are typical members, and dominants, of midwestern stream benthos communities.

DIVERSITY

Diversity indices attempt to summarize community structure so that the habitat and water qualities of different sampling locations may be compared. In the diversity index proposed by Shannon (1948), values of less than 1 indicate heavy pollution, values of 1 to 3 indicate moderate pollution, and values above 3 denote clean water areas. Diversity indices are most accurate when all taxa tested are identified to species. However, due to the poor taxonomic state of many aquatic groups, identifications to this level are often impossible. In such situations diversity indices lose some of their accuracy and meaning.

Diversity values over the course of the Shoal Creek study ranged from 1.37 (Station 4, January 1979) to 3.85 (Station 1, May 1979). Seasonal fluctuations were very similar at the three sampling locations (Fig. 4.4). No one station was clearly more or less diverse than any other over the course of the study period. A value of 3.85 was calculated for the control station near the end of the lake overflow period in May 1979, while lower values were calculated for Stations 2 and 4 during this same time period (3.64 and 3.38, respectively). However, the fact that the values calculated for all stations were well above 3.0 during this time frame indicates that there was little stress on benthic habitats.

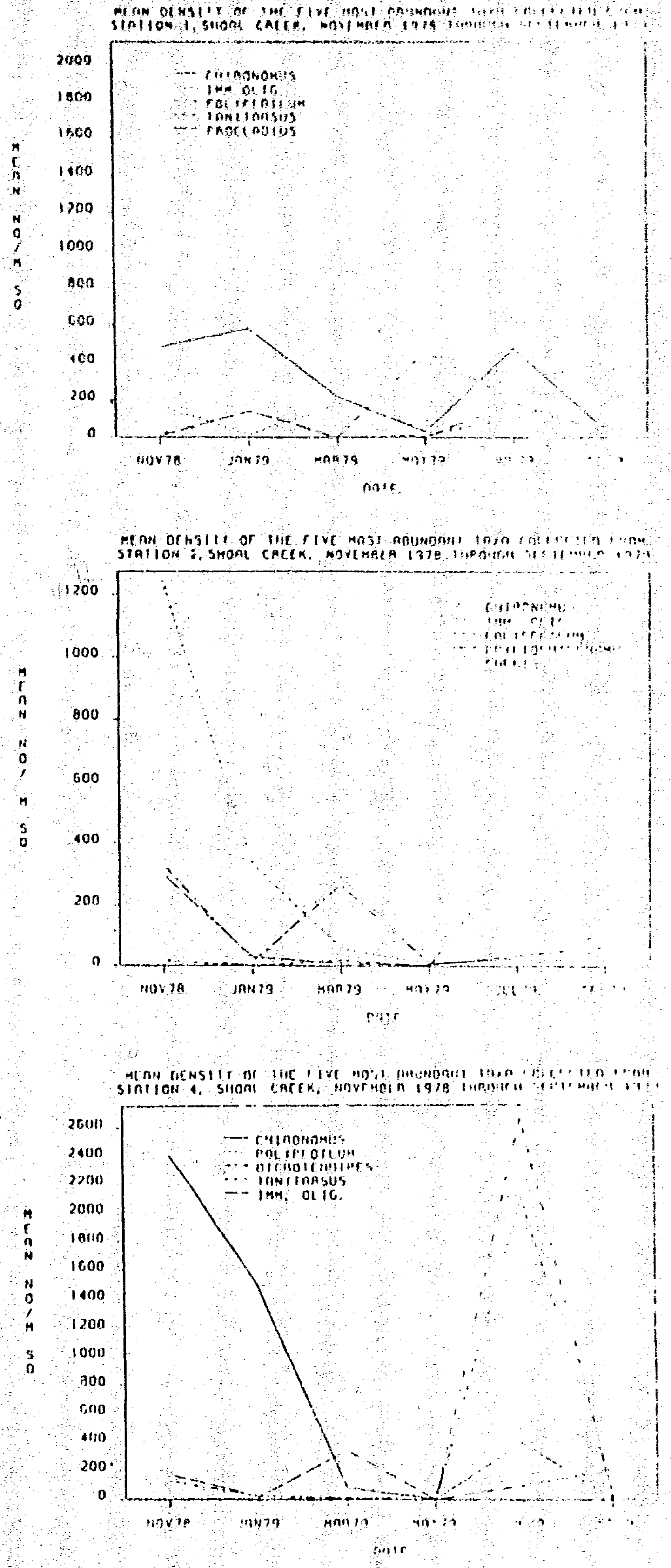


Figure 4.3. Mean density of the five most abundant taxa collected from each of Shoal Creek Stations 1, 2, and 4 from November 1978 through September 1979.

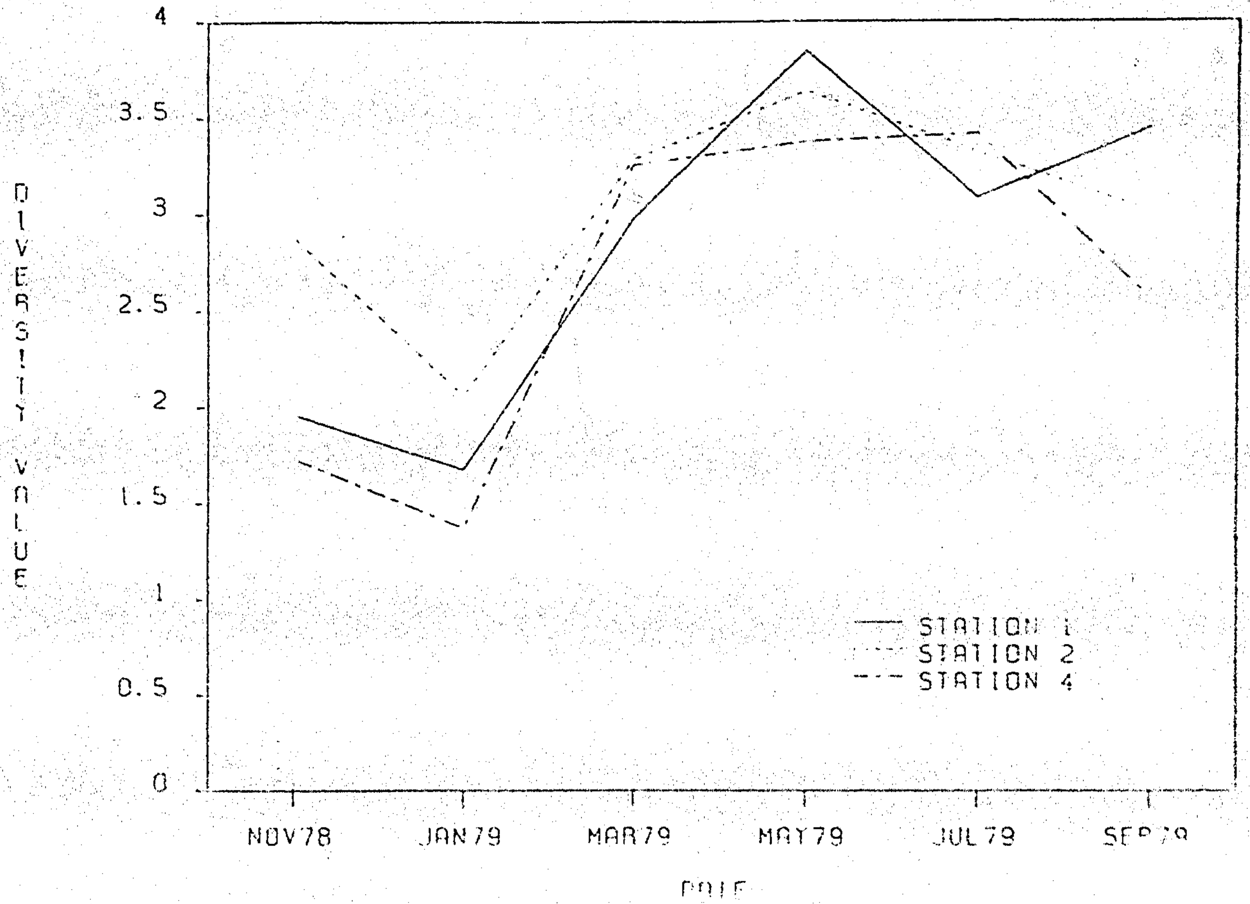


Figure 4.4. Diversity index values calculated from density means of Shoal Creek Stations 1, 2, and 4 from November 1978 through September 1979.

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SECTION 5

EFFECT OF A THERMAL DISCHARGE ON FISHES OF SHOAL CREEK

by

Lance G. Perry

ABSTRACT

An investigation of fish distribution, abundance, and species composition in the East Fork of Shoal Creek was initiated in September 1978 in an effort to assess the impact of thermal enrichment on the fish community. Species composition of the East Fork ichthyofauna was found to be similar to that reported previously from the area. Although artificial temperature elevations were rare during the study, no pronounced thermal influences on species distribution or abundance were detected. Anticipated occurrences of thermal enrichment in the creek (presumably during the spring) probably would not exert a lethal impact upon exposed fishes, but may alter time and/or duration of spawning activities and rate of development during early life. It is unlikely, however, that the survival capacity of the stream populations would be jeopardized unless critical spawning grounds were regularly inundated with excess heat. A worst-case (midsummer) occurrence of thermal enrichment may elevate water temperatures to lethal levels, but such an event presumably would represent a temporary and localized event only, one that local fishes could circumvent by avoiding the disturbed area.

INTRODUCTION

Coffeen Lake was constructed to serve as a cooling water facility for Central Illinois Public Service Company's Coffeen Power Station. Since closure of the dam was completed, impounding McDavid Branch, an intermittent tributary of Shoal Creek's East Fork, the potential has existed for occasional thermal enrichment of the area immediately below the dam. Frequency of occurrence, magnitude, and duration of thermal loading in the East Fork cannot be predicted with certainty since those events that could produce an increase in water temperature occur at irregular intervals. The release of thermal effluents from the lake is ultimately regulated by water level; it must exceed 590 ft in elevation (above mean sea level) in order to establish and maintain a discharge over the spillway. Beyond that initial requirement, the capacity of heated lake water to induce temperature elevations in the creek is contingent upon power plant operation (amount of electricity being generated), and ambient water temperatures, factors that typically vary on a seasonal basis.

Although the biological impacts of periodic additions of excess heat in Shoal Creek are numerous and potentially significant, no comprehensive investigations aimed at evaluating thermal effects have been conducted in the 16 years since impoundment. An opportunity was provided, however, in association with the Coffeen Lake studies, to determine species composition, distribution, and relative abundance of fishes inhabiting reaches that are occasionally subjected to thermal enrichment. The primary objectives of this study were to compare the above-stated parameters at ambient and thermally influenced locations and to relate those findings to published accounts of past fisheries surveys in order to note any changes in the local ichthyofauna that may have occurred since impoundment.

METHODS AND MATERIALS

Fishes were sampled at Stations 1, 2, 3, and 4 (Figure 1.1, Section 1, herein) on 28 September and 30 November 1978, and on 5 April, 18 May, and 20 July 1979. Station 1 was located in an area unaffected by thermal discharges from the lake, whereas Stations 2, 3, and 4 received occasional thermal inputs. Sampling at each station consisted of one bag seine haul of 15 meter distance in a downstream direction. It was originally intended to sample each station every other month (bimonthly) but an ice cover in January and March precluded collecting attempts during those months.

All fishes were preserved in 10% formalin and identified to species (except hybrid sunfishes) in the laboratory. Identifications were accomplished with the aid of Smith (1979) and that reference also served as a source of information on the prior status of the Shoal Creek fish community. Scientific and common names of fishes used herein follow Bailey et al. (1970).

RESULTS AND DISCUSSION

Fish collecting efforts in Shoal Creek yielded a total of 915 individuals representing seven families and 22 species (excluding hybrid sunfishes). Minnows (Family Cyprinidae) were represented by 9 species and were of greatest importance numerically, comprising 71% of the total catch. Other taxa, in descending order of numerical importance, included sunfishes (Centrarchidae, 5 species and 15% of total catch), topminnows (Cyprinodontidae, 1 species and 8%), suckers, (Catostomidae, 3 species and 2%), darters (Percidae, 2 species and 2%), shad (Clupeidae, 1 species and 2%), and catfishes (Ictaluridae, 1 species and 0.2%). Species encountered most frequently included the red shiner (*Notropis lutrensis*, 32% of total catch), sand shiner (*N. stramineus*, 14%), bluntnose minnow (*Pimephales notatus*, 13%), and bluegill (*Lepomis macrochirus*, 10%).

The assemblage of fishes found in the study area appeared to be typical of the region based upon earlier reports. Of 23 species known from the area (Smith 1979), 18 were encountered in the present study. Four species that were represented in our collections, including the golden shiner (*Notemigonus crysoleucas*), bigmouth buffalo (*Ictiobus cyprinnelus*), quillback (*Carpiodes cyrpinus*), and black bullhead (*Ictalurus melas*), were not found previously in the immediate study area but were recorded from adjacent localities within the East Fork system. Fishes designated as either decimated, rare, or restricted in Illinois by Smith (1979) were not encountered nor was their presence documented by previous investigators.

No outstanding differences in species composition, temporal occurrence, or abundance of individuals were detected in a comparison of the ambient station with thermally-influenced stations. Stations 1 (ambient), 2, and 3 each yielded a total catch comprised of six families and 14-17 species, and the Station 4 catch included seven families and 17 species. Those findings do not necessarily reflect thermal influences in the creek, however, since the input of heated lake water was not continuous throughout the period of study. Snow melt and spring rains maintained lake levels sufficiently high to sustain an intermittent discharge over the spillway from early March to mid-May (1979) only. Therefore, of five monthly samples obtained during the past year, only the month of April represented a period of potential thermal impact in the study area. The temperature of the discharged effluent on the April sampling date was 27°C at the time of release from the plant (J. L. Kennedy, personal communication). Recorded water temperatures at Shoal Creek sampling stations were much lower however: Station 1 (ambient) = 8.2°C, Station 2 = 10.9°C, Station 3 = 9.5°C, and Station 4 = 9.5°C. Although water temperatures at test stations were slightly higher than ambient, it is doubtful that the observed increases were of sufficient magnitude to produce a noticeable disparity in distributions of fishes between heated and ambient sites. That was supported by our findings in that the April collections were similar in species composition and abundance at the four stations. In view of the preliminary and somewhat cursory nature of those collections, however, the data were considered inadequate for making any definitive judgements on the general well-being of Shoal Creek fishes or predicting their responses to thermal inputs. It is, perhaps, of greater utility to review the basic ecological requirements of the local ichthyofauna in order to allow a prediction, based upon inferential evidence, of changes in the fish community that may have been produced by thermal enrichment. The remainder of this report is devoted to that end.

Any modification of the natural thermal regime in aquatic systems may significantly alter normal physiological and behavioral functioning of exposed fishes. Because fishes in temperate regions have adapted to a rather stringent annual thermal regime, and since their metabolic rates are directly related to water temperature, daily activities and biorhythmic cycles (migrations, reproductive timing, etc.) are often keyed to seasonal temperature cycles. Accordingly, artificial temperature elevations may affect fishes in numerous, diverse, and complex ways. The complexity is evidenced by a multiplicity of possible interactions involving lethal and sublethal temperature effects on the one hand, and varying degrees of temperature sensitivities exhibited by the various life stages (egg, larval, juvenile, and adult) on the other. A knowledge of life history strategies, habitat requirements, and temperature tolerances of Shoal Creek fishes is required, therefore, before inferences can be drawn regarding their vulnerability to thermal impacts. A summation of those data, derived from the literature, is presented in Tables 5.1 and 5.2, and the following discussion is in reference to those findings.

In general, fishes exhibiting the lowest temperature tolerances also exhibit the earliest and possibly the shortest spawning seasons. In Shoal Creek, this includes the suckers, darters, and among the minnows, the creek chub (Semotilus atromaculatus). Four of those species, the creek chub, creek chubsucker (Erimyzon oblongus), white sucker (Catostomus commersoni), and johnny darter (Etheostoma nigrum) are characteristic of Pfleiger's (1971) Ozark and Ozark prairie faunal regions and, as such, probably require a clear water and rocky bottom habitat for long-term existence. Clear water appears to be the principal requirement of the slough darter (Etheostoma gracile) as well, an inhabitat of Pfleiger's (1971) lowland faunal region. The remaining members of those familia groups typify either the prairie assemblage (quillback and blackside darter, Percina maculata), usually inhabiting moderately low gradient, warmwater streams, or the "wide ranging" group (bigmouth buffalo) which are believed to exhibit a relatively broader range of tolerances for water temperature extremes, turbidity, level of dissolved oxygen, volume of flow, and substrate composition than the aforementioned species. As a group, the minnows appear to possess a greater tolerance for high water temperatures than the suckers or darters (Table 5.2). Most are spring and early summer spawners and a few have spawning seasons extending into late summer. A wide range of environmental tolerances is suggested by their designation as either prairie stream inhabitants or wide-ranging in distribution (Table 5.1). Two species, the silverjaw minnow (Ericymba buccata) and stoneroller (Campostoma anomalum) apparently have more stringent habitat requirements than the others and display a greater affinity for clear water and rocky substrates. The gizzard shad (Dorosoma cepedianum), black bullhead, blackstripe topminnow (Fundulus notatus), and the sunfishes all

Table 5.1 Relative abundance (R = rare, C = common, A = abundant) and selected ecological characteristics of fishes from the East Fork of Shoal Creek.

Taxon	Relative Abundance	Ecological Characteristics†			
		Faunal Region	Preferred Spawning Substrate	Spawning Season	Extended Spawning Period
Clupeidae					
Gizzard shad	C	wide-ranging	variable, often a pelagic spawner	spring-early summer	
Cyprinidae					
Bluntnose minnow	A	wide-ranging	undersurface of submerged objects	late spring-summer	
Creek chub	C	Ozark-prairie	rocky	spring	
Fathead minnow	C	prairie	same as bluntnose	late spring-summer	X
Golden shiner	R	wide-ranging	submerged vegetation	late spring-summer	X
Red shiner	A	prairie	variable	late spring-summer	X
Redfin shiner	A	wide-ranging	sunfish nests	late spring-summer	X
Silverjaw minnow	C	Ozark	rocky	spring-early summer	
Silvery minnow	*	lowland	silt-detritus	spring	
Stoneroller	*	Ozark-prairie	rocky	spring	
Suckermouth minnow	R	prairie	rocky	spring-early summer	
Catostomidae					
Bigmouth buffalo	R	wide-ranging	variable	late spring	
Creek chubsucker	*	Ozark	rocky	spring	
Quillback	R	prairie	sand	spring	
White sucker	R	Ozark-prairie	rocky	spring	
Ictaluridae					
Black bullhead	R	wide-ranging	variable	late spring-early summer	
Cyprinodontidae					
Blackstripe topminnow	A	wide-ranging	submeged vegetation and detritus	lage spring-summer	X

Table 5.1 Relative abundance (R = rare, C = common, A = abundant) and selected ecological characteristics of fishes from the East Fork of Shoal Creek (cont.).

Taxon	Relative Abundance	Ecological Characteristics†			
		Faunal Region	Preferred Spawning Substrate	Spawning Season	Extended Spawning Period
Centrarchidae					
Bluegill	A	wide-ranging	rocky	late spring-summer	X
Green sunfish	C	wide-ranging	variable	late spring-summer	X
Largemouth bass	R	wide-ranging	variable	late spring-early summer	
Lepomis hybrids	R				
Longear sunfish	C	Ozark-lowland	rocky	late spring-summer	X
Orangespotted sunfish	*	prairie	rocky	late spring-summer	X
White crappie	R	wide-ranging	variable, usually near submerged vegetation	spring-early summer	
Percidae					
Blackside darter	R	prairie	sand,gravel	spring	
Johnny darter	C	Ozark-prairie	undersurface of submerged objects	spring	
Slough darter	*	lowland	submerged objects, detritus	late spring	

†From Pflieger (1971), Scott and Crossman (1973), Balon (1975), Pflieger (1975), and Smith (1979).
*Species known from the area (Smith (1979) but not found in the present study.

Table 5.2 Approximate lethal temperatures of fishes from the East Fork of Shoal Creek.

Species	Lethal Temperature (°C)*				
	32	34	36	38	40
Creek chub	X				
Bigmouth buffalo	X				
Creek chubsucker	X				
Quillback	X				
White sucker	X				
Blackside darter	X				
Johnny darter	X				
Slough darter	X				
Bluntnose minnow		X			
Fathead minnow		X			
Golden shiner		X			
Red shiner		X			
Redfin shiner		X			
Sandshiner		X			
Silverjaw minnow		X			
Silvery minnow		X			
Stoneroller		X			
Suckermouth minnow		X			
Black bullhead			X		
Green sunfish			X		
Longear sunfish			X		
White crappie			X		
Gizzard shad				X	
Bluegill				X	
Largemouth bass				X	
Orangespotted sunfish				X	
Blackstripe topminnow					X

*From Bush et al. (1974). Lethal temperatures for species not listed therein were inferred from those given for closely related species.

have recorded temperature tolerances greater than 35°C (Table 5.2). Their wide-ranging nature implies a capability for survival in diverse habitats and, among Shoal Creek fishes, the greatest abilities to withstand extreme or unfavorable environmental conditions. In addition, several members of that group have protracted spawning seasons, a strategy that may enhance reproductive success in habitats that are subject to temporary or intermittent environmental perturbations as exemplified by the incidence of thermal enrichment in Shoal Creek.

It is unlikely that heated effluents entering Shoal Creek could impose a significant lethal impact on resident fishes even though surface temperatures in the discharge arm of Coffeen Lake have at times reached 43°C (see "Thermal Mapping", Part I, Section 2, herein), a figure cited as lethal for most local species. The reasoning behind that assumption is two-fold. First, upon entering the lake, thermally-enriched effluents are dispersed and subjected to turbulence, creating a large area for heat exchange with the atmosphere. The heated effluent must flow out of the discharge arm of the lake (Figure 1.1, Section 1, herein) and over the reservoir spillway before entering Shoal Creek, a distance greater than 3 km from the point of release. As a result, some reduction in discharge temperature could be expected before the creek fishes are exposed to the effluent. Secondly, the highest water temperatures in the discharge arm can generally be expected in mid or late summer because of the prevalence of high ambient water temperatures, relatively low lake levels, and peak power consumption; the latter necessitating the use of large volumes of cooling water. Any discharge of lake water over the spillway at that time of year must be considered exceptional since heavy precipitation in late summer is uncommon. During the period of most intense thermal loading, therefore, the heated effluent would pose no threat to Shoal Creek fishes since it would usually remain within the confines of the lake. Nonetheless, a comprehensive assessment of the effects of heat stress in Shoal Creek should include all potential impacts associated with the occurrence of a worst-case themal exposure on the one hand, and a more typical, predictable event on the other.

The worst-case scenario presumably would include a mid or late summer thermal discharge because, as discussed above, thermal loading of the lake is greatest at that time. Because high water levels are required to produce a discharge from the lake, a relatively high volume of flow in Shoal Creek would be insured as well, thus acting to resist or buffer temperature increases and establishing access routes (by connecting isolated pools) that would enable fishes to move to other locations. As a result, even if temperatures exceeded known lethal levels at certain localities, the high water would offer exposed fishes the option of moving upstream to unaffected areas or traveling downstream until heat dissipation rendered water temperatures more favorable. Reports of fish kills in nature as a direct result of thermal enrichment of surface waters are conspicuously rare, even for temperature-sensitive forms. One might logically assume that the ability to detect and avoid harmful temperatures is one reason for the lack of such findings. That contention is supported by McFarlane (1976) who determined that stream fishes avoided potentially lethal thermal effluents emanating from cooling condensers but rapidly repopulated the affected stream sections once the flow of heated water ceased. Stream fishes were also found to be capable of traveling great distances to occupy previously vacated stream sections that were affected by drought (Larimore et al. 1959). Escapement is apparently a common strategy among stream fishes providing a means of avoiding deleterious effects of locally extreme or unfavorable environmental conditions.

Whereas lethal effects of elevated water temperatures on fishes are relatively easy to predict, given accurate tolerance data and consistent responses on the part of the fishes, sublethal effects lend themselves less readily to accurate evaluation. Quantitative as well as qualitative changes are possible consequences of thermal enrichment, and these can occur at all levels of organization within the fish community. In Shoal Creek, a typical-case thermal exposure would occur during the springtime rainy season when water levels are high and consumer power demands are low. As a result, a lethal temperature increase in Shoal Creek would be improbable. Most resident fishes are involved in spawning activities at that time of year, however, and artificially elevated water temperatures on the spawning grounds could affect reproductive processes. The consequences of disrupting or modifying such natural functions are, as yet, speculative. The paucity of gravel substrates in the study area suggests that fishes preferring or requiring rocky substrates for spawning (Table 5.1) may migrate out of the affected area prior to spawning, thus inadvertently avoiding areas subject to thermal additions in the spring. Among fishes that do spawn in the area, time of spawning may be advanced and eggs and larvae of those fishes may experience an accelerated rate of development when exposed to elevated temperatures. This can be perceived as either an enhancement or a hindrance to reproductive efforts. An accelerated growth rate and earlier spawning season, for example, would offer various selective advantages to earlier spawned individuals compared to conspecifics spawned later in the season. On the other hand, more rapid development during early life may prevent synchronization of peak plankton production with the onset of external feeding in larvae, thereby reducing their chances of survival through the critical first feeding stages. Those effects would be more pronounced among larvae that are displaced downstream after hatching and utilize areas other than the immediate spawning grounds for feeding and growth. In addition, eggs and larvae at thermally influenced locations could be exposed to sustained high water temperatures or extreme temperature fluctuations because, unlike adult fishes, their limited motilities may prevent escapement. It is thus evident that the rigid dependency of life history phenomena on the annual thermal regime make specific impacts of unnatural temperature increases difficult to discern or verify. Any unnatural temperature elevation may alter the capacity of a species to survive in an affected region by modifying spawning time or location, nest building and guarding activities, or survivorship of eggs and larvae (see for example, Rosenthal and Alderice 1976).

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