ORNL/TM-13183

OAK RIDGE NATIONAL LABORATORY

LOCKHEED MARTIN

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LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
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ACRONYMS

ANOVA	analysis of variance
AO	Agreed Order
BBK	Big Bayou Creek kilometer
BMAP	Biological Monitoring and Abatement Program
BMP	Biological Monitoring Program
CTM	critical thermal maximum
DO	dissolved oxygen
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPT	Emphemeroptera, Plecoptera, Trichoptera
ESD	Environmental Sciences Division
ETOH	ethyl alcohol
GLM	general linear model
ID	internal diameter
K	condition factor
KDOW	Kentucky Division of Water
LED	light-emitting diode
LT_{50}	median lethal temperature
LT_{100}	temperature at which 100% mortality occurs
LUK	Little Bayou Creek kilometer
MAK	Massac Creek kilometer
MS-222	tricaine methanesulfonate
NIST	National Institute of Standards and Technology
NTU	nephelometric turbidity unit
ORNL	Oak Ridge National Laboratory
PCB	polychlorinated biphenyl
PCC	Paducah Community College
PGDP	Paducah Gaseous Diffusion Plant
PVC	polyvinyl chloride
RED/MAC	redfin shiner/Massac Creek water experiment
RED/001	redfin shiner/Outfall K001 water experiment
ROL/MAC	central stoneroller/Massac Creek water experiment
ROL/001	central stoneroller/Outfall K001 water experiment
RTM	Ryan TempMentor
SAS	Statistical Analysis System
SD	standard deviation
TL	total length
TRAC	Teacher Research Associate Program
TRC	total residual chlorine
TTD	time to death
TVA	Tennessee Valley Authority
USEC	United States Enrichment Corporation

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EXECUTIVE SUMMARY

The development of a biological monitoring plan (Kszos et al. 1994a) for the receiving streams of the Paducah Gaseous Diffusion Plant (PGDP) began in the late 1980s, because of an Agreed Order (AO) issued in September 1987 by the Kentucky Division of Water (KDOW). Five years later, in September 1992, more stringent effluent limitations were imposed upon the PGDP operations when the KDOW reissued Kentucky Pollutant Discharge Elimination System permit No. KY 0004049. This action prompted the U.S. Department of Energy (DOE) to request a stay of certain limits contained in the permit. An AO is being negotiated between KDOW, the United States Enrichment Corporation (USEC), and DOE that will require that several studies be conducted, including this stream temperature evaluation study, in an effort to establish permit limitations. All issues associated with this AO have been resolved, and the AO is currently being signed by all parties involved.

The proposed effluent temperature limit is 89°F (31.7°C) as a mean monthly temperature. In the interim, temperatures are not to exceed 95°F (35°C) as a monthly mean or 100°F (37.8°C) as a daily maximum. This study includes detailed monitoring of instream temperatures, benthic macroinvertebrate communities, fish communities, and a laboratory study of thermal tolerances.

Instream Temperature Monitoring

An integral part of this study involved the monitoring of instream water temperatures. Temperature recording units, logging instream water temperatures at 2 hour intervals, were deployed at 15 sites in the Paducah area. Temperature monitoring focused on PGDP outfalls suspected of having a thermal impact on the receiving streams, Big Bayou and Little Bayou Creeks.

This subtask provided a detailed record of the water temperatures associated with Massac Creek kilometer (MAK) 13.8, Little Bayou Creek kilometer (LUK) 7.2, and Big Bayou Creek kilometers (BBK) 9.1, 10.0, and 12.5, as well as Outfalls K001, K006, K008, and K010/011, and those sections of receiving streams immediately above and below these discharges. Data analyzed in this report cover the period from July 1993 to November 1995.

Weekly temperature surveys conducted by PGDP personnel from July 13 through September 28, 1993, showed that temperatures are consistently elevated along the east bank of Big Bayou Creek downstream from Outfall K001. Temperatures appear to be well mixed approximately 60 m below the mouth of K001. Discharge from Outfall K011 elevated temperatures in Little Bayou Creek such that the effect was seen across the entire width of the stream, with complete mixing observed within 25 m of the outfall discharge.

Temperature recorder data indicate that at no time during this study did temperatures at the reference sites (MAK 13.8, BBK 12.5, and Ohio River intake) exceed the temperature limit proposed for the effluents. Furthermore, there were no bi-hourly temperature observations of instream sites that exceeded the proposed or interim effluent limits at these sites. However, the stream reaches associated with Outfalls K001 and K011 did have higher temperatures than comparable reference stream reaches. No reference site was established on Little Bayou Creek.

The proposed monthly temperature limit was exceeded in Outfalls K010/011 on four occasions during the study period (July 1993, July 1994, and July and August 1995). Temperatures at LUK 7.2 were reduced considerably compared with the upstream sites, but were still elevated compared with reference sites. Because the stream channel is narrow (approximately 1 m) near Outfall K010/011, prolonged elevated temperatures may act as a barrier to aquatic biota. The maximum bi-hourly temperature recorded at the study sites was 36.7°C (Big Bayou Creek 25 m downstream of Outfall K001), 6°C higher than the maximum temperature recording at MAK 13.8 or BBK 12.5.

Discharges from Outfalls K001, K006, and K010 appear to be the greatest thermal contributors to their respective receiving streams. However, discharges from Outfalls K008 and K009 also contribute to the total thermal load on Big Bayou Creek. Nonetheless, there were no exceedances of the proposed or interim effluent limits at any of Big Bayou Creek's instream sampling sites (BBKs 12.5, 10.4, 10.0, and 9.1), although exceedances did occur in Outfall K001, which discharges into Big Bayou Creek. Temperatures in the outfalls and the receiving streams were elevated compared with the reference sites.

Benthic Macroinvertebrate Community Monitoring

The purpose of this subtask was to evaluate benthic macroinvertebrate data collected since 1991 for the PGDP Biological Monitoring Program (BMP) specifically for evidence that may suggest adverse thermal effects. Benthic macroinvertebrate samples have been collected quarterly (March, June, September, and December) since September 1991 from three study sites downstream of effluent discharges from PGDP, including two sites on Big Bayou Creek (BBK 9.1 and BBK 10.0) and one site on Little Bayou Creek (LUK 7.2). Two reference sites were sampled concurrently, including one on Big Bayou Creek upstream of all effluent discharges (BBK 12.5) and one on Massac Creek (MAK 13.8) southeast of the PGDP Reservation. All samples collected from each quarter of the first year of the study (September 1991–March 1992) were processed to provide a more detailed baseline. In subsequent years only samples collected in the March, September, and December sampling periods were processed.

At each site on each sampling date, three random samples were taken from a riffle with a Surber sampler. Organisms were identified to the lowest practical taxon and enumerated.

Most major taxonomic groups of macroinvertebrates typically found in streams were represented at all study sites and reference sites during the 4 years covered by the BMP study. Included at these sites was a mixture of taxa often considered tolerant (e.g., worms and true midges) and intolerant (e.g., mayflies, stoneflies, and caddisflies) of poor water quality. No obvious patterns of presence/absence of taxa distinguished the two reference sites from the study sites, although fewer stonefly taxa were collected at BBK 9.1 and BBK 10.0 than at the reference sites and LUK 7.2.

The macroinvertebrate communities at all sites exhibited extensive changes in density, taxonomic richness, and taxonomic richness of the mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) (EPT richness) between each sampling period and between years within a sampling season. Mean values for EPT richness at the three study sites were lower (< a factor of 2) than those for reference site BBK 12.5 from December 1993 through March 1995, but the values at these sites differed little from those for reference site MAK 13.8 during this period. Values for density at BBK 10.0 and BBK 9.1 occasionally seemed high compared with the reference sites, but large differences never persisted for more than two consecutive sampling periods.

The abundances of mayflies, stoneflies, and caddisflies were strongly "seasonal" at all five sites. The mayflies and caddisflies, although nearly always present at all sites, were clearly most abundant during the

September sampling periods. No persistent site differences were discernable in these groups, although BBK 9.1 most often had the highest densities of both groups. The stoneflies were rare at all sites in all of the September sampling periods. With few exceptions, stonefly densities were clearly and consistently higher at reference site BBK 12.5 than at all other sites, including reference site MAK 13.8 in the March and December sampling periods; this difference was most likely a major reason for the highly significant site effects obtained in the two-way analysis of variances (ANOVAs) for these two sampling periods. The results for reference site MAK 13.8 were more ambiguous. Only the March data appeared to indicate that densities of the stoneflies at MAK 13.8 may have been different from those at the three heated study sites. In March, stonefly richness values at reference site BBK 12.5 were clearly and consistently higher than those at the three heated study sites, but values at MAK 13.8 were not distinctly different from those of the three heated study sites until the 1994 and 1995 sampling periods. During the December sampling periods, mean richness values for the stoneflies were one or less at all sites with few exceptions. Although richness values for stoneflies tended to be higher at reference site BBK 12.5 than at most other sites, the richness data from this group suggest that the stoneflies were numerically insignificant at these sites.

Site differences in community structure of the macroinvertebrate communities between reference sites and study sites in Big Bayou Creek and Little Bayou Creek were not clearly discernable from the available data and the parameters evaluated in this study. Interpretation of the results of this study as a finding of no impact should be made cautiously, because excessive variability (i.e., between-sample, spatial, and temporal) can sometimes prevent detection of impacts. The inability to detect effects or differences with biological data from field studies is a common problem that increases as anthropogenic stresses become more subtle.

There was no strong evidence that the mayflies or caddisflies at BBK 9.1, BBK 10.0, or LUK 7.2 were being subjected to conditions unusually different from those of the reference sites. There was some evidence suggesting that stonefly density and richness may have been suppressed at these study sites. Even so, the benthic macroinvertebrate data collected during this 4-year period provide no conclusive evidence that the macroinvertebrate communities of Big Bayou and Little Bayou creeks are being adversely affected by thermal discharges.

Fish Community Monitoring

The use of field survey data to analyze the impacts of elevated temperatures on fish communities has many limitations. Many heated effluents contain other contaminants or stressors that can have as much of an effect on fish distributions as temperature. Comparisons of fish distributions above and below heated effluents are also compounded by complexities of habitat, seasonal movements, feeding forays, and behavioral adjustments. Given these complicating factors, a general correspondence of fish distribution trends with the observed temperature regimes may only suggest a possible influence of temperature. The quantitative samples of the fish community were collected in the spring and fall at three sites near the PGDP and at two reference sites. Qualitative samples of the fish community were collected at four sites near the PGDP on a quarterly schedule from November 1993 through November 1995.

The quantitative and qualitative samples collected in Big Bayou Creek indicate that fewer species are found in areas downstream of Outfalls K001, K006, and K008 than in a comparable reference stream. The species missing from Big Bayou Creek include more of the species classified as less tolerant of degraded environmental conditions. Also, more of the species occurring at the Big Bayou Creek sites can be classified as tolerant to such conditions. At a community level, the fish abundance measures do not reflect a substantial difference between the heated Big Bayou Creek sites and reference sites. These patterns correlate with higher mean temperatures at the Big Bayou Creek sites than at the Massac Creek reference site. Literature values for upper lethal and critical thermal maximum (CTM) temperatures from laboratory studies indicate that the temperatures occurring instream below the outfalls should not be lethal to the majority of fish in the core species assemblage. The absence of the more sensitive species from these communities may be influenced by these slightly higher temperatures, but much of the critical laboratory data is deficient for these species. These absent species may indicate that temperatures occasionally increase beyond the preferred range up to levels that prompt seasonal avoidance.

Within the K001 Outfall ditch, the impact of elevated temperatures appears to be more substantial, as might be expected. Here the temperature pattern shows quite a few excursions up to levels that represent lethal or CTM temperatures. These patterns are also reflected by the species richness and catch per unit effort data, where the lowest values occur in the summer sampling when temperatures are highest. Although the fish occurring in the K001 Outfall ditch are also exposed to higher concentrations of chemicals than fish in Big Bayou Creek proper, the acute impact of these stressors may be less than that of temperature. Effluent toxicity tests of K001 conducted from 1990 through 1995 found only 4 of 23 tests in which potential instream toxicity was indicated.

The two sampling sites evaluated in Little Bayou Creek for temperature effects indicate that some impact is occurring, but only in a limited area. The species richness and density data at LUK 7.2 did not differ substantially from the comparable reference site. This corresponds with the relatively benign temperatures seen at LUK 7.2, which were well below upper lethal and CTM values. In contrast, a pattern of impact on fish distribution was observed for the sampling site below K010/K011. Sampling temperatures at this site were similar to those seen at K001 and were higher than temperatures at other sites. Some of the recorded temperatures exceeded upper lethal, CTM, and avoidance temperatures for core assemblage species. The species richness and catch per unit effort corresponded to the variations in temperatures; lower values were observed during summer sampling periods when temperatures were greatest. These low values could be associated with proximity to outfalls and a resulting high exposure to chemical stressors. However, effluent toxicity tests of K010/K011 conducted from 1990 through 1995 found only 3 of 31 tests in which potential instream toxicity was indicated.

Laboratory Evaluations of Thermal Tolerances

In July 1995, field sampling of aquatic faunal communities was supplemented by a laboratory study of the thermal tolerances of two native fishes: the central stoneroller (*Campostoma anomalum*) and the redfin shiner (*Lythrurus umbratilis*). The thermal tolerance experiments conducted using redfin shiners revealed critical (median lethal) temperatures of 32.7°C (in Massac Creek water) and 37.2°C (in K001 water). In experiments using central stonerollers, critical temperatures were 38.1°C (in Massac Creek water) and 38.2°C (in K001 water). Most test fish were collected from Massac Creek or its tributaries, at temperatures of 22.7–25.1°C. The fish were acclimated to a temperature of 25°C, the same temperature to which fish were exposed during the first hour of testing. A heating rate of 1°C/h was used, and testing continued until there was 100% mortality of non-control fish. The laboratory studies were conducted in water from the MAK 13.8 reference site as well as water from Outfall K001. It was hypothesized that the hyperthermic tolerances of these fish might be greater in reference stream water than in outfall water. This hypothesis was not validated by the laboratory experiments.

A statistical analysis of time to death (TTD) vs condition factor (K) was made for each of the four experiments on transformed data. Neither of the redfin shiner experiments showed a significant association between K and TTD; however, central stonerollers with a K>1 tended to have a significantly shorter TTD (in both experiments) than those with K<1.

There was not a significant water effect on the TTD for central stonerollers, as there was with redfin shiners. The median TTD for central stonerollers was approximately 800 min in Massac water and 834 min in K001 water (the mean TTDs were approximately 739 and 788 min, respectively). The median TTD for redfin shiners was approximately 527 min in Massac water and 772 min in K001 water (the mean TTDs were approximately 530 and 732 min, respectively). These data, when combined with the fact that even control mortality was higher in Massac Creek water, indicate that both species do better in K001 water, whether under hyperthermic stress or static thermal conditions. Nonetheless, these results should not be interpreted as an indication that Outfall K001 water is better for fish than Massac Creek water.

The difference in thermal tolerances observed in redfin shiners was likely related to differences in the chemical compositions of the two types of test water (e.g., conductivity and hardness are much higher in Outfall K001 water than in Massac Creek water). Evidence in the literature as well as these laboratory studies of thermal tolerance clearly indicate that central stonerollers have a higher hyperthermic tolerance than do redfin shiners. The median lethal temperatures that were observed in these laboratory studies, when combined with the existing literature on lethal temperature data, should be considered in any assessment of the distribution and abundance of fish in and around PGDP outfalls and receiving streams.

Summary, Conclusions, and Recommendations

A study of outfall and receiving stream temperatures showed a 1- to 2-kilometer elevated-temperature zone in Big Bayou and Little Bayou creeks immediately below PGDP Outfalls K001 and K010, respectively. Within the outfalls and in immediately adjacent receiving stream zones, maximum summer temperatures reach 34–38°C, sufficient to cause mortality in some fish species if sustained for several hours.

The analysis of 4 years of benthic macroinvertebrate data (collected from three thermally impacted sites and two reference stream sites) was inconclusive in determining an adverse effect due to thermal impacts, but did not rule out the potential for subtle, undetected impacts.

The analysis of fish population data collected during this same period generally revealed a lack of intolerant species from the communities of Big Bayou Creek and Little Bayou Creek associated with PGDP outfalls. Distribution data indicated that some species were absent from the most thermally impacted stream sites during the summer months.

The published information and our own thermal tolerance studies indicate that instream temperatures above 36°C can cause mortality in some species of fish found in Big Bayou and Little Bayou creeks. Due to the presumption of an associated chemical load from outfalls, any impacts on the fish communities could not be attributed solely to increased temperature. Laboratory studies of two species did indicate, however, increased hyperthermic tolerance and survival in Outfall K001 (as compared with reference site water).

It is recommended that the temperature of effluents from Outfalls K001, K006, K008, and K010 be lowered prior to discharge into Big Bayou and Little Bayou creeks. Several options are proposed to address this recommendation. These include (a) increase shading of open water areas of outfalls through the use of supplemental plantings (of shade trees) or by establishing riparian buffer zones to prevent the cutting of native vegetation, (b) determine whether a lower discharge point from storage lagoons (e.g., for Outfall K006) would result in lower effluent temperatures, (c) evaluate the need for additional cooling towers or other engineering controls, (d) consider the addition of raw Ohio River water to effluents, and (e) find ways to reduce the quantity or the temperature of heated discharges. Other alternatives focus on compliance monitoring criteria, such as moving the temperature monitoring point from within the outfall to below the mixing zones. Unlike the options which address the recommendation, these alternatives are not likely to affect the resident fauna because they do not allow for lowering of instream temperatures.

1. INTRODUCTION

(W. K. Roy)

The development of a biological monitoring plan (Kszos et al. 1994a) for the receiving streams of the Paducah Gaseous Diffusion Plant (PGDP) began in the late 1980s, because of an Agreed Order (AO) issued in September 1987 by the Kentucky Division of Water (KDOW). Five years later, in September 1992, more stringent effluent limitations were imposed upon the PGDP operations when the KDOW reissued Kentucky Pollutant Discharge Elimination System permit No. KY 0004049. This action prompted the U.S. Department of Energy (DOE) to request a stay of certain limits contained in the permit. An AO is being negotiated between KDOW, the United States Enrichment Corporation (USEC), and DOE that will require that several studies be conducted, including this stream temperature evaluation study, in an effort to establish permit limitations. All issues associated with this AO have been resolved, and the AO is currently being signed by all parties involved. The proposed effluent temperature limit is 89°F (31.7°C) as a mean monthly temperature (Roy et al. 1994). In the interim, temperatures are not to exceed 95°F (35°C) as a monthly mean or 100°F (37.8°C) as a daily maximum. This report addresses the findings of a temperature study, performed to determine potential impacts of elevated temperature discharges from the PGDP on nearby aquatic fauna.

The temperature study consisted of the following subtasks: (1) to provide a detailed record of temperatures associated with the discharges from Outfalls K001, K008, and K010/011 and those reaches of Big Bayou and Little Bayou creeks associated with these discharges, (2) to evaluate the associated benthic macroinvertebrate communities, (3) to examine the distribution and abundance of fishes associated with these sites, and (4) to conduct thermal tolerance laboratory experiments on two species of fish. The objectives of these subtasks were to develop an accurate assessment of actual site temperatures so that any potential adverse effects on the benthic macroinvertebrate and fish communities could be related to temperature, and to determine through laboratory studies whether outfall temperatures were high enough to cause mortality in some fish.

An integral part of this study involved the monitoring of instream water temperatures. Temperature recording units which log instream water temperatures at 2-hour intervals, were deployed at 15 sites (Figs. 1.1 and 1.2) by personnel from the Environmental Science Division (ESD) of Oak Ridge National Laboratory (ORNL). Temperature monitoring at most sites was terminated in November 1995, after a minimum of 12 months of data collection. However, more than 2 years of temperature data exist for several of the sites. Temperature recorders were placed in four outfalls (Outfalls K001, K006, K008, and K011) suspected of having a temperature impact on Big Bayou and Little Bayou creeks. Recorders were also placed approximately 25 m above and below the mouths of Outfalls K001 and K011, in Big Bayou and Little Bayou creeks, respectively. In June 1994, Outfall K011 water was diverted through Outfall K010, at which point the Outfall K011 temperature recorders were transferred as well. The references to "Outfall K010/011" contained in this report reflect this diversion of water and the fact that work was performed both before and after the change was implemented. Additional temperature recorders were deployed in the Ohio River embayment at Tennessee Valley Authority's (TVA) Shawnee Power Plant, from which the PGDP draws its raw intake water. This site, though part of a much larger body of water, provides temperature data on water unimpacted by thermal influences of the PGDP. Results of the instream temperature

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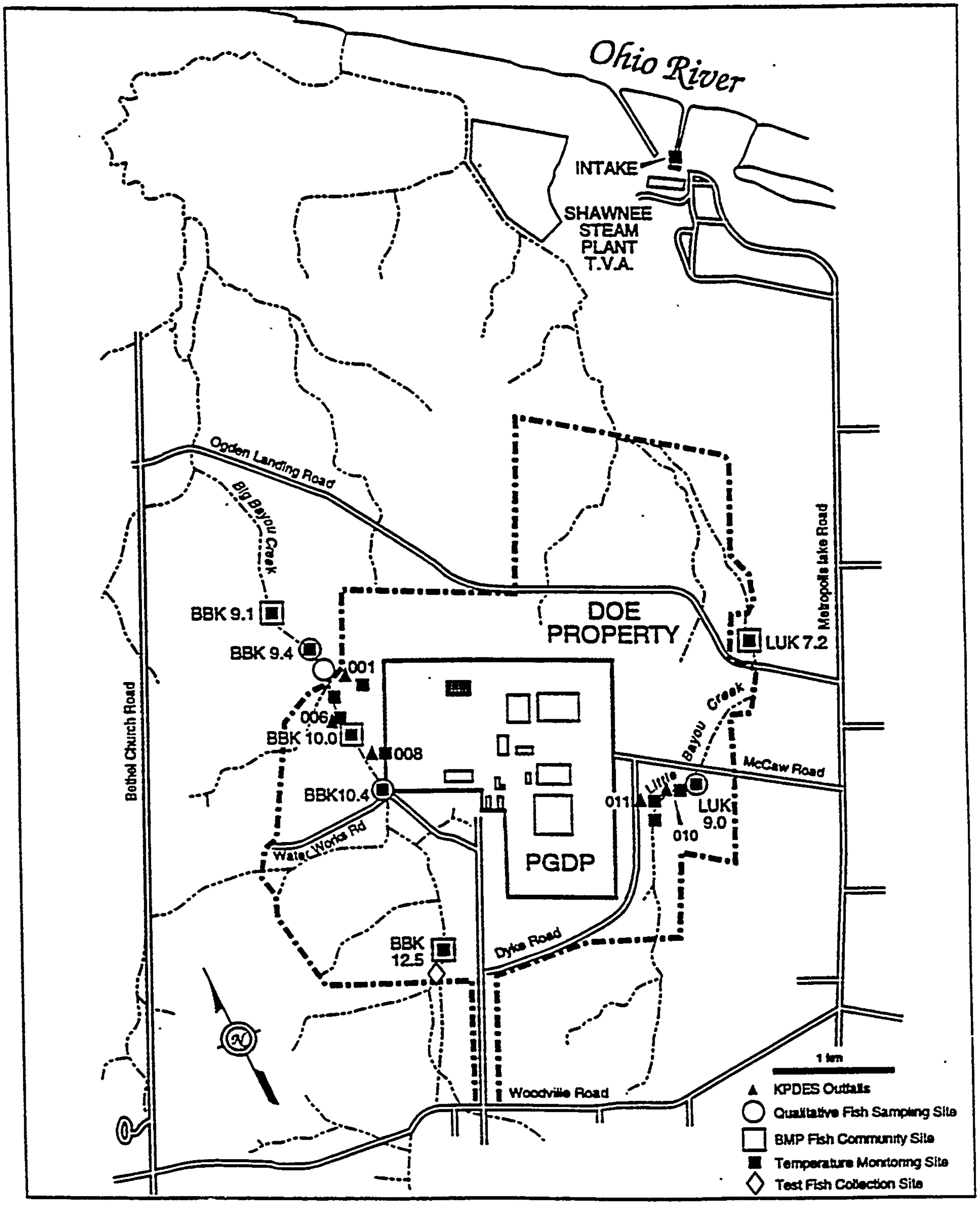

Fig. 1.1. Locations of temperature monitoring, ecological sampling, and test fish collection sites on the Paducah Gaseous Diffusion Plant (PGDP) reservation and the Shawnee Steam Plant. KPDES = Kentucky Pollutant Discharge Elimination System; BMP = Biological Monitoring Program; BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; and TVA = Tennessee Valley Authority.

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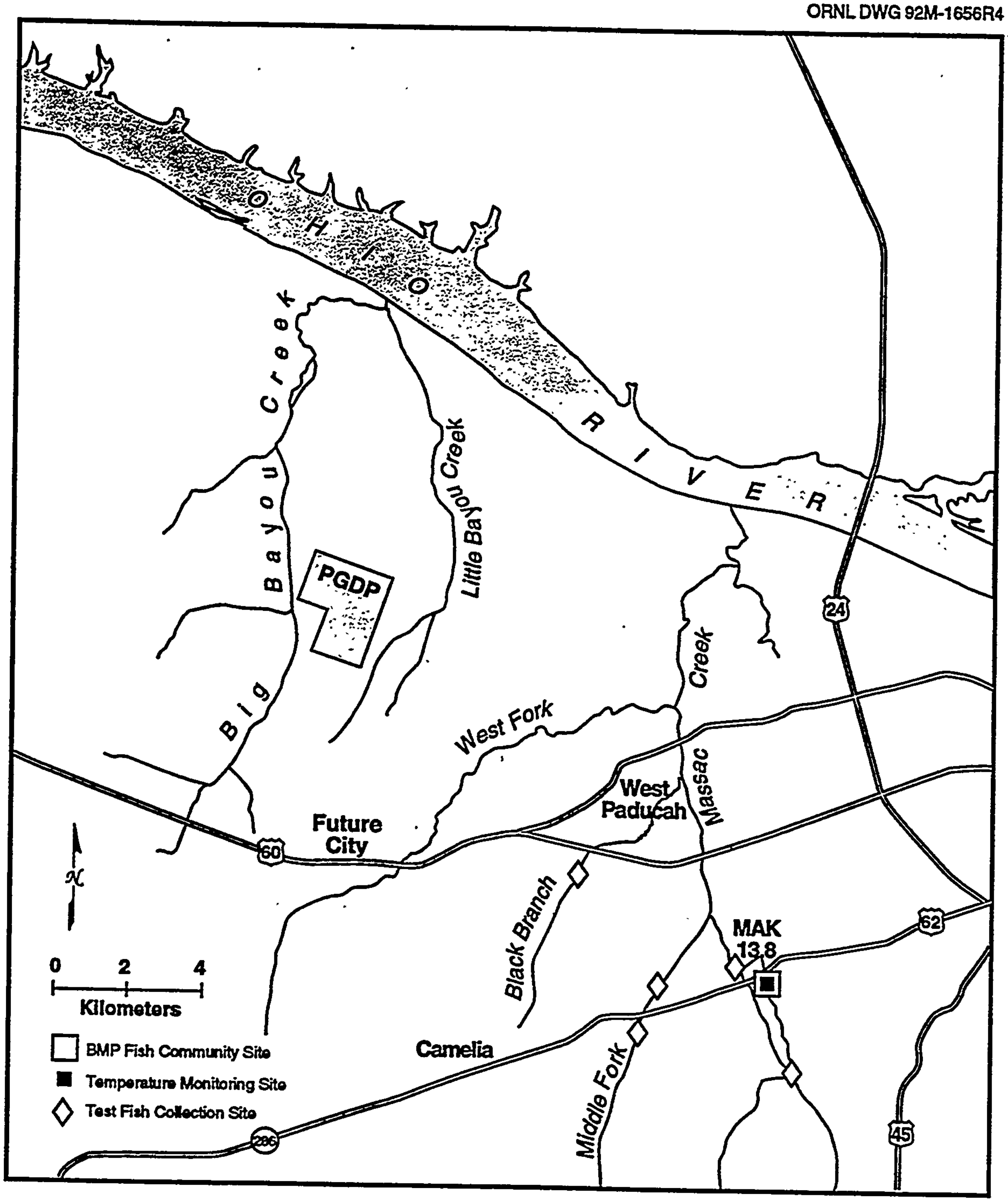

Fig. 1.2. Location of temperature monitoring, ecological sampling, and test fish collection sites in Massac Creek and its tributaries. MAK = Massac Creek kilometer; PGDP = Paducah Gaseous Diffusion Plant; BMP = Biological Monitoring Program.

monitoring are detailed in Sect. 2. These data also include instream temperatures from five extensively monitored Biological Monitoring Program (BMP) sites.

Quantitative sampling of benthic macroinvertebrate and fish communities has been ongoing at five sites near the PGDP for over 4 years. This sampling is conducted at Big Bayou Creek kilometers (BBK) 9.1, 10.0, and 12.5, Little Bayou Creek kilometer (LUK) 7.2, and Massac Creek kilometer (MAK) 13.8. These tasks are performed by personnel from the Environmental Sciences Division of ORNL as part of the BMP (Kszos et al. 1994a, 1994b). Benthos sampling is conducted quarterly using a Surber sampler, while fish populations are sampled semi-annually using a three pass removal estimate adopted from Carle and Strub (1978). In addition, quarterly qualitative fish surveys have been conducted in Outfall K001, Big Bayou Creek below Outfall K001 and above Outfall K008, and Little Bayou Creek below Outfall K010/011. Results of the benthic macroinvertebrate and fish sampling are reported in Sects. 3 and 4, respectively.

The monitoring of instream water temperatures and potentially impacted aquatic faunal communities was supplemented by a laboratory study of the thermal tolerances of two native fish species; the central stoneroller (*Campostoma anomalum*) and the redfin shiner (*Lythrurus umbratilis*). Testing was conducted the last week of July 1995, at a time when these fish are normally experiencing annual high temperatures. Testing was conducted in two types of water; water from the MAK 13.8 reference site (under the assumption that it would be relatively free of contaminants), and water from Outfall K001 (under the assumption that if any contaminants were present it could affect the thermal tolerance test results relative to "clean" water). In each of the four experiments (2 species x 2 treatments), fish were exposed to a 1°C/h increase in temperature. Testing was begun at 25°C and continued until there was 100% mortality of non-control fish. Details of these thermal tolerance experiments are in Sect. 5.

2. INSTREAM TEMPERATURE MONITORING

(R. L. Hinzman and W. K. Roy)

2.1 OBJECTIVES

The purpose of this subtask was to provide data to support the objective of this study: to provide a detailed record of temperatures associated with Outfalls K001, K008, and K010/K011 as well as those sections of the receiving streams immediately above and below these discharges. These data were also used to support efforts to determine whether the temperature of discharges from Outfalls K001, K008, and K010/011 are adversely affecting fauna currently occupying these stream reaches or are precluding the existence of certain species that might otherwise occupy these reaches.

2.2 METHODS

2.2.1 Equipment

Temperatures were recorded using RTM2000 TempMentors (Ryan Instruments, Redmond, Washington). The manufacturer certifies a circuit board accuracy of ± 0.3°C and thermistor interchangeability of ± 0.2°C. The resolution is 0.1°C, the range is −32°C to 70°C, and all units were factory calibrated. Each unit came in a waterproof case; the bottom half of the case contains the thermistor sensor with the top half clear for viewing the display. The two halves were connected using an O-ring and quick-attach coupler (clamp seal). PGDP personnel were provided with spare parts to minimize data loss should repairs be needed. All units were numbered serially for individual identification and contained appropriate information on ownership and contact personnel at PGDP and ORNL.

2.2.2 Sample Sites

There were 18 TempMentors deployed at 15 sites (Table 2.1); Outfalls K001 and K010/011 and the Ohio River intake each had a backup recorder.

2.2.2.1 Little Bayou Creek

Little Bayou Creek received discharges from five outfalls. The outfall of concern in regards to elevated temperatures was Outfall K011. Initially a recorder was placed in Little Bayou Creek approximately 25 m upstream and downstream from the discharge of Outfall K011. Outfalls K002, K010, K011, and K012 were combined at the C-617 pond and were previously discharged through Outfall K011 continuously to Little Bayou Creek. After PCBs were detected in sediments from Outfall K011 in June 1994, the combined C-617 lagoon discharge was diverted on a full-time basis to Outfall K010. Since that time, Outfall K011 discharges during rainfall events only. The temperature monitor in Outfall K011 was moved to Outfall K010 in June 1994. The combined discharges to Outfall K010 included discharges from once-through cooling water, roof and floor drains, sink drains, extended aeration sewage treatment system, switchyard runoff, condensate, and surface runoff.

2.2.2.2 Big Bayou Creek

Big Bayou Creek receives discharges from 10 outfalls (Outfalls K001, K004, K005, K006, K008, K009, K014, K015, K016, and K017). Outfall K001 was the primary outfall of interest in regard to elevated temperatures. Outfall K001 received discharges from recirculating cooling water blowdown treatment effluent, coal-pile runoff, once-through cooling water, surface runoff, roof and floor drains, treated uranium solutions, and sink drains. Recorders were placed in Big Bayou Creek approximately

Table 2.1. Location of temperature monitors

Recorder	Location	Notes
1	LUK 7.2	LUK = Little Bayou Creek kilometer
2	25 m downstream of Outfall K010 (LUK 9.0)	
3	Outfall K010/011	Moved from Outfall K011 June 1994
4	Outfall K010/011 backup	Moved from Outfall K011 June 1994
5	25 m upstream of Outfall K010/011	
6	BBK 9.1	BBK = Big Bayou Creek kilometer
7	25 m downstream of Outfall K001	
8	Outfall K001	
9	Outfall K001 backup	
10	25 m upstream of Outfall K001	
11	BBK 10.0	
12	Outfall K006	
13	Outfall K008	
14	Big Bayou Creek 30 m upstream of Water Works Road (BBK 10.4)	
15	BBK 12.5	
16	MAK 13.8	MAK = Massac Creek kilometer
17	Ohio River intake	
18	Ohio River intake backup	

25 m upstream and downstream from the discharge of Outfall K001. Initial investigations indicated sufficient thermal mixing occurs at this distance downstream of the mouth of the outfalls (Sect. 2.2.4, Appendix A).

2.2.2.3 Biological monitoring sites

One TempMentor was placed in each of the BMP benthic macroinvertebrate and fish community sites (Figs. 1.1 and 1.2) including one offsite reference site in Massac Creek at kilometer 13.8 (Fig. 1.2). Temperature monitors were placed at the intake to the Ohio River in November 1994 to evaluate the temperature of water used for plant processes.

2.2.2.4 Preliminary monitoring

Data collected during the last half of 1993 suggested that the temperatures of Outfalls K001 and K011 did not exceed the 95°F (35°C) monthly average interim effluent limit. However, some temperatures did exceed the proposed effluent limit of 89°F (31.7°C) and the stream reaches associated with these outfalls did have higher temperatures than comparable reference streams. These were preliminary results based on a mid-summer deployment, so it was not unreasonable to expect that mean monthly temperatures in excess of 95°F would occur. The elevated temperatures at BBK 10.0 (relative to BBK 12.5) suggested that outfalls other than K001 were influencing Big Bayou Creek. To evaluate the contributions of these outfalls to the

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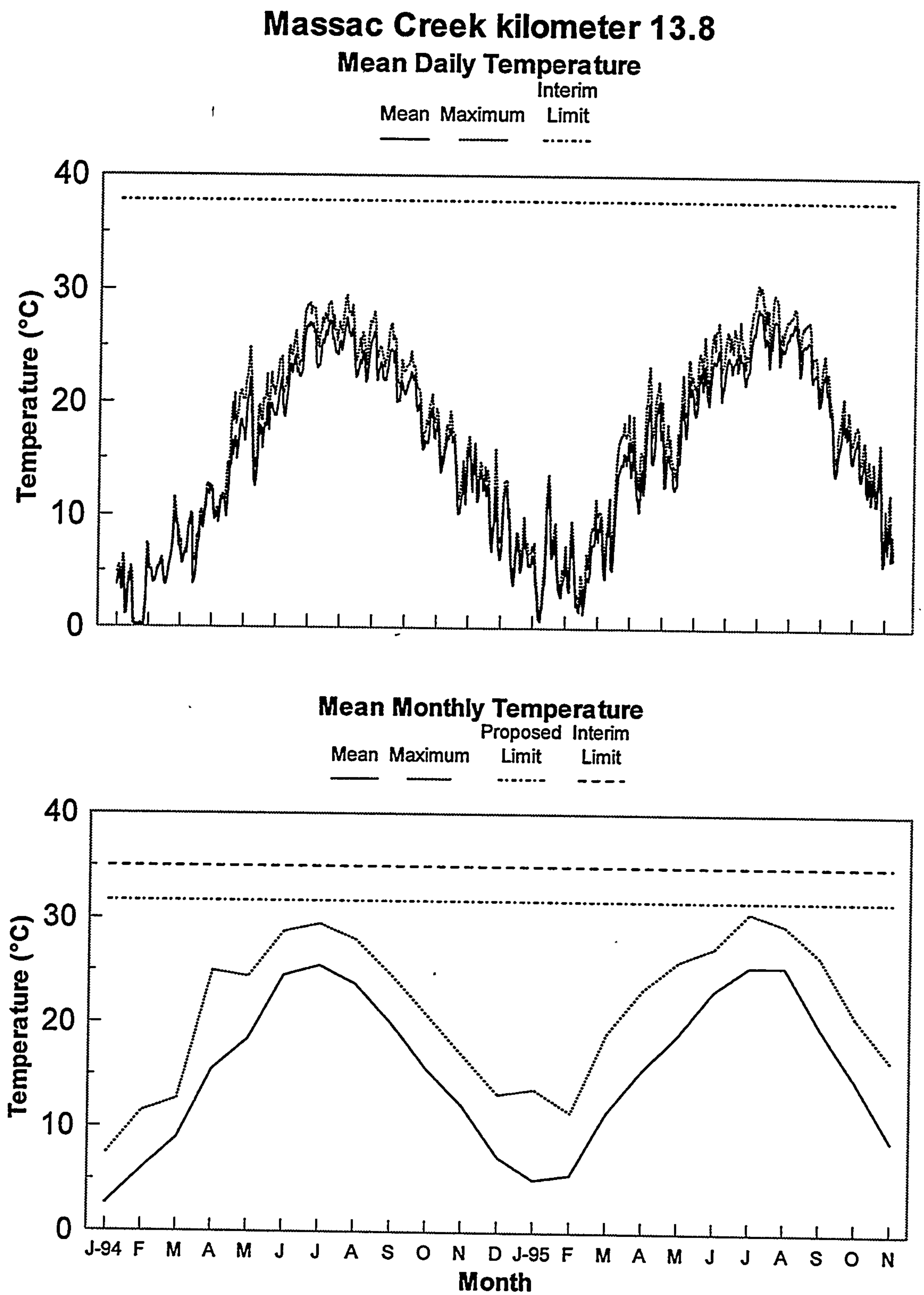

Fig. 2.1. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures at reference site, Massac Creek kilometer 13.8, January 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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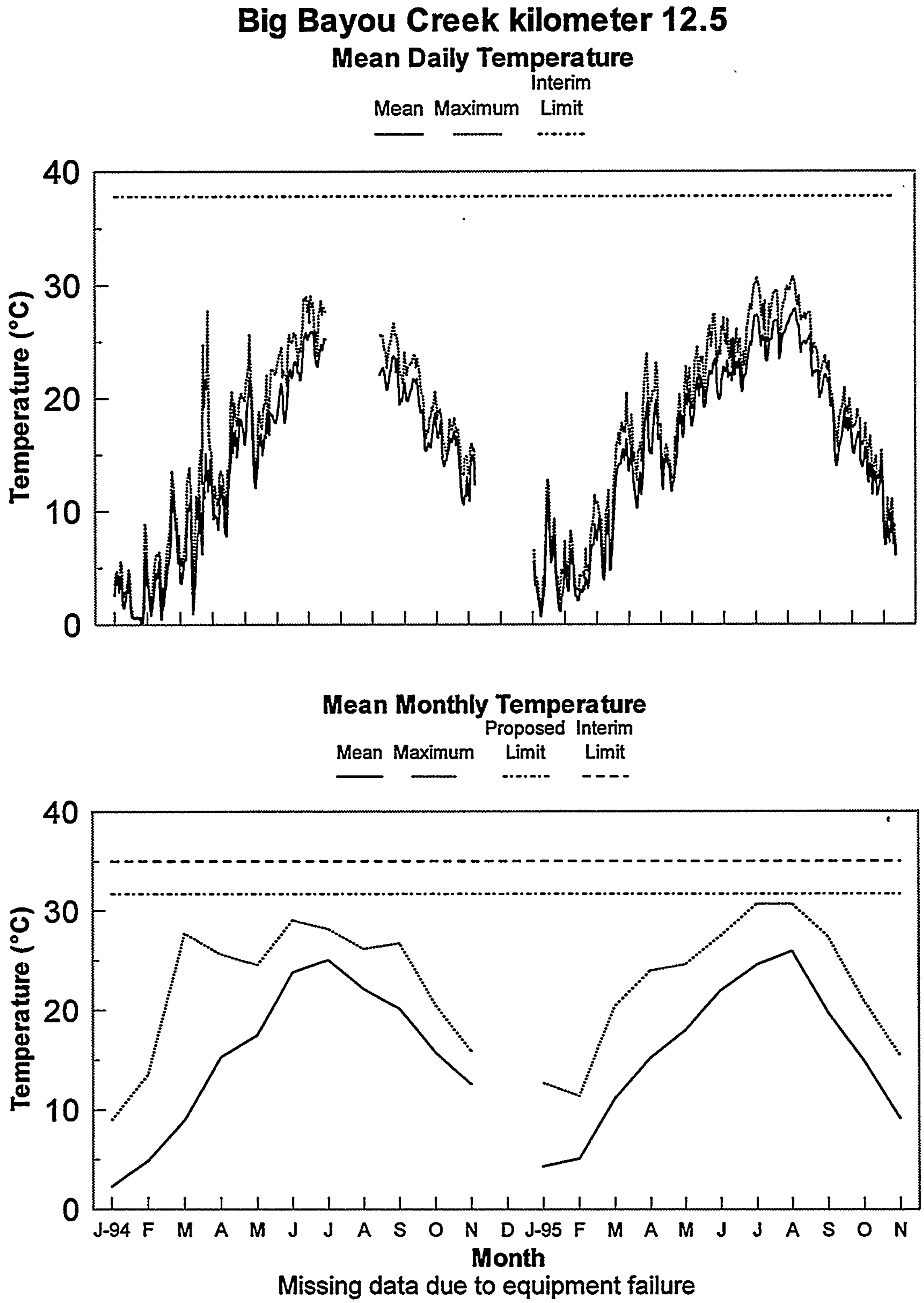

Fig. 2.2. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures at reference site, Big Bayou Creek kilometer 12.5, January 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

thermal regime of Big Bayou Creek, temperature recorders were installed in Outfalls K008 and K006 and in Big Bayou Creek just above the crossing at Water Works Road (BBK 10.4, below Outfall K009).

These additional deployments provided a better understanding of the thermal impacts of the PGDP and helped assess the impact of Outfall K001 on Big Bayou Creek.

2.2.3 Placement Details

Each TempMentor was attached to the inside of a standard 8 in. cinder block using size 12 insulated solid copper wire. The block was then connected to an appropriate anchoring point on shore (e.g., tree root or stake) using nylon or polypropylene rope. In high visibility areas, the blocks were placed under an undercut bank or tree root to minimize theft or dislodgement. It was important that the thermistor side of the casing be oriented down in shallow streams or in streams that experienced wide fluctuations in water level. In such instances, the block was further anchored near the center of the stream channel to prevent movement of the TempMentor toward the bank after a heavy rain. This was accomplished by, in addition to the anchor line, driving a 50–75 cm, 13-mm-diam steel rod (0.5 in. rebar) into the stream bed and placing the open end of the cinder block over it.

2.2.4 Verification Inspections

PGDP personnel conducted monthly inspections of the TempMentors in the field. The recorders were also inspected as soon as reasonably possible following heavy rain events. Special attention was given to the integrity of the waterproof seals, although leaks were very rare. This monitoring limited the occurrence of nonfunctioning or improperly deployed units and minimized the probability of missing or inaccurate data.

For verification purposes, a field data sheet or notebook entry was made with each inspection. The entry included the date, TempMentor location, serial number of unit, current temperature, current time, any special comments, and the initials of the person checking the recorder.

2.3 INSTREAM TEMPERATURE PROFILES

2.3.1 Methods

PGDP personnel conducted weekly temperature surveys in Big Bayou Creek beginning at Outfall K001 and in Little Bayou Creek beginning at Outfall K011 from July 13 through September 28, 1993. Temperature data were collected at 10-m intervals for 90 m downstream of each outfall, using a digital thermometer (readings to the nearest 0.1 °C). The profile consisted of 3 temperature readings taken at each 10-m interval (30 readings/site/week). At each sampling interval, a cross section of the creek may be envisioned as consisting of three equal width sections. Temperatures were taken at mid-depth in the center of each of the three sections. Drawings of the cross sections are presented in Appendix A.

2.3.2 Results

In Big Bayou Creek downstream from Outfall K001, there appeared to be a temperature plume that hugged the east bank of the stream. A natural trough on the east bank and an island near the center of the stream may have contributed to the length of the plume. A shallow area approximately 50 to 60 m downstream of the outfall seemed to be the first area where mixing occurred. Temperatures appeared to be well mixed beyond this zone.

Outfall K011 elevated temperatures in Little Bayou Creek. The effect was seen across the entire width of the stream and continued the entire length of the area surveyed. Mixing occurred within less than 25 m of the outfall discharge. PGDP staff noted that the effect of thermal inputs from Outfall K011 may have affected temperatures as far downstream as McCaw Road.

2.4 IMPLEMENTATION AND ANALYSIS

TempMentors were deployed in the field on July 1, 1993, and May 16–17, 1994, and remained in place until November 1995. The recorders were programmed to log data at 2-hour intervals. Under optimal conditions with fresh alkaline batteries, the estimated maximum deployment time is 530 days. The data were downloaded onto a portable PC at intervals not exceeding 6 months. Additional information concerning transferal and analysis of water temperature data can be found in Ryon (1992b). Data analyzed in this report cover the study period January 1994–November 1995, although modifications were made at some sites due to missing data, or later deployment dates. Data collected outside this time period are reported as appropriate.

Summary statistics (mean, standard deviation, maximum, and minimum) were calculated for each site by week, month, and year, using SAS (1988b) PROC MEANS procedure. Mean and maximum daily and monthly temperatures were graphed for each site and compared with the respective proposed and interim limits. For those sites where exceedances occurred, individual (collected every 2 hours) observations for the month with the most exceedances were graphed and compared with the corresponding ambient air temperatures as measured at Barkely Field Airport and provided by the Midwestern Climate Center in Champaign, Illinois.

2.5 RESULTS

Graphs of the daily mean and maximum, and monthly mean and maximum temperature for each site are shown in Figs. 2.1–2.21. The interim daily maximum effluent limit (37.8°C) and proposed (31.7°C) and interim (35.0°C) monthly mean effluent limits are shown for comparison.

2.5.1 Reference Sites

Temperature monitors were placed at three reference sites (MAK 13.8, BBK 12.5, and Ohio River intake; Figs. 2.1–2.3). MAK 13.8 and BBK 12.5 are also BMP community task sampling locations. Although there are no thermal limits on instream waters, stream temperatures were compared with the proposed and interim effluent temperature limits for the purpose of analysis. There were no exceedances of the proposed or interim effluent limits at the reference sites. In addition, there were no bi-hourly observations that exceeded the proposed or interim effluent limits at these sites. Mean monthly temperatures at MAK 13.8 ranged from 2.7 to 25.5°C; the maximum bi-hourly observation was 30.7°C. The yearly average at MAK 13.8 was 15.1 ± 7.8 (mean ± SD) in 1994 and 16.3 ± 7.6 in 1995. Mean monthly temperatures at BBK 12.5 ranged from 2.3 to 25.9°C; the maximum bi-hourly observation was 30.7°C. The yearly average at BBK 12.5 was 14.1 ± 7.6°C in 1994 and 15.9 ± 7.6°C in 1995. The mean monthly temperatures in the Ohio River uptake ranged from 5.5 to 28.5°C; the maximum bi-hourly observation was 30.2°C. The yearly average in the Ohio River uptake in 1995 was 18.1 ± 7.9°C.

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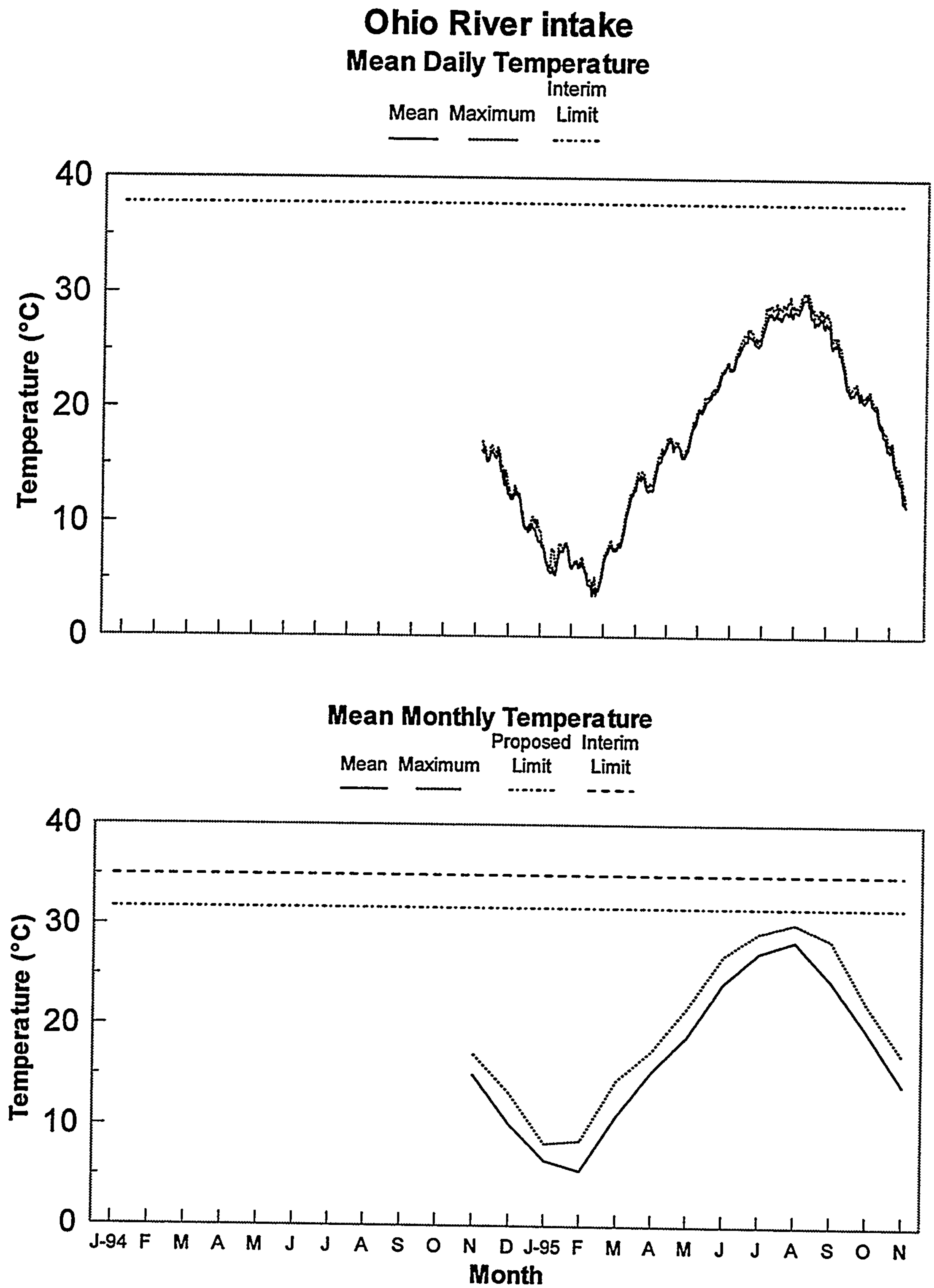

Fig. 2.3. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures at the Ohio River intake, November 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

2.5.2 Little Bayou Creek

Four locations were monitored on Little Bayou Creek (Outfall K010/011, 25 m upstream and downstream of Outfall K010/011, and LUK 7.2). Graphs of the mean daily and mean monthly temperatures are presented in Figs. 2.4–2.7.

There were no exceedances of the proposed or interim effluent limits at the site 25 m upstream from the Outfall K010/011 discharge (Fig. 2.4). Mean monthly temperatures ranged from 2.9 to 25.6°C; the maximum bi-hourly observation was 32.6°C. Mean (± SD) yearly temperatures were 14.4 ± 7.1°C and 16.3 ± 7.2°C in 1994 and 1995 respectively. These temperatures are very similar to those at both the upstream Big Bayou Creek (BBK 12.5) and Massac Creek reference sites.

Temperatures in Outfalls K010 and K011 were elevated compared with the reference sites (Fig. 2.5). Exceedances of the proposed mean monthly limit occurred in July 1993 at Outfall K011, and in July 1994 and July and August 1995 in Outfall K010. An evaluation of the most recent exceedances revealed that in July 1995, 63% of the bi-hourly observations in Outfall K010 were ≥31.7°C, 14 % were ≥35.0°C, and none were ≥37.8°C. In August 1995, 80% of the bi-hourly observations in Outfall K010 were ≥31.7°C, 26% were ≥35.0°C, and 2% were ≥37.8°C. Mean monthly temperatures in Outfall K011 ranged from 10.2 to 33.4°C; the maximum bi-hourly observation was 36.5°C. Mean monthly temperatures in Outfall K010 ranged from 13.8 to 33.4°C; the maximum bi-hourly observation was 38.6°C. Mean (± SD) yearly temperatures in Outfall K011 were 23.8 ± 8.4°C in 1993 and 25.1 ± 3.6°C in 1994. Mean yearly temperatures in Outfall K010 were 25.4 ± 6.0°C in 1994 and 24.2 ± 7.1°C in 1995.

Although there were no temperatures greater than the proposed or interim effluent limits in Little Bayou Creek 25 m downstream of Outfalls K011 or K010, temperatures were elevated compared with reference sites (Fig. 2.6). An evaluation of the month with the highest mean monthly temperature (August 1995) showed that 31% of the bi-hourly observations at this site were ≥31.7°C and 3% were ≥35.0°C. No bi-hourly observations exceeded 37.8°C. Mean monthly temperatures downstream of Outfall K011 ranged from 8.3 to 31.1°C; the maximum bi-hourly observation was 35.8°C. Mean monthly temperatures downstream of Outfall K010 ranged from 9.4 to 30.6°C; the maximum bi-hourly temperature was 36.7°C. The mean (± SD) yearly temperatures in 1993 and 1994 downstream of Outfall K011 were 31.7 ± 8.6 and 11.8 ± 5.0°C, respectively; data were only available for 6 months in 1993. Average yearly temperatures downstream of Outfall K010 in 1994 and 1995 were 16.4 ± 5.8 and 21.2 ± 8.0°C, respectively; data were only available for 4 months in 1994.

Temperatures at LUK 7.2 were only slightly elevated compared with those at Massac Creek and upper Big Bayou Creek and Little Bayou Creek upstream of Outfall K010/011 (Fig. 2.7). In August of 1995, only 1% of the bi-hourly observations were ≥31.7°C and there were no observations ≥35.0°C. The mean monthly temperatures ranged from 4.5 to 28.6°C; the maximum bi-hourly observation was 33.6°C. The mean (± SD) yearly temperatures at LUK 7.2 were 16.6 ± 7.7 and 18.3 ± 8.2°C in 1994 and 1995 respectively.

A plot of the mean monthly temperatures from January 1994 to November 1995 demonstrates that temperatures were clearly elevated in Outfall K010, yet declined sharply just 25 m downstream of the outfall, and returned to approximately 2°C higher than reference levels by the time the water reached LUK 7.2 (Fig. 2.8). An examination of the bi-hourly data for August 1995 shows that water temperatures were typically highest from 2:00 to 8:00 p.m. (Fig. 2.9), while ambient air temperatures were highest from about

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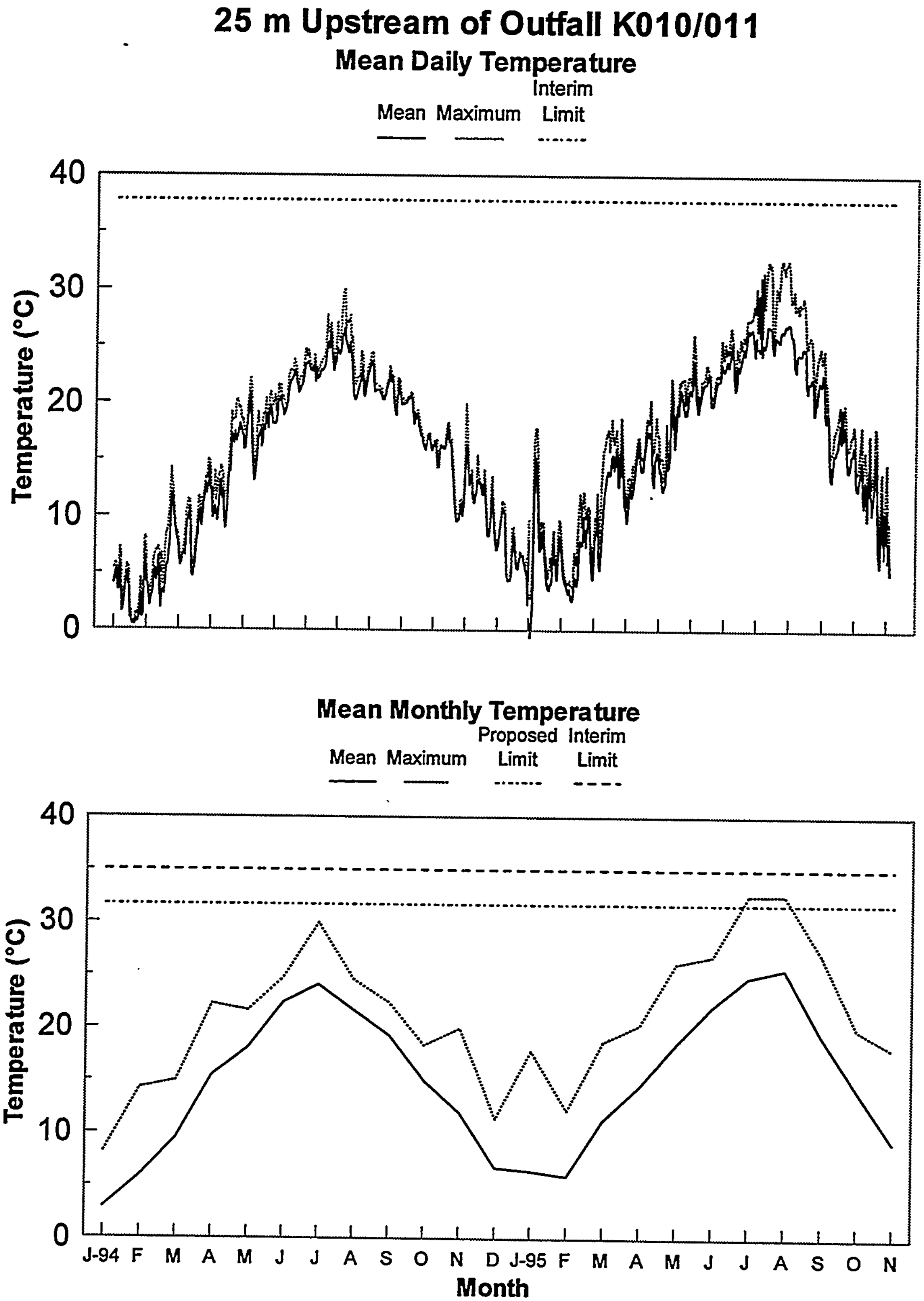

Fig. 2.4. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Little Bayou Creek 25 m upstream of Outfall K010/011, January 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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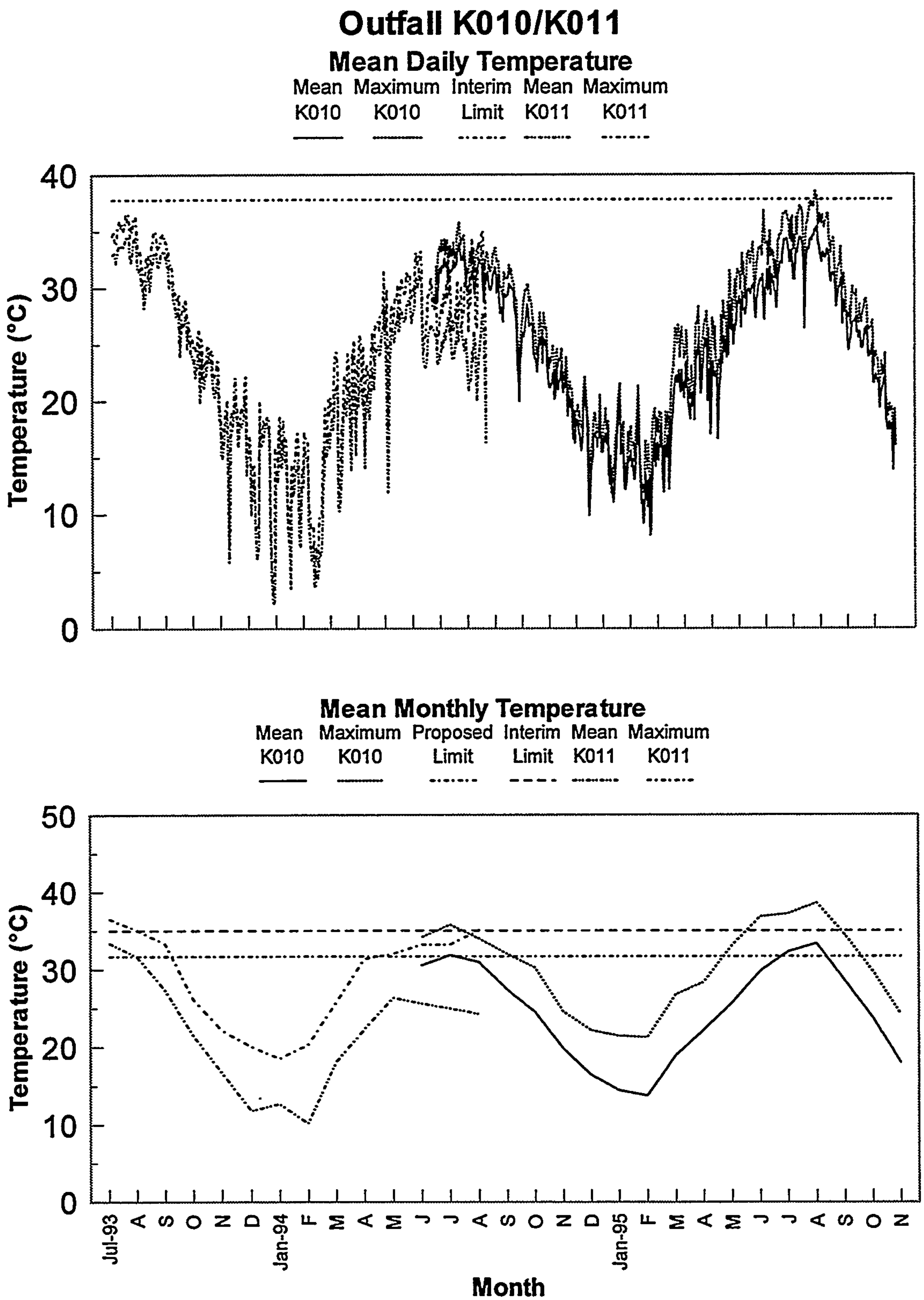

Fig. 2.5. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Outfall K011, July 1993 through August 1994, and Outfall K010, June 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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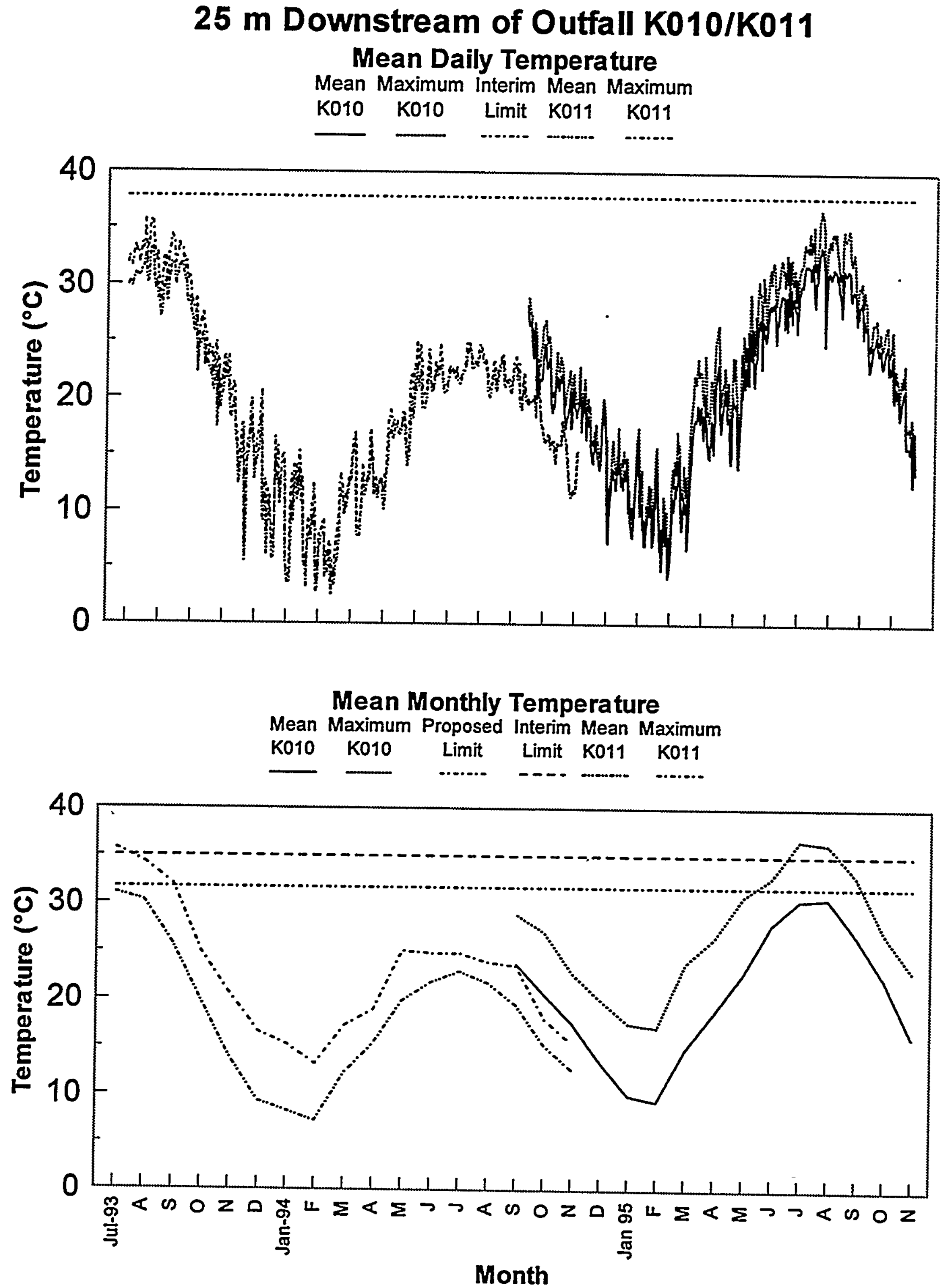

Fig. 2.6. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures 25 m downstream of Outfall K011, July 1993 through November 1994, and 25 m downstream of Outfall K010, September 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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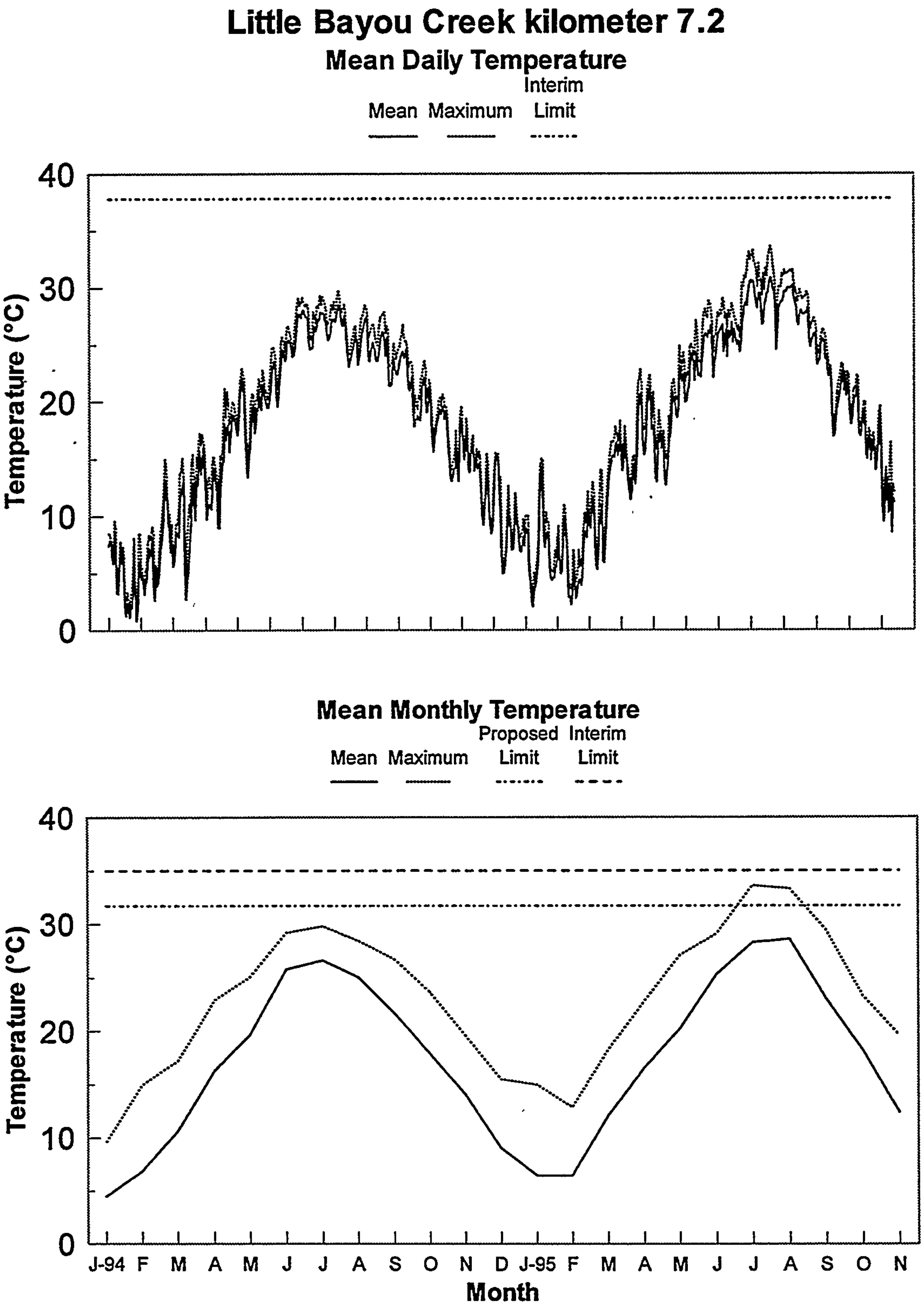

Fig. 2.7. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Little Bayou Creek at kilometer 7.2, January 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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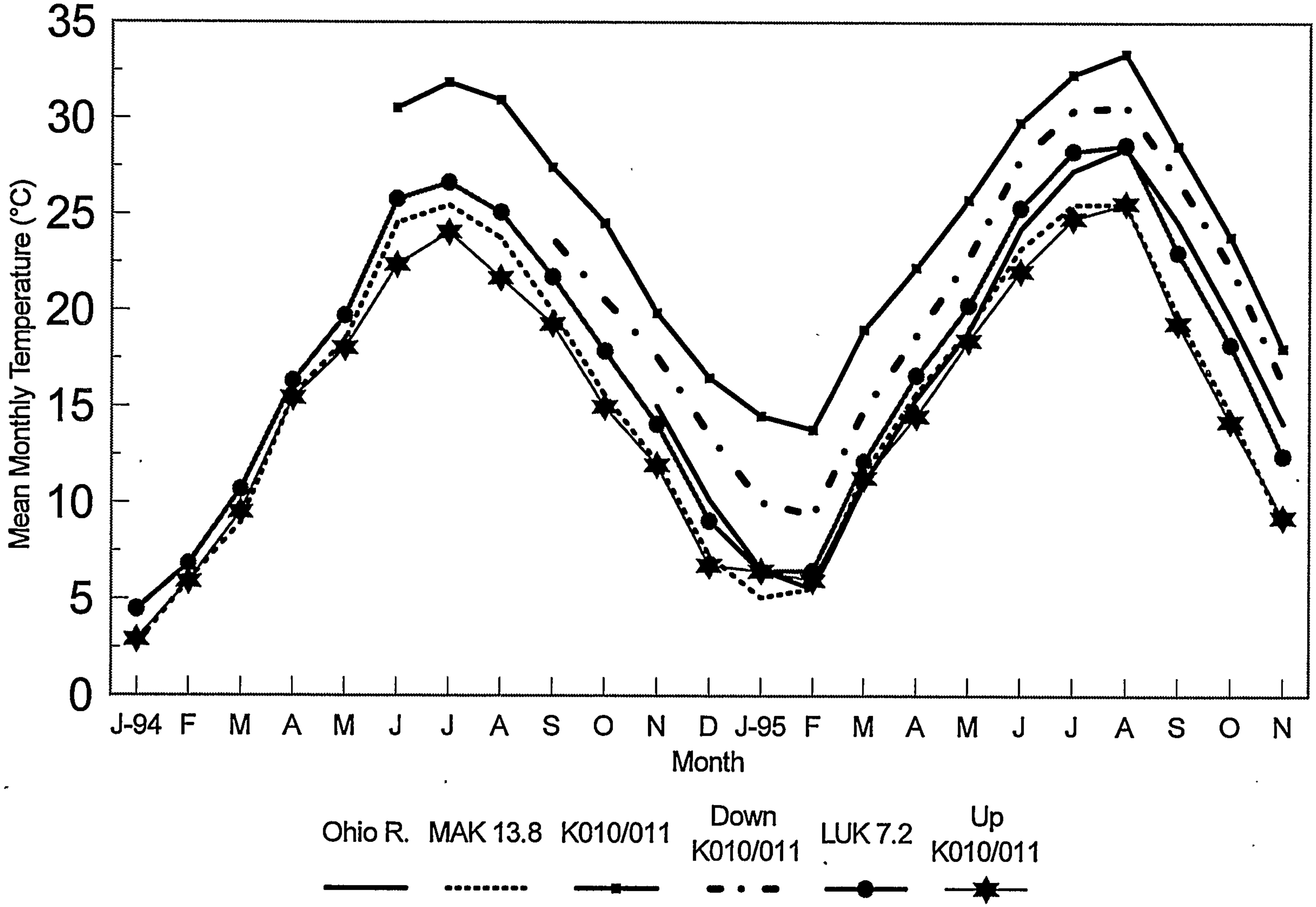

Fig. 2.8. Plot of mean monthly temperatures for the Ohio River intake, Massac Creek at kilometer 13.8 (MAK 13.8; reference site), Outfall K010/011, Little Bayou Creek 25 m upstream (Up K010/011) and downstream (Down K010/011) of Outfall K010/011, and Little Bayou Creek at kilometer (LUK) 7.2, January 1994 through November 1995.

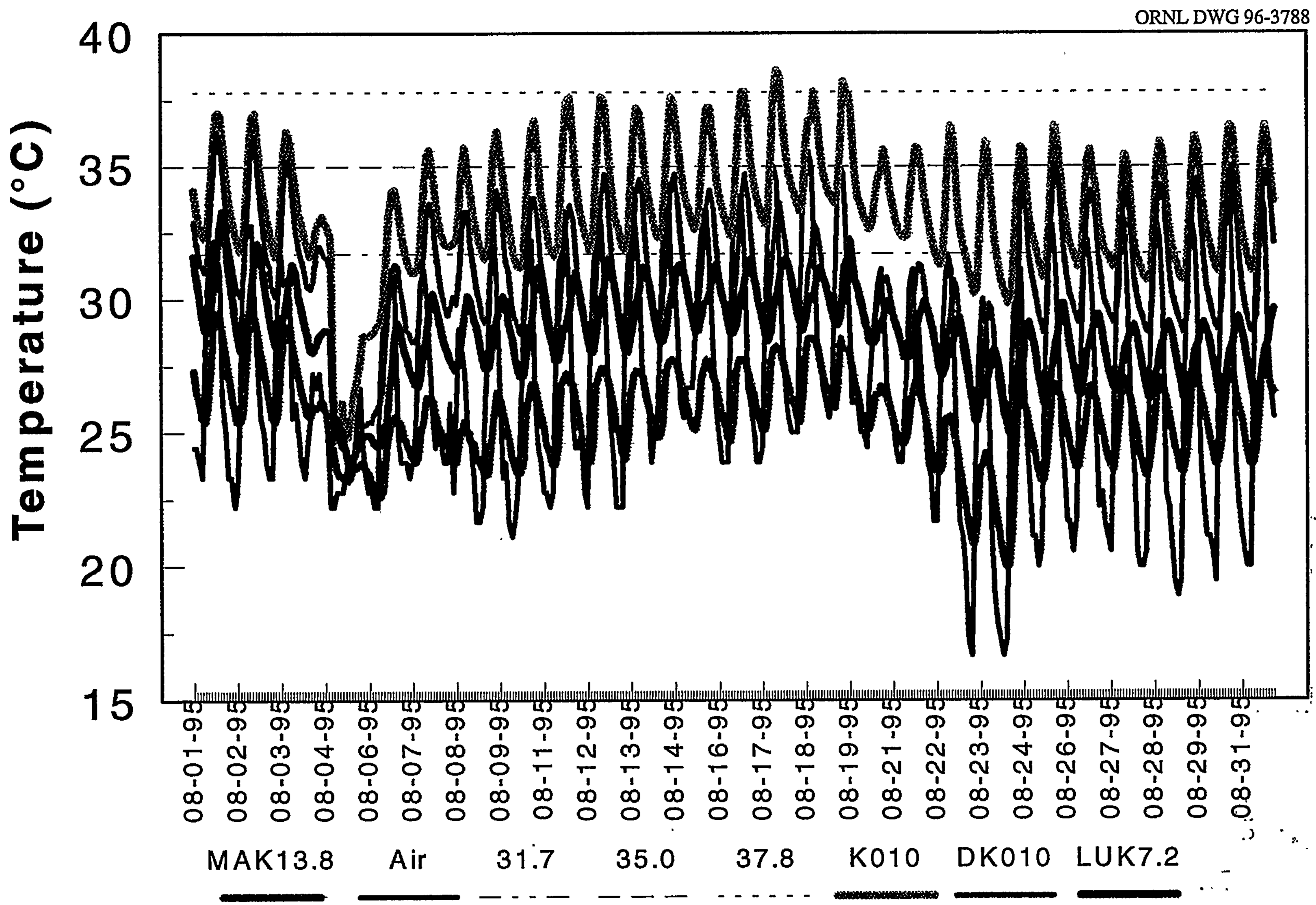

Fig. 2.9. Plot of bi-hourly temperatures at Massac Creek kilometer (MAK) 13.8 (reference), Outfall K010, Little Bayou Creek 25 m downstream of Outfall K010, and Little Bayou Creek kilometer (LUK) 7.2, compared with ambient air temperatures collected at Barkley Field, August 1995.

10:00 a.m. to 6:00 p.m. Although outfall and stream temperature patterns follow ambient air temperature patterns, discharges to the stream from Outfall K010 in August 1995 were clearly the major contributor to elevated stream temperatures. Stream temperatures in Little Bayou Creek 25 m downstream of Outfall K010 were 1° to 4°C higher than ambient air temperatures. Temperatures at LUK 7.2 were generally less than ambient air temperatures. Temperatures at reference streams, MAK 13.8, and BBK 12.5 never exceeded ambient air temperatures.

2.5.3 Big Bayou Creek

Temperature monitors were placed in four BMP community task sampling locations on Big Bayou Creek at BBKs 12.5, 10.4, 10.0, and 9.1. Monitors were also placed in Outfalls K008, K006, and K001, and 25 m upstream and downstream of Outfall K001. Data for BBK 12.5, which is upstream of PGDP discharges, are included in the discussion on reference sites (Sect. 2.5.1 and Fig 2.2).

Temperatures in site BBK 10.4 (Fig. 2.10) were slightly higher than those at BBK 12.5 (Fig. 2.2). There were no instream temperatures greater than the proposed or interim effluent limits at this site. The mean monthly temperatures ranged from 4.5 to 26.7°C; the maximum bi-hourly observation was 34.7°C. The mean (± SD) yearly temperatures at Water Works Road were 19.1 ± 7.5°C for May through December 1994 and 16.9 ± 8.6°C for 1995. Two outfalls (K009 and K017) discharge to Big Bayou Creek upstream of BBK 10.4. Outfall K017 discharges only surface runoff and is not likely a source of thermal inputs. Outfall K009 discharges surface drainage, roof and floor drains, condensate, once-through cooling water, and sink drains. The average flow is 1.7 million liters per day. Discharges from Outfall K009 and reduced canopy at BBK 10.4 may account for the slight increase in mean temperatures at this site.

There were no exceedances of the proposed or interim effluent limits at Outfall K008 (Fig. 2.11). However, elevated temperatures were detected in the outfall. The range of monthly mean temperatures was 12.3 to 30.5°C; the maximum bi-hourly observation was 34.8°C. Mean (± SD) yearly temperatures in the outfall were 23.7 ± 5.0°C from May through December 1994 and 21.6 ± 6.5°C in 1995. Contributing processes to Outfall K008 include surface drainage, roof and floor drains, once-through cooling water, paint shop discharge, condensate, instrument shop cleaning area, metal cleaning rinse water, and sink drains.

Site BBK 10.0 is located downstream of Outfall K008 and upstream of Outfall K006. There were no instream temperatures greater than the proposed or interim effluent limits at this site (Fig. 2.12). However, temperatures were elevated compared with Big Bayou Creek sites BBK 10.4 and BBK 12.5. Mean monthly temperatures ranged from 4.0° to 29.0°C; the maximum bi-hourly observation was 34.0°C. Mean (± SD) yearly temperatures were 14.4 ± 8.0 in 1994 and 18.8 ± 7.9°C in 1995. The average temperature in 1994 appears to be low due to missing data during summer months for that year. The yearly average at BBK 10.0 is approximately 3°C higher than at BBK 12.5 and 2°C higher than at BBK 10.4. This additional temperature increase is likely the result of Outfall K008 discharges.

There were no exceedances of the proposed or interim effluent limits in Outfall K006 (Fig. 2.13); however, temperatures were elevated. Mean monthly temperatures ranged from 4.4 to 31.6°C; the maximum bi-hourly observation was 36.7°C. The mean (± SD) yearly temperature for May through December 1994 was 21.7 ± 7.9°C. The mean yearly temperature was 19.2 ± 9.9°C in 1995. In August 1995, when the mean monthly temperature was 31.6°C, 46% of the bi-hourly observations were ≥31.7°C

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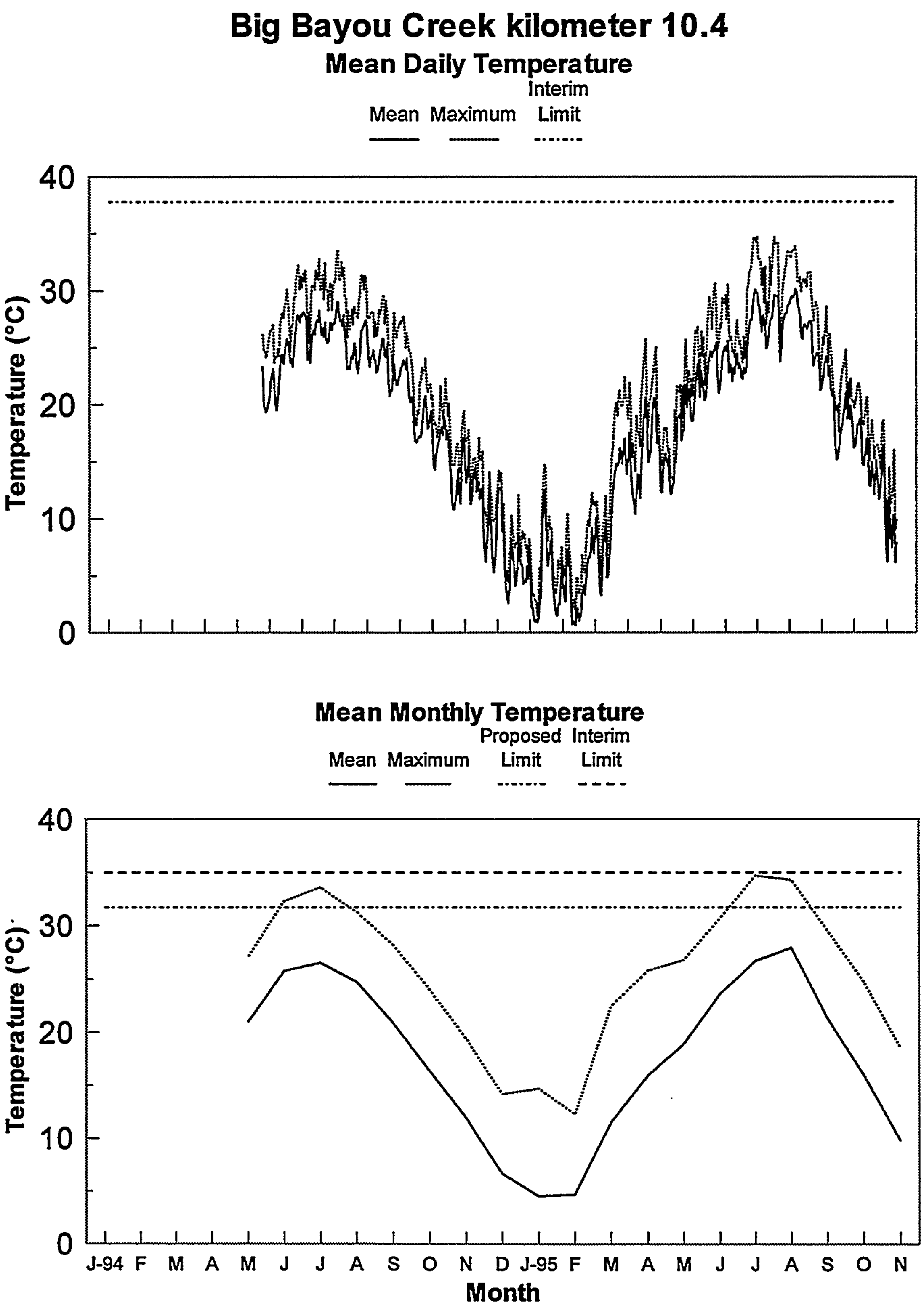

Fig. 2.10. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Big Bayou Creek at kilometer 10.4, May 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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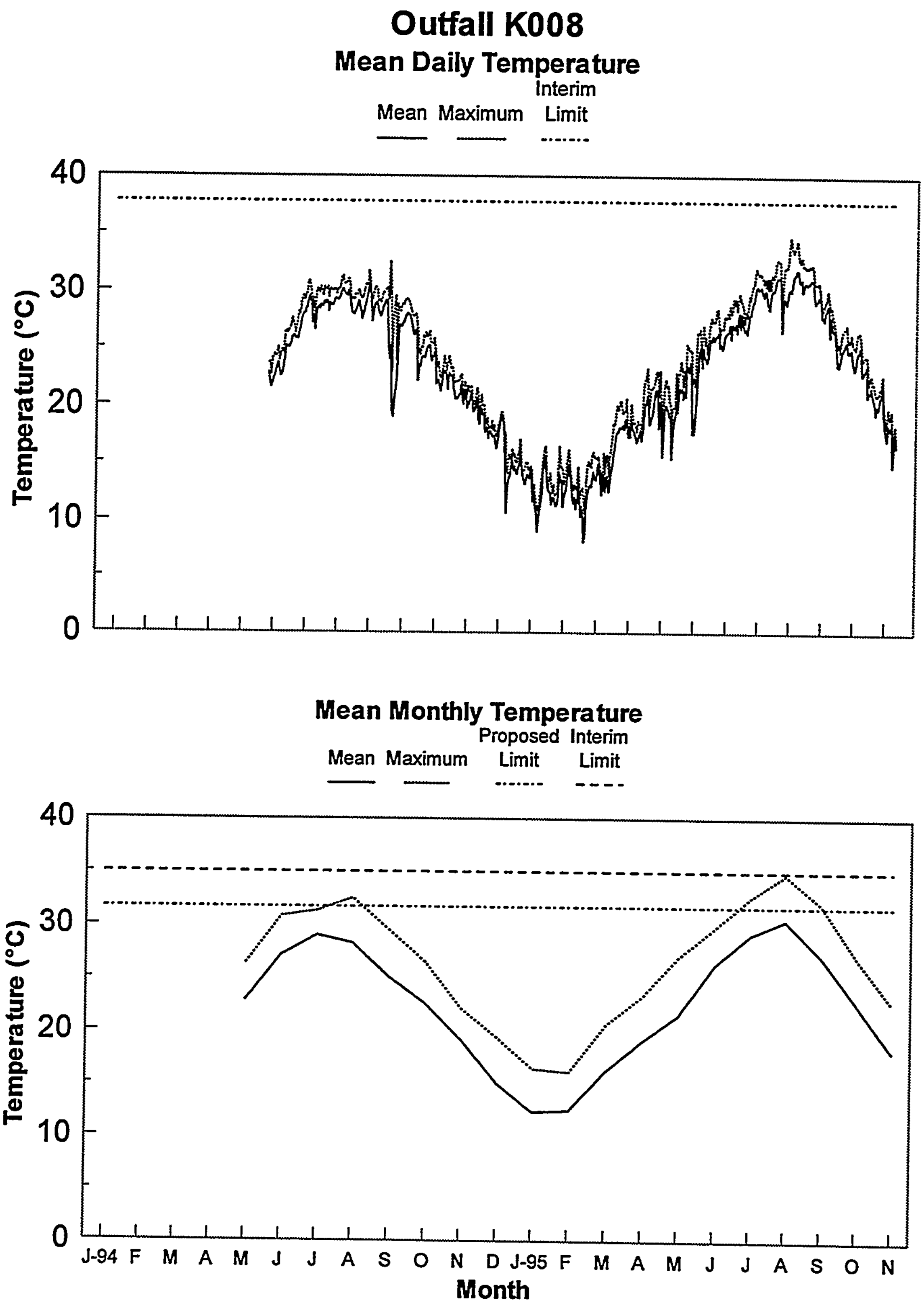

Fig. 2.11. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Outfall K008, May 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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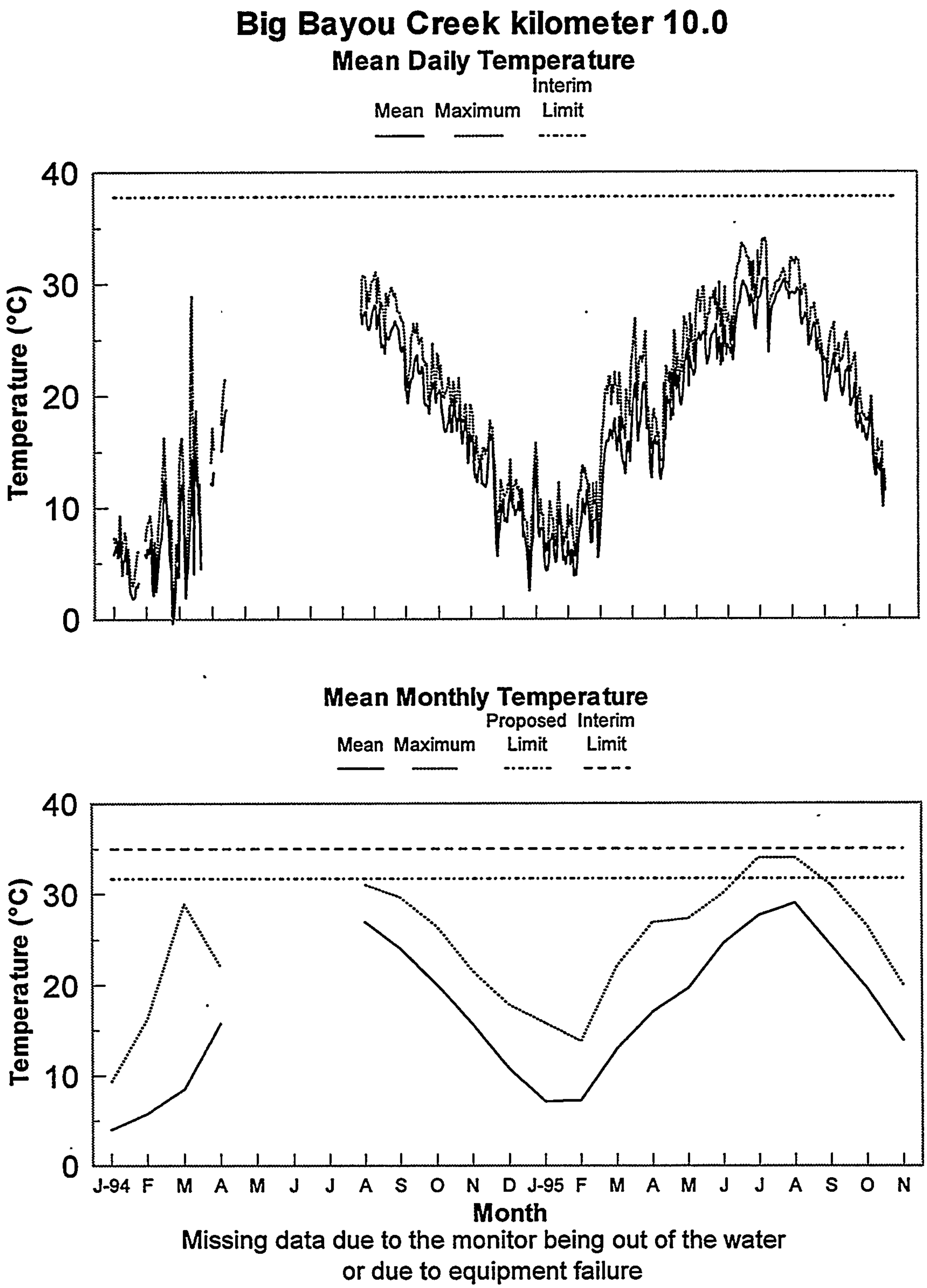

Fig. 2.12. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Big Bayou Creek at kilometer 10.0, January through April 1994 and August 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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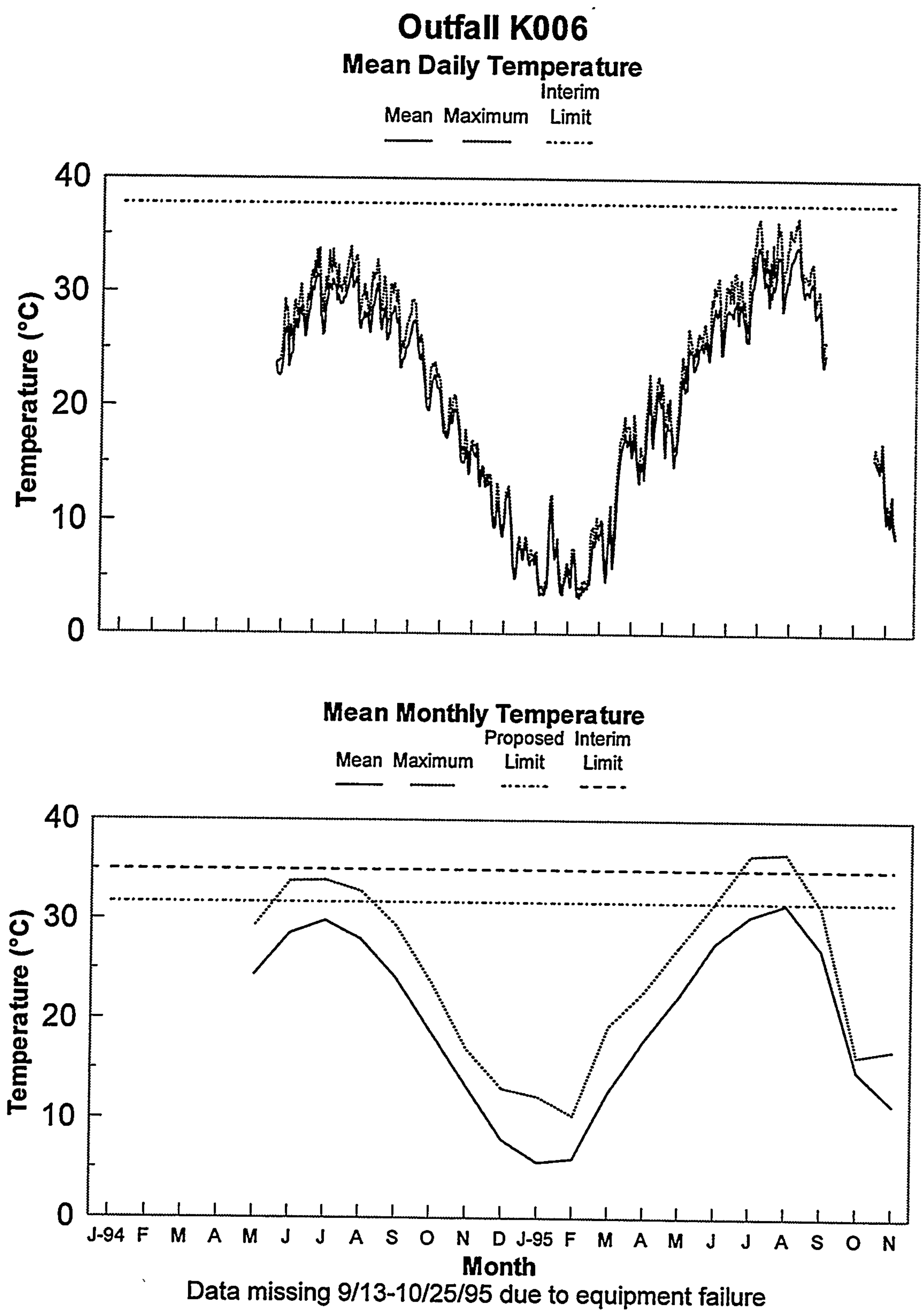

Fig. 2.13. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Outfall K006, May 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

and 6% of the observations were ≥35.0°C. Outfall K006 receives discharges from the C-611 secondary lagoon and Outfall K005 discharges from the C-611 primary sludge lagoon. Contributing processes include water treatment plant sludge, sand filter backwash, and laboratory sink drains.

Temperatures in Big Bayou Creek, 25 m upstream of Outfall K001 (Fig. 2.14), were elevated compared with reference sites; however, there were no instream temperatures greater than the proposed or interim effluent limits at this site. The range of mean monthly temperatures was 3.6° to 30.0°C. The maximum bi-hourly observation recorded was 46.7°C, however, the recorder was noted to be out of the water during an inspection shortly after this temperature was recorded and should be interpreted with caution. The maximum observation in August 1995, when most of the sites recorded maximum observations for the year, was 35.5°C. Average (± SD) yearly temperatures were 17.0 ± 8.7°C and 18.5 ± 8.7°C in 1994 and 1995 respectively. Average yearly temperatures do include data recorded when the monitor was found to be out of the water. Because we have no way of knowing how long the recorder was exposed, and because the temperatures follow typical diel patterns, we did not eliminate high temperatures from the data set. Therefore, the value for the yearly average is a slightly elevated estimate. In August 1995, 22% of the bi-hourly observations were ≥31.7°C; only one observation exceeded 35.5°C. Although thermal inputs from Outfall K006 could be increasing receiving water temperatures, these inputs seem to have been dissipated by the time the water reaches this site, approximately 0.5 km downstream.

The proposed monthly effluent limit was exceeded in July and August 1993 at Outfall K001 (Fig. 2.15). Mean monthly temperatures at Outfall K001 ranged from 5.7 to 32.9°C; the maximum bi-hourly observation was 38.8°C. Mean (± SD) yearly temperatures were 22.6 ± 9.5 for July through December 1993, 19.1 ± 7.8 in 1994, and 20.8 ± 7.8 in 1995. In August 1995, 38% of the bi-hourly observations were ≥31.7°C and 2% were ≥35.0°C. Average temperatures were about 2°C higher at Outfall K001 than in Big Bayou Creek 25 m upstream of Outfall K001. Contributing processes to Outfall K001 include effluent from recirculating cooling water blowdown, coal-pile runoff, once-through cooling water, surface runoff, roof and floor drains, treated uranium solutions, and sink drains. Discharge from this outfall is the highest of any of the outfalls to Big Bayou Creek, averaging 6.2 million liters per day.

Water temperatures in the receiving stream 25 m downstream of Outfall K001 (Fig. 2.16) were elevated compared with temperatures 25 m upstream of the outfall (Fig. 2.14), although no instream temperatures were greater than the proposed or interim effluent limits during the study period. Mean monthly temperatures ranged from 13.6 to 30.3°C. The maximum observed bi-hourly observation was 56.1°C, however the recorder was found out of the water in the subsequent survey, so this measurement, and other similarly elevated measurements, are in error. The maximum temperature in July and August 1995, when maximum temperatures were recorded at other Big Bayou Creek sites, was 36.7°C. Average (± SD) yearly temperatures at this site were 25.2 ± 4.4°C for May through November 1994, and 22.9 ± 5.9°C for March through November 1995. In August 1995, 24% of the bi-hourly observations were ≥31.7°C and 3% were ≥35.0°C. Because of the incomplete data record, results for this site should be interpreted with caution. Elevated readings in July 1994 probably inflated the mean temperature for this site. The mean for 1995 may be sightly elevated since temperatures in the coldest months (January and February) are missing. However, the mean 1995 temperature 25 m downstream of Outfall K001 is 4.5°C higher than the mean 1995 temperature 25 m

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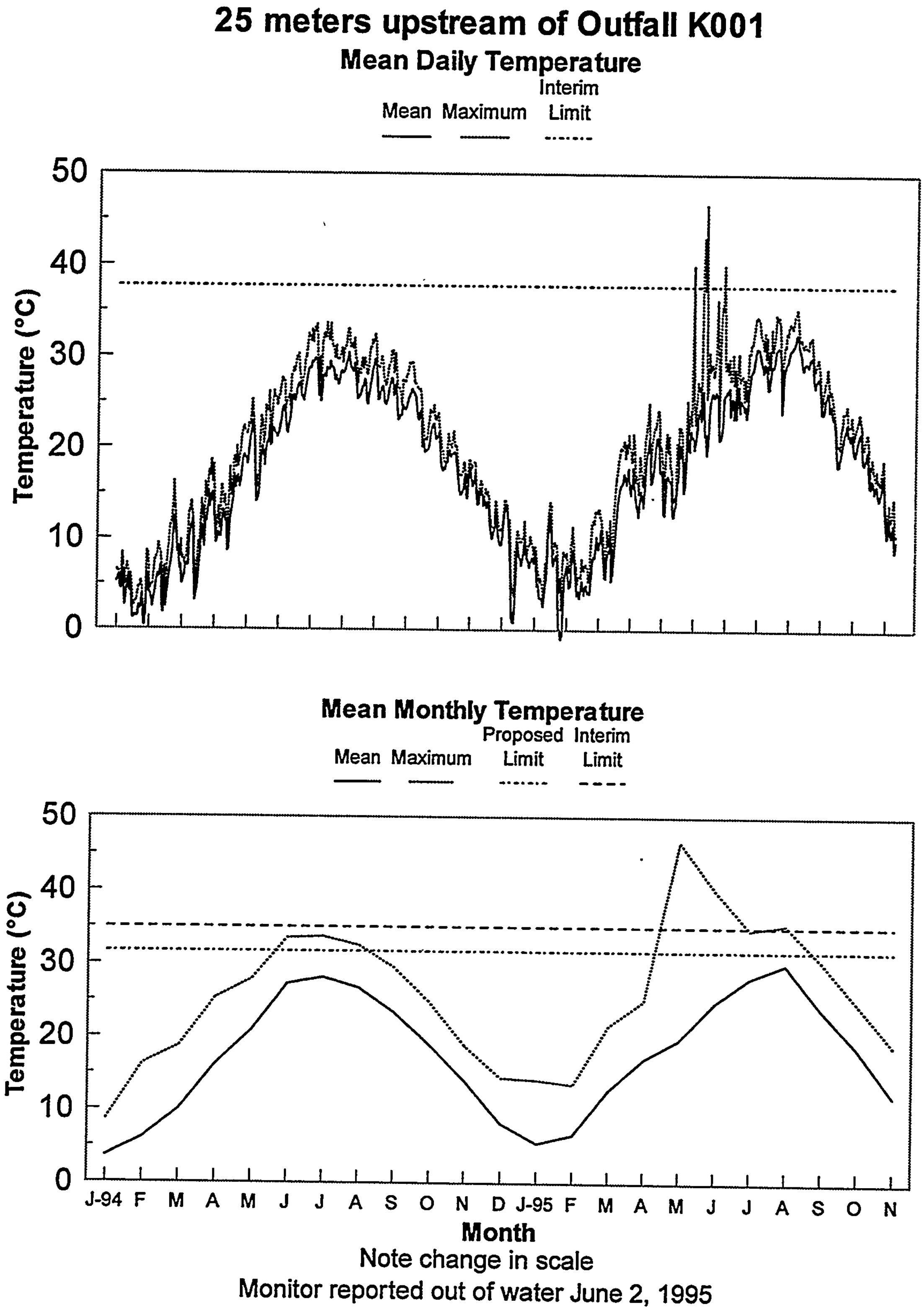

Fig. 2.14. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Big Bayou Creek 25 m upstream from Outfall K001, January 1994 through November 1995, compared with the respective proposed and interim effluent temperature limits.

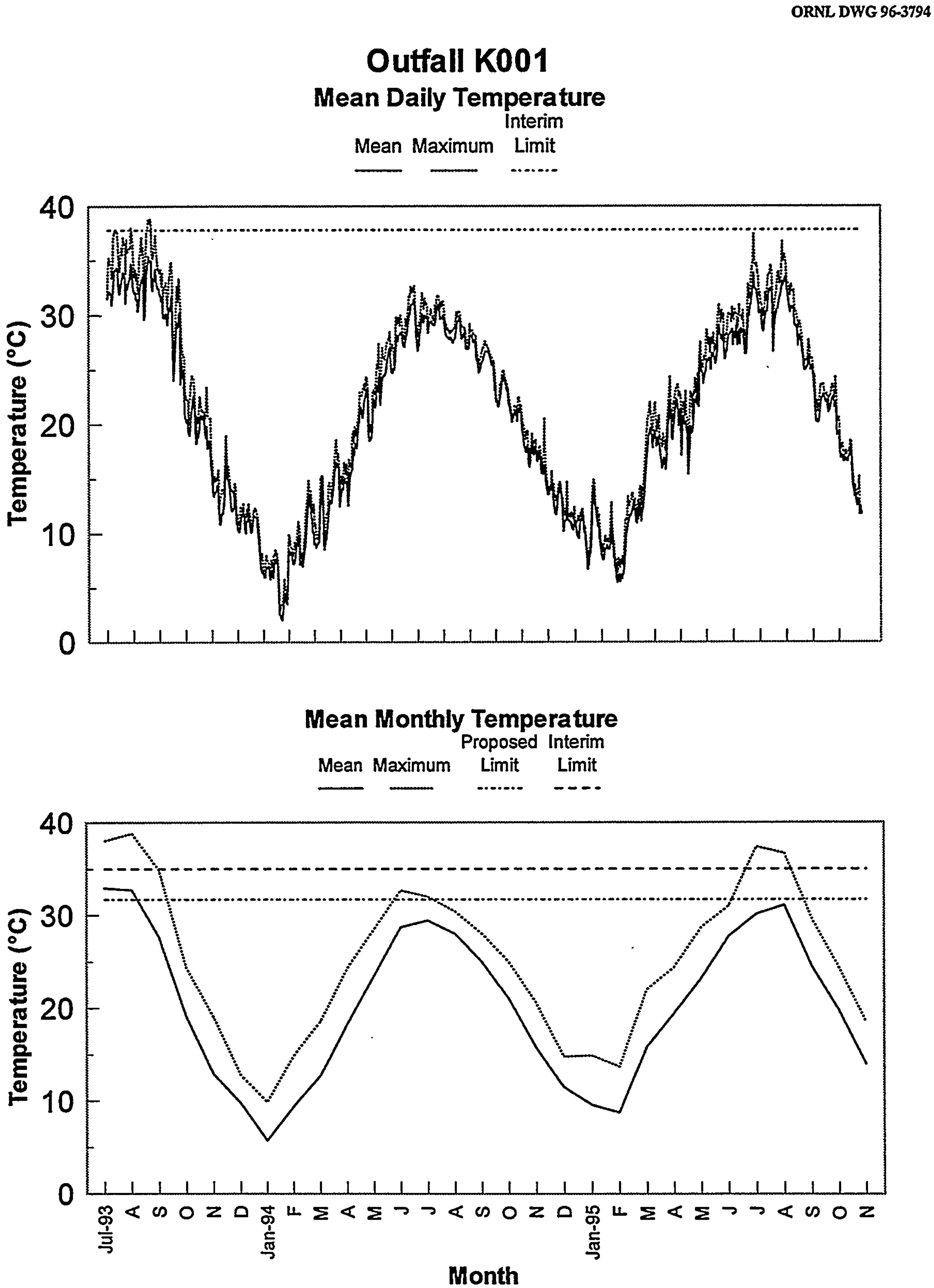

Fig. 2.15. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Outfall K001, July 1993 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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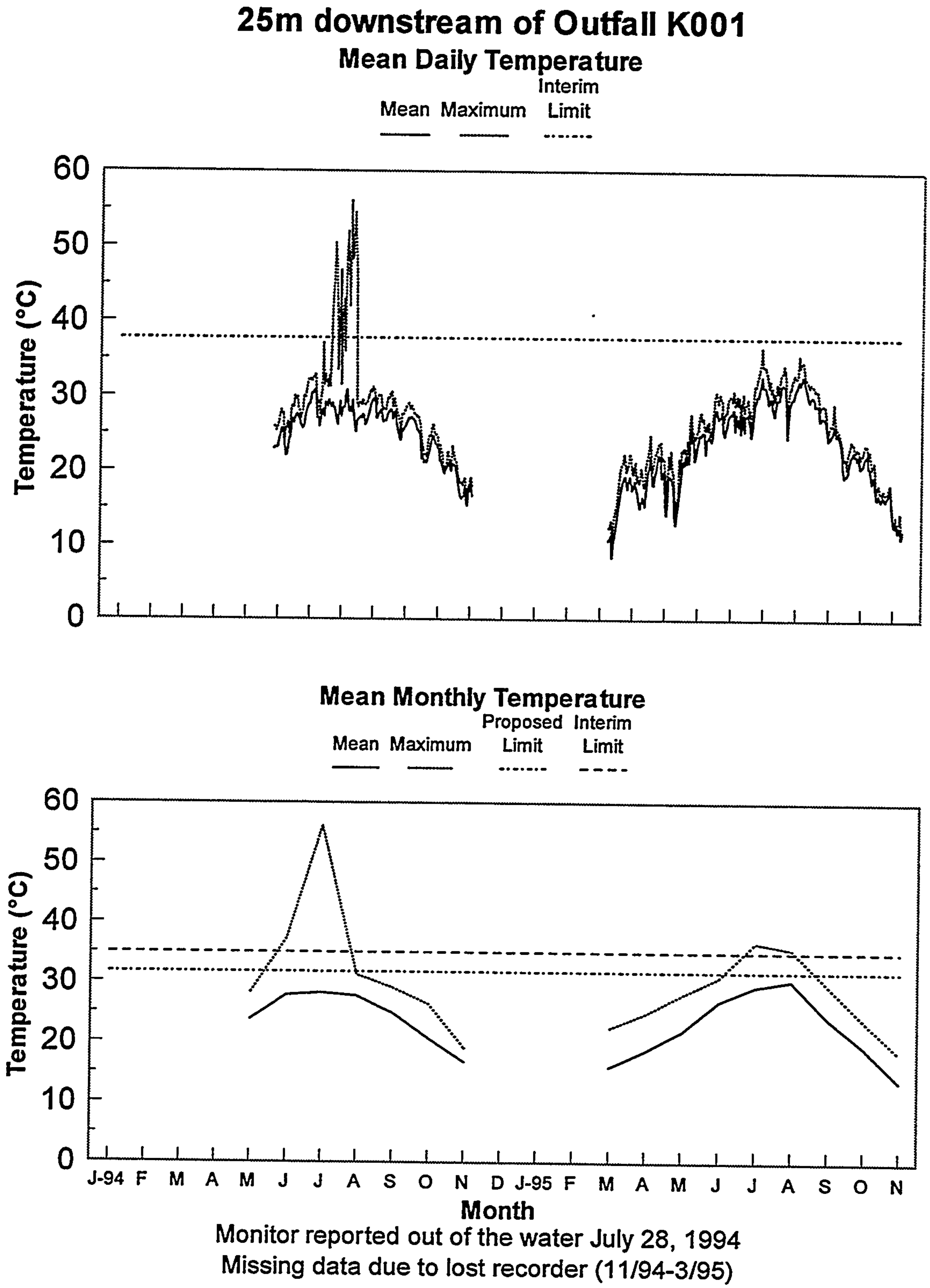

Fig. 2.16. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Big Bayou Creek 25 m downstream from Outfall K001, May through November 1994 and March through November 1995, compared with the respective proposed and interim effluent temperature limits.

upstream of the outfall. Given that the temperature in Outfall K001 is approximately 2.5°C higher on a yearly average than the upstream site, the influence of the outfall can be seen downstream in Big Bayou Creek.

The water temperatures in the most downstream site (BBK 9.1) monitored on Big Bayou Creek (Fig. 2.17) were similar to those at BBK 10.4 (Fig. 2.10). There were no instream temperatures greater than the proposed or interim effluent limits at BBK 9.1. Mean monthly temperatures ranged from 4.1 to 30.3°C; the maximum bi-hourly observation was 34.7°C. Average (± SD) yearly temperatures were 17.6 ± 8.4°C in 1994 and 16.3 ± 7.6°C in January through May and August through November 1995. Temperatures at this site in 1994 indicated an approximate overall increase in temperature of 3.5°C over the 3.5 km studied.

A plot of the mean monthly temperature for the instream Big Bayou Creek sites shows the increase in water temperature resulting from cumulative inputs of the outfalls (Fig. 2.18). In general, mean temperatures in the stream increase with each additional outfall input. The effects of the inputs are greatest in summer months. Instream temperatures begin to decrease approximately 0.5 km downstream of the last outfall (K001), however temperatures are still elevated compared with reference streams. In summer months the increase was as much as 5°C.

Plots of bi-hourly temperatures for August 1995 compared with a reference stream (MAK 13.8), upstream and downstream sites in the receiving stream and ambient air temperatures show the thermal impact of Outfalls K008, K006, and K001 on Big Bayou Creek (Fig 2.19–2.21). An examination of discharge practices at these sites seems warranted.

2.6 DISCUSSION

Instream temperatures at the reference sites (MAK 13.8, BBK 12.5, and Ohio River intake) were never greater than the proposed or interim effluent limits at any time during the study. Furthermore, there were no bi-hourly observations that exceeded the proposed or interim effluent limits at these sites. While temperature fluctuations in these sites closely followed diel ambient air patterns, there were no bi-hourly water temperature observations greater than or equal to the corresponding ambient air temperatures for the temperature record examined (August 1995). The maximum bi-hourly observation was 30.7°C at both MAK 13.8 and BBK 12.5.

Water temperatures in Little Bayou Creek upstream from Outfall K010/011 were similar to reference sites, while those downstream from Outfall K010/011 were elevated. The proposed monthly limit was exceeded in the outfalls on four occasions during the study period (July 1993, July 1994, July and August 1995). As shown by the profiles conducted by PGDP personnel, mixing occurred within 25 m downstream of the outfall; and they noted the mixing seemed to mitigate, to some extent, the effects of the elevated temperatures. This note seems to be substantiated by the temperature monitoring data, as there were no instream temperatures greater than the proposed or monthly effluent limits at this site. Temperatures at LUK 7.2 were reduced considerably compared with the upstream sites, but were still elevated compared with reference sites or at the site 25 m upstream of Outfall K010/011. Because the stream channel is narrow (approximately 1 m) near Outfall K010/011, prolonged elevated temperatures may act as a barrier to aquatic biota (see Sects. 3 and 4 for further discussion). The maximum bi-hourly temperature was 36.7°C at the instream sites, 6°C higher than the maximum temperature recording at MAK 13.8 or BBK 12.5. There

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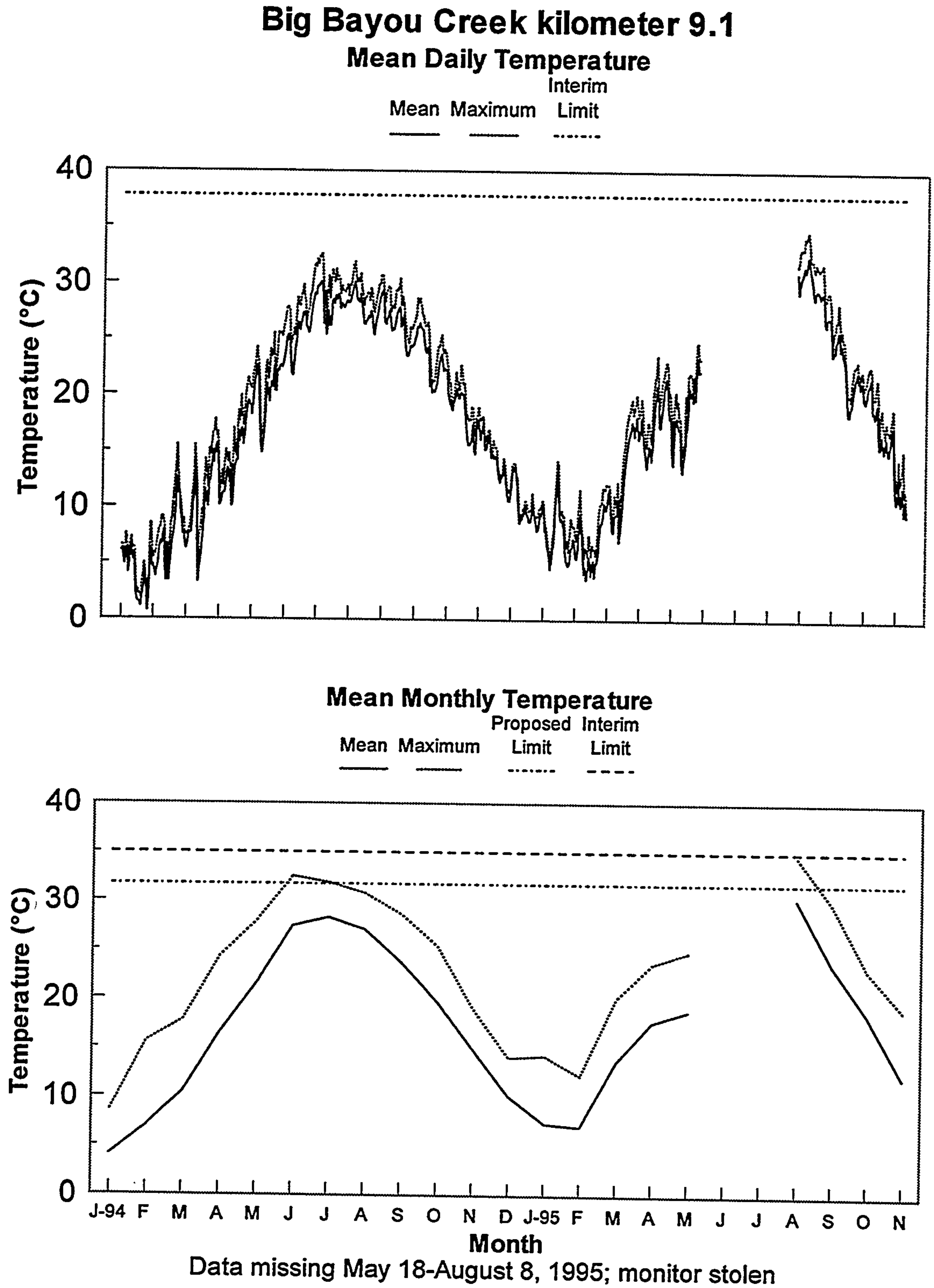

Fig. 2.17. Mean daily (maximum observation) and mean monthly (maximum observation) temperatures in Big Bayou Creek at kilometer 9.1, January 1994 through May 1995 and August 1995 through November 1995, compared with the respective proposed and interim effluent temperature limits.

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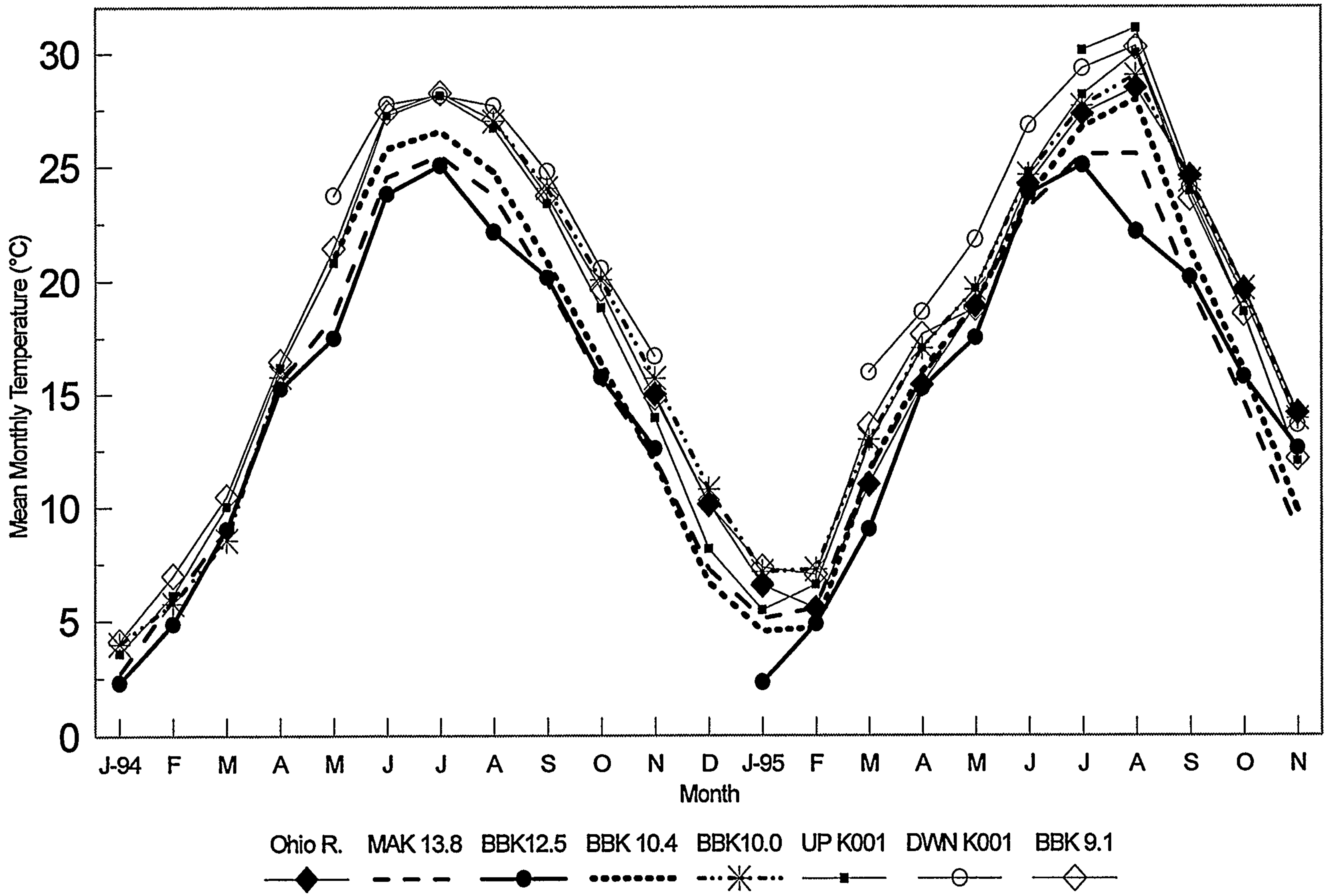

Fig. 2.18. Plot of mean monthly temperatures for the Ohio River intake, Massac Creek at kilometer 13.8 (MAK 13.8; reference site), Big Bayou Creek kilometer (BBK) 12.5, 10.4, 10.0, 25 m upstream and downstream of Outfall K001, and BBK 9.1, January 1994 through November 1995.

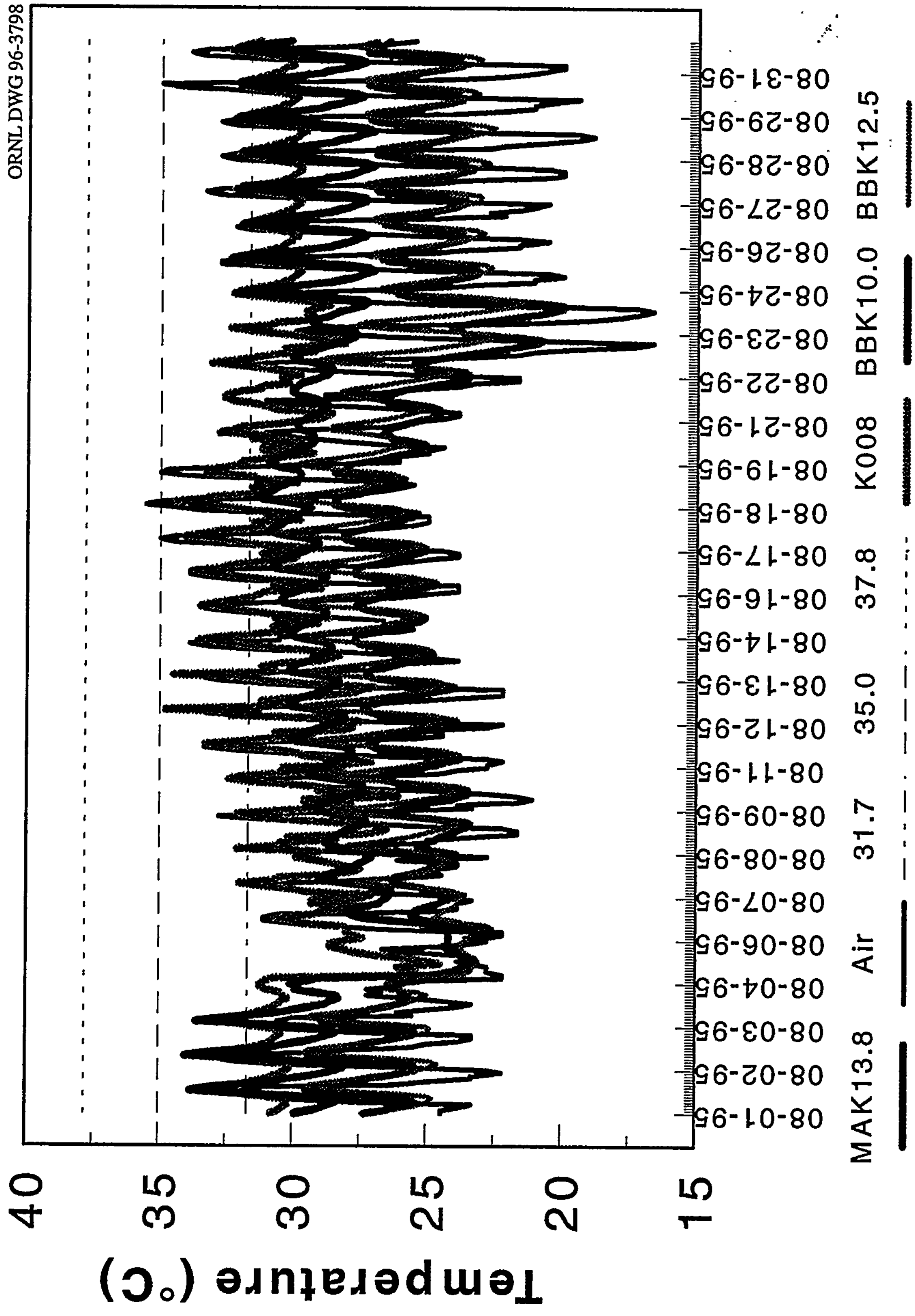

Fig. 2.19. Plot of bi-hourly temperatures at Massac Creek kilometer (MAK) 13.8, Outfall K008, Big Bayou Creek kilometer (BBK) 10.0 and 12.5, compared with ambient air temperatures collected at Barkley Field, August 1995.

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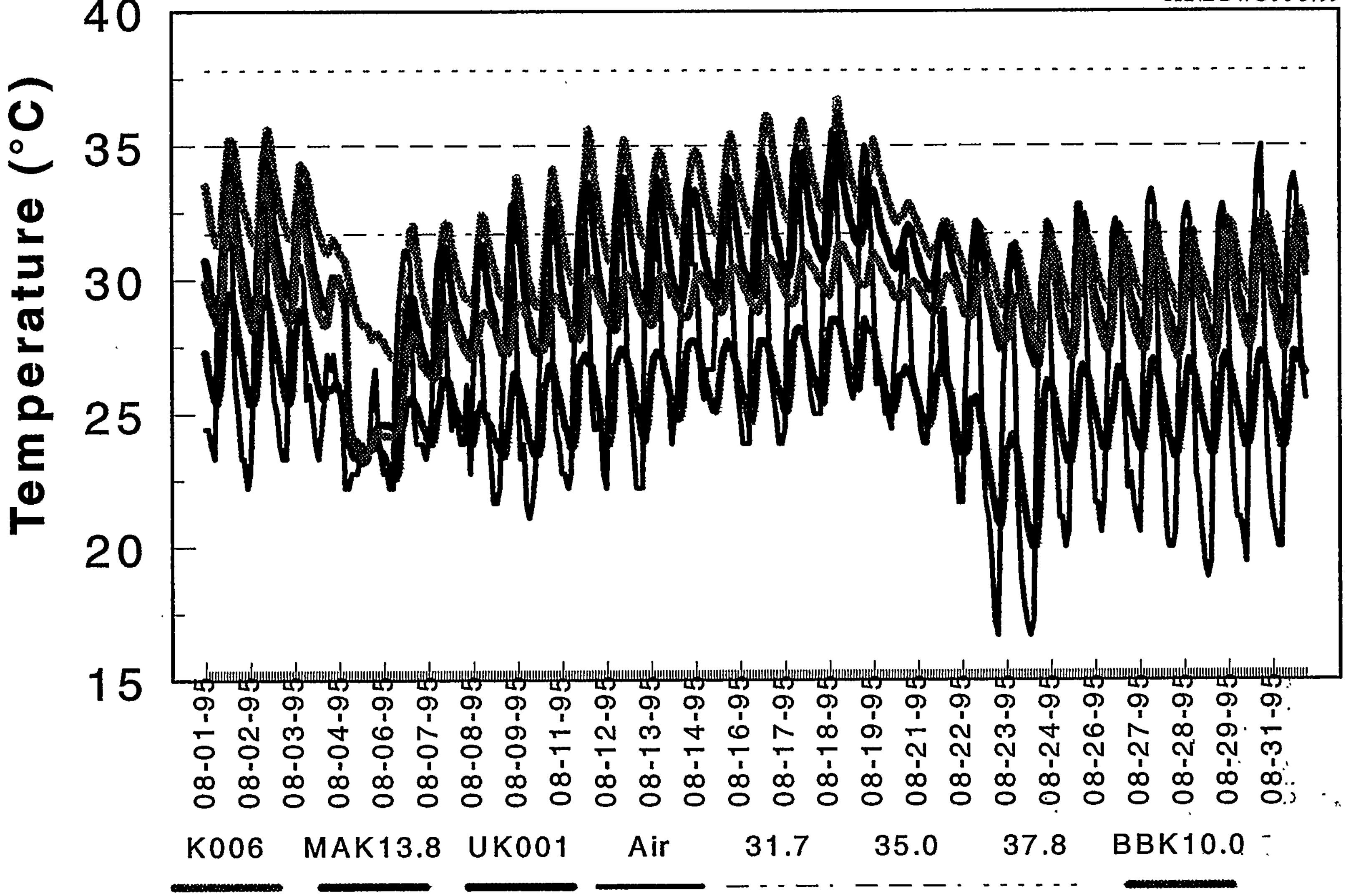

Fig. 2.20. Plot of bi-hourly temperatures at Massac Creek kilometer (MAK) 13.8, Outfall K006, Big Bayou Creek 25 m upstream of Outfall K001, and Big Bayou Creek kilometer 10.0, compared with ambient air temperatures collected at Barkley Field, August 1995.

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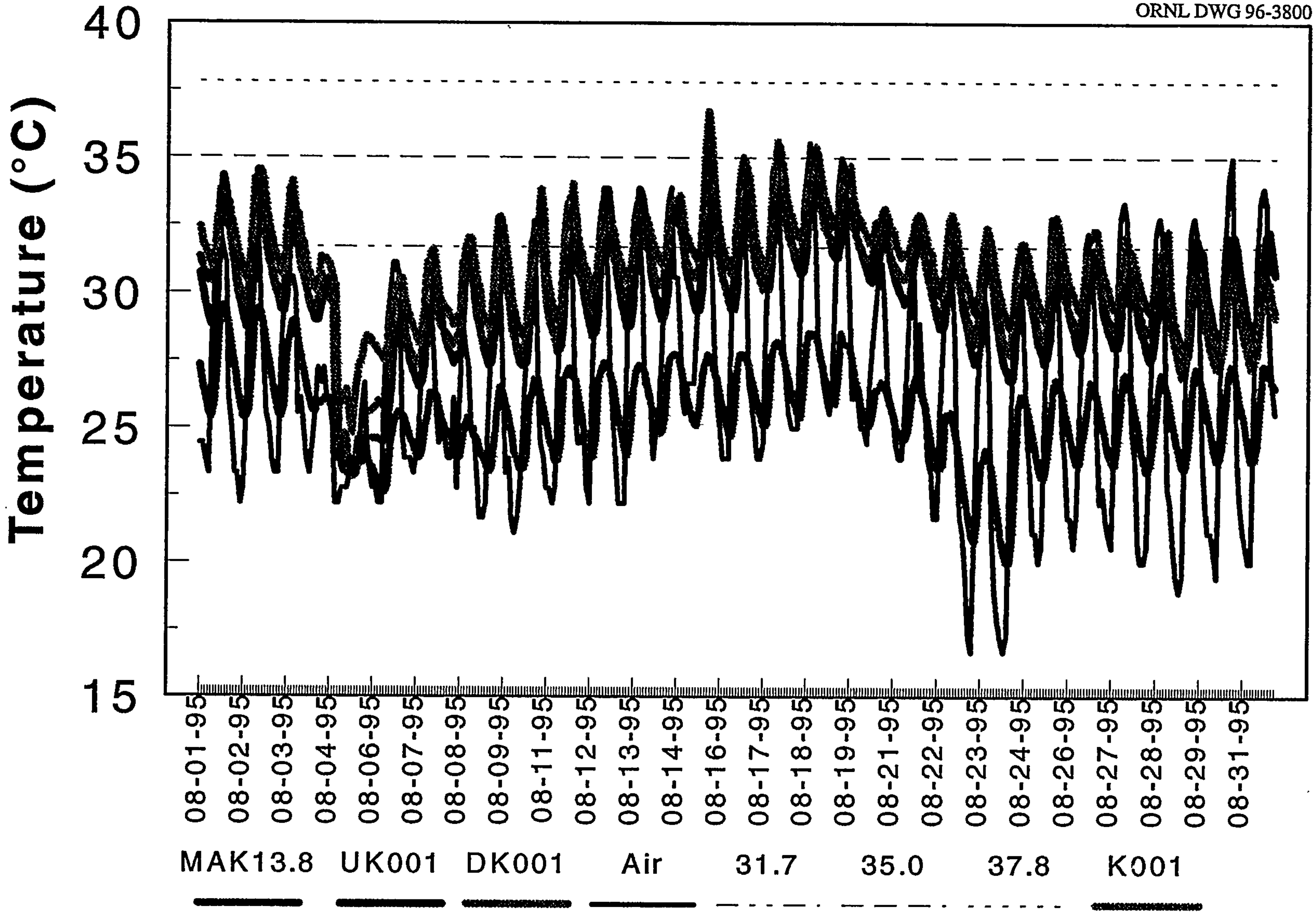

Fig. 2.21. Plot of bi-hourly temperatures at Massac Creek kilometer (MAK) 13.8, Outfall K001, and Big Bayou Creek 25 m upstream and downstream of Outfall K001, compared with ambient air temperatures collected at Barkley Field, August 1995.

did not appear to be a strong seasonal pattern to the effect of discharges from Outfall K010/011 on Little Bayou Creek, although the difference in temperatures between the reference and upstream sites, compared with the downstream sites (LUK 7.2 and 25 m downstream of Outfall K010/011), were slightly greater in summer months than in winter months.

There were no instream temperatures greater than the proposed or interim effluent limits at any of the instream sampling sites on Big Bayou Creek (BBKs 12.5, 10.4, 10.0, and 9.1). The only outfall discharging to Big Bayou Creek with exceedances during the study period was Outfall K001; those exceedances occurred in July and August 1993. However, temperatures in the outfalls and the receiving stream were elevated compared with reference sites. The maximum instream temperature recorded (for those observations when data were not in question due to the possibility of the monitor being out of the water) was 36.7°C at the site 25 m downstream of Outfall K001. Because of stream bottom features, the effect of elevated temperatures on aquatic biota downstream of Outfall K001 may not be as pronounced as one might expect. A natural trough extended for approximately 50 m along the left bank of the stream and created a plume of elevated temperatures along the bank; an island from about 30 to 50 m in the center of the stream further isolated the plume. The plume remain isolated for approximately 50 to 60 m, at which point mixing occurred in a shallow area. Temperatures in the mixing zone were approximately 2.5°C less than those in the plume. For those species that could avoid the plume, thermal inputs at this site may not have created a barrier for colonization of the area or to upstream migration past the outfall (see Sects. 3 and 4 for further discussion). The maximum bi-hourly temperature (for those observations when data were not in question due to the possibility of the monitor being out of the water) for Big Bayou Creek was 36.7°C at the instream sites; 6°C higher than the maximum temperature recording at the reference sites, MAK 13.8 and BBK 12.5. Outfall K001, the only outfall to support a fish community, had a maximum bi-hourly temperature of 38.8°C. There appears to be a stronger seasonal influence on the effect of temperature from outfall discharges into Big Bayou Creek. Average monthly temperatures at instream sites in winter months are often only 1 or 2°C higher than at the reference sites, while temperatures in the summer may differ by as much as 8°C.

Outfall K010, K001, and K006 appear to be the greatest thermal contributors to the respective receiving streams. However, Outfalls K008 and K009 also contribute to the total thermal load on Big Bayou Creek.

3. BENTHIC MACROINVERTEBRATES

(*J. G. Smith* and *M. R. Smith*)

3.1 INTRODUCTION

Temperature plays a major role in growth and survival of aquatic invertebrates directly through physiological effects, and indirectly by affecting nutrition (Anderson and Cummins 1979; Vannote and Sweeney 1980; Sweeney 1984; Ward and Stanford 1982). An optimum temperature is thought to exist for each species at which growth and reproduction are maximized (Vannote and Sweeney 1980). On either side of a species' optimum, growth and reproduction will decline, although the extent of decline may be affected to some extent by the food supply. Under non-optimal but nonlethal conditions for a species, the density will be low; if temperatures go too far in either direction, death will inevitably occur, and extirpation will result if the extreme temperatures persist. Increases in the natural thermal regime should favor those species having higher optimal temperatures or broader thermal tolerance ranges (Perry et al. 1987). Thus, if a temperature change is of a sufficient amount and the change persists long enough, several species should be affected and the effects should ultimately be detectable through changes in community composition and structure. The purpose of this subtask was to evaluate the data collected on benthic macroinvertebrates since 1991 for the PGDP BMP for evidence of adverse thermal effects.

3.2 MATERIALS AND METHODS

Benthic macroinvertebrate samples were collected quarterly (March, June, September, and December) from September 1991 to March 1995 from three heated study sites (i.e., sampling sites downstream of effluent discharges from PGDP) including BBK 9.1 and BBK 10.0 located downstream of outfalls K001, respectively, on Big Bayou Creek, and one site on Little Bayou Creek (LUK 7.2) located downstream at outfall K010/011 (Fig. 1.1). Two reference sites were sampled concurrently, including one on Big Bayou Creek upstream of all effluent discharges (BBK 12.5) and one on Massac Creek (MAK 13.8) southeast of the PGDP Reservation (Figs. 1.1 and 1.2). These reference sites were selected from 24 sites visited on 13 streams before the BMP was initiated [Memorandum from J. M. Loar (ORNL) to T. G. Jett (PGDP), January 16, 1991]. Of these 24 sites, MAK 13.8 and BBK 12.5 were considered the most similar to the study sites in Big Bayou Creek and Little Bayou Creek, and they also appeared to be the least affected by anthropogenic factors. Thus, although they do not represent pristine conditions, they were two of the least impacted sites available at the start of the BMP. Because undisturbed communities of different streams are not identical, having more than one reference site was necessary to provide a more accurate estimate of the normal characteristics of macroinvertebrate communities of the area. All samples collected from each quarter of the first year of the study (September 1991–March 1992) were processed to provide a more detailed baseline. In subsequent years, only samples collected in the March, September, and December sampling periods were processed.

At each site on each sampling date, three random samples were collected with a Surber sampler (0.09 m^2 or 1 ft^2) equipped with a 363-μm mesh net. Samples were collected from riffles only because this type of habitat often possesses the greatest variety of benthic organisms (e.g., Hynes 1970; Platts et al. 1983), and limiting collections to a single type of habitat reduces inter-sample variability (e.g., Plafkin et al. 1989; Resh and McElravy 1993). Samples were placed in pre-labeled, polyurethane-coated, glass jars and preserved with ~80% ethyl alcohol

(ETOH). To prevent sample decomposition due to dilution of the preservative, the ETOH in each jar was replaced within 7 days of collection. Just before sample collection, dissolved oxygen, conductivity, temperature, and pH were measured with a Horiba U-7 Water Quality Checker. Water depth, location within the riffle (distance from permanent head-stakes on the stream bank), visual estimate of the relative current velocity (very slow, slow, moderate, or fast), and substrate types (visual estimate) based on a modified Wentworth particle size scale (Loar et al. 1985), were recorded for each sample. A detailed description of procedures employed for site evaluation and sample collection, storage, and maintenance can be found in Smith (1992).

In the laboratory, each sample was first placed in a U. S. Standard No. 60-mesh (250-µm openings) sieve and rinsed with tap water. Small aliquots of a sample were then placed in a white, water-filled tray, and the organisms were removed from the sample debris with forceps. This process was repeated with the remaining sample until it was entirely sorted. Finally, organisms were identified to the lowest practical taxon and enumerated. Details of laboratory sample processing are available in Wojtowicz and Smith (1992).

Data were analyzed with Statistical Analysis System software and procedures (SAS 1988a, 1988b). Statistical analyses were performed on the macroinvertebrate community estimates of density, total taxonomic richness, and taxonomic richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT richness), and the individual estimates of density and richness for the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). Season-specific data (i.e., March, September, and December) for each response were analyzed with a two-way analysis of variance (ANOVA) with site and year as the main effects; $p < 0.05$ was considered statistically significant. Before doing the ANOVAs, values for each response were transformed as recommended by Elliot (1977) (i.e., $\log_{10}(X+1)$ for density values, and square root of X+0.5 for richness values, where X = the individual observed values for the responses).

3.3 RESULTS

3.3.1 Community Responses

Most major taxonomic groups of macroinvertebrates typically found in streams were represented at all sites during the 4 years covered by the BMP (Appendix B, Table B.1). Included at these sites was a mixture of taxa often considered tolerant (e.g., worms and true midges) or intolerant (e.g., mayflies, stoneflies, and caddisflies) of poor water quality. No obvious patterns of presence/absence of taxa distinguished the two reference sites from the study sites, although fewer stonefly taxa were collected at BBK 9.1 and BBK 10.0 than at the reference sites and LUK 7.2.

The macroinvertebrate communities at all sites exhibited extensive changes in density, taxonomic richness, and EPT richness between each sampling period and between years for a sampling season (Figs. 3.1–3.3; Table 3.1). Differences among some sites for each parameter were demonstrated with statistical analyses (Table 3.1). However, the presence of an interaction between site and sampling year for each sampling season for all but one test (EPT richness for the March sampling periods), and the patterns displayed in the plots of mean values (Figs. 3.1–3.3) indicated that no persistent differences existed among sites. Values for these three parameters for either of the three heated study sites generally fell within or near the range exhibited by the reference sites. Values for density at BBK 10.0 and BBK 9.1 were occasionally very high compared with the

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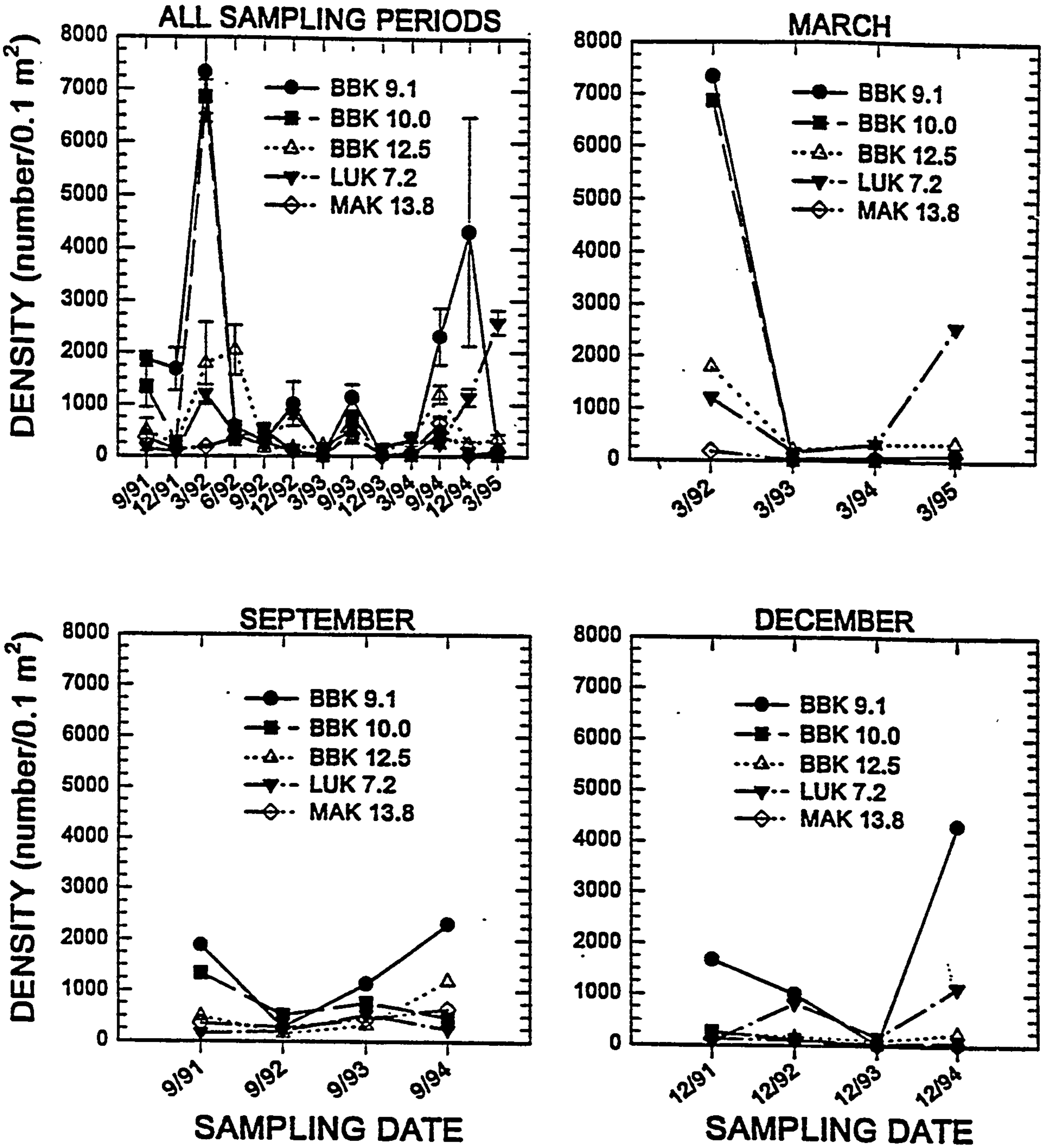

Fig. 3.1. Mean total density of benthic macroinvertebrates for all sampling periods combined and then subset by sampling month for Big Bayou Creek, Little Bayou Creek, and Massac Creek, September 1991–March 1995. Vertical bars in graph for all sampling period represent ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

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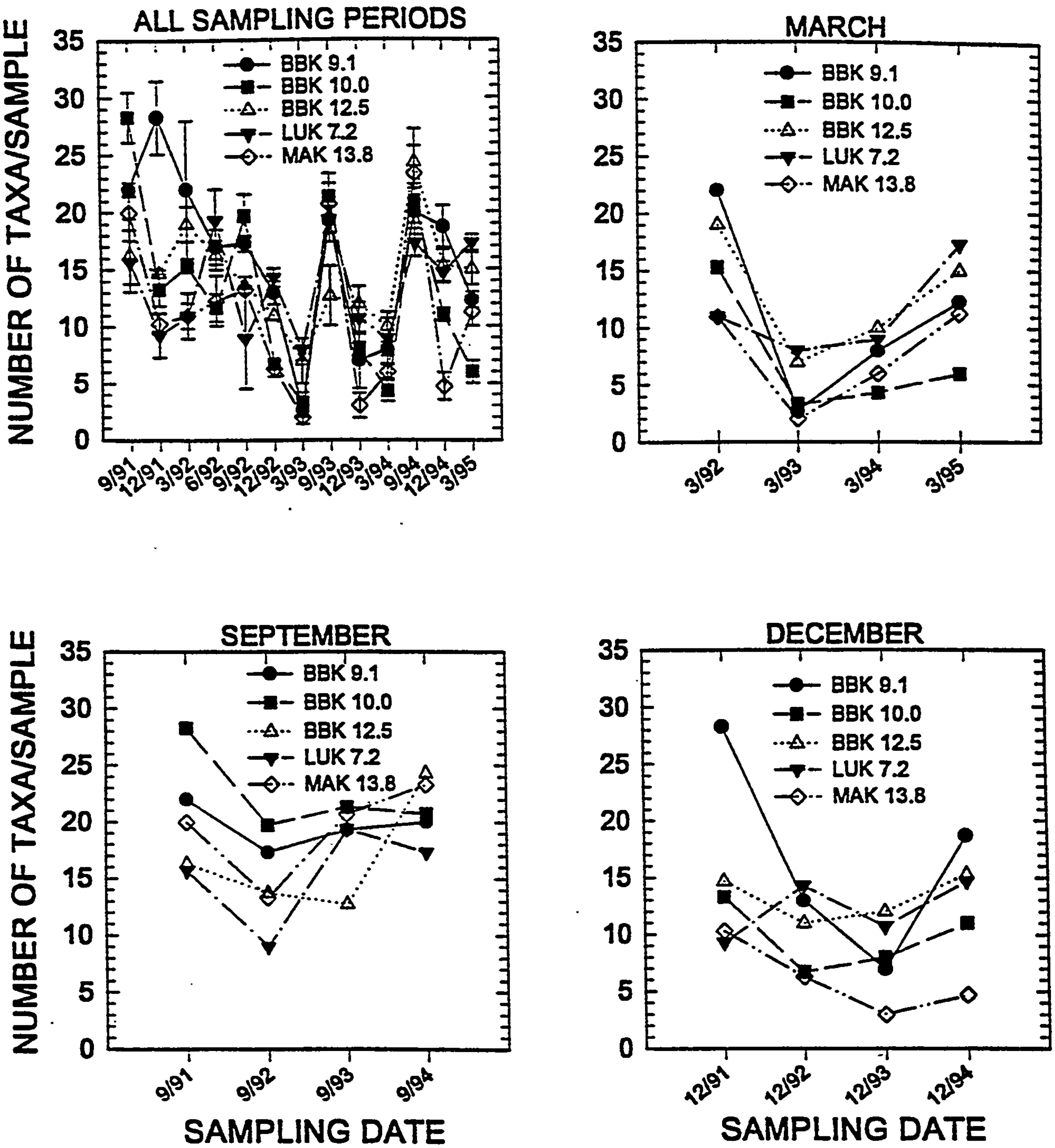

Fig. 3.2. Mean taxonomic richness of the benthic macroinvertebrate communities in Big Bayou Creek, Little Bayou Creek, and Massac Creek for all sampling periods combined and then subset by sampling month, September 1991–March 1995. Vertical bars in graph for all sampling period represent ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

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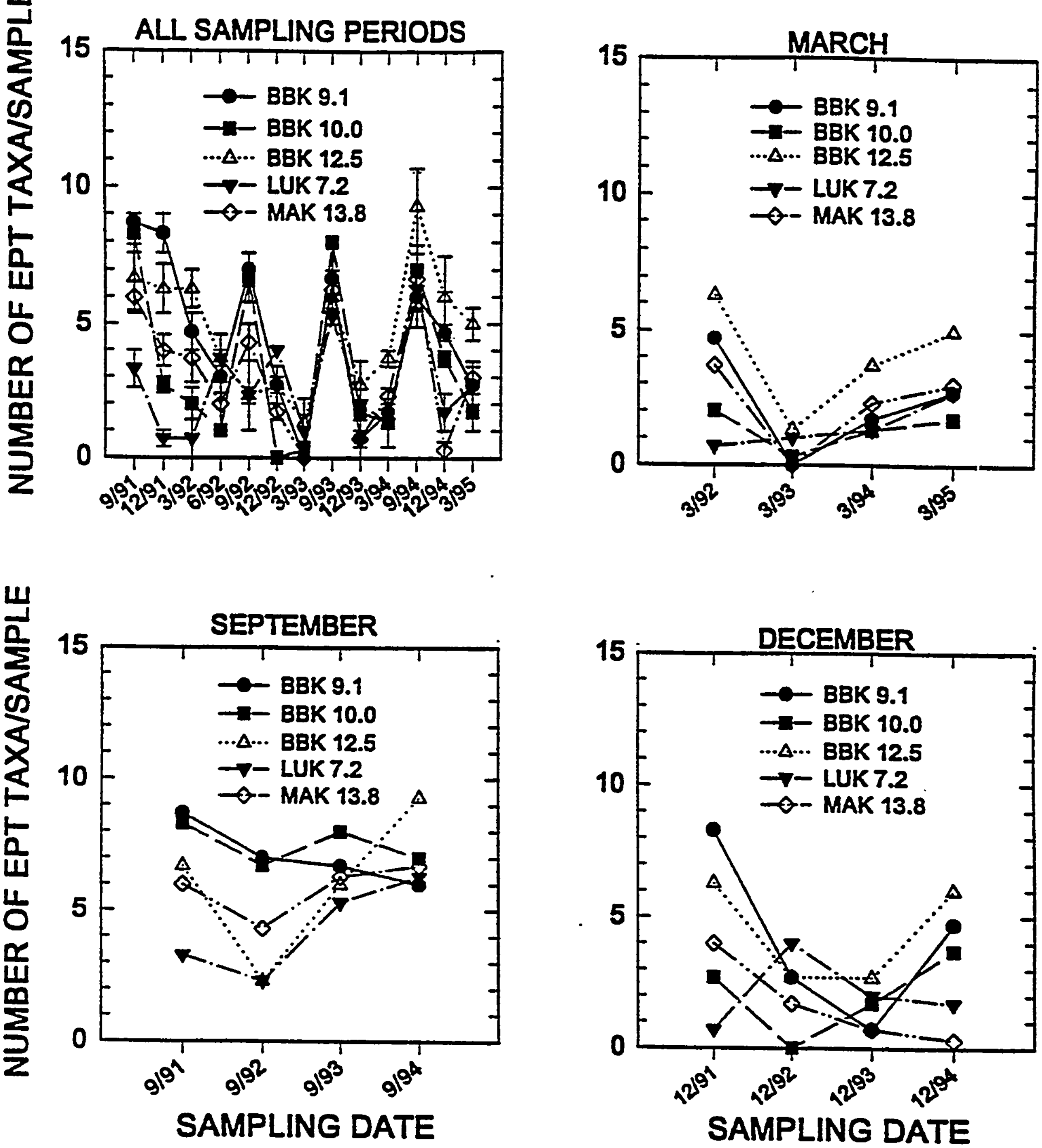

Fig. 3.3. Mean taxonomic richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT richness) of the benthic macroinvertebrate communities in Big Bayou Creek, Little Bayou Creek, and Massac Creek for all sampling periods combined and then subset by sampling month, September 1991–March 1995. Vertical bars in graph for all sampling period represent ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

Table 3.1. Results of the seasonal two-way analysis of variances (ANOVA) for density, total taxonomic richness, and richness of the Ephemeroptera, Plecoptera, and Trichoptera (EPT) of the benthic macroinvertebrate communities in Big Bayou Creek, Little Bayou Creek, and Massac Creek, September 1991 through March 1995

Comparison/Source of Variation		Density		Total Richness		EPT Richness	
	df[a]	*f*-value	*p*-value	*f*-value	*p*-value	*f*-value	*p*-value
March							
Site	4,40	51.43	0.0001	17.54	0.0001	8.52	0.0001
Year	3,40	160.33	0.0001	82.56	0.000	25.13	0.0001
Site X Year	12,40	18.88	0.0001	5.64	0.0001	1.33	0.2401
September							
Site	4,40	13.50	0.0001	6.97	0.0002	8.95	0.0001
Year	3,40	9.56	0.0001	9.76	0.0001	9.85	0.0001
Site X Year	12,40	3.42	0.0017	2.31	0.0238	2.96	0.0050
December							
Site	4,40	29.93	0.0001	31.38	0.0001	16.98	0.0001
Year	3,40	33.43	0.0001	22.13	0.0001	18.63	0.0001
Site X Year	12,40	9.10	0.0001	6.63	0.0001	11.17	0.0001

[a]df = degrees of freedom

reference sites, but these large differences never persisted more than two consecutive sampling periods.

The Chironomidae (true midges) were clearly one of the most abundant taxonomic groups at all five sites (Fig. 3.4). This was particularly true at LUK 7.2 and MAK 13.8 where the relative numerical abundance of this group was rarely <60%. These two sites differed, however, in the relative abundances of the oligochaetes (worms) and EPT taxa. At LUK 7.2 the oligochaetes often accounted for more than 10% of the invertebrates collected, while the EPT taxa generally accounted for ≤10% of the density. With few exceptions, the oligochaetes comprised <5% of the total density at MAK 13.8, while the EPT taxa generally accounted for ≥10% of the total density. At the three sites in Big Bayou Creek, the only discernable difference among the three sites was also in the relative abundances of the Oligochaeta. At BBK 12.5, the oligochaetes generally accounted for < 5% of the total density, but at BBK 9.1 and BBK 10.0 this group frequently accounted for more than 10% of the total density.

3.3.2 Ephemeroptera, Plecoptera, and Trichoptera

The abundances of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) were strongly "seasonal" at all five sites (Figs. 3.5, 3.7, and 3.9). The mayflies and caddisflies were nearly always present at all sites, and they were clearly most abundant during the September sampling periods (Figs. 3.5 and 3.9). No persistent site differences were discernable in these groups, although

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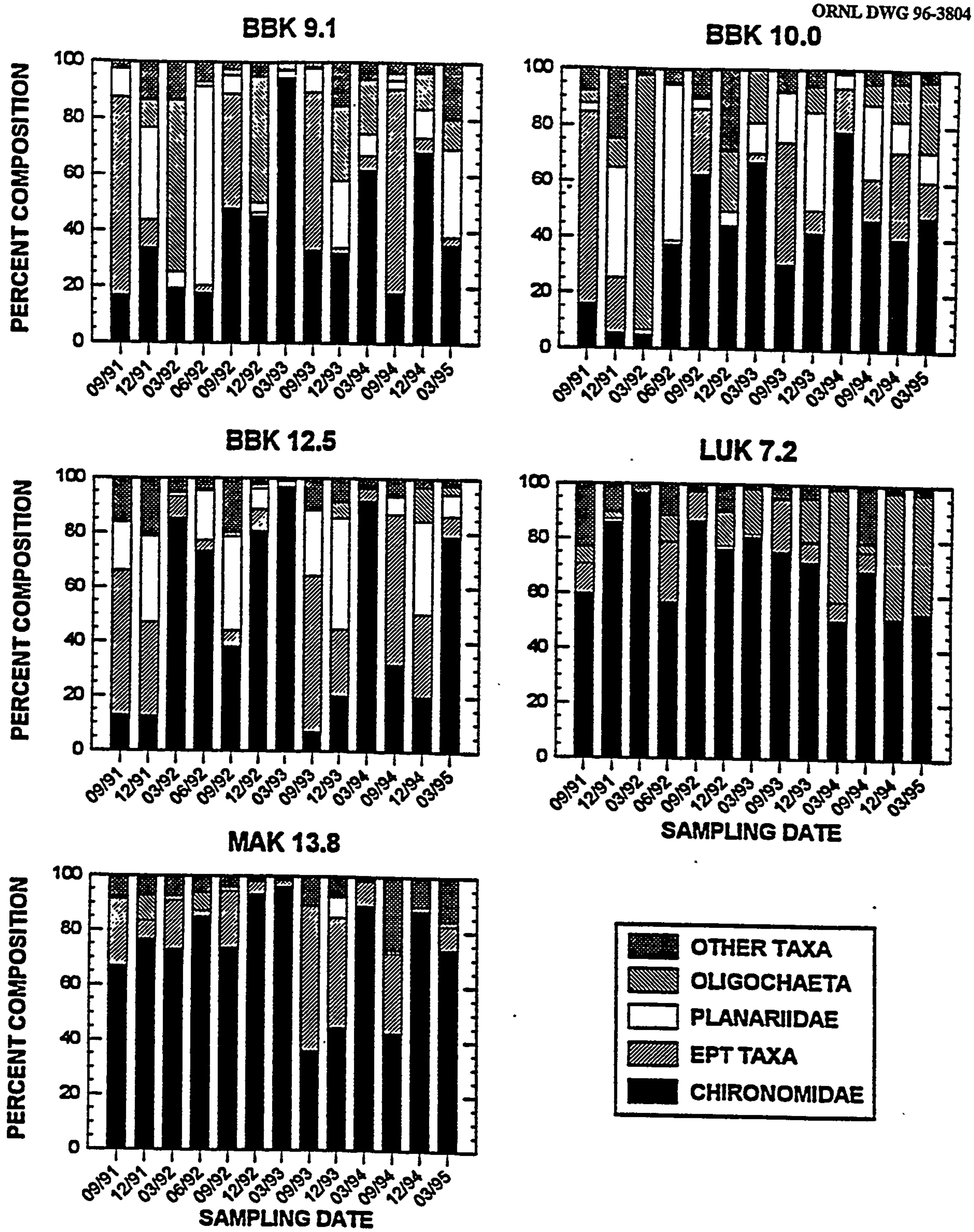

Fig. 3.4. Mean percent composition (percentage of total density) by sampling date of selected benthic macroinvertebrate groups in Big Bayou Creek, Little Bayou Creek, and Massac Creek, September 1991–March 1995. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

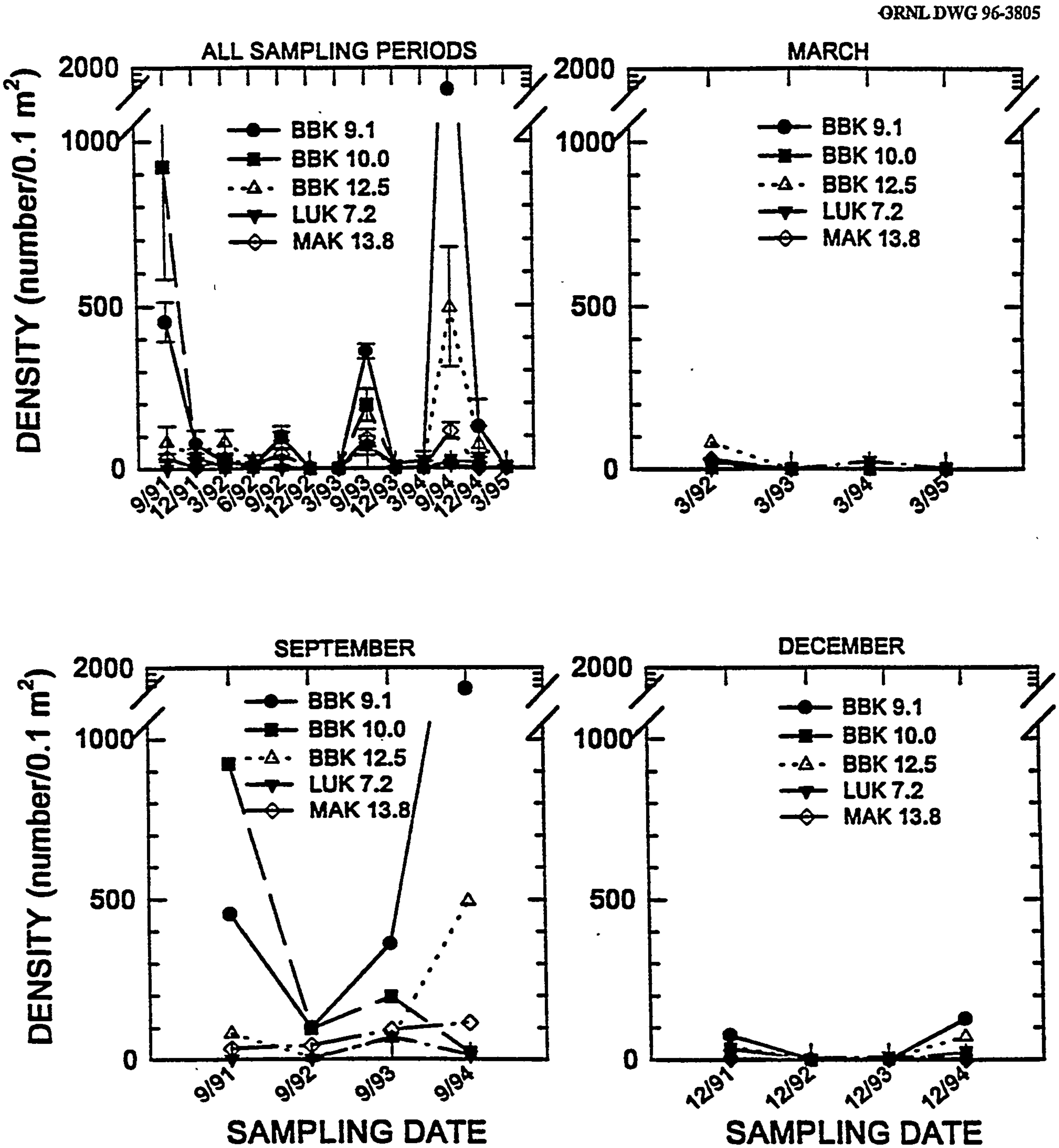

Fig. 3.5. Mean density of the Ephemeroptera in Big Bayou Creek, Little Bayou Creek, and Massac Creek for all sampling periods combined and then subset by sampling month, September 1991–March 1995. Vertical bars in graph for all sampling period represent ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

BBK 9.1 most often had the highest densities of both groups, which may, in part, account for the strong site effect detected with the two-way ANOVA (Table 3.2). The influence of season was not as great on taxonomic richness of the mayflies and caddisflies, although the highest values for all sites still generally occurred during the September sampling periods (Figs. 3.6 and 3.10). Site differences were suggested by the results of the two-way ANOVAs for the September and December data. However, only the mayfly richness values for BBK 9.1 and BBK 10.0 in the September sampling periods were persistently higher than at the other sites which was a trend not observed across the December sampling periods. Furthermore, mayfly and caddisfly richness values for the heated study sites usually fell within the range of those observed for the reference sites. Exceptions were mayfly richness during the first two sampling periods, and caddisfly richness during the December 1991 and September 1994 sampling periods.

The stoneflies were rare at all sites in all of the September sampling periods (Figs. 3.7 and 3.8). With few exceptions, densities of the stoneflies were clearly and consistently higher at reference site BBK 12.5 than at all other sites, including reference site MAK 13.8 in the March and December sampling periods; this difference was likely a major reason for the highly significant site effects obtained in the two-way ANOVAs for these two sampling periods (Table 3.2). The results for MAK 13.8 were more ambiguous (Fig 3.7). Only the March data appeared to indicate that densities of the stoneflies at MAK 13.8 may have been different from those at the three heated study sites, but this difference was evident in only 1994 and 1995. However, the large amount of variation exhibited at all sites during the study in the parameters evaluated would make any conclusions of real and persistent site differences premature. March results for stonefly richness were similar to those for density; richness values at BBK 12.5 were clearly and consistently higher than those at the three heated study sites, while at MAK 13.8 values were not distinctly different from those of the three heated study sites until the 1994 and 1995 sampling periods. During the December sampling periods, mean richness values for the stoneflies were 1 or less at all sites with few exceptions. Although values for stonefly richness tended to be higher at BBK 12.5 than at most other sites, the fact that richness of this group was averaging one or less taxon per sample and densities were generally less than five individuals/0.1 m^2 suggests that the stoneflies were numerically insignificant at these sites.

3.4 DISCUSSION

Total taxonomic richness and EPT richness of benthic macroinvertebrate communities are two parameters commonly used to detect degraded conditions in streams in the Oak Ridge, Tennessee, area (e.g., Cada et al. 1995; Smith 1993; Smith 1995) and elsewhere (e.g., Plafkin et al. 1989; Resh and McElravy 1993). However, as anthropogenic stresses become more subtle, the ability to statistically detect impacts with these and other parameters obtained from field studies such as these, becomes more difficult because of excessive data variability (e.g., Osenberg et al. 1994; Underwood 1994). In the current study, differences between reference sites and study sites in Big Bayou Creek and Little Bayou Creek in the macroinvertebrate communities were not clearly discernable from the available data and the parameters evaluated. Interpretation of the results of this study as a finding of no impact, however, should be made cautiously, because considerable variability (i.e., between-sample, spatial, and temporal) did exist in the data.

Observed patterns in relative abundances of some major taxonomic groups

Table 3.2. Results of the seasonal two-way analysis of variances (ANOVA) on densities and taxonomic richness values for the Ephemeroptera, Plecoptera, and Trichoptera of the benthic macroinvertebrate communities in Big Bayou Creek, Little Bayou Creek, and Massac Creek, September 1991 through March 1995

Comparisons/Source of Variation	df[a]	Density		Richness	
		f-value	*p*-value	*f*-value	*p*-value
Ephemeroptera					
March					
Site	4,40	2.35	0.0709	1.64	0.1830
Year	3,40	31.18	0.0001	25.88	0.0001
Site X Year	12,40	3.04	0.0041	1.22	0.3050
September					
Site	4,40	66.75	0.0001	22.91	0.0001
Year	3,40	27.18	0.0001	6.90	0.0007
Site X Year	12,40	13.15	0.0001	5.16	0.0001
December					
Site	4,40	6.88	0.0003	6.40	0.0004
Year	3,40	15.53	0.0001	14.37	0.0001
Site X Year	12,40	6.13	0.0001	5.97	0.0001
Plecoptera					
March					
Site	4,40	32.22	0.0001	12.75	0.0001
Year	3,40	12.72	0.0001	5.50	0.0029
Site X Year	12,40	4.05	0.0004	1.64	0.1186
September					
Site	4,40	1.00	0.4166	1.33	0.2743
Year	3,40	0.44	0.7253	0.33	0.8013
Site X Year	12,40	1.00	0.4166	0.89	0.5649
December					
Site	4,40	14.17	0.0001	6.40	0.0004
Year	3,40	3.02	0.0410	3.41	0.0265
Site X Year	12,40	1.43	0.1909	2.60	0.0116

Table 3.2 (continued)

Comparisons/Source of Variation	df[a]	Density *f*-value	Density *p*-value	Richness *f*-value	Richness *p*-value
Trichoptera					
March					
Site	4,40	12.78	0.0001	5.41	0.0014
Year	3,40	13.05	0.0001	3.26	0.0312
Site X Year	12,40	6.60	0.0001	3.25	0.0025
September					
Site	4,40	7.84	0.0001	1.31	0.2815
Year	3,40	14.40	0.0001	8.75	0.0001
Site X Year	12,40	1.82	0.0775	1.53	1.528
December					
Site	4,40	55.72	0.0001	20.94	0.0001
Year	3,40	13.90	0.0001	9.86	0.0001
Site X Year	12,40	11.15	0.0001	5.84	0.0001

[a]df = Degrees of freedom.

may have indicated the presence of some imbalance in community composition and, thus, the presence of a subtle impact. Oligochaetes frequently accounted for more than 10% of the total community density at the three heated study sites, a pattern not observed at the reference sites. A predominance of oligochaetes in a macroinvertebrate community can occur for several reasons, such as the presence of excessive nutrients and organic matter (e.g., Wiederholm 1984) or other conditions that can contribute to an excess supply of food (e.g., altered temperatures). The proportion of the EPT taxa at LUK 7.2 was frequently lower than at the other four sites, which is a characteristic also often associated with excesses in nutrients or organic matter (Wiederholm 1984).

If subtle differences existed among sites in macroinvertebrate community structure because of an anthropogenic stress such as elevated temperatures, these differences may only be detectable through closer examination of those taxa potentially most sensitive to the stress of concern. The mayflies, stoneflies, and caddisflies are often considered some of the least tolerant taxa to abnormal changes in environmental conditions (e.g., Camargo 1994; Hilsenhoff 1988; Lenat 1993). Stonefly nymphs occur mainly in cool running water (Elliot 1987; Harper and Stewart 1984) and may, therefore, be the most sensitive of these three orders to elevated temperatures. However,

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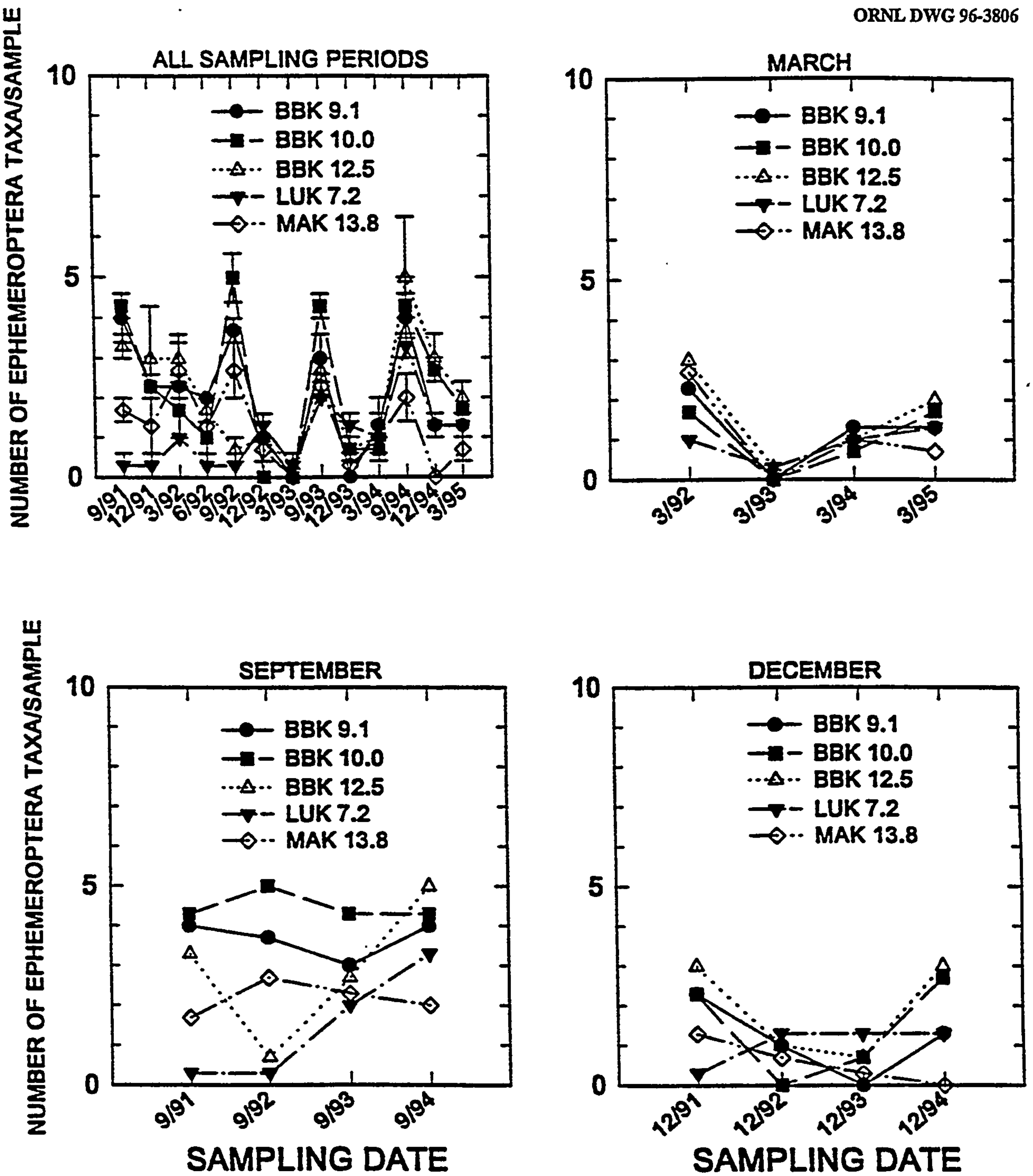

Fig. 3.6. Mean taxonomic richness of the Ephemeroptera in Big Bayou Creek, Little Bayou Creek, and Massac Creek for all sampling periods combined and then subset by sampling month, September 1991– March 1995. Vertical bars in graph for all sampling period represent ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

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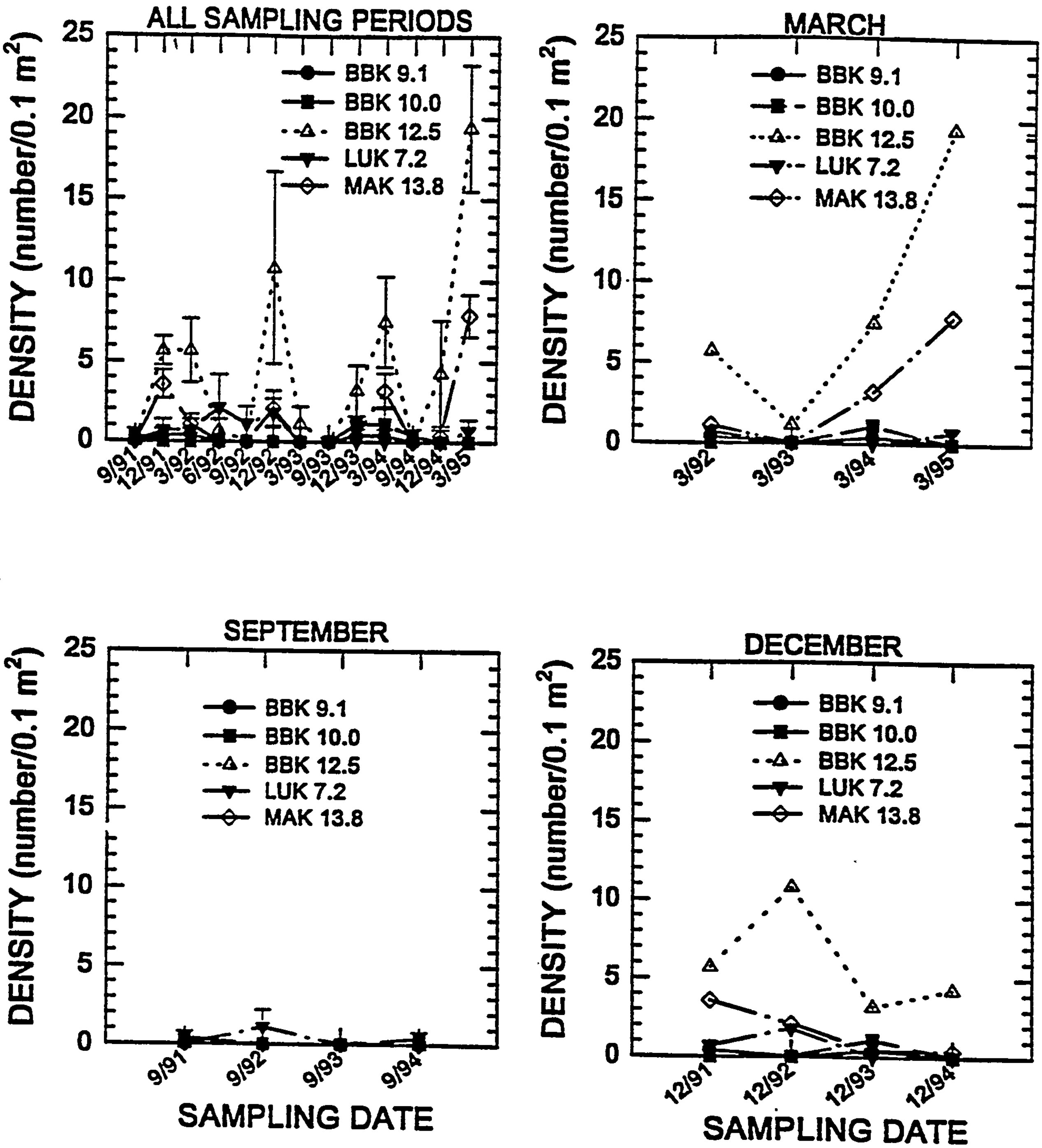

Fig. 3.7. Mean density of the Plecoptera in Big Bayou Creek, Little Bayou Creek, and Massac Creek for all sampling periods combined and then subset by sampling month, September 1991–March 1995. Vertical bars in graph for all sampling period represent ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

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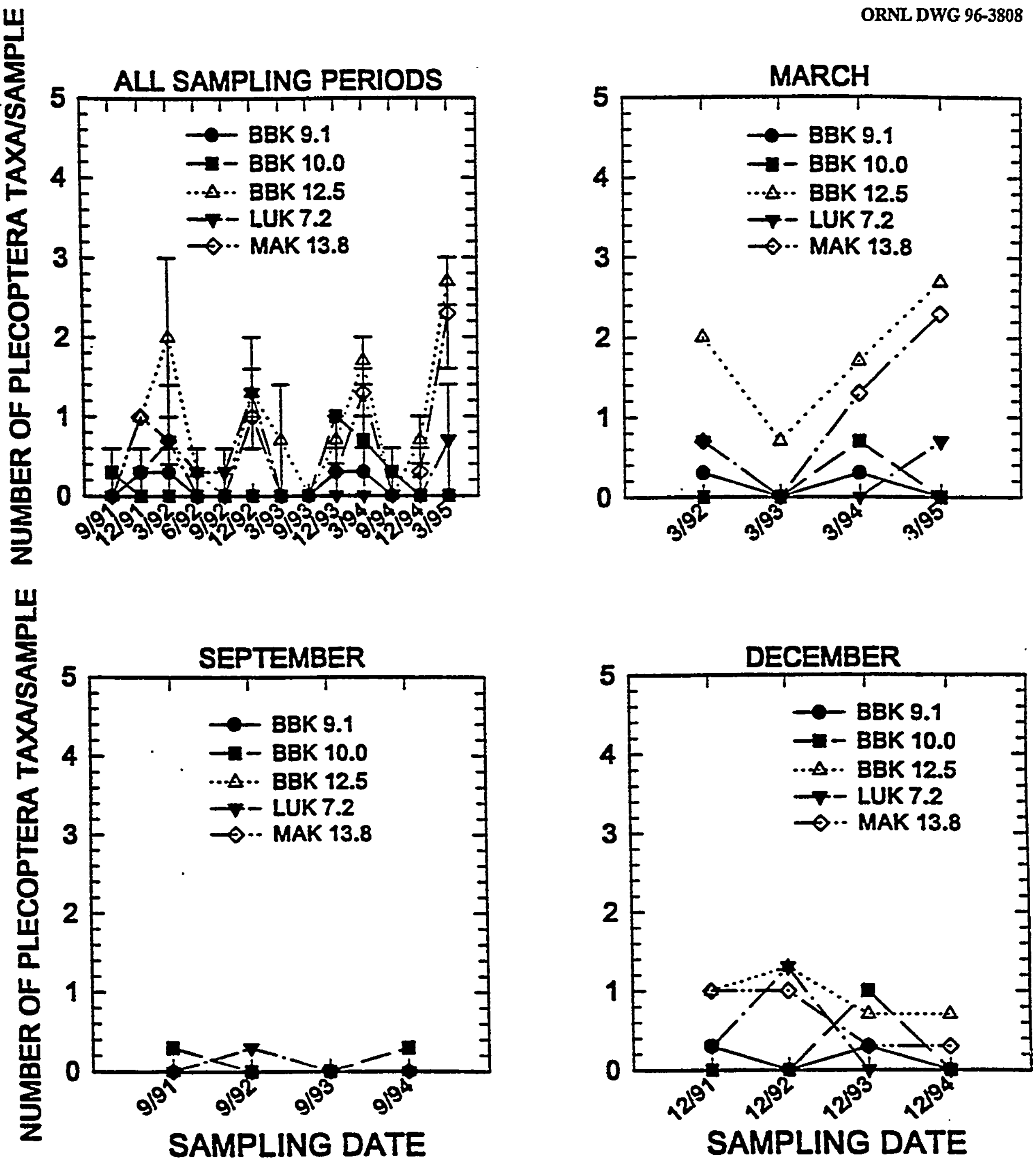

Fig. 3.8. Mean taxonomic richness of the Plecoptera in Big Bayou Creek, Little Bayou Creek, and Massac Creek for all sampling periods combined and then subset by sampling month, September 1991–March 1995. Vertical bars in graph for all sampling period represent ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

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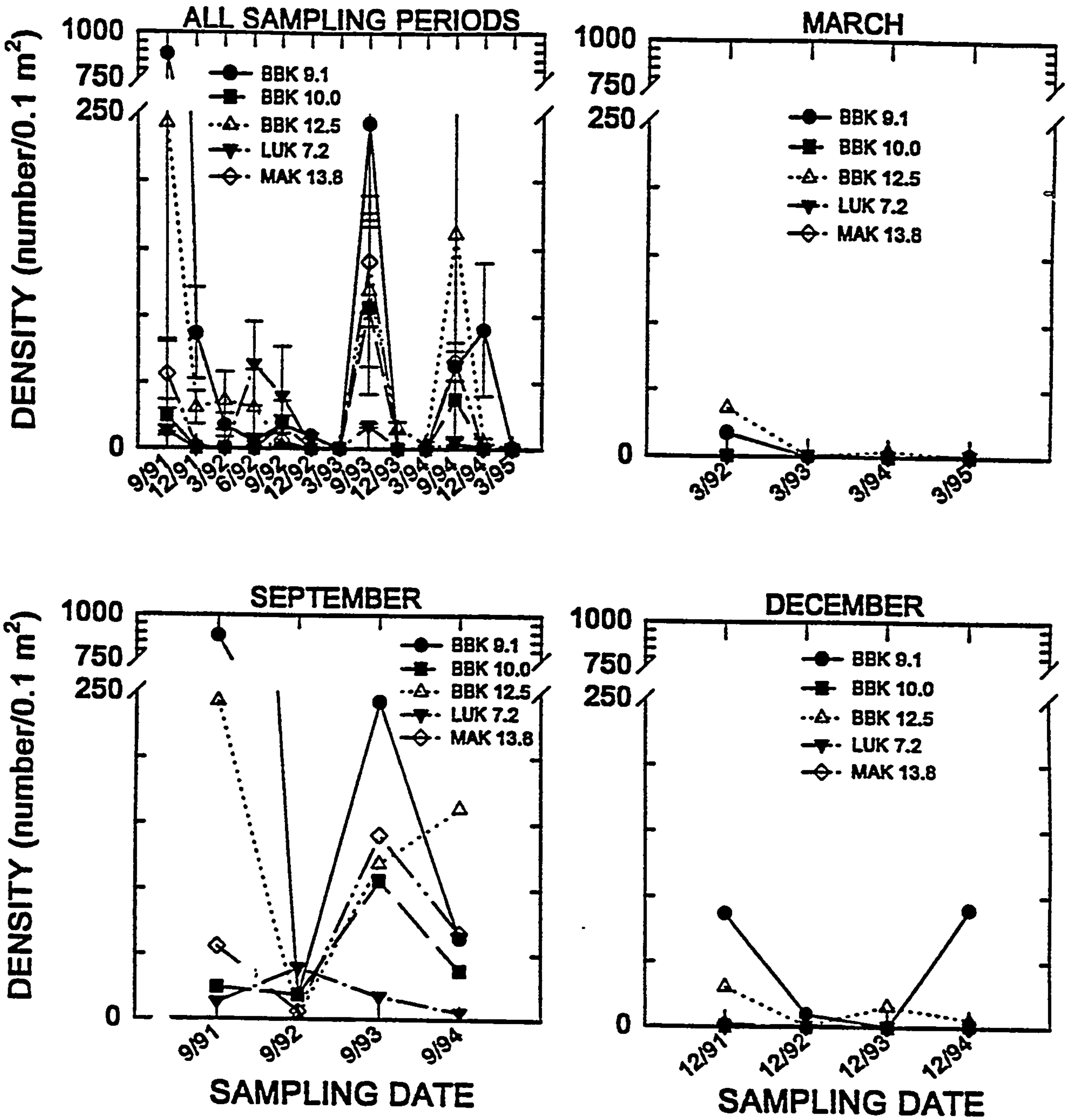

Fig. 3.9. Mean density of the Trichoptera in Big Bayou Creek, Little Bayou Creek, and Massac Creek for all sampling periods combined and then subset by sampling month, September 1991–March 1995. Vertical bars in graph for all sampling period represent ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

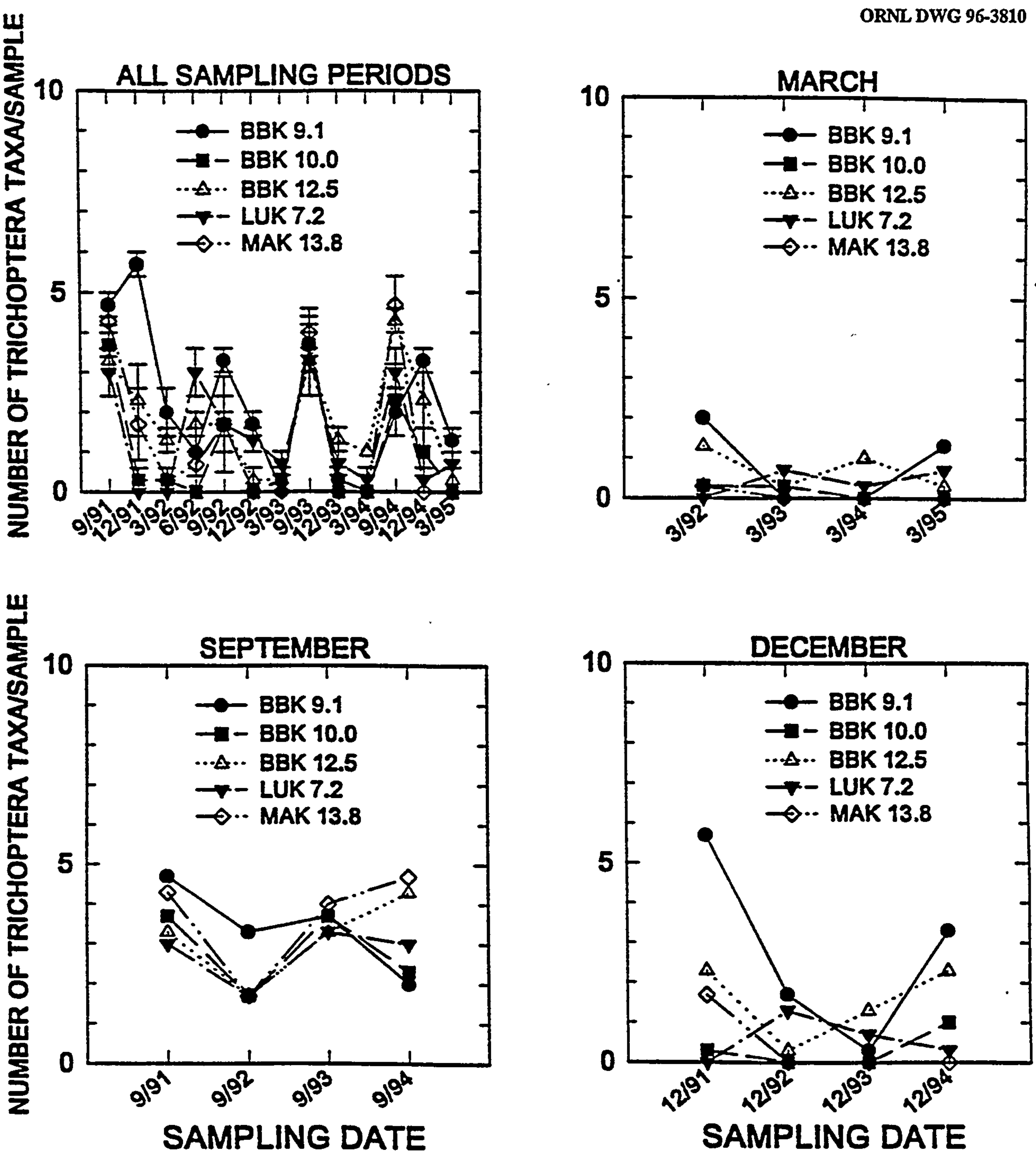

Fig. 3.10. Mean taxonomic richness of the Trichoptera in Big Bayou Creek, Little Bayou Creek, and Massac Creek for all sampling periods combined and then subset by sampling month, September 1991–March 1995. Vertical bars in graph for all sampling period represent ± 1 SE. BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

because exceptions to broad generalizations of pollution tolerances usually exist, caution is necessary in interpreting the ecological condition of such groups.

There was no strong evidence that the mayflies or caddisflies at BBK 9.1, BBK 10.0, or LUK 7.2 were being subjected to conditions unusually different from those of the reference sites. Although values for densities and richness of these taxa at the heated study sites sometimes fell out of the range of values exhibited at the reference sites, this deviation did not persist. Furthermore, the mayflies and caddisflies of all sites including the reference sites were numerically dominated by taxa often considered as pollution tolerant (e.g., Lenat 1993) such as *Baetis*, *Caenis*, *Tricorythodes*, *Chimarra*, and *Cheumatopsyche*.

There was evidence suggesting that stonefly density and richness may have been suppressed at the heated study sites. However, only reference site BBK 12.5 was clearly different from the heated study sites. The Massac Creek reference site exhibited extensive temporal variation that limited detection of any persistent pattern of difference from the three study sites. Furthermore, the low densities and richness of this order at all five sites suggest that this order may play at most, only a minor role in the ecology of these sites. In the absence or lack of readily available historical information on the macroinvertebrate communities of these streams and nearby streams, it is unknown whether these low values are normal or the result of unnatural stress(es). Because the evaluated parameters of the stoneflies at the study sites did not clearly fall out of the range of both reference sites, it cannot be conclusively stated that the stoneflies were adversely affected.

Although temperature effects on macroinvertebrates could not be detected, temperatures at BBK 9.1, BBK 10.0, and LUK 7.2 (Sect. 2) were within or near the range of temperatures reported as potentially detrimental to macroinvertebrates. Mixed responses have been reported for temperatures between 30°C and 35°C (Stangenberg and Pawlaczyk 1961; Langford 1971; Benda and Proffitt 1974), but temperatures exceeding 35°C are probably detrimental to many species of invertebrates (Benda and Proffitt 1974; Coutant 1962; Coutant 1970; Wurtz and Renn 1965). Many species of stoneflies appear to be negatively affected at temperatures of 20 to 25°C (e.g., Nebeker and Lemke 1968; Elliot 1987; Elliot 1988; Mutch and Pritchard 1986; Wiederholm 1984), although there are some species that apparently tolerate temperatures of around 30°C (Nebeker and Lemke 1968). Some species of caddisflies within the genera *Chimarra*, *Hydropsyche*, and *Cheumatopsyche* appear to tolerate temperatures of up to 35°C (Moulton et al. 1992; Poff and Matthews 1986). Temperatures for some mayflies are lethal at 20°C (Wiederholm 1984), but some species of *Stenonema* can tolerate temperatures in excess of 25°C (Lewis 1974), and some species of *Caenis* can tolerate temperatures of about 30°C (Poff and Matthews 1986; Rogers 1982). These published accounts imply that many macroinvertebrate taxa currently occurring in Big Bayou Creek and Little Bayou Creek could be living near their upper thermal limits; thus, steps should be taken to ensure that further thermal loading does not occur.

3.5 CONCLUSIONS

Benthic macroinvertebrate data covering a 4 year period provided no conclusive evidence that the macroinvertebrate communities of Big Bayou Creek and Little Bayou Creek are being adversely affected by thermal discharges. Because major impacts are normally detectable from field studies such as this, major impacts can be ruled out. However, because data ambiguity limited the ability to detect differences, the presence of some subtle impacts cannot be ruled out. Furthermore, impacts to stream reaches closer to the thermal outfalls cannot be ruled out, because these areas were not sampled.

4. FISH COMMUNITY MONITORING

(M. G. Ryon)

4.1 INTRODUCTION

Fish population and community studies can be used to assess the ecological effects of changes in water quality and habitat. These studies offer several advantages over other indicators of environmental quality (see Karr et al. 1986, Karr 1987) and are especially relevant to assessment of the biotic integrity of Little Bayou and Big Bayou creeks. Monitoring of fish communities has been used by the BMAP in ESD for receiving streams at ORNL (Loar et al. 1991), K-25 Site (Loar et al. 1992; Ryon 1993a), the Portsmouth, Ohio, facility (Ryon 1994f), and the Y-12 Plant (Loar et al. 1989; Ryon 1992a; Southworth et al. 1992), with some programs operational since 1984. Changes in the fish communities in these systems have indicated recovery (Ryon 1994b, 1994d) as well as documented impacts (Ryon 1993b, 1994c).

The objectives of the instream fish monitoring were (1) to characterize spatial and temporal patterns in the distribution and abundance of fishes in Little Bayou and Big Bayou creeks as affected by heated effluents from selected outfalls (K001, K006, K008, and K010/K011) and (2) to try to associate absence or presence of fish species with published temperature data.

4.2 STUDY SITES

Quantitative sampling of the fish community was conducted at five sites. Three sites are located on Big Bayou Creek (BBK 12.5, BBK 10.0, and BBK 9.1; Fig. 1.1), one on Little Bayou Creek (LUK 7.2, Fig. 1.1), and one offsite reference station is located on Massac Creek (MAK 13.8, Fig. 1.2). MAK 13.8 was chosen as a reference site for BBK 9.1 and BBK 10.0. The upper site on Big Bayou Creek (BBK 12.5) was selected as a smaller reference site to be comparable to LUK 7.2. These sites are part of the current BMP for PGDP and sampling was conducted at the scheduled intervals for that program. A detailed description of each site is given in Smith et al. (1994).

A total of four qualitative sampling sites were established to evaluate the fish community in the areas of potentially elevated temperatures. One site was located in Little Bayou Creek below the outfall of concern. Originally, this was Outfall K011 (stream site LUK 9.2). Because of PCB contamination in the outfall channel, the discharge was rerouted in early June 1994 through Outfall K010, and the stream monitoring was moved to LUK 9.2. Three sites were located in Big Bayou Creek watershed, with sites in the discharge channel of Outfall K001, in Big Bayou Creek immediately below the outfall (BBK 9.4), and later, at a site above Outfall K008 near Water Works Road (BBK 10.4). These sites were sampled at roughly quarterly intervals to provide data on seasonal changes in species distributions in relation to changes in temperature.

The two sites in Big Bayou Creek were normally 4 to 6 m in width, less than a meter in depth, and included several pool and riffle sequences. The downstream site, BBK 9.4, was bordered by second-growth forest, with a high canopy allowing primarily filtered sunlight to reach the stream channel. The upstream site, BBK 10.4, passed through an open field with only shrubs and small trees providing a riparian zone of less than 5 m in width. This allowed greater penetration of direct sunlight and resulted in high algal growth in some seasons. Both sites had a mixture of small gravel and hardpan clay substrates and a slow to moderate flow rate. Average sample lengths were 120 to 150 m.

The K001 outfall ditch was much narrower (1 m width), shallower (<0.5 m depth), and had a faster flow rate than the Big Bayou Creek sites. The substrate was similar, and pool and riffle habitats were represented. The riparian zone was the same as at BBK 9.4. The LUK 9.0/9.2 site was intermediate between the Big Bayou Creek sites and K001. The width was usually 1–2 m and depths were between 0.5 and 1 m. The substrate had less gravel, with more silt and hardpan clay. The riparian zones were more developed than the narrow zone along BBK 10.4, but with fewer large trees than at BBK 10.4 and K001. The flow was slow to moderate. One unique factor influencing the LUK 9.0/9.2 sites was the sporadic presence of beaver dams. These dams occurred both in and above the sites, but because of control efforts by PGDP, they were not permanent structures. Average sample lengths at the K001 and LUK 9.0/9.2 sites were 70 to 90 m.

4.3 MATERIALS AND METHODS

Quantitative sampling of the fish populations at four sites in the Big Bayou Creek watershed and at one site in a reference stream, Massac Creek, was conducted by electrofishing in March and September 1994 and 1995. Data from these samples were used to estimate species richness and population size (numbers per unit area). Fish sampling sites either overlapped or were within 100 m of the sites included in the benthic macroinvertebrate monitoring task. Qualitative fish sampling was conducted by electrofishing beginning in November 1993 and concluding in November 1995 (Table 4.1). Data from these samples were used to determine the species richness, number of specimens, and catch per unit effort. All field sampling was conducted according to standard procedures (Ryon 1992b).

4.3.1 Quantitative Field Sampling Procedures

Stream sampling was conducted using two or three Smith-Root backpack electrofishers, depending on stream size. Each unit can deliver up to 1200 V of pulsed direct current in order to stun fish. After 0.64-cm-mesh seines were placed across the upper and lower boundaries of the fish sampling site to restrict fish movement, a five to nine person sampling team electrofished the site in an upstream direction on three consecutive passes. Stunned fish were collected and stored, by pass, in seine-net holding pens (0.64-cm-diam mesh) or in buckets during further sampling.

Following the electrofishing, fish were anesthetized with MS-222 (tricaine methanesulfonate), identified, measured (total length), and weighed using Pesola spring scales. Individuals were recorded by 1-cm size classes and species. After ten individuals of a species-size class were measured and weighed, additional members of that size class were only measured. Length-weight regressions based on the weighed individuals were used to estimate missing weight data.

After processing fish from all passes, the fish were allowed to fully recover from the anesthesia and returned to the stream. Any additional mortality that occurred as a result of processing was noted at that time. Following completion of fish sampling, the length, mean width, mean depth, and pool:riffle ratio of the sampling reach were measured at each site.

4.3.2 Qualitative Field Sampling Procedures

Qualitative sampling involved electrofishing a limited length of stream for one pass and collecting all stunned fish. A three- to five-person sampling team

Table 4.1. Sample sites and dates for the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek, November 1993 to November 1995

Sample date	LUK 9.0	LUK 9.2	BBK 9.4	K001	BBK 10.4
November 2–3, 1993		X	X	X	
March 6–7, 1994			X	X	
March 22–23, 1994		X			
May 16–17, 1994		X	X	X	
August 15–16, 1994		X	X	X	X
November 6–7, 1994	X		X	X	X
March 13–14, 1995	X		X	X	X
May 16–17, 1995	X		X	X	X
July 25–26, 1995	X		X	X	X
November 13–14, 1995	X		X	X	X

Note: LUK = Little Bayou Creek kilometer, BBK = Big Bayou Creek kilometer.

electrofished upstream using one or two Smith-Root backpack electrofishers. The sample reach began at a consistent location in the stream and sampling proceeded upstream no further than a designated stopping point. Stunned fish were netted, placed in buckets, and given to a two- to three-person shore crew for processing. The shore crew counted and identified all specimens; easily identifiable species were immediately released downstream from the sampling crew. Species that were more difficult to identify were preserved in 10% formaldehyde and taken to the ESD laboratory for positive identification. The duration of the electrofishing effort (in minutes per electrofisher) and the length of stream sampled (in meters) were recorded.

4.3.3 Data Analysis

Quantitative species population estimates were calculated using the method of Carle and Strub (1978). To calculate density per unit area, total numbers were divided by the surface area (in square meters) of the study reach. These data were compiled and analyzed by a comprehensive Fortran 77 program developed by ESD staff (Railsback et al. 1989). Qualitative samples were compared using total number of species and specimens and the relative abundance of the specimens (catch per minute electrofished).

4.4 RESULTS

4.4.1 Quantitative Sampling

4.4.1.1 Species richness and composition

A total of 35 fish species were found at the 5 sites on Big Bayou Creek, Little Bayou Creek, and Massac Creek (Table 4.2) for the March and September 1994–1995 samples. BBK 9.1 and BBK 10.0 had 28 and

Table 4.2. Species composition of quantitative samples in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March and September 1994 and 1995

	Sites[a]				
Species[b]	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Clupeidae					
Gizzard shad (*Dorosoma cepedianum*)	1[c]	0	1	0	1
Cyprinidae					
Central stoneroller (*Campostoma anomalum*)	4	4	4	4	4
Red shiner (*Cyprinella lutrensis*)	1	1	2	4	1
Steelcolor shiner (*Cyprinella whipplei*)[d]	1	0	1	0	4
Common carp (*Cyprinus carpio*)	1	0	0	0	1
Mississippi silvery minnow (*Hybognathus nuchalis*)	1	1	0	1	2
Ribbon shiner (*Lythrurus fumeus*)[d]	1	0	0	2	3
Redfin shiner (*Lythrurus umbratilis*)[d]	2	2	3	3	4
Golden shiner (*Notemigonus crysoleucas*)	1	0	0	3	1
Suckermouth minnow (*Phenacobius mirabilis*)	0	1	1	3	0
Bluntnose minnow (*Pimephales notatus*)	1	3	4	4	4
Fathead minnow (*Pimephales promelas*)	0	0	1	0	0
Creek chub (*Semotilus atromaculatus*)	1	4	4	4	4
Catostomidae					
White sucker (*Catostomus commersoni*)	3	0	3	0	4
Creek chubsucker (*Erimyzon oblongus*)	3	3	4	1	4
Bigmouth buffalo (*Ictiobus cyprinellus*)	2	0	0	0	0
Spotted sucker (*Minytrema melanops*)	4	0	0	0	2
Golden redhorse (*Moxostoma erythrurum*)	1	0	0	0	2
Ictaluridae					
Black bullhead (*Ameiurus melas*)	1	0	0	0	0
Yellow bullhead (*Ameiurus natalis*)	4	2	4	3	4
Aphredoderidae					
Pirate perch (*Aphredoderus sayanus*)	1	0	1	2	4
Cyprinodontidae					
Blackspotted topminnow (*Fundulus olivaceus*)	4	4	4	4	4
Poeciliidae					
Western mosquitofish (*Gambusia affinis*)	2	2	1	4	2

Table 4.2 (continud)

Species[b]	Sites[a] BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Centrarchidae					
Green sunfish (*Lepomis cyanellus*)	4	4	4	3	4
Warmouth (*Lepomis gulosus*)	1	0	1	2	2
Bluegill (*Lepomis macrochirus*)	4	3	4	3	4
Longear sunfish (*Lepomis megalotis*)	4	4	4	3	4
Hybrid sunfish	3	1	2	0	2
Redspotted sunfish (*Lepomis miniatus*)[d]	0	0	0	1	0
Spotted bass (*Micropterus punctulatus*)	4	2	2	1	4
Largemouth bass (*Micropterus salmoides*)	3	2	2	1	1
White crappie (*Pomoxis annularus*)	1	0	0	0	0
Percidae					
Bluntnose darter (*Etheostoma chlorosomum*)	0	0	0	1	0
Slough darter (*Etheostoma gracile*)	0	0	0	3	3
Logperch (*Percina caprodes*)	0	1	0	0	4
Blackside darter (*Percina maculata*)[d]	0	0	0	0	4
TOTAL SPECIES	28	17	21	23	28

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991) and Etnier and Starnes (1993). For complete references, please see Sect. 7 of this document.

[c]Numbers represent the number of sampling periods ($N = 4$) that a given species was collected at the site , and the numeral zero indicates that the species was not collected.

[d]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

17 species for the 2 sampling years, compared to 28 species at the reference stream, MAK 13.8. The LUK 7.2 site had 23 species during the 2 years, while the comparable reference site, BBK 12.5 had 21 species. Mean species richness for MAK 13.8, BBK 9.1, and BBK 10.0 was 21.0, 15.5, and 11.0, respectively (Table 4.3). At LUK 7.2 and BBK 12.5, the mean richness was 15.0 and 13.0, respectively. At all sites, species richness was higher in the September samples than in March. The core species assemblage at the sites included central stoneroller (*Campostoma anomalum*), redfin shiner (*Lythrurus umbratilis*), bluntnose minnow (*Pimephales notatus*), creek chub (*Semotilus atromaculatus*), blackspotted top minnow (*Fundulus olivaceus*), creek chubsucker (*Erimyzon oblongus*), yellow bullhead (*Ameiurus natalis*), green sunfish (*Lepomis cyanellus*), bluegill (*L. macrochirus*), longear sunfish (*L. megalotis*), and spotted bass (*Micropterus punctulatus*). These species occurred at all sites at least once, and at most sites three or four times out of four sampling periods (Table 4.2).

Table 4.3. Total fish density and species richness for March and September 1994–1995 at sampling sites[a] in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek

Measurement expressed in individuals per square meter

Sampling periods	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
March 1994					
Density	0.97	1.36	3.09	3.82	1.49
Species richness	13	10	12	20	17
September 1994					
Density	1.19	5.57	4.26	3.76	5.74
Species richness	16	12	15	8	25
March 1995					
Density	0.27	0.83	3.79	2.23	0.63
Species richness	11	8	11	13	18
September 1995					
Density	3.45	8.44	3.21	5.09	5.14
Species richness	22	14	14	19	24
Means 1994–95					
Density	1.47	4.06	3.59	3.73	3.26
Species richness	15.5	11.0	13.0	15.0	21.0

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

4.4.1.2 Density

Quantitative estimates of density were similar or higher at all sites during the September samples than during the March samples (Table 4.3). This was the pattern in previous PGDP samples (Ryon 1994a, 1994e, 1995) and has been the dominant pattern for the BMAP sampling conducted at the approximately 50 sites in the Oak Ridge, Tennessee, area since 1985 (Loar 1992, Ryon 1992c; Southworth et al. 1992). The higher fall density reflects recruitment of fish into the community and normally occurs at all sites, unless a substantial impact has occurred. Total densities were similar between BBK 10.0 and MAK 13.8, with levels at BBK 9.1 less than the levels at the other two sites (Table 4.3). Densities at LUK 7.2 and BBK 12.5 were very similar, especially mean levels.

Densities of individual species varied slightly between sites, with less variation among the two species with the highest values (Appendix C, Tables C.1 to C.4). During most sampling at BBK 9.1, BBK

10.0, and MAK 13.8, the species present in highest or next highest numbers were the central stoneroller or longear sunfish. At BBK 10.0, stonerollers comprised more than 80% of the total fish numbers, far exceeding the proportion of the fish community at MAK 13.8 or BBK 9.1. The high densities of central stoneroller (a scraping herbivore) in Big Bayou Creek probably reflected greater algal growth resulting from nutrient enrichment by PGDP discharges. The longear sunfish is a generalist feeder and the primary centrarchid in the PGDP area streams. At LUK 7.2, the species with the highest densities were bluntnose minnow, red shiner (*Cyprinella lutrensis*), and western mosquitofish (*Gambusia affinis*) (Tables C.1 to C.4). The BBK 12.5 reference site was similar to downstream Big Bayou Creek sites with highest densities for longear sunfish and central stoneroller.

4.4.2 Qualitative Sampling

A total of 35 species were found at the 4 sites sampled qualitatively from November 1993 to 1995 (Table 4.4). The two sites on Big Bayou Creek (BBK 9.4 and BBK 10.4) had the highest number of species, as well as the highest mean species richness. The species found most frequently in sampling at these sites included central stoneroller, red shiner, bluntnose minnow, creek chub, yellow bullhead, blackspotted topminnow, green sunfish, bluegill, and longear sunfish. This community composition is very similar to that found in sampling at quantitative sites in the Big Bayou Creek watershed. The highest catch per unit effort was found at BBK 10.4 (Table 4.4), with a similar level of abundance at the site below K010/011 in Little Bayou Creek (LUK 9.0/9.2).

The species richness and catch per effort at the four qualitative sites indicated some changes that corresponded temporally to changes in temperature. The numbers of species at LUK 9.0/9.2 and at K001 declined during the summer sampling period compared to cooler seasons or to concurrent sampling at BBK 9.4 and BBK 10.4 (Fig. 4.1). The number of species actually was the highest in the summer at BBK 10.4, the coolest site, and was substantially higher than either LUK 9.0/9.2 or K001 sites. Although one would expect fewer species at LUK 9.0/9.2 and K001 based on their smaller stream size, the seasonal pattern of utilization should be similar to the other sites. Catch per unit effort responded similarly to species richness, where the lowest abundance was seen in summer sampling at LUK 9.0/9.2 and K001 (Fig. 4.1), but remained high at both Big Bayou Creek sites. Although the BBK 10.4 site is above most of the potential chemical impacts associated with the PGDP, the BBK 9.4 site is not. A primary difference between these two Big Bayou Creek sites and the K001 and LUK 9.0/9.2 sites appears to be temperature. Further, when temperature abates from the very high levels, catch per effort improves at both LUK 9.0/9.2 and K001 (Fig. 4.1).

4.4.3 Temperature Patterns Associated With Fish Sampling

As discussed in Sect. 2, instream temperature monitors provided data on the existing temperature patterns when fish sampling was conducted. The temperature patterns were examined for the week prior to sampling (mean and maximum values), the 4 weeks prior to sampling (mean monthly), and the date of sampling (mean daily). These values are provide in Appendix C, associated with the sampling data in Tables C.1 through C.13. The impact of the temperature would be most severe if the levels were high enough to cause mortality, or to cause the fish to avoid that section of the stream. Below these high levels, a slight temperature

Table 4.4. Species composition, number of specimens, and catch per unit effort [a] of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek, November 1993 to 1995

Species[b]	Sites[c]			
	LUK 9.0/9.2	BBK 9.4	K001	BBK 10.4
Clupeidae				
Gizzard shad (*Dorosoma cepedianum*)	–	6	1	1
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	2	9	9	6
Grass carp (*Ctenopharyngodon idella*)	–	1	–	–
Red shiner (*Cyprinella lutrensis*)	8	3	5	3
Steelcolor shiner (*Cyprinella whipplei*)[d]	–	1	–	–
Common carp (*Cyprinus carpio*)	–	1	2	–
Miss. silvery minnow (*Hybognathus nuchalis*)	–	1	–	–
Ribbon shiner (*Lythrurus fumeus*)[d]	–	2	–	–
Redfin shiner (*Lythrurus umbratilis*)[d]	2	1	1	5
Golden shiner (*Notemigonus crysoleucas*)[d]	4	3	3	3
Suckermouth minnow (*Phenacobius mirabilis*)	1	1	3	–
Bluntnose minnow (*Pimephales notatus*)	7	2	1	6
Creek chub (*Semotilus atromaculatus*)	5	4	5	6
Catostomidae				
White sucker (*Catostomus commersoni*)	–	2	–	2
Creek chubsucker (*Erimyzon oblongus*)	3	3	2	6
Bigmouth buffalo (*Ictiobus cyprinellus*)	–	2	–	1
Black buffalo (*Ictiobus niger*)[d]	–	1	–	–
Spotted sucker (*Minytrema melanops*)	1	3	–	–
Golden redhorse (*Moxostoma erythrurum*)[d]	–	–	–	1
Ictaluridae				
Black bullhead (*Ameiurus melas*)[d]	–	1	–	2
Yellow bullhead (*Ameiurus natalis*)	7	8	7	6
Aphredoderidae				
Pirate perch (*Aphredoderus sayanus*)	–	–	–	1
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	9	9	9	6
Poeciliidae				
Western mosquitofish (*Gambusia affinis*)	7	3	–	4

Table 4.4 (continued)

Species[b]	Sites[c]			
	LUK 9.0/9.2	BBK 9.4	K001	BBK 10.4
Centrarchidae				
Flier (*Centrarchus macropterus*)	–	1	–	1
Green sunfish (*Lepomis cyanellus*)	8	9	9	6
Warmouth (*Lepomis gulosus*)	4	–	–	1
Orangespotted sunfish (*Lepomis humilis*)[d]	–	1	–	–
Bluegill (*Lepomis macrochirus*)	6	9	8	6
Longear sunfish (*Lepomis megalotis*)	9	9	9	6
Redear sunfish (*Lepomis microlophus*)	–	–	–	2
Hybrid sunfish (*Lepomis*)	–	6	4	3
Spotted bass (*Micropterus punctulatus*)	2	6	2	3
Largemouth bass (*Micropterus salmoides*)	1	2	1	4
White crappie (*Pomoxis annualaris*)	–	–	–	2
Percidae				
Slough darter (*Etheostoma gracile*)	3	–	1	–
TOTAL SPECIES	19	29	18	25
MEANS:				
SPECIMENS	277	540	182	1136
SPECIES	9.7	12.1	8.8	15
CATCH/UNIT EFFORT[a]	10.28	8.83	6.85	10.78

[a]Catch per unit effort is number of fish per minute of electrofishing.

[b]Species identifications were performed in the field and/or confirmed in the laboratory on preserved specimens collected during the surveys. Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, please see Sect. 7 of this document.

[c]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer.

[d]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

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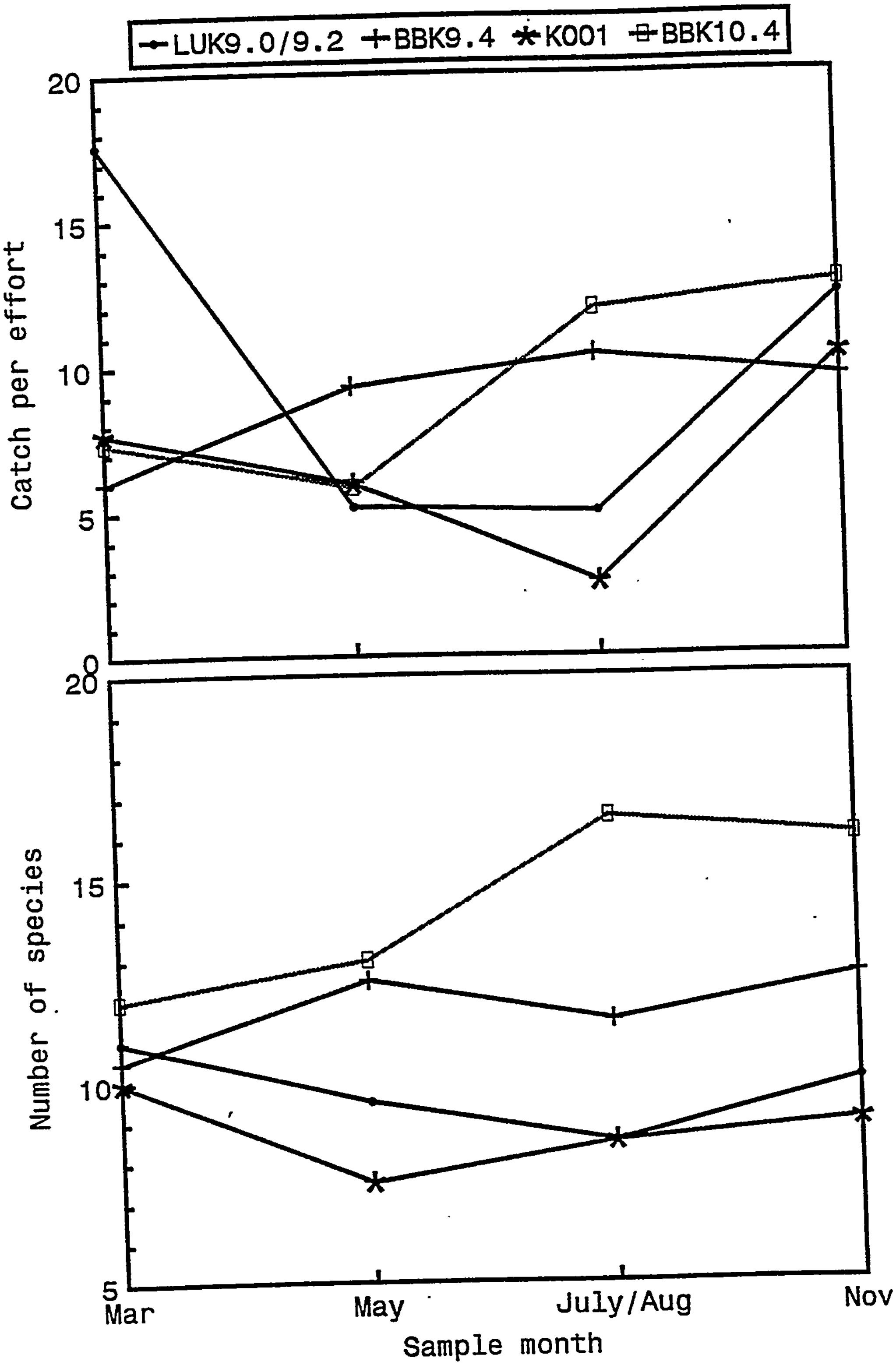

Fig. 4.1. Catch per unit effort (min) and number of species in qualitative samples of Big Bayou Creek (BBK), Little Bayou Creek (LUK), and Outfall 001 (K001), November 1993 through November 1995.

increase could have more subtle impacts, such as reduced reproductive effectiveness.

Temperature data associated with the quantitative sampling indicated that fish communities at BBK 9.1 and BBK 10.0 were, in general, exposed to warmer water than the comparable reference stream, MAK 13.8 (Tables C.1 through C.4). In September samples, these sites had temperatures consistently 3 to 5°C higher than at the reference site. The pattern was similar in March sampling, only with a smaller temperature difference. A similar pattern was seen between LUK 7.2 and the BBK 12.5 reference; temperatures at LUK 7.2 were 2 to 3°C warmer than at BBK 12.5. For the qualitative samples, the temperature data indicate that the BBK 10.4 site was the coolest location, as might be expected because most of the major outfalls from the plant (Fig. 2.2) occur downstream of this location (Tables C.5 to C.13). Temperatures at BBK 9.4, LUK 9.0/9.2, and K001 were generally 2 to 4°C warmer than those at BBK 10.4. The temperatures at LUK 9.0/9.2 were usually higher than those at BBK 9.4, and were at least equal to those found in K001. This suggests that the Little Bayou Creek site received a greater thermal impact from the outfall discharge than did Big Bayou Creek, at least at the sampled locations, perhaps due to the much lower flow in Little Bayou Creek. However, other outfalls to Big Bayou Creek contributed to the thermal load (see Sect. 2); thus, the overall impact on the creek may be greater than indicated by data just from the fish sampling locales.

In addition to the relative comparison of temperature between sites, the absolute values were compared for sampling dates at the sampling locations. The quantitative sites on lower Big Bayou Creek had maximum temperatures in fall sampling in the 28 to 29°C range, while the site on Little Bayou Creek only reached the 26°C range. Examination of temperature records for July 1993 through November 1995 at the quantitative sites found few days with temperatures in excess of 34°C; BBK 9.1 had 9 days with maximum temperatures reaching 34°C, and BBK 10.0 had 3 such days.

Temperature maximums during qualitative sampling periods reached higher levels and were elevated more frequently. At LUK 9.0/9.2, maximum temperatures during the May and August qualitative sampling dates ranged from 25 to 34°C, while the BBK 9.4 site had a range of 24 to 34°C. An examination of all maximum temperatures at the various sampling sites indicated that BBK 9.4 had 9, 1, and 2 days with maximums of 34, 35, and 36°C temperatures, respectively. For LUK 9.0/9.2, the number of days with maximums exceeding 34, 35, and 36°C were 21, 9, and 4, respectively. Again, as discussed in Sect. 2., even higher maximums were seen in the outfalls during these sampling periods, so the impact on other fish communities in Little Bayou and Big Bayou creeks may be greater than indicated by this limited data set. The number of maximum temperatures in a day over three summers of monitoring at Outfall K001 included 23, 19, 10, 12, and 5 days at 34 through 38°C, respectively. In two summers, Outfall K006 had 9, 9, and 5 days with maximums of 34, 35, and 36°C, respectively, while K008 had only 4 days with maximums of 34°C. In three summers, Outfalls K010/K011 had 44, 28, 24, 10, and 2 days with maximums in excess of 34 through 38°C, respectively.

4.4.4 Literature Analysis of Temperature Effects on Fish

In assessing the impacts of the temperature regime associated with Outfalls K001 and K010/011, published literature was reviewed to compare with the collected field distribution data. Temperatures that are lethal to fish, that fish choose to avoid, or that fish prefer (Coutant 1972, Hutchison

1976) were only available for a subset of the species occurring in the Big Bayou Creek watershed. The emphasis was placed on laboratory determinations of the temperatures, but some field data were also included.

The temperatures that prove lethal to fish species can be determined using a variety of techniques; most frequently determined are the upper lethal temperature (temperature at which 50% of test animals die) or the critical thermal maximum, CTM, (temperature at which 50% of test animals lose equilibrium) (Hutchison 1976, Hokanson 1977). These values provide an indication of when physiological processes in the fish are affected enough to produce significant mortality. The determinations of these levels are usually preceded by some degree of acclimation, and the upper lethal or CTM value is directly related to this acclimation temperature (Hutchison 1976, Murphy et al. 1976). Generally, the higher the acclimation temperature the higher the lethal or CTM temperature up to a maximum level (Becker and Genoway 1979, Armour 1991). Table 4.5 contains a compilation of lethal temperature data for fish species in the PGDP area.

Temperatures avoided or preferred by fish are also directly dependent on acclimation temperature. Generally, these values are determined in the laboratory by using test apparatus that provide a gradient of temperatures and monitoring the amount of time fish spend in each temperature area (e.g., Reynolds and Casterlein 1976). Field observations also can be used to determine these values, particularly data generated from collection activities associated with heated effluents from power plant operations (see reviews by Coutant 1968–1980). Table 4.6 contains preference and avoidance temperature data for fish species in the PGDP area.

The published values indicate that temperatures of 30.3°C to 38.1°C can be lethal for the species occurring in Big Bayou and Little Bayou creeks, even with acclimation to temperatures of 20–26°C (Table 4.5). Temperatures at these levels have been recorded in the outfall-associated sections of the streams, although not for extended periods (Sect. 2.). Avoidance temperatures are only slightly lower than the lethality or CTM temperatures (Table 4.6), which suggests most species could persist in heated areas of the creeks, perhaps migrating to cooler waters only infrequently. The occupation by fish of heated effluents virtually right up to the lethal temperatures has been reported for warmwater species (Lowe and Heath 1969, Reynolds and Thomson 1974, Reynolds and Casterlein 1976, Cech et al. 1990). An additional factor to consider is the limited amount of temperature data for most species occurring in the affected streams; CTM or upper lethal temperatures were found for only 18 of the 35 species collected during this study. Many of the species without temperature data included fish that are generally sensitive to stressors, and might be more susceptible to high temperatures, such as the ribbon shiner (*Lythrurus fumeus*), spotted sucker (*Minytrema melanops*), or various darter species. The lack of these data can make some of the conclusions less certain. Even for the species that have published lethality, CTM, or avoidance temperatures, necessary additional data on the impacts of high temperatures on processes such as reproduction, growth, or health of the species are missing (Armour 1991). Temperatures that might affect these processes would likely be intermediate between the preference and lethal temperatures, a range that for most of the fish in the Big Bayou watershed would include a considerable portion of the summer temperature profiles.

A large database evaluation of the relationship between temperature and fish distributions has been conducted for several years following the lead of Biesinger et al. (1979). This "Fish and Temperature

Table 4.5. Critical thermal maximum (CTM) and upper lethal temperature information on fish species occurring in Big Bayou Creek and Little Bayou Creek

Species[a]	Acclim. Temp. (°C)	CTM (°C)	Upper Lethal (°C)	Reference
Clupeidae				
Gizzard shad (*Dorosoma cepedianum*)	25		34.0–34.5	Hart 1952[b]
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	25		38.1	Roy et al. (Sect. 5)
	26	37.2		Smale and Rabeni 1995a
	20	35.5		Mathews 1987
Red shiner (*Cyprinella lutrensis*)	26	38.1		Smale and Rabeni 1995a
	20	36.4		Mathews 1987
Spotfin shiner (*Cyprinella spiloptera*)	30		36	Cherry et al. 1977
Common carp (*Cyprinus carpio*)	26		35.7	Black 1953[b]
Redfin shiner (*Lythrurus umbratilis*)	25		32.7–37.2	Roy et al. (Sect. 5)
	26	36.2		Smale and Rabeni 1995a
	20	35.5		Mathews 1987
Golden shiner (*Notemigonus crysoleucas*)	26	36.8		Smale and Rabeni 1995a
	25		33.5	Hart 1952[b]
Emerald shiner (*Notropis atherinoides*)	20	34.7		Mathews 1987
	25		30.7	Hart 1947[b]
Sand shiner (*Notropis stramineus*)	26	37.0		Smale and Rabeni 1995a
	20	36.1		Mathews 1987
Bluntnose minnow (*Pimephales notatus*)	26	36.6		Smale and Rabeni 1995a
	25		33.3	Hart 1947[b]
Creek chub (*Semotilus atromaculatus*)	26	35.7		Smale and Rabeni 1995a
	25		30.3	Hart 1947[b]
	25		31.5	Hart 1952[b]
	30		31.5	Hart 1952[b]
Catostomidae				
White sucker (*Catostomus commersoni*)	26	34.9		Smale and Rabeni 1995a
	25		29.3	Hart 1947[b]
Ictaluridae				
Black bullhead (*Ameiurus melas*)	26	38.1		Smale and Rabeni 1995a
Yellow bullhead (*Ameiurus natalis*)	26	37.9		Smale and Rabeni 1995a
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	26	38.8		Smale and Rabeni 1995a
Poeciliidae				
Western mosquitofish (*Gambusia affinis*)	25		37.0	Hart 1952[b]
	30		37.0	Hart 1952[b]

Table 4.5 (continued)

Species[a]	Acclim. Temp. (°C)	CTM (°C)	Upper Lethal (°C)	Reference
Centrarchidae				
Green sunfish (*Lepomis cyanellus*)	26	37.9		Smale and Rabeni 1995a
	20	36.5		Mathews 1987
Orangespotted sunfish (*Lepomis humilis*)	20	37.2		Mathews 1987
Bluegill (*Lepomis macrochirus*)	26	37.9		Smale and Rabeni 1995a
	20	36.8		Mathews 1987
	25		33.0	Hart 1952[b]
	27		36.0	Peterson and Schutsky 1976
	30		33.8	Hart 1952[b]
Longear sunfish (*Lepomis megalotis*)	26	37.8		Smale and Rabeni 1995a
	20	36.5		Mathews 1987
	25		35.6	Neill et al. 1966[c]
	30		36.8	Neill et al. 1966[c]
Largemouth bass (*Micropterus salmoides*)	26	36.3		Smale and Rabeni 1995a
	25		34.5	Hart 1952[b]
	30		36.4	Hart 1952[b]

[a]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For complete references, please refer to Sect. 7 of this document.
[b]As cited in Talmage and Opresko (1981).
[c]As cited in Coutant (1972).

Table 4.6. Preference and avoidance temperatures for fish occurring in Big Bayou and Little Bayou creeks

Species[a]	Preference Temp (°C)	Avoidance Temp (°C)	Reference
Clupeidae			
Gizzard shad (*Dorosoma cepedianum*)	19.0–20.5		Reutter and Herndendorf 1976[b]
		30	Gammon 1973[c]
Cyprinidae			
Stoneroller (*Campostoma anomalum*)	24[d]		Mathews 1987
	25.3–28.6[e]	29–33[d]	Cherry et al. 1975
Red shiner (*Cyprinella lutrensis*)	23.7;18.2[d]		Mathews 1987
	21.8–25.1		Mathews and Hill 1979
Spotfin shiner (*Cyprinella spiloptera*)	27.3–30.6[e]	30–33	Cherry et al. 1975
Common carp (*Cyprinus carpio*)	31.8	33.5	Neill and Magnuson 1974
		34.5	Gammon 1973[c]
		35	Pitt et al. 1956[c]

Table 4.6 (continued)

Species[a]	Preference Temp (°C)	Avoidance Temp (°C)	Reference
Redfin shiner (*Lythrurus umbratilis*)	13.2[d]		Mathews 1987
Golden shiner (*Notemigonus crysoleucas*)	27–28		Ecological Analysts, Inc. 1978[b]
Bluntnose minnow (*Pimephales notatus*)	26.6–28.9[e]	30–31	Cherry et al. 1975
Catostomidae			
White sucker (*Catostomus commersoni*)	22.8–26.1		Reynolds and Casterlein 1978a[b]
Buffalo species (*Ictibous sp.*)		34.5	Gammon 1973[c]
Poecillidae			
Western mosquitofish (*Gambusia affinis*)	27	29.5–35	Bacon et al. 1967[c]
Ictaluridae			
Yellow bullhead (*Ameiurus natalis*)	27.6		Reynolds and Casterlein 1978b[b]
	28.3		Reutter and Herndendorf 1976[b]
Centrarchidae			
Green sunfish (*Lepomis cyanellus*)	30.4–30.7[e]	33	Cherry et al. 1975
Orangespotted sunfish (*Lepomis humilis*)	21[d]		Mathews 1987
Bluegill (*Lepomis macrochirus*)	30.7	33.5	Peterson and Schutsky 1976
	31.1–32.3		Reynolds and Casterlein 1976
	31.8	33.4	Beitinger 1976
	31.2–31.4[e]	33–34	Cherry et al. 1975
Longear sunfish (*Lepomis megalotis*)	20.8[d]		Mathews 1987
Spotted bass (*Micropterus punctulatus*)	32.2–31.4[e]	33–34	Cherry et al. 1975
Largemouth bass (*Micropterus salmoides*)	26.7–30.0		Reynolds and Casterlein 1976
White crappie (*Pomoxis annualaris*)	10.4–19.8		Reutter and Herndendorf 1976[b]

[a]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For complete references, please refer to Sect. 7 of this document.
[b]As cited in Talmage and Opresko (1981).
[c]As cited in Coutant (1977).
[d]Mean temperature in a preference gradient including 83% of recorded fish positions.
[e]Values were measured after acclimation to temperatures of 24 and 27°C, respectively.

Database Matching System" continues to gather data on field distributions and measured temperature and provides the 95th percentile temperature for many species (Eaton et al. 1995). This temperature is an estimate of the upper tolerance limit based on field observations. For fish occurring in the PGDP area (Burr and Warren 1986), the published values include (Eaton et al. 1995): 27.3°C for white sucker (*Catostomus commersoni*), 30.8°C for golden shiner (*Notemigonus crysoleucas*), 31.3°C for white crappie (*Pomoxis annularis*), 31.4°C for common carp (*Cyprinus carpio*), 31.5°C for gizzard shad (*Dorosoma cepedianum*), 31.7°C for bluegill, 31.7°C for green sunfish, and 31.7°C for largemouth bass (*Micropterus salmoides*).

Published temperature data for the core species assemblage at the quantitative sites

Published temperature data for the core species assemblage at the quantitative sites (Sect. 4.4.1) suggests that temperatures in excess of 36°C (at acclimation of 26°C) would be needed to produce the initial loss of equilibrium as seen in the CTM evaluations. The comparable avoidance and preference temperatures for this group of species would be 31–34°C and 27–32°C, respectively. The narrow range of values spanning preference temperatures to CTM temperatures indicates that these species can adapt fairly well to elevated temperatures and would be expected to occur regularly in the sampling areas of Big Bayou and Little Bayou creeks. Published temperature data for the core species assemblage at the qualitative sites (Sect. 4.4.2) suggests that temperatures in excess of 37°C (at acclimation of 26°C) would be needed to produce the initial loss of equilibrium as seen in the CTM evaluations. The species encountered less frequently in the sampling (e.g., golden shiner, white sucker, and black bullhead *Ameiurus melas*) had CTM temperatures of 34.9 to 38.1°C, with preference temperatures of 25–30°C. The lower frequency of these species at the sampling sites may be due in some cases to greater sensitivity to high temperatures, but could be equally influenced by considerations of outfall chemistry, habitat suitability, or food availability.

Specifically, there are some fish that belong to families that are usually restricted to cooler waters (e.g, the darters) or have lower measured CTM temperatures (Table 4.5); the collection data indicate there are distribution patterns for these species that may be based on avoidance to high temperatures. The redfin shiner has a published CTM of 35.5; they were collected only rarely at the four qualitative sites and in only one summer sample at BBK 10.4 (Tables C.4 to C.13). The white sucker has a published CTM of 34.9; they were collected only four times and only at the BBK 9.4 or BBK 10.4 sites. The creek chub has a published CTM of 35.7°C; it was found frequently at the four qualitative sites, but in only half of the summer sample periods. The sand shiner (*Notropis stramineus,* CTM = 36.1–37.0°C), the spotfin shiner (*Cyprinella spiloptera,* lethal temp = 36°C), and the emerald shiner (*Notropis atherinoides,* CTM = 34.47°C) were not taken in qualitative samples near PGDP, but have been collected in previous qualitative sampling of lower Little Bayou Creek (Ryon 1994a, 1994e, 1995). The slough darter (*Etheostoma gracile*), ribbon shiner, steelcolor shiner (*Cyprinella whipplei*), Mississippi silvery minnow (*Hybognathus nuchalis*), and spotted sucker were collected infrequently in qualitative samples, and never in summer samples. Other fish species that were not collected in qualitative sampling, but have been collected in reference streams near the PGDP or in lower reaches of Big Bayou and Little Bayou creeks beyond the immediate impact area of the PGDP, included the blackside darter (*Percina maculata*), mud darter (*Etheostoma asprigene*), bluntnose darter (*Etheostoma chlorosomum*), tadpole madtom (*Noturus gyrinus*), and river shiner (*Notropis blennius*). Because measured responses to high temperatures are not published for these last groups of species, the periods of elevated temperatures associated with the PGDP outfalls cannot be eliminated as a cause for their absence from the streams in the vicinity of the PGDP.

The use of CTM or lethal temperature data to evaluate impacts does not directly address potentially substantial impacts on fish populations that can occur at lower temperatures. Effects on growth, reproductive success, or health status of individual specimens (e.g., parasitism rate) can occur at less than maximum levels or can occur in seasons other than summer when temperature maximums occur. The U.S. Environmental Protection Agency (EPA) recognized these concerns and suggested the use of formulas to predict or calculate possible temperature levels that would be protective of non-lethal effects such as reduced growth (Coutant 1972). In general, these allow temperature limits to be supported based on the knowledge of lethal temperature and optimum temperatures. By applying equation 1, a temperature is derived for a maximum sustained weekly temperature which should avoid significant effects on fish growth, reproduction, or health (Coutant 1972, Armour 1991).

$$\text{maximum sustained temperature} = \text{optimum temperature} + \frac{\text{ultimate incipient lethal temperature} - \text{optimum temperature}}{3} \quad [1]$$

Some of these calculated maximum sustained temperatures reported for fish in the PGDP area were 25.9°C for bluegill, 27.8°C for white sucker, 28.2°C for emerald shiner, and 30.5°C for largemouth bass (Coutant 1972). These values for adults would apply only to temperatures beyond the mixing zone that occur for periods of a week or longer and would be most appropriately applied to fish populations monitored at the quantitative sample sites. Based on these criteria, existing temperature regimes exceed the calculated values for at least some of these species and may be, in part, responsible for the observed distribution patterns.

4.5 DISCUSSION

The use of field survey data to analyze the impacts of elevated temperatures on fish communities has many limitations. Many heated effluents contain other contaminants or stressors that can have as equal an effect on fish distributions as temperature (Yoder and Gammon 1976, Teppen and Gammon 1976). Comparisons of fish distributions above and below heated effluents are also compounded by complexities of stream habitat (Teppen and Gammon 1976, Baltz et al. 1987), seasonal movements (Hutchison 1976, Yoder and Gammon 1976), feeding forays (Neill and Magnuson 1974, Cherry et al. 1977), and behavioral adjustments.

Individual fish species can show extreme limitations in temperature selection with more variability tied to age or size class of individuals (Coutant 1985). Field data can be enhanced by comparison with appropriate laboratory determinations of tolerances, but such data are not usually comprehensive for an entire roster of species in a fish community. Smale and Rabeni conducted a laboratory (1995a) and field study (1995b) to determine the correlation between measured physical tolerances and observed field distributions under natural conditions. From their field study they generated critical temperature maximums for 34 species. However, the companion field study observed 51 species in the headwater streams they surveyed, requiring them to make some assumptions regarding the temperature sensitivities of these additional 17 species. They concluded that laboratory tests under the necessary limited conditions (e.g., acclimation to one temperature) provided at best a range of relative tolerances (Smale and Rabeni 1995a) rather than absolute temperature maximums for each species. Further, under the limited observed field temperature maximums (~29°C), a positive correlation between laboratory maximums and field distributions was not observed. A similar conclusion was also reached by Mathews (1987) regarding the association of laboratory derived thermal maximums and natural temperature variations in thermally "harsh" environments. Whether the same conclusions would have been reached by Smale and Rabeni or Mathews under thermally enriched field conditions is unclear. Given these complicating factors, a general correspondence of fish distribution trends with the observed temperature regimes may only suggest a possible influence of temperature.

4.5.1 Big Bayou Creek

The quantitative samples collected in Big Bayou Creek indicate that fewer species are found in areas downstream of Outfalls K001, K006, and K008 than in a comparable reference stream or a reference site on the same stream. The species missing from Big Bayou Creek include species classified as less tolerant to degraded environmental conditions (Karr et al. 1986; Ohio EPA 1988). Also, more of the species occurring at the Big Bayou Creek sites can be classified as tolerant to such conditions than those at reference sites (Ryon, 1994a, 1994e, 1995). At a community level, the fish densities do not reflect a substantial difference between the Big Bayou Creek and reference sites. However, the densities at BBK 9.1 and BBK 10.0 include more specimens of tolerant species than occur in the reference stream. These patterns correlate with higher mean temperatures at the quantitative Big Bayou Creek sites than at the Massac Creek reference. Literature values for upper lethal and CTM temperatures from laboratory studies indicate that the temperatures occurring at BBK 9.1 and BBK 10.0 should not be lethal to the majority of fish in the core species assemblage. The absence of the more sensitive species from these communities may be influenced by these slightly higher temperatures, but there are few laboratory data for these species. Data on preference temperatures or calculated maximum sustainable temperatures also support a minimal impact of temperature for the most common fish species at these sites.

The qualitative samples at BBK 9.4 and BBK 10.4 show a similar pattern of minimal impacts from temperatures associated with Outfalls K001, K006, and K008. The species richness and catch per unit effort do not indicate that these sites are receiving substantial impacts beyond the scope of other Big Bayou Creek sites within the influence of the PGDP. The core species assemblage is very similar to that of the quantitative sites; these species have almost the same upper lethal and CTM temperatures. The measured stream temperatures indicate that BBK 9.4, below K001, receives a greater thermal input than at BBK 10.4. The impact at BBK 10.4 appears very minimal, certainly no more than at BBK 10.0 or BBK 9.1. However, the species composition at BBK 9.4 does suggest that some species (e.g., redfin shiners or white suckers) are absent from the site during the warmer months. The absence of such species may indicate that temperatures occasionally increase beyond the preferred range up to levels that prompt seasonal avoidance.

Within the K001 Outfall stream, the impact of elevated temperatures appears to be more substantial, as might be expected. Here the temperature pattern shows quite a few excursions up to levels that represent lethal or CTM temperatures. These patterns are also reflected by the species richness and catch per unit effort data, where the lowest values occur in the summer sampling when temperatures are highest. The impact on the fish species that venture up the K001 stream is magnified by the habitat restrictions in this section; the faster flow rate and narrow channel structure reduce the available backwater habitats that might be used as refuges when temperatures reach critical levels. Although the fish occurring in the K001 Outfall stream are also exposed to higher concentrations of chemicals than fish in Big Bayou Creek proper, the acute impact of these stressors may be less than that of temperature. Effluent toxicity tests of K001 conducted from 1990 through 1995 found only 4 of 33 tests in which the toxicity unit exceeded 1, which would indicate potential instream toxicity to *Pimephales promelas* larvae or *Ceriodaphnia dubia* (Kszos and Sumner 1996).

4.5.2 Little Bayou Creek

The two sampling sites evaluated for temperature effects indicate that some impact is occurring, but only in a limited area. The qualitative site, LUK 9.0/9.2, below the K010/K011 Outfalls shows far greater influence of high temperature than the quantitative site at LUK 7.2.

During 1994 and 1995, the species richness and density data at LUK 7.2 did not differ substantially from the comparable reference site at BBK 12.5. Although there have been some indications of problems in earlier sampling at this site (Ryon 1994a, 1994e), during this 2 year period only minor differences between the species composition at each site were noted. This observation corresponds with the relatively benign temperatures seen at LUK 7.2, which were well below upper lethal and CTM values. The temperature pattern at LUK 7.2 was elevated above that measured at BBK 12.5, but without the high maximum temperatures seen at sites closer to outfall discharges. The frequency of redfin shiner occurrence in samples of LUK 7.2 is an example of how the slight elevation in temperature from comparable reference patterns does not seem to translate to widespread impacts on the fish community.

In contrast, a pattern of impact on fish distribution was observed for the Little Bayou Creek sampling site (LUK 9.0/9.2) below K010/K011. Sampling temperatures at this site were similar to those seen at K001 and were higher than temperatures at other qualitative sites in Big Bayou Creek. The temperatures were 1 to 4°C higher at LUK 9.0/9.2 than at LUK 7.2, although lower than temperatures in the actual outfall. Some of the reported temperatures exceeded upper lethal and CTM values for core assemblage species. Other temperature values reached avoidance levels during some months. The species richness and catch per unit effort corresponded to the variations in temperatures; lower values were observed during summer sampling periods when temperatures were greatest. The occurrence of some species, such as the redfin shiner, was limited to non-summer months at LUK 9.0/9.2. Again, these low values could be associated with the site's proximity to the outfalls and a resulting high exposure to chemical stressors. However, effluent toxicity tests of K010/K011 conducted from 1990 through 1995 found only 3 of 31 tests in which potential instream toxicity was indicated to *Pimephales promelas* larvae or *Ceriodaphnia dubia* (Kszos and Sumner 1996).

5. LABORATORY EVALUATIONS OF THERMAL TOLERANCES

(*W. K. Roy, M. K. McCracken, and R. A. Norman*)

5.1 INTRODUCTION

Four laboratory experiments were performed by personnel from ESD at Paducah Community College (PCC). Experiments were conducted July 26–30, 1995, using seine-collected central stonerollers (*Campostoma anomalum*) and redfin shiners (*Lythrurus umbratilis*). The fish were collected from Massac Creek kilometer ~13.4–13.8 and ~15.9–16.3, Middle Fork Massac Creek kilometer ~3.6–4.0, Black Branch (a tributary to Middle Fork Massac Creek) kilometer ~3.2–3.6, and Big Bayou Creek kilometer ~11.9–12.5, McCracken County, Kentucky (Figs. 1.1 and 1.2). The water temperature at time of collection ranged from 22.7–25.1 °C, and all fish were acclimated a minimum of 24-h at 25 °C prior to testing. A digital temperature recorder, already in place at MAK 13.8, revealed water temperatures at this site on the days of fish collection and the 24-h period preceding the first collection ranged from 22.7–28.3 °C. Likewise, a temperature recorder in place at BBK 12.5 showed that water temperatures ranged from 22.0–25.4 °C on the days of collection and the 24-h period preceding the first collection. It appears likely from these data that the test fish were naturally exposed to temperatures in the range of 22.0–28.3 °C in the 24-h period prior to collection, although the range of temperatures experienced by an individual would be somewhat narrower.

The water in which the thermal tolerance tests were conducted came from Outfall K001 (Fig. 1.1) at the weir and from Massac Creek on the downstream side of the Highway 62 bridge (Fig. 1.2). Temperature monitors were in place adjacent to the outfall water collection site and approximately 150 m upstream of the Massac Creek collection site. Care was taken not to disturb bottom sediments as water was collected in plastic buckets and transferred to 50 L carboys for transport back to PCC. Since most fish were collected from Massac Creek or its tributaries, all fish were acclimated in Massac Creek water regardless of which water type they were exposed to during testing. All water used for acclimating or testing of fish had been collected no more than 48 h prior to use. Upon completion of the experiments, Massac Creek water was disposed of through the laboratory process drains, and outfall water was returned to Outfall K001 for disposal.

5.2 METHODS

5.2.1 Thermal Tolerance Testing Equipment

Laboratory testing was carried out in 7.5 L (22 × 22 × 24 cm) aquaria immersed in three water baths to a depth of approximately 17 cm (Fig. 5.1). Each of the water baths consisted of a fiberglass tank (55 × 55 × 210 cm) containing a digital immersion (heating) circulator (Fisher Scientific model 7305). The circulators distributed process water (drawn from the PCC laboratory) throughout the baths at a rate of 15 L/min. Attached to the pump nozzle of each circulator was a short section of 0.5 in. (12.7 mm) diameter Nalgene tubing, distally connected to a 120 cm length of 0.25 in. (6.4 mm), schedule 80 polyvinyl chloride (PVC) tubing with a solid end cap. Pairs of 3/16 in. (4.8 mm) diameter holes, 180° opposed, had been drilled at 3-in. (7.6 cm) intervals down the length of the PVC tube, with adjacent pairs of holes being offset 90° from each other. This perforated PVC tube (diffuser tube) was elevated approximately 4 cm off the floor of the water bath tank and positioned longitudinally in the center of the

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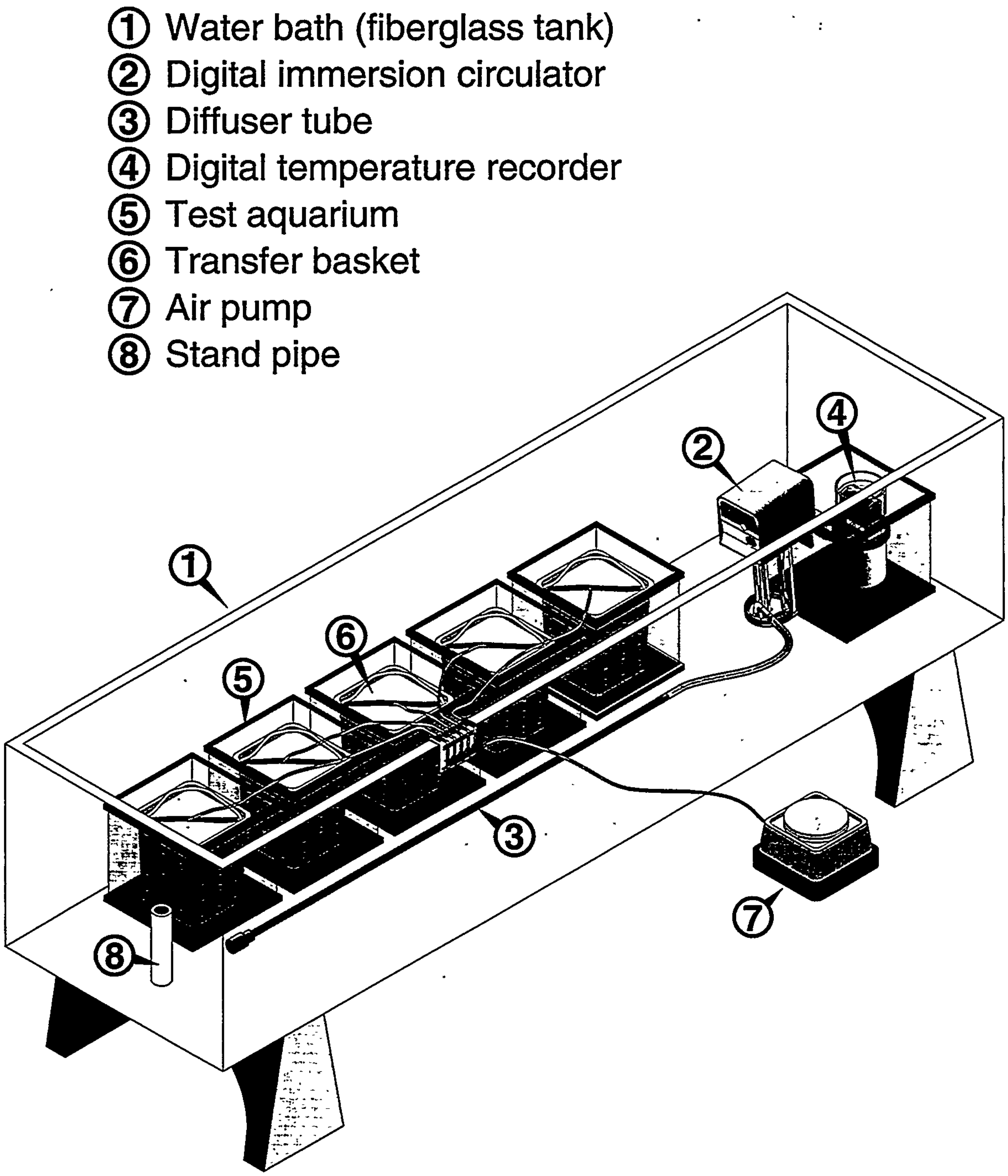

Fig. 5.1. Experimental design of thermal tolerance testing apparatus. Figure shows a water bath with digital immersion circulator and attached diffuser tube, digital temperature recorder, and a partial setup of test aquaria, transfer baskets, and aeration system.

bath. An equal number (either two or five, depending on the experiment) of aquaria were lined up on either side of the PVC tube. Preliminary testing indicated that this arrangement allowed for a more even distribution of heated water throughout the bath than would have been attained with the immersion circulator alone.

Half of the aquaria that were immersed in the water baths contained a plastic Rubbermaid container of 1.3 gal (5 L) capacity. These containers (baskets) served as a mechanism for transferring fish while minimizing stress. Each basket had 48 holes, 0.147 in. (3.7 mm) in diameter, drilled in 4 rows of 12 and spaced 1.5 in. (38.1 mm) apart, with the bottom-most row being 1.0 in. (25.4 mm) from the bottom of the container. Attached to the top of each basket was a plastic-coated wire bail handle, 5/32 in. (4.0 mm) in diameter. All transfer baskets retained the original Rubbermaid canister lid, modified by cutting a diagonal slit to accommodate the basket's handle and an air stone. Even with the lids, one fish from the central stoneroller/Massac Creek (ROL/MAC) test escaped through the slit and became crushed between the side of the aquarium and the basket.

Each aquarium was aerated by a 1 in. (25 mm) cylinder air stone with air supplied by a diaphragm-type, rheostatically controlled air pump. Standard aquarium airline tubing (3/16 in. ID) was fed through the slit in the basket lid. Experiments were conducted under lighted conditions (artificial, plus indirect natural lighting through windows) although light reaching the test aquaria was reduced due to the opaque nature of the basket lids and the sides of the water bath tanks. Lighting during acclimation approximated a 14-h light : 10-h dark regime. No light measurements were taken.

5.2.2 Thermal Tolerance Test Procedures

During the experiment, fish were exposed to a given temperature for 1 h. At the end of each hour, the baskets were raised, draining all but approximately 500 ml of water. The basket, with fish, was then transferred to the other water bath/aquaria setup, which was at 1°C higher temperature for the next hour. During this time, the water bath from which the fish just came (now void of fish) was raised 2°C. When another hour transpired, the baskets were again raised and partially drained, and the fish were returned to their original water bath, which was now 1°C higher than their exposure during the previous hour. This process was repeated until 100% mortality of test fish had been achieved. The goal of this design was to approximate "square-wave" changes in temperature in 1°C increments every hour. Square-wave testing is commonly used in toxicant dosing and provides a readily comparable (Mattice et al. 1981) and easy to interpolate database, which is particularly important in thermal tolerance testing due to the interdependence of time and temperature. To reduce aquarium effects, or the effect of any potential thermal gradation in the water bath, a basket transfer scheme was utilized that minimized the number of times a basket of fish could appear in the same aquarium. As can be seen in Tables D.1 and D.2, a basket would appear in the same aquarium twice only if there were fewer than ten aquaria per water bath.

Three fiberglass tanks (water baths) were used in each experiment. Tanks "A" and "B" were test tanks in which the temperature increased each hour. Tank "C" was the control water bath, with the temperature in this tank remaining at the 25°C start temperature throughout the experiment. At any given time, only the aquaria in the control bath and one of the test baths contained fish. This was due to the fact that the test fish were transferred at the end of each hour to different aquaria in the other water bath. The control bath always contained fish, but at the end of each hour the control fish were transferred to different aquaria within the control bath, so that all fish received the same amount of handling. Although all control fish were in tank "C", the aquaria within this tank were designated "aquaria C" (those that contained fish during odd-numbered test hours) and "aquaria D" (those that contained fish during even-numbered test hours).

The experiments began with fish in ten test aquaria in tank "A" [only four in the redfin shiner/Massac Creek (RED/MAC) test] and four control aquaria in tank "C". At the onset of a test, fish were evenly distributed from the acclimation/holding tank into the aquaria, without regard to size or general appearance, until the appropriate number of fish had been distributed. There were ten fish per aquarium in the redfin shiner/Outfall K001 (RED/001) and the ROL/MAC experiments. Due to limitations in collecting, only five fish per aquarium were used in the RED/MAC and central stoneroller/Outfall K001 (ROL/001) experiments. Because handling of fish was kept to an absolute minimum prior to testing, several non-target species were inadvertently included in the RED/001 and the ROL/MAC experiments. There were 9 such fish (out of 140) in the RED/001 test and 2 (out of 140) in the ROL/MAC test. The disposition of the non-target fish was ignored in determining all results; however, it is interesting to note that the last seven surviving fish in the RED/001 experiment were non-target species [central stoneroller and bluntnose minnow (*Pimephales notatus*)]. These results are consistent with the findings of Smale and Rabeni (1995a), at least in terms of relative order with respect to time to death (TTD). Their study of the hyperthermia tolerances of 34 species of fish, using a 2°C/h heating rate, showed that redfin shiners have a lower critical temperature than either bluntnose minnows or central stonerollers.

As mortalities occurred during the experiments, dead fish were removed with a 2 in. (5.1 cm) nylon aquarium dipnet. Upon removal, total length was measured to the nearest 0.1 cm using a fish measuring board and wet weight was measured to the nearest 0.01 g using an Ohaus 300 top-loading balance. These data were recorded on data sheets that also contained the time of death, basket number, and the number of the aquarium in which the fish expired. Because a fish remains in the same basket throughout the test, but the basket is moved to a different aquarium each hour, it would be possible for all mortality to occur within the same aquarium due to varying TTD. The range of mortality by aquaria for all four experiments combined was 0 to 10 deaths/aquarium, but lacks significance due to basket rotation schedules (Tables D.1 and D.2) and the fact that little mortality is to be expected until fish begin to approach their thermal maximum (Coutant 1970).

5.2.3 Temperature Control

The water baths worked exceptionally well for maintaining a constant temperature. In fact, the range of minimum and maximum temperatures logged by the automated data recorder in the control bath varied by less than 0.5°C for all four tests combined (Tables D.4–D.7). The test baths, however, required nearly constant attention to ensure that target temperatures were achieved, but not exceeded, prior to the upcoming basket rotation. It was customary to replenish some of the bath with hot process water immediately after the baskets (and fish) had been rotated to the other water bath. At the higher test temperatures, bath water (in the tank devoid of fish) was raised slightly above the target temperature immediately after the baskets were rotated, and then brought back down to the target temperature shortly before the fish were reintroduced. This process helped to minimize any effect of lag in temperature between the bath and the aquaria (test) water. To prevent heat loss to the air, pieces of 3/4 in. (19 mm) thick Styrofoam sheets were floated on the surface of exposed portions of the water bath. Tables D.4–D.7 contain the mean, range, and standard deviation of temperatures recorded by the automated temperature recorders.

A non-test (minus basket, fish, and air stone) aquarium containing an RTM digital temperature recorder (Ryan Instruments) was set up in each water bath (Fig. 5.1). These recorders were programmed to log temperatures at 2-min intervals, and should approximate the actual test temperatures experienced by the fish. Additionally, temperature was measured twice per hour in each aquarium with a digital NIST (National Institute of Standards and Technology)-traceable thermocouple thermometer (Digi-Sense model no. 8528-10 JTEK) and a fast response type-T probe. This thermometer was also used to measure water temperature twice per hour in the non-test aquaria that contained the temperature recorders. The mean of the 30 temperature readings logged each hour by the RTM recorder was adjusted based on the difference in readings taken with the digital thermometer (Tables D.4–D.7).

Achieving and maintaining proper water bath temperature was facilitated by the light-emitting diode (LED) readouts on the digital immersion circulators. These readouts displayed temperature to 0.1 °C, have an accuracy of ±0.05 °C, and were periodically checked against the digital thermometer readings.

5.2.4 Water Chemistry Measurements

Water chemistry measurements including pH, dissolved oxygen (DO), and ammonia concentrations were taken as part of the laboratory thermal tolerance tests. These measurements were taken on an hourly/bi-hourly basis for each aquaria during all laboratory tests for the purpose of determining whether factors other than temperature were responsible for fish mortality. The pH values were read on an hourly basis according to EPA method 150.1 (EPA 1979) with an Orion model 520A pH Meter. The meter was calibrated daily with pH 4.0 and pH 10.0 buffers. DO concentrations were measured twice per hour with a YSI model 51B Oxygen Meter per EPA method 360.1 (EPA 1979). The meter was calibrated daily according to manufacturers instructions. Ammonia concentrations were determined by a colorimetric method adopted from Verdouw et al. (1978) using a Milton Roy Spectronic 401 Spectrophotometer.

Means were calculated for pH and DO content on an aquarium-wide basis and on an hourly basis across all aquaria. The data were complied and analyzed using a Lotus computer spreadsheet (Lotus 1991). Total ammonia was calculated for all tests from a grab sample collected during odd numbered test hours from an aquarium in each of water baths A and C. Comparisons of pH and DO were done using General Linear Models (GLM) procedure (SAS 1988b), since some of the comparisons were made from unequal data sets. Water chemistry data for GLM comparisons were analyzed with SAS software and procedures (SAS 1988a, 1988b). GLM was used to compare among aquaria, the interaction between aquaria and time, and the effects of time on each experiment with respect to pH and DO concentrations. A lower limit R^2 value of 0.25 was used as the cutoff value for determining whether the GLM models accounted for a significant portion of the variation in pH and DO concentrations (Yoccoz 1991). When comparisons did not exceed the cutoff value, it was not considered practical to look further into the model. Tukey's studentized range test (SAS 1988b) at an alpha level of 0.05 was used to compare mean pH and DO concentrations between aquaria.

Chemical characterization of water from the two field collection sites (MAK 13.8 and Outfall K001) was also performed. Turbidity and total residual chlorine (TRC) measurements were taken on the collection water at the time of collection for use in the laboratory studies. Other measurements including pH, conductivity, alkalinity, hardness, and DO are reported in Kszos and Sumner (1996) for periods before (May 1995) and after (August 1995) thermal tolerance testing was conducted.

5.3 WATER CHEMISTRY RESULTS AND DISCUSSION

(B. A. Carrico, R. P. Hoffmeister, and W. K. Roy)

5.3.1 Field Sites

The turbidity of MAK 13.8 water used in the Massac water experiments was 11 NTU; K001 water used in the outfall water experiments was 8 NTU. These measurments were made with an HF Instruments model DRT 15 turbidity meter. No TRC could be detected by amperometric titration (EPA 1979) in samples of either water. Because of other ongoing BMP monitoring, additional water chemistry data which brackets the thermal tolerance test dates are available for these two sites (Kszos and Sumner 1996). Grab samples taken for seven consecutive days beginning May 10, 1995, and again on August 9, 1995, at MAK 13.8 show no detectable TRC. Likewise, TRC was undetectable in 24-h composite samples taken for seven consecutive days (same dates) from Outfall K001.

Other water chemistry parameters such as pH, conductivity, alkalinity, hardness, and DO were measured at MAK 13.8 and Outfall K001 during the 7-day period beginning on these two dates. The mean of the pH values over the 7-day period in May at Outfall K001 was nearly two units more basic than at the MAK 13.8 reference site (9.13 and 7.23, respectively). The conductivity, on average, for the same week was ten times greater at the outfall than at the reference site (1315 μS/cm and 136 μS/cm, respectively). The mean hardness value at Outfall K001 was 336 mg/L as $CaCO_3$, while that at MAK13.8 was 53 mg/L as $CaCO_3$, over a six-fold difference. There was little difference in mean alkalinity and DO values between the two sites during the May sampling week. Mean alkalinity at Outfall K001 was 38 mg/L as $CaCO_3$ and at MAK 13.8 was 33 mg/L as $CaCO_3$ (Kszos and Sumner 1996). Mean DO at the outfall was 8.5 mg/L and at the reference site was 8.3 mg/L.

Of the five water chemistry parameters examined, all but alkalinity were greater at Outfall K001 than at MAK 13.8 during the sampling week of August 9, 1995. Mean alkalinity was slightly higher at the reference site compared to Outfall K001 (37 mg/L as $CaCO_3$ and 31 mg/L as $CaCO_3$, respectively). The mean pH value was 8.54 at the Outfall and 7.42 at MAK 13.8. Outfall K001 had conductivity measurements more than five times greater, on average, than MAK 13.8 (754 μS/cm vs. 132 μS/cm). Mean hardness was nearly four times greater at the outfall (185 mg/L as $CaCO_3$) than at MAK13.8 (48 mg/L as $CaCO_3$) (Kszos and Sumner 1996). Mean DO was 8.3 mg/L at the outfall and 7.4 mg/L at MAK 13.8.

5.3.2 Laboratory Studies

5.3.2.1 Redfin shiner/Outfall K001 experiment

The test using redfin shiners in Outfall K001 water showed no appreciable difference in hourly mean pH levels over time (Table D.9). These values ranged from 7.84 to 8.06 in aquaria A, 7.86 to 8.07 in aquaria B, 7.44 to 7.99 in aquaria C, and 7.45 to 8.03 for aquaria D. Fluctuations in hourly mean pH showed no consistent pattern. The individual aquarium mean pH values also differed little over the life of the test. The GLM procedure used to compare pH values revealed significant differences with respect to time only (Table 5.1).

There was a slight tendency for hourly mean DO concentrations in this experiment to decrease over time in all aquaria. Hourly means in aquaria A ranged from 6.0 to 7.5 mg/L, while those in aquaria B ranged from 5.7 to 7.2 mg/L. The control aquaria C had hourly means ranging from 6.7 to 7.5 mg/L. Aquaria D ranged from 6.8 to 7.6 mg/L. The individual aquarium mean DO values differed only slightly over the course of the test. The GLM procedure revealed highly significant differences in DO concentrations among aquaria and over time ($p < 0.01$). There were no significant differences detected in a comparison of the interaction between aquaria and time ($p = 0.99$). The GLM procedure produced an R^2 value of 0.60 (Table 5.1), indicating that most of the variation in DO content was accounted for by the model. Tukey's test (SAS 1988b) revealed that the differences in mean DO concentration were due to aquarium 9 (concentrations were significantly lower than in aquariums 2 and 3) and aquarium 10 (concentrations were significantly lower in this aquarium than in aquariums 1, 2, 3, and 4). Ammonia concentrations in the test aquarium A (grab samples from the same aquarium throughout the experiment) ranged from 0.079 to 0.164 mg N/L and in the control aquarium C from 0.092 to 0.164 mg N/L (Table D.9).

5.3.2.2 Central stoneroller/Outfall K001 experiment

The test using central stonerollers in Outfall K001 water resulted in no significant hourly mean pH value differences in any of the experimental aquaria (Table D.9). Hourly means in test aquaria A ranged from 7.71–7.87 and in aquaria B from 7.79–8.03. The control aquaria C had means ranging from 7.73–7.85 while aquaria D ranged from 7.80–8.35. The individual mean values again fluctuated slightly over time. The individual aquarium mean pH values did not differ appreciably. Comparison of pH values with the GLM procedure revealed no significant differences in comparisons among aquaria, or the in interaction between aquaria and time (Table 5.1).

The hourly mean DO concentrations also fluctuated over time. Test aquaria A and B ranged from 6.1–6.5 mg/L and 5.9–6.6 mg/L, respectively. The control aquaria C and D ranged from 6.3–6.8 mg/L and 6.3–7.1 mg/L, respectively. A comparison of DO concentrations among aquaria, and the interaction of aquaria and time were shown to be non-significant (Table 5.1). Ammonia concentrations in the test aquarium A ranged from 0–0.133 mg N/L and in the control aquarium C from 0.007–0.141 mg N/L (Table D.9).

5.3.2.3 Redfin shiner/Massac Creek experiment

Data resulting from the experiment using redfin shiners in Massac Creek water are shown in Table D.8. Hourly mean pH values in all four aquaria show a slight increase over time. The range in aquaria A is 7.80–7.99 and in aquaria B the range is 7.83–8.02. The control aquaria had ranges from 7.89 to 7.99 and 7.98 to 8.06 for aquaria C and D, respectively. The individual aquarium mean pH values for both test aquaria A and B showed a pattern of becoming more basic with an increase in basket number designation. The basket means in the control aquaria remained relatively unchanged. The GLM procedure used to compare pH values revealed no significant differences in any of the parameters included in the model (Table 5.1).

Table 5.1. Results of general linear model on pH and dissolved oxygen (DO)

Experiment	Parameter	Aquarium (*p* value)[a]	Time (*p* value)	Aquarium *Time (*p* value)	$R^{2(b)}$
RED/001[c]	pH	1.00	<0.01*	1.00	0.43
	DO	<0.01*	<0.01*	0.99	0.60
ROL/001[d]	pH	0.04	<0.01*	0.04	0.79
	DO	0.04	<0.01*	0.04	0.43
RED/MAC[e]	pH	0.91	0.14	0.91	0.50
	DO	<0.01*	<0.01*	<0.01*	0.51
ROL/MAC[f]	pH	1.00	0.05	1.00	0.51
	DO	0.03	<0.01*	0.03	0.44

[a]*p* value = probability value
[b]R^2 = proportion of variation explained by parameters included in model
[c]RED/001 = redfin shiner/Outfall K001 experiment
[d]ROL/001 = central stoneroller/Outfall K001 experiment
[e]RED/MAC = redfin shiner/Massac Creek experiment
[f]ROL/MAC = central stoneroller/Massac Creek experiment
* Indicates significant differences.

The hourly mean concentrations for DO showed a decreasing trend over time in the test aquaria A and B. Their ranges were 6.0–6.8 mg/L for aquaria A and 5.5–6.6 mg/L for aquaria B. Control aquaria C and D had fluctuating hourly mean concentrations ranging from 6.0 to 6.7 mg/L in aquaria C and from 6.3 to 7.2 mg/L in aquaria D. There were slight fluctuations in the four individual aquarium mean DO concentrations. A comparison of DO concentrations among aquaria, over time, and the interaction between aquaria and time, revealed highly significant differences (Table 5.1). The GLM procedure produced an R^2 value of 0.51, indicating that the model accounted for a substantial portion of the variation in DO content. Tukey's test revealed that the differences in mean DO concentrations were due to aquarium 3, which contained significantly lower DO concentrations than aquarium 1. Ammonia levels in the test aquarium A increased over time. Levels ranged from 0.103 mg N/L in the first hour to 0.230 mg N/L in the thirteenth hour. Ammonia concentrations in the control aquarium C ranged from 0.125 to 0.175 mg N/L (Table D.8).

5.3.2.4 Central stoneroller/Massac Creek experiment

Results of the central stoneroller experiment using Massac Creek water are shown in Table D.8. The hourly mean pH values for test aquaria A and B showed a slight increase over time. The range for aquaria A was 7.85–7.94, while the range for aquaria B was 7.86–7.95. The control aquaria had hourly mean pH values of 7.91–7.96 for aquaria C and 7.95–8.03 for aquaria D. There was little variation in individual aquarium mean pH values. No significant differences in pH values were observed for any of the parameters examined by the GLM (Table 5.1).

The hourly mean DO concentrations showed no obvious trends toward increasing or decreasing over time. DO concentrations ranged from 5.7 to 6.4 mg/L in aquaria A and from 5.7 to 6.3 mg/L in aquaria B. Aquaria C ranged from 6.2 to 6.6 mg/L, and aquaria D ranged from 6.4 to 7.0 mg/L. The GLM procedure used to compare DO concentrations among aquaria and the interaction between aquaria and time revealed no significant differences. There was, however, a significant difference in DO concentrations over time (Table 5.1). The ammonia concentrations in both the test aquarium A and the control aquarium C increased through time. In aquarium A, the first hour concentration was 0.080 mg N/L compared with 0.285 mg N/L in the thirteenth hour. In the control aquarium C, the concentration ranged from 0.082 mg N/L in the first hour to 0.218 mg N/L in the eleventh hour (Table D.8) before falling slightly near the conclusion of the test.

5.4 THERMAL TOLERANCE TEST RESULTS AND DISCUSSION

(*W. K. Roy and J. J. Beauchamp*)

Because length and weight data were obtained postmortem, condition factors (K) could be calculated for individual fish using the formula $K = 100\ (\text{weight}/\text{length}^3)$, with weight in grams and total length in centimeters (Hile 1936). The condition factor is a generalized indicator of overall health and can reflect the integrated effect of both nutritional status and metabolic stress (Adams and McLean 1985). Condition factor and TTD data are summarized in Table D.3.

For purposes of these experiments, death was defined as a loss of equilibrium combined with cessation of opercular movement and no response to stimuli. TTD for individual fish was determined in minutes, and a statistical comparison of the relation between TTD and K was made for each of the four experiments (Figs. D.1–D.4) on transformed data (SAS 1988b). Since the majority of control fish were still alive at the end of the experiment, an actual TTD could not be reported for these fish. Consequently, control fish were not included in these analyses.

Due to the negative skewness on the distribution of TTDs vs K (i.e., the majority of fish survive low temperatures early in the experiment, and many mortalities occur at high temperatures late in the experiment), the analyses were performed on a transformed TTD which was a scaled third power of the observed TTD. Neither of the redfin shiner experiments showed a significant association ($p > 0.6$) between K and TTD; however, there was a significant association ($p < 0.01$) between K and TTD in each of the central stoneroller experiments. The range of condition factors for central stonerollers tested was 0.72–1.27 (Table D.3), with total length (TL) ranging from 3.7 to 7.6 cm, and weight ranging from 0.50 to 3.65 g. Redfin shiners had condition factors in the range of 0.54–1.03, with TL ranging from 3.8 to 7.5 cm and weight ranging from 0.39 to 3.12 g. Central stonerollers with a $K > 1$ tended to have a shorter TTD than those with $K < 1$. For central stonerollers, the analysis of covariance showed that there was a significant association between transformed TTD and K ($p < 0.01$), but there was no significant difference ($p = 0.26$) in these relations for the ROL/001 and ROL/MAC experiments (i.e., no significant water effect).

Because the (presumably) healthiest central stonerollers (higher K) died early in both tests, the data were examined for a possible relationship between TL or wet weight and early mortality. An analysis of all stonerollers that died in the first 600 min (10 h) of the experiments ($n = 4$ for ROL/001 and $n = 16$ for ROL/MAC) shows that they had a mean TL of 5.8 (4.6–6.3) cm and a mean weight of 2.09 (1.22–2.90) g. The mean length of all stonerollers was 5.5 (3.7–7.6) cm and the mean weight was 1.77 (0.5–3.65) g. From these data, there is no evidence that the relatively high condition factors in these early mortalities are associated with either an unusually low TL or an unusually high weight. It is uncertain whether any differential mortality could be associated with sex, but there is no reason to believe that the higher K stonerollers were not equally represented with males and females. Based on data from Etnier and Starnes (1993), the stonerollers we tested would be in the 1+ year class (achieve standard length of 35–65 mm after 1 year) and spawning should have been completed at least six weeks prior to collection. No tubercles were observed on any of the stonerollers tested, nor were postmortem sex determinations made. Water chemistry measurements taken throughout the experiments (Tables D.8 and D.9) gave no indication that DO was limiting or that ammonia concentrations could be contributing to premature mortality. Smale and Rabeni (1995a) report mean critical DO concentrations of 1.17 and 0.95 mg/L for redfin shiners and central stonerollers, respectively. Due to the effects of pH and temperature on ammonia toxicity, reporting of critical ammonia concentrations is more involved. It can be seen from the EPA (1986) ammonia criteria tables that 96-h average total ammonia concentrations (for nonsalmonids) should not exceed 0.76 mg/L N at 25°C (pH 8.00) or 0.55 mg/L N at 30°C (pH 8.00). The 1-h concentrations for total ammonia at the same pH value are 5.6 mg/L at 25°C and 4.0 mg/L at 30°C. The highest total ammonia concentration measured in any of the experiments was 0.285 mg/L N (Table D.8).

In their natural environs, fish with high K values could be expected to maintain a competitive edge over conspecifics with lower condition factors. Fish with a high K value generally have a high lipid content (C. C. Coutant, Oak Ridge National Laboratory, personal communication, Jan. 16, 1996), which is important for long-term energy use and generally reflects overall fat storage and nutritional status of fish (Adams et al. 1992). It is unclear whether a relationship between lipid content and thermal tolerances has ever been established in fish, although size-dependent variation in hyperthermia tolerances has been observed (Fry 1967, Cox 1974). The reduced surface-area-to-weight ratio of the higher K fish should argue in favor of increased tolerance to heat (or cold) stress. Becker and Genoway (1979) noted that the slower rate of heat penetration in larger organisms may affect upper critical thermal maxima. This principle clearly has merit, but over the range of sizes of fish we tested, it may not be particularly applicable. Perhaps the more robust (higher K) fish are simply less compliant in the confines of a 7.5 L aquarium, making them more susceptible to stress-related mortality. There were four mortalities of control fish from the two stoneroller tests ($n = 1$ for ROL/001 and $n = 3$ for ROL/MAC) during the first 600 min of testing. These fish were included in the previous discussion of length and weight analyses of early (< 600 min) mortalities.

Because a significant association between K and TTD had been established for stonerollers, but not redfin shiners, additional analyses were done on each species separately. For redfin shiners, an analysis of variance showed a significant ($p < 0.01$) water effect on the TTD, with the

TTD being significantly longer in the Outfall K001 water than the Massac Creek water. The mean TTD for redfin shiners in Massac water ($n = 20$) was 529.5 min, but in Outfall K001 water ($n = 92$) was 731.5 min (Table D.3). The earlier analysis for stonerollers did not show a significant ($p = 0.26$) water effect on the TTD. However, the mean TTD (787.5 min) for stonerollers in Outfall K001 water ($n = 50$) was still longer than the mean TTD (738.5 min) observed in Massac Creek water ($n = 98$). Due to the low number of fish and high control mortality in the RED/MAC experiment, caution should be exercised in interpreting the significant water effect on the TTD for redfin shiners. For reasons previously mentioned, these analyses do not include control mortality.

Mortality of control fish was high for all but the ROL/001 experiment. Control mortality was higher, regardless of species, in Massac water. Six of 39 (15%) control fish in the ROL/MAC experiment, and 6 of 14 (43%) in the RED/MAC experiment, expired before 100% mortality of test fish was achieved. By comparison, 6 of 39 control fish in the RED/001 experiment, and 1 of 20 (5%) control fish in the ROL/001 experiment died prior to test completion. The test results indicate that central stonerollers and redfin shiners do better in Outfall K001 water than in Massac Creek water, both when thermally (heat) stressed as well as in a static, ambient temperature state. This is especially curious since many of the test fish actually came from Massac Creek (or its tributaries), and redfin shiners have been collected only once (March 1995) in Outfall K001 and once (March 1995) at BBK 9.4 (see Table C.10), just downstream of the outfall, despite numerous sampling efforts.

It is unlikely that control mortality or low TTDs in test fish could be due to the relatively short (≥24 h) acclimation time used in these experiments, especially since the 25°C acclimation temperature was virtually the same as the collection temperatures of the test fish. The use of short acclimation times for hyperthermic testing should be further validated by the fact that thermal acclimation generally takes place in hours for increasing temperatures, but is not completed for several days for decreasing temperatures (Brett 1944). The range of temperatures naturally experienced by the test fish prior to capture can probably be discounted as a cause of control mortality as well, since fish acclimated to diel temperature fluctuations generally have an increased range of temperature tolerance (Feldmeth et al. 1974).

We chose a slow (1°C/h) heating rate for this study in part because one of the principal objectives was to determine if temperature alone could preclude relatively sensitive species (e.g., the redfin shiner) from existing in and around the PGDP outfalls. There is no way to test thermal preferences or avoidance temperatures of fish from these experiments, but we do know from instream temperature monitoring (Sect. 2) that temperature increases in excess of 1°C/h would seldom be encountered around these outfalls. It would be reasonable to expect fish to emigrate from these outfalls if the rate of temperature increase was substantial and/or approaching their avoidance temperature.

Because there are often considerable differences between laboratory tolerance values and lethal conditions in natural settings, we opted for a heating rate that could be encountered by fish in the Paducah area. Smale and Rabeni (1995a) report that with respect to temperature and dissolved oxygen concentrations, they were "unable to find a study in which laboratory measurements of lethal conditions have been shown to be equal to or even similar to conditions associated with deaths of the same species in the wild." In order to test the hypothesis that redfin shiners may be excluded from outfalls based solely on the outfall's maximum temperatures, it is only logical to conduct laboratory testing under a heating rate that could be experienced in the field. To do otherwise would be unrealistic, in part because abrupt temperature changes are rarely experienced by aquatic poikilotherms due to the relative thermal inertia of water (Becker and Genoway 1979).

Most tests that are used to determine critical thermal maxima utilize loss of equilibrium rather than death as a criteria. For this reason, and the fact that there are considerable inconsistencies in the usage of thermal tolerance terminology, our results are reported simply in terms of the median lethal temperature (LT_{50}) and the temperature at which 100% mortality occurs (LT_{100}) (Table D.3). The LT_{50} for redfin shiners was 32.7°C in reference water and 37.2°C in outfall water. Their LT_{100} values were 37.2°C and 38.9°C, respectively. The LT_{50} for central stonerollers was 38.1°C in reference water and 38.2°C in outfall water. Their LT_{100} values were 39.0°C and 38.8°C, respectively. As can be seen in the graphs of Fig. 2.15, the maximum water temperatures in Outfall K001 can be expected to occasionally exceed the median lethal temperature we determined for redfin shiners.

These laboratory study results indicate there is a potential for mortality to occur, particularly with redfin shiners, at the peak water temperatures observed in Outfalls K001, K006, and K010/011 (Sect. 2). However, as noted previously, laboratory measurements of lethal conditions may not be a good indicator of what to expect in natural environments. Clearly, these results should not be interpreted to mean that Outfall K001 water is better for fish than Massac Creek water. There is little doubt that the chemistry of the two types of test water had an effect on the thermal tolerances observed, and as noted in Sect. 5.3.1, both conductivity and hardness were substantially higher in Outfall K001 water than in Massac Creek water. Hutchison (1976), Stauffer, Jr. (1986), and others have noted the role that salinity and other chemical factors have had (sometimes unpredictably) on the thermal tolerances of fish. The median lethal temperatures that were observed in these laboratory studies are included in the table of CTM values reported by Ryon (Sect. 4, Table 4.5), and when combined with the existing literature on lethal temperature data (Table 4.5), should be considered in any assessment of the distribution and abundance of fish in and around PGDP outfalls and receiving streams.

6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

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This study of outfall temperatures and the effects on stream temperatures and fauna in Big Bayou Creek and Little Bayou Creek concluded that noticeable alterations occur on instream temperatures, and some sectors of the fauna may be responding to these changes. The effects are wide ranging, and several alternatives are suggested in response to the observed effects.

6.1 SUMMARY

Instream temperatures in both Big Bayou Creek and Little Bayou Creek show a consistent elevation in comparison to reference streams (Sect. 2). Temperatures in the water supply inlet at the Ohio River, in upper Big Bayou Creek above the plant effluents, and in Massac Creek, a local stream receiving agricultural and low-density urban inputs, were 2–5 °C lower than temperatures measured at sites in the streams receiving effluents from PGDP. Areas of Little Bayou Creek and Big Bayou Creek immediately below Outfalls K001 and K010/011 demonstrated the highest temperatures, but a zone of elevated temperatures extended at least 1 kilometer downstream of the heated effluents. Within the outfalls and in immediately adjacent zones, maximum temperatures in the summer reached 34–38 °C. When compared with the proposed limits (31.8 °C monthly mean), outfall temperatures resulted in a total of six exceedances. When compared with the interim limits (35 °C monthly mean), these same temperatures produced no exceedances. However, actual stream temperatures did not exceed either the proposed or interim limits. The magnitude of the regulatory problem depends upon where temperature is measured and whether a more restrictive outfall limit would produce substantial improvements in the stream communities.

The stream fauna were evaluated for impacts through assessments of the benthic macroinvertebrate (Sect. 3) and fish (Sect. 4) communities, and by conducting a laboratory thermal tolerance study (Sect. 5) of two fish species. The benthic invertebrates were studied at three thermally altered sites in Big Bayou Creek and Little Bayou Creek, and the fish communities were studied at seven thermally altered sites. These thermally altered sites were compared with two reference sites where there were no known thermal effluents. The laboratory study focused on two common, native species and exposed them to non-effluent and effluent water in a slowly rising (1 °C/h) temperature bath.

Benthic macroinvertebrate data covering a 4-year period provided no conclusive evidence that the macroinvertebrate communities of Big Bayou Creek and Little Bayou Creek are being adversely affected by thermal discharges. However, because of excessive data variability which can limit one's ability to detect differences, the possible presence of some subtle impacts cannot be ruled out.

The fish communities in Big Bayou Creek and Little Bayou Creek contained fewer species than in comparable reference sites. The species found in the reference sites, but not in the study sites, were generally less tolerant to stress. The presence of these common fish species was indicative of their ability to tolerate the observed range of temperatures resulting from the thermal discharges. The distribution and population data for the core species assemblage at the sites indicated that reproduction and growth of these species were not being substantially impacted by the thermal discharges. Most of these species had published CTM or upper lethal temperatures that were exceeded by measured stream temperatures only infrequently. However, there were some species on a comprehensive fish species list that may be adversely affected by the increased temperature regime. Distribution data for some species indicated that they were absent from the most thermally impacted sections of the streams during the hotter months of the year. These species were found in areas adjacent to the outfalls during cooler months or in upstream sections where the thermal impacts were less severe. Other species present in area streams, that were absent altogether from Big Bayou Creek and Little Bayou Creek, often belonged to species groups that are considered more sensitive, such as percids or catostomids. The absence of some species could not be specifically associated with thermal effluents due to the lack of published information on the thermal tolerance of many of these species. The published information on thermal tolerances for species occurring in Big Bayou Creek and Little Bayou Creek suggested that instream temperatures above 31°C could cause fish to avoid sections of the streams, while temperatures above 36°C could be lethal if sustained for several hours. However, caution must be exercised in the interpretation of these data. Because of the associated chemical discharges in the thermally enriched effluents, an impact on the stream fish community cannot be solely, nor definitely, attributed to increased temperature. There is no guarantee that fish communities would improve if the temperature of Outfalls K001, K006, K008, and K010 were lowered.

The effect of temperature as it relates to the absence or reduced frequency of thermally sensitive fish species from PGDP outfalls and impacted reaches of receiving streams cannot be discounted. However, due to the complexities of aquatic ecosystems it is very difficult to show a causal relationship between a single stressor (e.g., high temperature) and a tangible measurement (e.g., species richness, density, etc.), to the exclusion of other potential confounding influences (e.g., habitat structure, predation, water quality, etc.). Evidence in the literature (Table 4.5) as well as our own laboratory studies of thermal tolerance (Sect. 5 and Table D.3) clearly indicate that central stonerollers have a higher hyperthermic tolerance than do redfin shiners. The absence of redfin shiners from some PGDP outfalls and associated receiving stream reaches could be explained by peak summer temperatures recorded in Outfalls K001, K006, and K010. These outfalls periodically experience temperatures sufficient to cause mortality (under laboratory conditions) to redfin shiners. It is not inconceivable, however, that some tolerant species might utilize these warm water refuges as a means to escape predators or avoid competition. Nonetheless, a reduction of the thermal discharges from PGDP would likely bring about improvements in the diversity of the region's aquatic faunal communities.

Both natural and anthropogenic factors may influence the health of aquatic communities. These factors include, but are not limited to, altered temperature, nutrient enrichment, the presence of toxicants, food availability, habitat structure, and altered flow regimes. Determining the effect(s) of a single factor may be difficult or impossible due to the presence of multiple, and possibly synergistic, factors. Improvements in the aquatic biota due to the reduction or elimination of one or more stressor(s) may be masked by the continued impacts of remaining stressors. It is clear from these studies, however, that temperatures in the outfalls, Little Bayou Creek, and Big Bayou Creek are elevated compared with reference sites. While decreasing thermal inputs into the receiving streams should result in healthier aquatic communities, it is possible that improvements may not be detected due to continued adverse impacts from other stressor(s). The ability to detect a response will also be affected by the magnitude of the change. For example, a temperature reduction of 1°C may result in no detectable biological change while a 5°C reduction may produce obvious effects.

6.2 CONCLUSIONS

Several primary conclusions can be drawn from this study.

- The instream temperatures of Big Bayou Creek and to a lesser degree Little Bayou Creek have been elevated above reference site temperatures by the thermal input from PGDP outfalls.
- These increased temperatures occasionally reach levels that literature studies have shown to have an influence on stream communities.
- Benthic macroinvertebrate community studies in Big Bayou Creek and Little Bayou Creek do not show any major impacts directly attributable to thermal alterations.
- Fish community studies indicate that there are possible impacts from thermal alterations, including potentially reduced species richness, and avoidance of the hotter portions of the creeks and outfalls by some species.
- Thermal tolerance laboratory studies indicate that two native fish species (the central stoneroller and redfin shiner), occurring in the affected streams have lethal temperatures within the range of temperatures seen in the thermally enriched parts of the system.

6.3 ALTERNATIVES AND RECOMMENDATIONS

Based on the results of this study, several alternative strategies are proposed for dealing with thermal inputs associated with Outfalls K001, K006, K008, and K010. A decision to implement any of the proposed strategies should be based on ecological data, engineering and cost constraints, and regulatory requirements.

Alternative 1. The temperature of effluents from Outfalls K001, K006, K008, and K010 should be lowered prior to discharge into Big Bayou Creek and Little Bayou Creek. Remedial actions to achieve this temperature reduction could be outfall specific or a systematic solution. Adverse impacts of the outfalls would be reduced to chemical and physical stresses; thermal impacts would no longer potentially restrict faunal composition or distributions within Big Bayou Creek and Little Bayou Creek. Exceedances of either the proposed or interim temperature criteria should be extremely rare.

Alternative 2. Change the compliance monitoring point for temperature from within the outfall channel to within the stream below the mixing zone for each outfall. This would not lower the instream temperatures and the faunal structure and composition would basically remain unchanged. Exceedances of the proposed or interim temperature criteria should be extremely rare.

Alternative 3. Change the compliance criteria for temperature from the proposed limit to the interim limit. This would not lower the instream temperatures and the faunal structure and composition would basically remain unchanged. Exceedances of the temperature criteria should be extremely rare.

Alternative 4. Keep the compliance criteria for temperature at the proposed limit. This would not lower the instream temperatures and the faunal structure and composition should basically remain unchanged. Occasional exceedances of the criteria would likely occur in summer months.

RECOMMENDATION. Alternative 1 is the recommended option based on an ecological assessment. The manner in which temperature of the effluents is reduced would be dependent on engineering and cost considerations. Possible approaches include: (1) increase shading of open water sections of outfalls by allowing native riparian growth in buffer zones or supplemental planting of riparian vegetation; (2) determine if a lower discharge point from storage lagoons (e.g, for Outfall K006) would result in lower effluent temperatures; (3) evaluate the need for additional cooling towers or engineering controls; (4) reduce or redirect heated effluents so that total thermal input to the creeks is reduced; (5) construct a series of small waterfalls, if stream gradient is sufficient, to dissipate heat; and (6) consider the addition of raw Ohio River water to effluents. The effectiveness of these options ranges from a potential lowering of summer maxima through increased shading to reducing effluent and instream temperatures down to levels appropriate for the Paducah region by adding cooler water from the Ohio River. The impact of these options on temperatures should be evaluated prior to full scale implementation, and the effects on Little Bayou Creek and Big Bayou Creek could be monitored by continued use of the existing BMP and instream temperature recording system. As the options are implemented, limited site specific surveys (e.g., qualitative surveys below Outfalls K001 and K010) could be added to the regular BMP sites.

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Appendix A

TEMPERATURE PROFILES OF LITTLE BAYOU CREEK DOWNSTREAM OF OUTFALL K011 AND BIG BAYOU CREEK DOWNSTREAM OF OUTFALL K001, JULY–AUGUST 1993

Table A.1. Temperature profiles for Little Bayou Creek downstream of Outfall K011–July and August 1993

	7-13-93			7-20-93			7-27-93			8-3-95		
		Time	Air (°C)		Time	Air(°C)		Time	Air (°C)		Time	Air (°C)
	Start:	1220	30.2	Start:	800	26.8	Start:	710	23.6	Start:	911	24.1
	Stop:	1305	30.4	Stop:	830	28.8	Stop:	732	26.5	Stop:	922	25.7
	Stream Temperature (°C)			Stream Temperature (°C)			Stream Temperature (°C)			Stream Temperature (°C)		
Distance Downstream (m)	Left Bank	Center	Right Bank	Left Bank	Center	Right Bank	Left Bank	Center	Right Bank	Left Bank	Center	Right Bank
0	33.0	33.6	34.0	31.2	30.5	32.0	29.6	28.1	31.6	26.7	28.1	28.8
10	33.5	33.6	33.7	31.6	31.6	31.6	30.7	30.9	30.8	28.1	28.1	28.0
20	33.1	33.6	33.0	31.5	31.5	31.5	30.7	30.7	30.8	28.0	28.0	28.0
30	33.5	33.6	33.5	31.5	31.5	31.3	30.6	30.7	30.7	27.8	27.8	27.8
40	33.6	33.7	33.6	31.4	31.5	31.4	30.6	30.7	30.6	27.8	27.8	27.8
50	33.6	33.8	33.7	31.4	31.3	31.4	30.7	30.6	30.6	27.8	27.8	27.8
60	33.8	33.9	33.8	31.3	31.3	31.3	30.6	30.6	30.6	27.9	27.8	27.8
70	33.5	33.8	33.7	31.2	31.3	31.2	30.3	30.5	30.5	27.8	27.8	27.8
80	33.7	33.8	33.7	31.2	31.3	31.1	30.5	30.5	30.5	27.8	27.8	27.8
90	33.5	33.7	33.2	31.3	31.2	31.2	30.5	30.5	30.5	27.8	27.8	27.8
Misc. Readings					7-20-93			7-27-93			8-3-93	
K011 Weir					32.7			32.1			28.8	
25 m upstream					23.6			24.3			20.5	
10 m upstream					23.7			32.5				
McCall Rd.					31.6							
Ogdon Landing					26.1			28.0			24.4	

Table A.2. Temperature profiles for Big Bayou Creek downstream of Outfall K001–July and August 1993

Distance Downstream (m)	7-13-93			7-20-93			7-27-93			8-3-95		
		Time	Air (°C)		Time	Air(°C)		Time	Air (°C)		Time	Air (°C)
	Start:	930	26.3	Start:	940	28.8	Start:	850	26.5	Start:	1010	25.7
	Stop:	1010	28.0	Stop:	1015	29.1	Stop:	915	29.0	Stop:	1030	26.8
	Stream Temperature (°C)			Stream Temperature (°C)			Stream Temperature (°C)			Stream Temperature (°C)		
	Left Bank	Center	Right Bank	Left Bank	Center	Right Bank	Left Bank	Center	Right Bank	Left Bank	Center	Right Bank
0	31.4	28.6	28.3	31.7	30.0	30.0	30.7	29.6	28.5	31.4	28.4	28.5
10	31.0	28.7	28.1	31.3	30.0	30.0	30.7	29.7	29.5	31.2	28.8	28.2
20	30.8	30.3	29.5	31.3	30.7	30.3	30.6	30.3	29.8	30.9	30.2	28.9
30	29.8	29.7	28.9	31.3	30.6	30.0	30.6	30.3	29.7	30.8	30.2	29.2
40	30.5	30.4	28.8	30.8	30.5	30.1	30.3	30.2	29.8	30.3	30.1	29.2
50	30.3	30.3	28.7	30.9	30.6	30.0	30.6	30.5	29.8	30.3	30.2	29.2
60	30.3	30.3	28.7	30.9	30.6	30.0	30.6	30.5	29.8	30.3	30.2	29.2
70	29.8	29.6	29.2	30.7	30.5	30.1	30.2	30.1	29.8	30.1	29.7	29.4
80	29.6	29.7	29.7	30.5	30.5	30.5	30.1	30.2	30.1	29.7	29.8	29.7
90	29.6	29.7	29.5	30.3	30.3	30.3	30.2	30.2	30.1	29.8	29.8	29.7

ORNL-DWG 96M-1041A

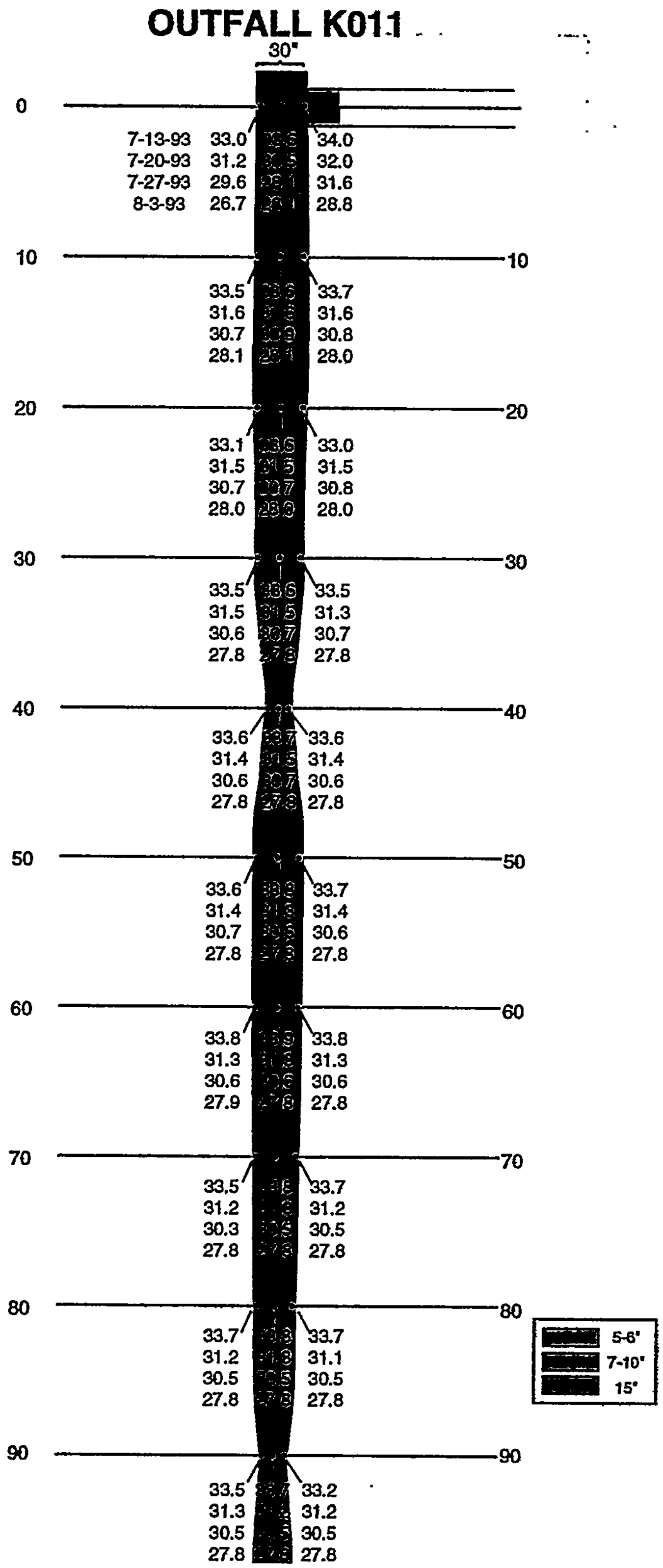

Fig. A.1. Instream temperature profile for Little Bayou Creek downstream of Outfall K011 on four dates in July and August 1993. Data were collected at 10 m intervals for 90 m downstream of the outfall. Temperature readings were taken on each date (for each 10-m interval) at mid-depth midway in the left third of the stream, in the middle of the stream channel, and midway in the right third of the stream. Stream depths (in inches) were taken at each 10-m interval and a depth profile is diagramed.

ORNL-DWG 96M-1042A

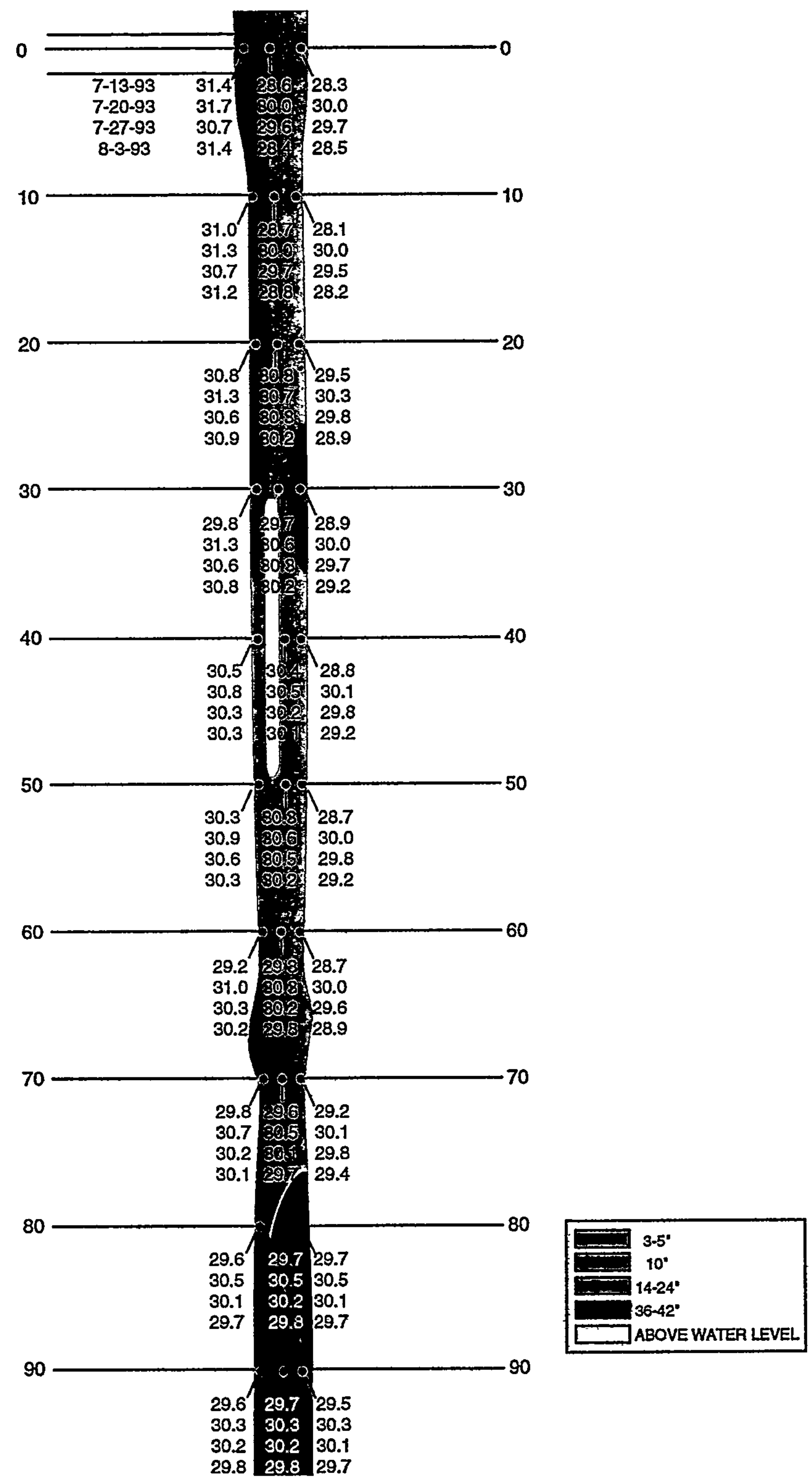

Fig. A.2. Instream temperature profile for Big Bayou Creek downstream of Outfall K001 on four dates in July and August 1993. Data were collected at 10 m intervals for 90 m downstream of the outfall. Temperature readings were taken on each date (for each 10-m interval) at mid-depth midway in the left third of the stream, in the middle of the stream channel, and midway in the right third of the stream. Stream depths (in inches) were taken at each 10-m interval and a depth profile is diagramed.

Appendix B

CHECKLIST OF BENTHIC MACROINVERTEBRATE TAXA COLLECTED FROM BIG BAYOU CREEK, LITTLE BAYOU CREEK, AND MASSAC CREEK IN PADUCAH, KENTUCKY, SEPTEMBER 1991 TO MARCH 1995

Table B.1. Checklist of benthic macroinvertebrate taxa collected from Big Bayou Creek, Little Bayou Creek, and Massac Creek in Paducah, Kentucky, September 1991–March 1995[a,b]

Taxon	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Coelenterata					
Hydrozoa					
Hydridae					
Hydra	1	1,2	2	–	–
Turbellaria					
Planariidae	1,2,3,4	1,2,3,4	1,2,3,4	1,3,4	3,4
Nemertea	1,2,3,4	1,2,3	1,2,3,4	1,2,3	1,3,4
Nemertea?	–	–	2	–	–
Nematomorpha					
Gordiidae					
Gordius	–	–	4	–	4
Nematoda	1,4	1	1,2,4	1,2,3,4	1,2,4
Annelida					
Hirudinea					
Glossiphoniidae					
Helobdella	–	2,3	3	–	–
Oligochaeta	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Tubificidae					
Branchiura sowerbyi	2,3,4	–	–	1	–
Crustacea					
Amphipoda					
Talitridae					
Hyalella azteca	1	1,2	–	–	–
Decapoda	–	–	–	–	1
Hydracarina	1,4	1,4	4	2,3,4	2,4
Hydrachnidae	–	–	1	1,3	1,3
Hygrobatidae					
Atractides	1	–	1	–	1
Hygrobates	1,2,3	1,2,3	1	1	–
Lebertiidae					
Lebertia	–	–	–	3	1
Limnesiidae					
Limnesia	–	2	–	–	–
Pionidae					
Piona	1	–	–	–	–
Torrenticolidae					
Torrenticola	1,3	1,2,3	3	1,2,3	1,2,3

Table B.1 (continued)

Taxon	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Insecta					
Ephemeroptera	–	–	–	3	–
Baetidae	1,3	1,2,4	1,4	1,3,4	1,2,3
Baetis	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Centroptilum	4	4	4	4	–
Paracloeodes	–	4	–	–	–
Pseudocloeon	–	–	1	–	–
Caenidae					
Caenis	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Ephemerellidae					
Eurylophella	2	–	–	–	–
Ephemeridae	–	–	4	–	–
Hexagenia	4	–	–	–	–
Heptageniidae	1	1,2,3,4	1,4	1	1
Stenacron	–	2,4	3,4	4	–
Stenonema	1,2,3,4	1,2,3,4	1,3,4	4	1,2
Oligoneuridae					
Isonychia	1,3	1	–	–	–
Tricorythidae					
Tricorythodes	1,2,3,4	1,2,3	3	–	4
Odonata	–	1,2	2	–	–
Anisoptera					
Corduliidae/Libellulidae	–	–	4	–	–
Gomphidae	–	–	–	3	–
Dromogomphus	1	–	–	–	–
Progomphus	–	–	–	1,3,4	1
Libellulidae					
Erythemis simplicicollis	–	1	–	–	–
Libellula	–	1	–	–	–
Macromiidae					
Macromia	–	1	4	3,4	–
Zygoptera	1	1	–	–	–
Calopterygidae					
Calopteryx	–	–	1	1	1
Hetaerina	–	1	–	1	–
Coenagrionidae	–	1	–	–	–
Argia	1,3,4	1,2,4	4	2,3	2
Enallagma	–	1	–	–	–
Ischnura	–	1	1	–	–
Plecoptera	1	1	1,3	1,2	1
Capniidae	–	3	1,3	1	1,3
Allocapnia	3	3	2,3,4	2,4	2,3,4
Chloroperlidae					
Haploperla	–	–	–	2	–
Leuctridae	–	–	3	–	–
Nemouridae	3	–	2	–	3
Amphinemura	–	–	1,2,4	1	1,4

Table B.1 (continued)

Taxon	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Plecoptera (cont.)					
Perlidae					
Eccoptura?	–	4	–	–	–
Perlidae/Perlodidae	–	–	4	–	–
Perlodidae	–	–	–	2,4	–
Isoperla	–	–	1,4	2	4
Megaloptera					
Corydalidae					
Corydalus cornutus	3,4.	1,3	1,3	1,2,3	4
Sialidae					
Sialis	–	–	4	–	–
Trichoptera	1	1,2,3	1,2,3	1	1,2,3
Hydropsychidae	1,2,3,4	1,2,3	3	1,2,3	1,2,3,4
Cheumatopsyche	1,2,3,4	1,2,3,4	1,3,4	1,2,3,4	1,2,3,4
Hydropsyche	1,2,4	4	1,2,3,4	1,2,3,4	1,3,4
Hydroptilidae	4	4	2	–	–
Hydroptila	1,4	1,4	1,2,4	1,2,3,4	4
Leptoceridae	–	–	–	–	4
Oecetis	1,4	1	1,4	1,3,4	1
Oecetis?	–	–	–	4	–
Molannidae					
Molanna	–	–	–	–	4
Philopotamidae	3	–	–	–	–
Chimarra	1,2,3	1,2,3,4	1,2,3,4	1,2,4	1,3,4
Polycentropodidae	3	–	–	–	–
Polycentropus	–	–	1	–	–
Coleoptera	–	4	–	–	–
Elmidae	1	–	–	–	
Dubiraphia	1,4	3	1,2,3	1,2,3,4	–
Optioservus	–	–	2	–	1
Stenelmis	1,2,3,4	1,3,4	1,3	1,2,3,4	1,3,4
Gyrinidae					
Dineutus	–	–	–	1	1
Haliplidae					
Peltodytes	–	1	–	–	–
Hydrophilidae	–	2	–	–	–
Berosus	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Enochrus	–	1	–	–	–
Hydrobius	–	–	–	1	–
Psephenidae					
Ectopria	–	4	–	–	–
Diptera	–	–	3	1	1
Ceratopogonidae	1,4	3,4	1,2,3,4	3,4	2,3,4
Atrichopogon	–	1,2	1,2	–	–
Bezzia	1	1	1,2	1	1,2,3
Culicoides	1	1	1	1,3	–

Table B.1 (continued)

Taxon	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Diptera (cont.)					
Dasyhelea	–	4	4	4	–
Monohelea	1	1	–	–	–
Palpomyia	–	–	1	–	1
Probezzia	1	–	–	1	–
Chaoboridae					
Chaoborus	3	–	–	–	3
Chironomidae	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Chironomini	1,2,3,4,	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Orthocladiinae	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Tanypodinae	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Tanytarsini	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Dolichopodidae	–	4	–	–	–
Empididae					
Chelifera	1	1	1	–	–
Hemerodromia	1,2,4	1,2,3,4	1,2,3,4	1,2,4	3,4
Phoridae	3	–	–	–	–
Simuliidae	1	–	2,3	2	–
Prosimulium	–	–	–	–	4
Simulium	1,2,3,4	1,2,3,4	1,2,4	1,2,4	1,2,3,4
Stegopterna	–	–	2,4	–	4
Tabanidae					
Chrysops	4	–	3	–	–
Tabanus	1	1	–	1	–
Tipulidae	–	1,2	2	–	3
Erioptera	–	1	3	–	1
Erioptera?	–	–	–	4	–
Helius	–	1	–	–	–
Limonia	–	–	–	2	–
Tipula	–	2	1,2,4	1	–
Mollusca					
Gastropoda	4	4	–	–	–
Ancylidae	–	–	–	1,3	1,3
Ferrissia fragilis	1	1	1,4	1,3,4	3,4
Hydrobiidae	–	–	–	1	–
Lymnaeidae	–	–	–	1	–
Fossaria	–	–	–	1	–
Pseudosuccinea collumella	–	–	–	3	1
Physidae					
Physella	4	1,3	–	1,2,4	1,2,4
Planorbidae	–	1,3	–	–	4
Gyraulus deflectus	1	–	–	–	–
Gyraulus parvus	1	3	–	–	–
Menetus dilatatus	1,3	1,3	–	1,4	1,4
Bivalvia					
Corbiculidae					
Corbicula fluminea	1,2,3	–	–	4	–

Table B.1 (continued)

Taxon	BBK 9.1	BBK 10.0	BBK 12.5	LUK 7.2	MAK 13.8
Mollusca (cont.)					
Sphaeriidae	2	–	–	2,3	–
Musculium	1,2	–	–	3,4	–
Pisidium	–	–	–	1,3	3
Sphaerium	1	–	–	–	–

[a]BBK = Big Bayou Creek kilometer; LUK = Little Bayou Creek kilometer; MAK = Massac Creek kilometer.

[b]The numbers associated with each taxon and site indicate the sampling years (i.e., the 1 year cycle beginning with the first collection date) that the taxon was collected at least once, with 1 = September 1991–June 1992, 2 = September 1992– March 1993, 3 = September 1993– March 1994, and 4 = September 1994– March 1995. A blank indicates that a lower level of classification (e.g., family, genus, or species) was possible at one or more sites, and a dash (–) indicates that the taxon was not collected or that all collected taxa within the group were identifiable to a lower level of classification at one or more sites.

Appendix C

FISH DENSITY, SPECIES COMPOSITION, AND CATCH PER UNIT EFFORT FOR QUANTITATIVE AND QUALITATIVE SAMPLES OF BIG BAYOU CREEK, LITTLE BAYOU CREEK, AND MASSAC CREEK, NOVEMBER 1993 THROUGH NOVEMBER 1995

Table C.1. Fish densities in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March 1994

Unless otherwise stated, measurement expressed in number per square meter

Species[b]	Sites[a]				
	BBK9.1	BBK10.0	BBK12.5	LUK7.2	MAK13.8
Stoneroller	0.32	1.18	1.67	0.21	0.60
Red shiner	–	0.01	–	0.18	–
Steelcolor shiner[c]	<0.01	–	–	–	0.01
Ribbon shiner	–	–	–	0.07	0.01
Redfin shiner[c]	–	<0.01	–	0.11	0.06
Golden shiner	–	–	–	<0.01	–
Suckermouth minnow	–	<0.01	0.01	0.16	–
Bluntnose minnow	–	<0.01	0.05	1.61	0.07
Creek chub	–	<0.01	0.25	0.21	0.03
White sucker	<0.01	–	<0.01	–	0.01
Creek chubsucker	<0.01	0.01	0.05	0.01	0.01
Spotted sucker	<0.01	–	–	–	–
Yellow bullhead	0.01	–	0.14	0.03	0.03
Pirate perch	–	–	–	0.07	0.01
Blackspotted topminnow	0.04	0.01	0.15	0.49	0.12
Western mosquitofish	–	–	–	0.02	–
Green sunfish	0.06	0.01	0.10	0.12	0.04
Warmouth	<0.01	–	–	0.02	–
Bluegill	0.01	–	0.03	<0.01	0.01
Longear sunfish	0.50	0.13	0.62	0.27	0.43
Hybrid sunfish	0.01	<0.01	0.01	–	–
Spotted bass	0.01	–	0.01	<0.01	0.01
Largemouth bass	<0.01	–	–	–	–
Bluntnose darter	–	–	–	0.08	–
Slough darter	–	–	–	0.16	–
Logperch	–	–	–	–	0.01
Blackside darter	–	–	–	–	0.03
Total density	0.97	1.36	3.09	3.82	1.49
STREAM TEMPERATURE[d]					
MONTHLY MEAN	9.63[e]	5.58[f]	8.10[e]	7.31[f]	8.19[e]
PRIOR WEEKLY MEAN	13.96	2.59	13.01	7.35	11.22
PRIOR WEEKLY MAX	17.77	8.91	27.72	10.14	12.70
SAMPLE DATE MEAN	13.94	12.12	12.50	13.03	12.00

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[d]Temperatures expressed in degrees Celcius.
[e]Sampled during week of March 22–23.
[f]Sampled during week of March 6–7.

Table C.2. Fish densities in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, September 1994

Unless otherwise stated, measurement expressed in number per square meter

	Sites[a]				
Species[b]	BBK9.1	BBK10.0	BBK12.5	LUK7.2	MAK13.8
Stoneroller	0.56	4.43	1.53	0.67	1.93
Red shiner	–	–	0.06	0.63	<0.01
Steelcolor shiner[c]	–	–	–	–	0.02
Miss. silvery minnow	–	–	–	–	0.17
Ribbon shiner[c]	0.01	–	–	–	<0.01
Redfin shiner[c]	0.06	–	0.05	–	0.08
Golden shiner	–	–	–	–	<0.01
Suckermouth minnow	–	–	–	0.01	–
Bluntnose minnow	–	0.01	0.13	0.88	0.12
Creek chub	–	0.01	0.35	1.34	0.38
White sucker	<0.01	–	<0.01	–	0.02
Creek chubsucker	0.01	0.01	0.04	–	0.30
Bigmouth buffalo	<0.01	–	–	–	–
Spotted sucker	<0.01	–	–	–	0.01
Golden redhorse	–	–	–	–	0.08
Black bullhead	<0.01	–	–	–	–
Yellow bullhead	0.01	0.03	0.05	0.09	0.07
Pirate perch	–	–	–	–	0.01
Blackspotted topminnow	0.10	0.38	0.90	0.12	0.60
Western mosquitofish	0.01	0.01	–	0.02	0.28
Green sunfish	0.06	0.01	0.10	–	0.24
Warmouth	–	–	<0.01	–	<0.01
Bluegill	0.08	0.03	0.04	–	0.19
Longear sunfish	0.27	0.61	0.96	–	1.20
Hybrid sunfish		–	–	–	0.01
Spotted bass	0.01	0.04	0.05	–	0.02
Largemouth bass	0.01	<0.01	<0.01	–	–
Slough darter	–	–	–	–	<0.01
Logperch	–	–	–	–	<0.01
Blackside darter	–	–	–	–	0.01
Total density	1.19	5.57	4.26	3.76	5.74
STREAM TEMPERATURE[d]					
MONTHLY MEAN	25.74	26.11	21.57	23.87	22.35
PRIOR WEEKLY MEAN	25.62	26.01	20.36	23.58	21.82
PRIOR WEEKLY MAX	28.60	29.65	24.03	26.73	24.56
SAMPLE DATE MEAN	26.08	25.91	21.24	24.22	21.88

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.

[c]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

[d]Temperatures expressed in degrees Celcius.

Table C.3. Fish densities in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, March 1995

Unless otherwise stated, measurement expressed in number per square meter

Species[b]	Sites[a]				
	BBK9.1	BBK10.0	BBK12.5	LUK7.2	MAK13.8
Stoneroller	0.07	0.73	1.85	0.21	0.63
Red shiner	–	–	0.05	1.26	–
Steelcolor shiner[c]	–	–	–	–	0.01
Redfin shiner[c]	<0.01	0.02	0.13	0.10	0.25
Golden shiner	–	–	–	0.01	–
Bluntnose minnow	–		0.24	0.27	0.24
Creek chub	–	0.01	0.50	0.14	0.15
White sucker	<0.01	–	–	–	<0.01
Creek chubsucker	–	–	0.02	–	0.02
Spotted sucker	<0.01	–	–	–	–
Golden redhorse	<0.01	–	–	–	–
Yellow bullhead	<0.01	–	0.07	–	0.01
Pirate perch	–	–	–	–	<0.01
Blackspotted topminnow	0.02	0.03	0.15	0.13	0.18
Western mosquitofish	–	–	–	0.08	–
Green sunfish	0.02	<0.01	0.04	0.01	0.06
Warmouth	–	–	–	<0.01	<0.01
Bluegill	0.01	<0.01	0.02	<0.01	0.01
Longear sunfish	0.13	0.04	0.72	0.01	0.52
Hybrid sunfish	<0.01	–	–	–	–
Spotted bass	0.01	–	–	–	<0.01
Slough darter	–	–	–	0.01	<0.01
Logperch	–	–	–	–	<0.01
Blackside darter	–	–	–	–	<0.01
Total density	0.27	0.83	3.79	2.23	2.09
STREAM TEMPERATURE[d]					
MONTHLY MEAN	8.00	7.61	5.92	7.27	6.34
PRIOR WEEKLY MEAN	8.93	8.07	6.71	8.46	7.24
PRIOR WEEKLY MAX	12.30	12.50	11.80	14.00	10.50
SAMPLE DATE MEAN	13.74	14.88	13.76	14.54	16.46

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[d]Temperatures expressed in degrees Celcius.

Table C.4. Fish densities in Big Bayou Creek, Little Bayou Creek, and a reference stream, Massac Creek, September 1995

Unless otherwise stated, measurement expressed in number per square meter

Species[b]	Sites[a]				
	BBK9.1	BBK10.0	BBK12.5	LUK7.2	MAK13.8
Gizzard shad	0.01	–	0.02	–	<0.01
Stoneroller	2.25	7.12	1.21	0.46	1.89
Red shiner	<0.01	–	–	0.64	–
Steelcolor shiner[c]	–	–	–	–	0.07
Common carp	<0.01	–	–	–	0.01
Miss. silvery minnow	0.05	<0.01	–	0.01	0.43
Ribbon shiner	–	–	–	0.02	0.07
Redfin shiner[c]	0.02	–	0.03	0.04	0.09
Golden shiner	<0.01	–	–	0.01	–
Suckermouth minnow	–	–	–	0.02	–
Bluntnose minnow	0.03	<0.01	0.21	1.68	0.22
Fathead minnow	–	–	<0.01	–	–
Creek chub	0.14	0.11	0.38	0.74	0.13
White sucker	–	–	0.01	–	0.01
Creek chubsucker	0.01	<0.01	0.02	–	0.25
Bigmouth buffalo	<0.01	–	–	–	–
Spotted sucker	0.01	–	–	–	<0.01
Golden redhorse	–	–	–	–	0.01
Yellow bullhead	0.02	0.02	0.12	0.23	0.02
Pirate perch	<0.01	–	<0.01	0.01	0.02
Blackspotted topminnow	0.23	0.33	0.36	0.24	0.34
Western mosquitofish	0.08	0.31	0.08	0.83	0.04
Green sunfish	0.04	0.08	0.27	0.06	0.19
Bluegill	0.04	0.03	0.04	0.01	0.07
Longear sunfish	0.50	0.40	0.46	0.02	0.80
Redspotted sunfish[c]	–	–	–	<0.01	–
Hybrid sunfish	<0.01	–	<0.01	–	<0.01
Spotted bass	0.01	0.01	–	–	<0.01
Largemouth bass	<0.01	0.03	0.03	0.01	0.01
White crappie	<0.01	–	–	–	–
Slough darter	–	–	–	0.06	–
Logperch	–	<0.01	–	–	0.06
Blackside darter	–	–	–	–	0.02
Total density	3.45	8.44	3.21	5.09	5.14
STREAM TEMPERATURE[d]					
MONTHLY MEAN	27.66	27.79	23.62	26.47	23.51
PRIOR WEEKLY MEAN	24.73	25.60	21.13	24.47	21.36
PRIOR WEEKLY MAXIMUM	28.30	28.30	23.70	26.40	24.50
SAMPLE DATE MEAN	24.00	25.83	22.02	25.33	25.26

[a]BBK = Big Bayou Creek kilometer, LUK = Little Bayou Creek kilometer, MAK = Massac Creek kilometer.

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991) and Etnier and Starnes (1993). For complete references, see Sect. 7 of this document.

[c]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

[d]Temperatures expressed in degrees Celcius.

Table C.5. Species composition, number of specimens, and catch per unit effort of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek,[a] November 1993
Unless otherwise stated, measurement expressed in number per square meter

Species[b]	LUK 9.2[c]	BBK 9.4[d]	K001[e]	BBK10.4
Clupeidae				
Gizzard shad (*Dorosoma cepedianum*)	–	3	1	NS[f]
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	7	430	59	
Red shiner (*Cyprinella lutrensis*)	17	2	2	
Ribbon shiner (*Lythrurus fumeus*)[g]	–	1	–	
Suckermouth minnow (*Phenacobius mirabilis*)	8	–	2	
Bluntnose minnow (*Pimephales notatus*)	33	–	–	
Creek chub (*Semotilus atromaculatus*)	5	–	–	
Catostomidae				
Creek chubsucker (*Erimyzon oblongus*)	–	–	3	
Ictaluridae				
Yellow bullhead (*Ameiurus natalis*)	6	2	4	
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	42	16	11	
Poeciliidae				
Western mosquitofish (*Gambusia affinis*)	20	–	–	
Centrarchidae				
Green sunfish (*Lepomis cyanellus*)	24	36	60	
Bluegill (*Lepomis macrochirus*)	–	9	3	
Longear sunfish (*Lepomis megalotis*)	20	118	17	
Orangespotted sunfish (*Lepomis humilis*)[g]	–	1	–	
Hybrid sunfish (*Lepomis*)	–	1	–	
Spotted bass (*Micropterus punctulatus*)	3	8	2	
Percidae				
Slough darter (*Etheostoma gracile*)	1	–	–	
TOTAL SPECIMENS	186	627	164	
TOTAL SPECIES	12	11	11	
CATCH/UNIT EFFORT[h]	4.77	10.45	5.13	
STREAM TEMPERATURE[i]				
MONTHLY MEAN	20.49	NS	19.81	
PRIOR WEEKLY MEAN	18.95		18.57	
PRIOR WEEKLY MAXIMUM	21.30		23.39	
SAMPLE DATE MEAN	14.88		13.99	

[a]Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Outfall 001 (K001).
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]One electrofisher used for 90 m and 39 min.
[d]One electrofisher used for 119 m and 60 min.
[e]One electrofisher used for 87 m and 32 min.
[f]NS = not sampled during this sample period.
[g]Species identification confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[h]Catch per unit effort is number of fish per minute of electrofishing.
[i]Temperatures expressed in degrees Celcius.

Table C.6. Species composition, number of specimens, and catch per unit effort of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek,[a] March 1994
Unless otherwise stated, measurement expressed in number per square meter

Species[b]	LUK 9.2[c]	BBK 9.4[d]	K001[e]	BBK10.4
Clupeidae				
Gizzard shad (*Dorosoma cepedianum*)	–	–	–	NS[f]
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	1	87	87	
Red shiner (*Cyprinella lutrensis*)	3	–	1	
Ribbon shiner (*Lythrurus fumeus*)[g]	–	1	–	
Golden shiner (*Notemigonus crysoleucas*)[g]	–	–	9	
Suckermouth minnow (*Phenacobius mirabilis*)	–	3	4	
Bluntnose minnow (*Pimephales notatus*)	5	–	–	
Creek chub (*Semotilus atromaculatus*)	–	–	3	
Catostomidae				
Creek chubsucker (*Erimyzon oblongus*)	1	–	3	
Ictaluridae				
Yellow bullhead (*Ameiurus natalis*)	1	3	1	
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	17	3	3	
Centrarchidae				
Green sunfish (*Lepomis cyanellus*)	10	21	16	
Bluegill (*Lepomis macrochirus*)	–	3	–	
Longear sunfish (*Lepomis megalotis*)	4	22	5	
Hybrid sunfish (*Lepomis*)	–	2	–	
Percidae				
Slough darter (*Etheostoma gracile*)	3	–	–	
TOTAL SPECIMENS	45	147	132	
TOTAL SPECIES	9	8	10	
CATCH/UNIT EFFORT[h]	1.41	5.65	4.89	
STREAM TEMPERATURE[i]				
MONTHLY MEAN	12.01[j]	NS	9.58[k]	
PRIOR WEEKLY MEAN	13.18		9.18	
PRIOR WEEKLY MAXIMUM	17.22		12.70	
SAMPLE DATE MEAN	13.59		13.81	

[a]Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Outfall 001 (K001).
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]One electrofisher used for 65 m and 32 min.
[d]One electrofisher used for 80 m and 26 min.
[e]One electrofisher used for 89 m and 27 min.
[f]NS = not sampled during this sample period.
[g]Species identification were confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[h]Catch per unit effort is number of fish per minute of electrofishing.
[i]Temperatures expressed in degrees Celcius.
[j]Sampled during week of March 22–23.
[k]Sampled during week of March 6–7.

Table C.7. Species composition, number of specimens, and catch per unit effort of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek,[a] May 1994
Unless otherwise stated, measurement expressed in number per square meter

Species[b]	LUK 9.2[c]	BBK 9.4[d]	K001[e]	BBK10.4
Clupeidae				
Gizzard shad (*Dorosoma cepedianum*)	–	5	–	NS[f]
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	–	321	22	
Grass carp (*Ctenopharyngodon idella*)	–	1	–	
Red shiner (*Cyprinella lutrensis*)	–	1	2	
Suckermouth minnow (*Phenacobius mirabilis*)	–	–	2	
Catostomidae				
Black buffalo (*Ictiobus niger*)	–	1	–	
Spotted sucker (*Minytrema melanops*)	1	2	–	
Ictaluridae				
Yellow bullhead (*Ameiurus natalis*)	1	6	8	
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	3	3	1	
Centrarchidae				
Flier (*Centrarchus macropterus*)	–	1	–	
Green sunfish (*Lepomis cyanellus*)	4	67	43	
Warmouth (*Lepomis gulosus*)	5	–	–	
Bluegill (*Lepomis macrochirus*)	2	79	19	
Longear sunfish (*Lepomis megalotis*)	4	130	10	
Hybrid sunfish (*Lepomis*)	–	–	4	
Spotted bass (*Micropterus punctulatus*)	1	7	–	
Largemouth bass (*Micropterus salmoides*)	–	1	–	
TOTAL SPECIMENS	21	625	111	
TOTAL SPECIES	8	14	8	
CATCH/UNIT EFFORT[h]	1.11	14.20	3.96	
STREAM TEMPERATURE[i]				
MONTHLY MEAN	17.68	NS	20.92	
PRIOR WEEKLY MEAN	20.34		22.71	
PRIOR WEEKLY MAXIMUM	25.09		27.44	
SAMPLE DATE MEAN	20.41		24.41	

[a]Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Outfall 001 (K001).
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]One electrofisher used for 71 m and 19 min.
[d]Two electrofishers used for 116 m and 44 min.
[e]One electrofisher used for 87 m and 28 min.
[f]NS = not sampled during this sample period.
[g]Species identification were confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[h]Catch per unit effort is number of fish per minute of electrofishing.
[i]Temperatures expressed in degrees Celcius.

Table C.8. Species composition, number of specimens, and catch per unit effort of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek,[a] August 1994
Unless otherwise stated, measurement expressed in number per square meter

Species[b]	LUK 9.2[c]	BBK 9.4[d]	K001[e]	BBK 10.4[f]
Clupeidae				
Gizzard shad (*Dorosoma cepedianum*)	–	2	–	–
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	–	305	14	407
Red shiner (*Cyprinella lutrensis*)	89	–	2	–
Golden shiner (*Notemigonus crysoleucas*)[g]	38	–	–	–
Bluntnose minnow (*Pimephales notatus*)	15	–	–	17
Creek chub (*Semotilus atromaculatus*)	3	–	–	74
Catostomidae				
Creek chubsucker (*Erimyzon oblongus*)	–	–	–	31
Bigmouth buffalo (*Ictiobus cyprinellus*)	–	7	–	1
Golden redhorse (*Moxostoma erythrurum*)	–	–	–	1
Ictaluridae				
Yellow bullhead (*Ameiurus natalis*)	–	3	–	21
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	4	11	1	45
Poeciliidae				
Western mosquitofish (*Gambusia affinis*)	39	–	–	108
Centrarchidae				
Green sunfish (*Lepomis cyanellus*)	–	55	20	18
Warmouth (*Lepomis gulosus*)	–	–	–	1
Bluegill (*Lepomis macrochirus*)	–	60	11	66
Longear sunfish (*Lepomis megalotis*)	3	91	3	262
Hybrid sunfish (*Lepomis*)	–	7	–	1
Spotted bass (*Micropterus punctulatus*)	–	16	5	15
White crappie (*Pomoxis annularis*)	–	–	–	1
TOTAL SPECIMENS	191	557	56	1067
TOTAL SPECIES	7	9	7	15
CATCH/UNIT EFFORT[h]	6.37	7.74	2.33	10.07
STREAM TEMPERATURE[i]				
MONTHLY MEAN	22.27[j]	27.78	28.90	25.78
PRIOR WEEKLY MEAN	21.66	27.62	28.19	24.98
PRIOR WEEKLY MAXIMUM	23.39	30.90	30.26	31.30
SAMPLE DATE MEAN	21.00	27.26	28.28	24.02

[a]Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Outfall 001 (K001).
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]One electrofisher used for 73 m and 30 min.
[d]Two electrofishers used for 130 m and 72 min.
[e]One electrofisher used for 100 m and 24 min.
[f]Two electrofishers used for 162 m and 106 min.
[g]Species identification were confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[h]Catch per unit effort is number of fish per minute of electrofishing.
[i]Temperatures expressed in degrees Celcius.
[j]Effluent had been rerouted through K010 during this sample period.

Table C.9. Species composition, number of specimens, and catch per unit effort of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek,[a] November 1994
Unless otherwise stated, measurement expressed in number per square meter

Species[b]	LUK 9.0[c]	BBK 9.4[d]	K001[e]	BBK 10.4[f]
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	–	218	184	615
Red shiner (*Cyprinella lutrensis*)	153	–	5	1
Redfin shiner (*Lythrurus umbratilis*)[g]	2	–	–	3
Golden shiner (*Notemigonus crysoleucas*)[g]	–	–	–	1
Bluntnose minnow (*Pimephales notatus*)	240	–	–	49
Creek chub (*Semotilus atromaculatus*)	6	–	–	20
Catostomidae				
White sucker (*Catostomus commersoni*)	–	–	–	3
Creek chubsucker (*Erimyzon oblongus*)	–	–	–	44
Bigmouth buffalo (*Ictiobus cyprinellus*)	–	3	–	–
Spotted sucker (*Minytrema melanops*)	–	4	–	–
Ictaluridae				
Black bullhead (*Ameiurus melas*)	–	1	–	–
Yellow bullhead (*Ameiurus natalis*)	3	1	1	14
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	5	18	3	94
Poeciliidae				
Western mosquitofish (*Gambusia affinis*)	98	1	–	59
Centrarchidae				
Green sunfish (*Lepomis cyanellus*)	3	51	28	14
Bluegill (*Lepomis macrochirus*)	2	25	7	43
Longear sunfish (*Lepomis megalotis*)	5	110	17	326
Hybrid sunfish (*Lepomis*)	–	4	1	–
Spotted bass (*Micropterus punctulatus*)	–	14	–	9
White crappie (*Pomoxis annularis*)	–	–	–	1
TOTAL SPECIMENS	517	450	246	1296
TOTAL SPECIES	10	11	7	16
CATCH/UNIT EFFORT[h]	22.48	7.26	8.20	12.0
STREAM TEMPERATURE[i]				
MONTHLY MEAN	19.86	19.33	19.94	15.25
PRIOR WEEKLY MEAN	19.26	16.44	17.23	12.40
PRIOR WEEKLY MAXIMUM	22.50	18.91	19.48	17.33
SAMPLE DATE MEAN	NM[j]	NM	17.27	14.80

[a]Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Outfall 001 (K001).
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]One electrofisher used for 75 m and 23 min.
[d]Two electrofishers used for 131 m and 62 min.
[e]One electrofisher used for 90 m and 30 min.
[f]Two electrofishers used for 162 m and 108 min.
[g]Species identification were confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[h]Catch per unit effort is number of fish per minute of electrofishing.
[i]Temperatures expressed in degrees Celcius.
[j]NM = not measured at this date.

Table C.10. Species composition, number of specimens, and catch per unit effort of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek,[a] March 1995

Unless otherwise stated, measurement expressed in number per square meter

Species[b]	LUK 9.0[c]	BBK 9.4[d]	K001[e]	BBK 10.4[f]
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	–	241	269	197
Red shiner (*Cyprinella lutrensis*)	217	1	–	3
Redfin shiner (*Lythrurus umbratilis*)[g]	2	3	1	29
Golden shiner (*Notemigonus crysoleucas*)[g]	41	2	3	–
Bluntnose minnow (*Pimephales notatus*)	525	1	–	56
Creek chub (*Semotilus atromaculatus*)	1	12	1	32
Catostomidae				
White sucker (*Catostomus commersoni*)	–	1	–	–
Creek chubsucker (*Erimyzon oblongus*)	1	5	–	8
Ictaluridae				
Yellow bullhead (*Ameiurus natalis*)	5	3	1	11
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	28	7	4	86
Poeciliidae				
Western mosquitofish (*Gambusia affinis*)	50	–	–	–
Centrarchidae				
Green sunfish (*Lepomis cyanellus*)	43	11	9	6
Warmouth (*Lepomis gulosus*)	6	–	–	–
Bluegill (*Lepomis macrochirus*)	9	9	4	15
Longear sunfish (*Lepomis megalotis*)	52	35	1	399
Hybrid sunfish (*Lepomis*)	–	1	1	–
Largemouth bass (*Micropterus salmoides*)	–	–	–	1
Percidae				
Slough darter (*Etheostoma gracile*)	–	–	1	–
TOTAL SPECIMENS	980	332	295	843
TOTAL SPECIES	13	13	10	12
CATCH/UNIT EFFORT[h]	33.79	6.38	10.54	7.39
STREAM TEMPERATURE[i]				
MONTHLY MEAN	9.50	NM[j]	10.18	5.74
PRIOR WEEKLY MEAN	9.59	10.50	11.98	6.92
PRIOR WEEKLY MAXIMUM	14.70	14.10	14.40	12.00
SAMPLE DATE MEAN	17.15	NM	15.56	13.73

[a]Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Outfall 001 (K001).
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]One electrofisher used for 72 m and 29 min.
[d]Two electrofishers used for 136 m and 52 min.
[e]One electrofisher used for 104 m and 28 min.
[f]Two electrofishers used for 150 m and 114 min.
[g]Species identification were confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[h]Catch per unit effort is number of fish per minute of electrofishing.
[i]Temperatures expressed in degrees Celcius.
[j]NM = not measured on this date.

Table C.11. Species composition, number of specimens, and catch per unit effort of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek,[a] May 1995

Unless otherwise stated, measurement expressed in number per square meter

Species[b]	LUK 9.0[c]	BBK 9.4[d]	K001[e]	BBK 10.4[f]
Clupeidae				
Gizzard shad (*Dorosoma cepedianum*)	–	1	–	–
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	–	106	74	101
Red shiner (*Cyprinella lutrensis*)	82	–	–	–
Redfin shiner (*Lythrurus umbratilis*)[g]	–	–	–	4
Golden shiner (*Notemigonus crysoleucas*)[g]	5	–	–	–
Bluntnose minnow (*Pimephales notatus*)	99	–	–	28
Creek chub (*Semotilus atromaculatus*)	–	1	2	25
Catostomidae				
Creek chubsucker (*Erimyzon oblongus*)	1	–	–	3
Bigmouth buffalo (*Ictiobus cyprinellus*)	–	2	–	–
Spotted sucker (*Minytrema melanops*)	–	1	–	–
Ictaluridae				
Black bullhead (*Ameiurus melas*)	–	–	–	1
Yellow bullhead (*Ameiurus natalis*)	3	3	1	2
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	43	3	1	33
Poeciliidae				
Western mosquitofish (*Gambusia affinis*)	14	–	–	–
Centrarchidae				
Green sunfish (*Lepomis cyanellus*)	32	10	6	14
Warmouth (*Lepomis gulosus*)	1	–	–	–
Bluegill (*Lepomis macrochirus*)	11	35	8	31
Longear sunfish (*Lepomis megalotis*)	12	44	4	322
Hybrid sunfish (*Lepomis*)	–	1	1	1
Spotted bass (*Micropterus punctulatus*)	–	1	–	5
Largemouth bass (*Micropterus salmoides*)	–	–	–	1
TOTAL SPECIMENS	303	208	97	571
TOTAL SPECIES	11	11	7	13
CATCH/UNIT EFFORT[h]	9.18	3.85	6.06	5.83
STREAM TEMPERATURE[i]				
MONTHLY MEAN	19.10	18.78	20.33	16.17
PRIOR WEEKLY MEAN	21.87	20.86	21.55	17.71
PRIOR WEEKLY MAXIMUM	26.10	24.10	24.60	21.70
SAMPLE DATE MEAN	23.48	NM[j]	24.79	21.38

[a]Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Outfall 001 (K001).
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]One electrofisher used for 66 m and 33 min.
[d]Two electrofishers used for 126 m and 54 min.
[e]One electrofisher used for 90 m and 16 min.
[f]Two electrofishers used for 165 m and 98 min.
[g]Species identification were confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[h]Catch per unit effort is number of fish per minute of electrofishing.
[i]Temperatures expressed in degrees Celcius.
[j]NM = not measured on this date.

Table C.12. Species composition, number of specimens, and catch per unit effort of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek,[a] July 1995

Unless otherwise stated, measurement expressed in number per square meter

Species[b]	LUK 9.0[c]	BBK 9.4[d]	K001[e]	BBK 10.4[f]
Clupeidae				
Gizzard shad (*Dorosoma cepedianum*)	–	7	–	1
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	–	769	64	1142
Red shiner (*Cyprinella lutrensis*)	19	–	–	1
Common carp (*Cyprinus carpio*)	–	–	3	–
Mississippi silvery minnow (*Hybognathus nuchalis*)	–	2	–	–
Redfin shiner (*Lythrurus umbratilis*)	–	–	–	1
Golden shiner (*Notemigonus crysoleucas*)[g]	3	3	6	–
Bluntnose minnow (*Pimephales notatus*)	10	–	–	12
Creek chub (*Semotilus atromaculatus*)	–	56	2	58
Catostomidae				
White Sucker (*Catostomus commersoni*)	–	1	–	1
Creek chubsucker (*Erimyzon oblongus*)	–	2	–	10
Ictaluridae				
Black bullhead (*Ameiurus melas*)	–	–	–	1
Yellow bullhead (*Ameiurus natalis*)	11	–	7	3
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	5	12	3	26
Poeciliidae				
Western mosquitofish (*Gambusia affinis*)	22	1	–	16
Centrarchidae				
Flier (*Centrarchus macropterus*)	–	–	–	1
Green sunfish (*Lepomis cyanellus*)	9	13	8	19
Warmouth (*Lepomis gulosus*)	–	–	–	–
Bluegill (*Lepomis macrochirus*)	1	43	11	8
Longear sunfish (*Lepomis megalotis*)	3	116	6	232
Redear sunfish (*Lepomis microlophus*)	–	–	–	3
Spotted bass (*Micropterus punctulatus*)	–	9	–	–
Largemouth bass (*Micropterus salmoides*)	1	5	1	10
TOTAL SPECIMENS	84	1039	112	1545
TOTAL SPECIES	10	14	10	18
CATCH/UNIT EFFORT[h]	3.50	12.99	2.73	13.79
STREAM TEMPERATURE[i]				
MONTHLY MEAN	29.62	28.58	29.63	25.69
PRIOR WEEKLY MEAN	31.62	30.56	31.50	28.37
PRIOR WEEKLY MAXIMUM	34.10	34.10	34.80	34.70
SAMPLE DATE MEAN	28.28	28.88	28.52	26.23

[a]Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Outfall 001 (K001).

[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.

[c]One electrofisher used for 66 m and 24 min.

[d]Two electrofishers used for 132 m and 80 min.

[e]One electrofisher used for 87 m and 41 min.

[f]Two electrofishers used for 129 m and 112 min.

[g]Species identification were confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.

[h]Catch per unit effort is number of fish per minute of electrofishing.

[i]Temperatures expressed in degrees Celcius.

Table C.13. Species composition, number of specimens, and catch per unit effort of the qualitative fish sampling conducted in Big Bayou Creek and Little Bayou Creek,[a] November 1995

Unless otherwise stated, measurement expressed in number per square meter

Species[b]	LUK 9.0[c]	BBK 9.4[d]	K001[e]	BBK 10.4[f]
Clupeidae				
Gizzard shad (*Dorosoma cepedianum*)	–	1	–	–
Cyprinidae				
Stoneroller (*Campostoma anomalum*)	–	608	362	790
Red shiner (*Cyprinella lutrensis*)	20	–	–	–
Steelcolor shiner (*Cyprinella whipplei*)	–	1	–	–
Common carp (*Cyprinus carpio*)	–	4	2	–
Redfin shiner (*Lythrurus umbratilis*)[g]	–	–	–	2
Golden shiner (*Notemigonus crysoleucas*)[g]	–	1	3	3
Suckermouth minnow (*Phenacobius mirabilis*)	–	–	–	–
Bluntnose minnow (*Pimephales notatus*)	–	1	2	18
Creek chub (*Semotilus atromaculatus*)	–	1	30	35
Catostomidae				
Creek chubsucker (*Erimyzon oblongus*)	–	1	–	14
Ictaluridae				
Yellow bullhead (*Ameiurus natalis*)	–	2	–	11
Aphredoderidae				
Pirate perch (*Aphredoderus sayanus*)	–	–	–	1
Cyprinodontidae				
Blackspotted topminnow (*Fundulus olivaceus*)	23	21	4	101
Poeciliidae				
Western mosquitofish (*Gambusia affinis*)	61	55	–	117
Centrarchidae				
Green sunfish (*Lepomis cyanellus*)	52	22	11	8
Warmouth (*Lepomis gulosus*)	3	–	–	–
Bluegill (*Lepomis macrochirus*)	–	35	5	14
Longear sunfish (*Lepomis megalotis*)	3	119	8	373
Redear sunfish (*Lepomis microlophus*)	–	–	–	4
Hybrid sunfish (*Lepomis*)	–	–	–	1
Spotted bass (*Micropterus punctulatus*)	–	1	–	2
Largemouth bass (*Micropterus salmoides*)	1	3	–	2
Percidae				
Slough darter (*Etheostoma gracile*)	6	–	–	–
TOTAL SPECIMENS	169	876	427	1496
TOTAL SPECIES	8	16	9	16
CATCH/UNIT EFFORT[h]	9.94	10.95	17.79	15.58
STREAM TEMPERATURE[i]				
MONTHLY MEAN	19.52	16.36	16.88	12.87
PRIOR WEEKLY MEAN	15.92	12.89	13.50	8.54
PRIOR WEEKLY MAXIMUM	18.40	14.60	15.70	14.50
SAMPLE DATE MEAN	13.50	11.83	12.15	7.89

[a]Big Bayou Creek kilometer (BBK), Little Bayou Creek kilometer (LUK), and Outfall 001 (K001).
[b]Common and scientific names according to the American Fisheries Society (Robins et al. 1991). For a complete reference, see Sect. 7 of this document.
[c]One electrofisher used for 83 m and 17 min.
[d]Two electrofishers used for 127 m and 80 min.
[e]One electrofisher used for 91 m and 24 min.
[f]Two electrofishers used for 127 m and 96 min.
[g]Species identification were confirmed by Dr. David A. Etnier, Department of Zoology, University of Tennessee.
[h]Catch per unit effort is number of fish per minute of electrofishing.
[i]Temperatures expressed in degrees Celcius.

Appendix D

PROCEDURES AND RESULTS OF FOUR THERMAL TOLERANCE EXPERIMENTS CONDUCTED ON REDFIN SHINERS (*LYTHRURUS UMBRATILIS*) AND CENTRAL STONEROLLERS (*CAMPOSTOMA ANOMALUM*) USING OUTFALL K001 AND MASSAC CREEK WATER, JULY 1995

Table D.1. Basket rotation chart for the test fish of the ROL/MAC,[a] RED/001,[b] and ROL/001[c] thermal tolerance experiments conducted July 1995

Basket Number

	1	2	3	4	5	6	7	8	9	10
H[d] 1	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
H 2	B2	B3	B4	B5	B6	B7	B8	B9	B10	B1
H 3	A3	A4	A5	A6	A7	A8	A9	A10	A1	A2
H 4	B4	B5	B6	B7	B8	B9	B10	B1	B2	B3
H 5	A5	A6	A7	A8	A9	A10	A1	A2	A3	A4
H 6	B6	B7	B8	B9	B10	B1	B2	B3	B4	B5
H 7	A7	A8	A9	A10	A1	A2	A3	A4	A5	A6
H 8	B8	B9	B10	B1	B2	B3	B4	B5	B6	B7
H 9	A9	A10	A1	A2	A3	A4	A5	A6	A7	A8
H 10	B10	B1	B2	B3	B4	B5	B6	B7	B8	B9
H 11	A10	A1	A2	A3	A4	A5	A6	A7	A8	A9
H 12	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
H 13	A2	A3	A4	A5	A6	A7	A8	A9	A10	A1
H 14	B3	B4	B5	B6	B7	B8	B9	B10	B1	B2
H 15	A4	A5	A6	A7	A8	A9	A10	A1	A2	A3

[a]ROL/MAC = Central stoneroller / Massac Creek water
[b]RED/001 = Redfin shiner / Outfall 001
[c]ROL/001 = Central stoneroller / Outfall 001
[d]H = hour

Note: Letters within chart designate water bath "A" or "B" and numbers within chart designate aquarium numbers.

Table D.2. Basket rotation charts for the control fish of the four thermal tolerance experiments and the test fish of the RED/MAC[a] thermal tolerance experiment conducted July 1995

Controls (all experiments)

Basket Number	11	12	13	14
H[b] 1	C1	C2	C3	C4
H 2	D2	D3	D4	D1
H 3	C3	C4	C1	C2
H 4	D4	D1	D2	D3
H 5	C2	C3	C4	C1
H 6	D1	D2	D3	D4
H 7	C4	C1	C2	C3
H 8	D3	D4	D1	D2
H 9	C1	C2	C3	C4
H 10	D2	D3	D4	D1
H 11	C3	C4	C1	C2
H 12	D4	D1	D2	D3
H 13	C2	C3	C4	C1
H 14	D1	D2	D3	D4
H 15	C4	C1	C2	C3

RED/MAC experiment

Basket Number	1	2	3	4
H 1	A1	A2	A3	A4
H 2	B2	B3	B4	B1
H 3	A3	A4	A1	A2
H 4	B4	B1	B2	B3
H 5	A2	A3	A4	A5
H 6	B1	B2	B3	B4
H 7	A4	A1	A2	A3
H 8	B3	B4	B1	B2
H 9	A1	A2	A3	A4
H 10	B2	B3	B4	B1
H 11	A3	A4	A1	A2
H 12	B4	B1	B2	B3
H 13	A2	A3	A4	A1
H 14	B1	B2	B3	B4

[a]RED/MAC = Redfin shiner / Massac Creek water
[b]H = hour
Note: All control fish were in a water bath designated "C", which contained aquaria labeled C1–C4 and D1–D4. The "A" and "B" letters within the RED/MAC chart designate the water bath, and numbers within both charts designate aquarium numbers.

Table D.3. Summary results of four thermal tolerance experiments conducted July 1995 on two fish species in two types of water, McCracken County, Kentucky

	Redfin Shiner[a] Massac water[c] (RED/MAC)	C. Stoneroller[b] Massac water (ROL/MAC)	Redfin Shiner Outfall water[d] (RED/001)	C. Stoneroller Outfall water (ROL/001)
[e]N (minus control)[a]	20	98	92	50
[f]Mean K^{test}	0.7575	0.9832	0.7925	0.9421
Min K^{test}	0.5814	0.7950	0.6084	0.7397
Max K^{test}	0.8998	1.2701	0.9986	1.1852
Std Dev^{test} (of mean K)	0.0803	0.1056	0.0695	0.0859
[g]Mean TTD^{test} (min)	529.5	738.5	731.5	787.5
Temp (°C) at mean TTD^{test}	32.71	37.12	37.24	37.04
Min TTD^{test} (min)	158.0	109.0	275.0	237.0
Max TTD^{test} (min)	817.0	853.0	849.0	853.0
Std Dev^{test} (of mean TTD)	210.2	165.5	107.4	132.8
Median TTD^{test} (min)	526.5	799.5	771.5	834.0
[h]LT_{50}^{test} (°C)	32.71	38.07	37.24	38.19
[i]LT_{100}^{test} (°C)	37.27	38.99	38.93	38.78
N (control)	14	39	39	20
% Control mortality	43	15	15	5
Mean $K^{control}$	0.7192	0.9125	0.7598	0.9030
Min $K^{control}$	0.5407	0.7842	0.6039	0.7175
Max $K^{control}$	0.9118	1.2534	1.0277	1.0968
Std $Dev^{control}$ (of mean K)	0.0904	0.0903	0.0755	0.0878
Mean $TTD^{control}$ (min) of mortalities only	422.2	454.8	622.3	126.0
Temp (°C) at mean $TTD^{control}$	25.03	25.00	25.09	25.17
Min $TTD^{control}$ (min)	208.0	83.0	427.0	126.0
Max $TTD^{control}$ (min)	592.0	717.0	808.0	126.0
Std $Dev^{control}$ (of mean TTD)	127.6	264.6	130.0	–
Median $TTD^{control}$ (min)	434.5	494.5	615.0	–

[a]Redfin Shiner = *Lythrurus umbratilis*
[b]C. Stoneroller = Campostoma anomalum
[c]Massac water = From Massac Creek kilometer 13.8, McCracken County, Kentucky.
[d]Outfall water = From Outfall 001, Paducah Gaseous Diffusion Plant
[e]N = Number of fish
[f]K = Condition factor = $100(W/L^3)$; where W = weight in grams, L = length in centimeters
[g]TTD = Time to death
[h]LT_{50} = Median lethal temperature
[i]LT_{100} = Temperature at which 100% mortality occurs

Table D.4. Summary of temperature data[a] from the RED/MAC[b] thermal tolerance experiment conducted July 1995

Hour	Target Temp (°C)	Mean Adjusted[c] Temp (°C)	Diff. from Target (°C)	Mean Recorded[d] Temp (°C)	Minimum Recorded Temp (°C)	Maximum Recorded Temp (°C)	Std. Dev. Recorded Values	Fre-quency
1	25.0	24.91	−0.09	24.60	24.50	24.70	0.04	30
2	26.0	25.72	−0.28	25.28	25.10	25.40	0.09	30
3	27.0	27.18	+0.18	26.87	26.60	27.00	0.07	30
4	28.0	28.09	+0.09	27.65	27.20	27.80	0.12	30
5	29.0	29.03	+0.03	28.72	28.30	29.20	0.22	30
6	30.0	29.94	−0.06	29.50	29.10	29.70	0.21	30
7	31.0	30.79	−0.21	30.48	30.40	30.50	0.04	30
8	32.0	31.53	−0.47	31.09	30.70	31.30	0.19	30
9	33.0	32.71	−0.29	32.40	32.40	32.40	0	30
10	34.0	33.24	−0.76	32.80	32.70	33.00	0.08	30
11	35.0	34.52	−0.48	34.21	34.10	34.30	0.06	30
12	36.0	34.99	−1.01	34.55	34.30	34.90	0.15	30
13	37.0	36.49	−0.51	36.18	36.10	36.20	0.04	30
14	38.0	37.27	−0.73	36.83	36.70	37.00	0.08	19
1	25.0	24.85	−0.15	24.55	24.30	24.70	0.09	30
2	25.0	25.04	+0.04	24.74	24.60	24.90	0.09	30
3	25.0	25.07	+0.07	24.77	24.60	24.90	0.07	30
4	25.0	25.06	+0.06	24.76	24.60	24.80	0.08	30
5	25.0	25.05	+0.05	24.75	24.60	24.90	0.09	30
6	25.0	25.05	+0.05	24.75	24.60	24.90	0.09	30
7	25.0	25.02	+0.02	24.72	24.60	24.80	0.08	30
8	25.0	25.03	+0.03	24.73	24.60	24.80	0.09	30
9	25.0	25.08	+0.08	24.78	24.60	24.90	0.07	30
10	25.0	25.09	+0.09	24.79	24.60	24.90	0.06	30
11	25.0	25.10	+0.10	24.80	24.70	24.80	0.02	30
12	25.0	25.10	+0.10	24.80	24.60	24.90	0.05	30
13	25.0	25.11	+0.11	24.81	24.80	24.90	0.03	30
14	25.0	25.06	+0.06	24.76	24.60	24.80	0.08	19

[a]First half of table (above line) is for test aquaria; second half of table is for control aquaria.
[b]RED/MAC = Redfin shiner / Massac Creek water
[c]Adjusted temperature = Adjustment of the mean recorded temperature based on 54 measurements taken during the experiment with a National Institute of Standards and Technology (NIST)-traceable digital thermometer.
[d]Recorded temperature = Data from Ryan Instruments Ryan TempMentor (RTM) temperature recorder, 2 min logging interval.

Table D.5. Summary of temperature data[a] from the ROL/MAC[b] thermal tolerance experiment conducted July 1995

Hour	Target Temp (°C)	Mean Adjusted[c] Temp (°C)	Diff. from Target (°C)	Mean Recorded[d] Temp (°C)	Minimum Recorded Temp (°C)	Maximum Recorded Temp (°C)	Std. Dev. Recorded Values	Fre-quency
1	25.0	24.83	−0.17	24.54	24.30	24.60	0.09	30
2	26.0	26.11	+0.11	25.89	25.80	26.00	0.04	30
3	27.0	27.11	+0.11	26.82	26.70	26.90	0.08	30
4	28.0	28.16	+0.16	27.94	27.90	28.10	0.06	30
5	29.0	29.05	+0.05	28.76	28.70	28.80	0.05	30
6	30.0	30.22	+0.22	30.00	30.00	30.10	0.02	30
7	31.0	30.82	−0.18	30.53	30.50	30.70	0.06	30
8	32.0	32.09	+0.09	31.87	31.60	32.00	0.11	30
9	33.0	32.84	−0.16	32.55	32.40	32.80	0.15	30
10	34.0	33.81	−0.19	33.59	33.50	33.60	0.03	30
11	35.0	34.60	−0.40	34.31	34.30	34.40	0.03	30
12	36.0	36.18	+0.18	35.96	35.90	36.10	0.06	30
13	37.0	37.12	+0.12	36.83	36.80	36.90	0.05	30
14	38.0	38.07	+0.07	37.85	37.70	38.00	0.11	30
15	39.0	38.99	−0.01	38.70	38.70	38.70	0	7
1	25.0	25.03	+0.03	24.76	24.60	24.90	0.08	30
2	25.0	25.19	+0.19	24.92	24.80	25.00	0.06	30
3	25.0	25.06	+0.06	24.79	24.50	24.80	0.05	30
4	25.0	25.15	+0.15	24.88	24.80	25.00	0.07	30
5	25.0	25.18	+0.18	24.91	24.80	25.00	0.04	30
6	25.0	25.09	+0.09	24.82	24.80	25.00	0.05	30
7	25.0	25.03	+0.03	24.76	24.50	24.80	0.08	30
8	25.0	25.00	0	24.73	24.50	24.80	0.07	30
9	25.0	25.05	+0.05	24.78	24.50	24.80	0.06	30
10	25.0	25.06	+0.06	24.79	24.50	24.80	0.06	30
11	25.0	25.07	+0.07	24.80	24.70	24.90	0.03	30
12	25.0	25.01	+0.01	24.74	24.50	24.80	0.10	30
13	25.0	25.01	+0.01	24.74	24.50	24.80	0.10	30
14	25.0	25.05	+0.05	24.78	24.60	24.80	0.05	30
15	25.0	25.01	+0.01	24.74	24.70	24.80	0.05	7

[a]First half of table (above line) is for test aquaria; second half of table is for control aquaria.
[b]ROL/MAC = Central stoneroller / Massac Creek water
[c]Adjusted temperature = Adjustment of the mean recorded temperature based on 57 measurements taken during the experiment with a National Institute of Standards and Technology (NIST)-traceable digital thermometer.
[d]Recorded temperature = Data from Ryan Instruments Ryan TempMentor (RTM) temperature recorder, 2 min logging interval.

Table D.6. Summary of temperature data[a] from the RED/001[b] thermal tolerance experiment conducted July 1995

Hour	Target Temp (°C)	Mean Adjusted[c] Temp (°C)	Diff. from Target (°C)	Mean Recorded[d] Temp (°C)	Minimum Recorded Temp (°C)	Maximum Recorded Temp (°C)	Std. Dev. Recorded Values	Fre-quency
1	25.0	25.10	+0.10	24.74	24.70	24.90	0.07	30
2	26.0	25.89	−0.11	25.69	25.30	25.90	0.16	30
3	27.0	27.30	+0.30	26.94	26.80	27.10	0.11	30
4	28.0	27.99	−0.01	27.79	27.70	27.90	0.07	30
5	29.0	29.09	+0.09	28.73	28.60	28.90	0.07	30
6	30.0	30.17	+0.17	29.97	29.70	30.20	0.12	30
7	31.0	31.15	+0.15	30.79	30.70	30.90	0.06	30
8	32.0	32.16	+0.16	31.96	31.80	32.20	0.08	30
9	33.0	32.99	−0.01	32.63	32.40	32.80	0.11	30
10	34.0	34.01	+0.01	33.81	33.70	34.00	0.07	30
11	35.0	34.90	−0.10	34.54	34.50	34.70	0.06	30
12	36.0	36.33	+0.33	36.13	35.90	36.20	0.08	30
13	37.0	37.24	+0.24	36.88	36.80	36.90	0.04	30
14	38.0	38.35	+0.35	38.15	37.70	38.30	0.13	30
15	39.0	38.93	−0.07	38.57	38.50	38.90	0.13	10
1	25.0	25.09	+0.09	24.82	24.60	25.00	0.11	30
2	25.0	25.21	+0.21	24.94	24.80	25.00	0.06	30
3	25.0	25.22	+0.22	24.95	24.80	25.00	0.06	30
4	25.0	25.24	+0.24	24.97	24.90	25.00	0.05	30
5	25.0	25.12	+0.12	24.85	24.80	25.00	0.07	30
6	25.0	25.05	+0.05	24.78	24.60	24.90	0.09	30
7	25.0	25.06	+0.06	24.79	24.60	24.90	0.05	30
8	25.0	25.07	+0.07	24.80	24.60	24.90	0.06	30
9	25.0	25.09	+0.09	24.82	24.70	25.00	0.06	30
10	25.0	25.07	+0.07	24.80	24.60	24.90	0.06	30
11	25.0	25.09	+0.09	24.82	24.60	25.00	0.09	30
12	25.0	25.06	+0.06	24.79	24.60	24.90	0.08	30
13	25.0	25.09	+0.09	24.82	24.80	25.00	0.05	30
14	25.0	25.05	+0.05	24.78	24.60	25.00	0.09	30
15	25.0	25.09	+0.09	24.82	24.80	24.90	0.04	11

[a]First half of table (above line) is for test aquaria; second half of table is for control aquaria.

[b]RED/001 = Redfin shiner / Outfall 001 water

[c]Adjusted temperature = Adjustment of the mean recorded temperature based on 58 measurements taken during the experiment with a National Institute of Standards and Technology (NIST)-traceable digital thermometer.

[d]Recorded temperature = Data from Ryan Instruments Ryan TempMentor (RTM) temperature recorder, 2 min logging interval.

Table D.7. Summary of temperature data[a] from the ROL/001[b] thermal tolerance experiment conducted July 1995

Hour	Target Temp (°C)	Mean Adjusted[c] Temp (°C)	Diff. from Target (°C)	Mean Recorded[d] Temp (°C)	Minimum Recorded Temp (°C)	Maximum Recorded Temp (°C)	Std. Dev. Recorded Values	Fre-quency
1	25.0	24.87	−0.13	24.59	24.30	24.70	0.08	30
2	26.0	26.04	+0.04	25.80	25.70	26.00	0.07	30
3	27.0	27.08	+0.08	26.80	26.60	26.90	0.09	30
4	28.0	28.14	+0.14	27.90	27.70	28.10	0.08	30
5	29.0	28.89	−0.11	28.61	28.50	28.80	0.09	30
6	30.0	30.08	+0.08	29.84	29.80	30.00	0.08	30
7	31.0	30.85	−0.15	30.57	30.50	30.80	0.07	30
8	32.0	32.00	0	31.76	31.60	31.90	0.09	30
9	33.0	32.73	−0.27	32.45	32.40	32.60	0.06	30
10	34.0	33.80	−0.20	33.56	33.20	33.60	0.09	30
11	35.0	34.58	−0.42	34.30	34.30	34.30	0	30
12	36.0	36.25	+0.25	36.01	35.90	36.20	0.04	30
13	37.0	37.04	+0.04	36.76	36.70	36.80	0.05	30
14	38.0	38.19	+0.19	37.95	37.70	38.00	0.10	30
15	39.0	38.78	−0.22	38.50	38.50	38.50	0	7
1	25.0	25.19	+0.19	25.00	25.00	25.10	0.02	30
2	25.0	25.13	+0.13	24.94	24.90	25.00	0.05	30
3	25.0	25.17	+0.17	24.98	24.90	25.00	0.04	30
4	25.0	25.18	+0.18	24.99	24.90	25.00	0.03	30
5	25.0	25.18	+0.18	24.99	24.80	25.00	0.04	30
6	25.0	25.19	+0.19	25.00	24.90	25.00	0.02	30
7	25.0	25.19	+0.19	25.00	24.90	25.00	0.02	30
8	25.0	25.19	+0.19	25.00	25.00	25.00	0	30
9	25.0	25.13	+0.13	24.94	24.80	25.00	0.06	30
10	25.0	25.08	+0.08	24.89	24.80	25.00	0.07	30
11	25.0	25.07	+0.07	24.88	24.80	25.00	0.07	30
12	25.0	25.03	+0.03	24.84	24.60	25.00	0.09	30
13	25.0	25.04	+0.04	24.85	24.80	25.00	0.06	30
14	25.0	25.08	+0.08	24.89	24.80	25.00	0.06	30
15	25.0	25.08	+0.08	24.89	24.80	24.90	0.04	7

[a]First half of table (above line) is for test aquaria; second half of table is for control aquaria.
[b]ROL/001 = Central stoneroller / Outfall 001 water
[c]Adjusted temperature = Adjustment of the mean recorded temperature based on 60 measurements taken during the experiment with a National Institute of Standards and Technology (NIST)-traceable digital thermometer.
[d]Recorded temperature = Data from Ryan Instruments Ryan TempMentor (RTM) temperature recorder, 2 min logging interval.

Table D.8. Summary of water chemistry data[a] from the RED/MAC[b] and ROL/MAC[c] thermal tolerance experiments conducted July 1995

RED/MAC Experiment				ROL/MAC Experiment			
Hour	Mean Do[d] (mg/L)	Mean pH[e]	NH_3-N[f]	Hour	Mean Do[d] (mg/L)	Mean pH[e]	NH_3-N[f]
1	6.8	7.80	0.103	1	6.3	7.85	0.080
2	6.6	7.83	NS[g]	2	6.3	7.92	NS
3	6.7	7.88	0.154	3	6.4	7.87	0.115
4	6.5	7.90	NS	4	6.1	7.86	NS
5	6.3	7.90	0.171	5	6.3	7.87	0.139
6	6.1	7.90	NS	6	6.3	7.87	NS
7	6.2	7.92	0.197	7	6.4	7.87	0.172
8	6.1	7.89	NS	8	6.3	7.93	NS
9	6.0	7.93	0.203	9	6.0	7.94	0.230
10	5.5	7.91	NS	10	5.9	7.95	NS
11	6.0	7.95	0.195	11	5.7	7.93	0.266
12	6.1	7.90	NS	12	5.8	7.90	NS
13	6.1	7.99	0.230	13	6.1	7.90	0.285
14	5.8	8.02	NS	14	5.7	7.94	NS
15	NS	NS	NS	15	NS	NS	NS
1	6.5	7.89	0.125	1	6.5	7.91	0.082
2	7.1	7.98	NS	2	6.6	7.97	NS
3	6.7	7.93	0.130	3	6.2	7.93	0.115
4	7.0	7.99	NS	4	6.7	7.99	NS
5	6.2	7.95	0.153	5	6.6	7.96	0.143
6	6.8	7.98	NS	6	6.8	7.98	NS
7	6.1	7.98	0.175	7	6.6	7.95	0.144
8	6.7	7.99	NS	8	7.0	8.01	NS
9	6.2	7.98	0.167	9	6.6	7.95	0.200
10	6.3	8.00	NS	10	6.8	8.03	NS
11	6.0	7.99	0.139	11	6.4	7.95	0.218
12	6.9	8.01	NS	12	6.4	7.97	NS
13	6.4	7.99	0.164	13	6.4	7.92	0.197
14	7.2	8.06	NS	14	6.4	7.95	NS
15	NS	NS	NS	15	NS	NS	NS

[a]First half of table (above line) is for test aquaria; second half of table is for control aquaria.
[b]RED/MAC = Redfin shiner / Massac Creek water
[c]ROL/MAC = Central stoneroller / Massac Creek water
[d]Mean DO = Mean of 2 dissolved oxygen concentration measurements per hour per aquarium
[e]Mean pH = Mean of 2 pH measurements per hour per aquarium
[f]NH_3-N = Total ammonia expressed as mg/L N. Grab sample from one aquarium.
[g]NS = Not sampled

Table D.9. Summary of water chemistry data[a] from the RED/001[b] and ROL/001[c] thermal tolerance experiments conducted July 1995

RED/001 Experiment				ROL/001 Experiment			
Hour	Mean Do[d] (mg/L)	Mean pH[e]	NH_3-N[f]	Hour	Mean Do[d] (mg/L)	Mean pH[e]	NH_3-N[f]
1	7.5	8.06	0.079	1	6.5	7.71	0
2	7.2	8.07	NS[g]	2	6.6	8.03	NS
3	7.2	8.01	0.134	3	6.5	7.75	0.038
4	7.2	7.97	NS	4	6.2	7.81	NS
5	6.5	7.98	0.115	5	6.4	7.81	0.110
6	6.8	7.99	NS	6	5.9	7.79	NS
7	6.1	7.92	0.164	7	6.1	7.78	0.108
8	6.3	7.91	NS	8	6.1	7.82	NS
9	6.7	8.03	0.089	9	6.4	7.83	0.115
10	7.0	8.04	NS	10	6.0	7.87	NS
11	6.5	7.84	NS	11	6.3	7.87	0.133
12	6.4	7.86	NS	12	6.3	7.84	NS
13	6.0	7.85	0.144	13	6.2	7.87	0.061
14	5.7	7.88	NS	14	6.4	7.86	NS
15	NS	7.95	NS	15	NS	NS	0.100
1	7.5	7.99	0.133	1	6.5	7.73	0.007
2	7.6	8.03	NS	2	6.6	8.35	NS
3	7.4	7.93	0.110	3	6.3	7.76	0.100
4	7.4	7.86	NS	4	6.4	7.98	NS
5	7.2	7.75	0.164	5	6.4	7.82	0.098
6	7.1	7.78	NS	6	6.3	7.85	NS
7	6.7	7.55	0.143	7	6.5	7.79	0.141
8	6.8	7.73	NS	8	6.5	7.84	NS
9	7.1	7.44	0.092	9	6.7	7.80	0.128
10	7.6	7.45	NS	10	7.1	7.80	NS
11	7.4	7.84	NS	11	6.8	7.85	0.092
12	7.2	7.82	NS	12	7.0	7.86	NS
13	7.1	7.84	0.174	13	6.6	7.84	0.069
14	7.0	7.82	NS	14	6.4	7.84	NS
15	NS	7.87	NS	15	NS	NS	0.074

[a]First half of table (above line) is for test aquaria, second half of table is for control aquaria.
[b]RED/001 = Redfin shiner / Outfall 001 water
[c]ROL/001 = Central stoneroller / Outfall 001 water
[d]Mean DO = Mean of 2 dissolved oxygen concentration measurements per hour per aquarium
[e]Mean pH = Mean of 2 pH measurements per hour per aquarium
[f]NH_3-N = Total ammonia expressed as mg/L N. Grab sample from one aquarium.
[g]NS = Not sampled

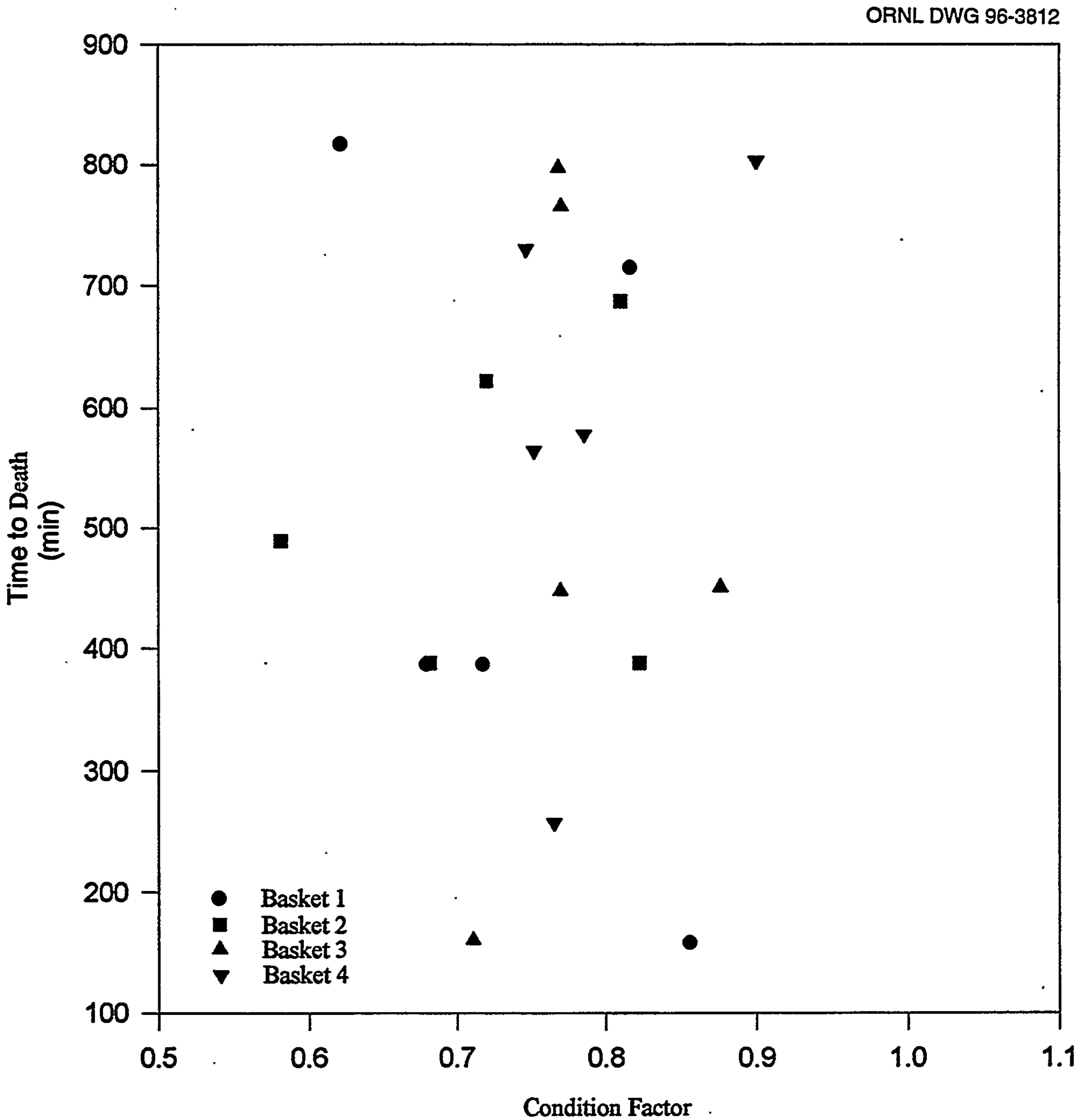

Fig. D.1. Plot of condition factor vs time to death for redfin shiners in Massac Creek water.

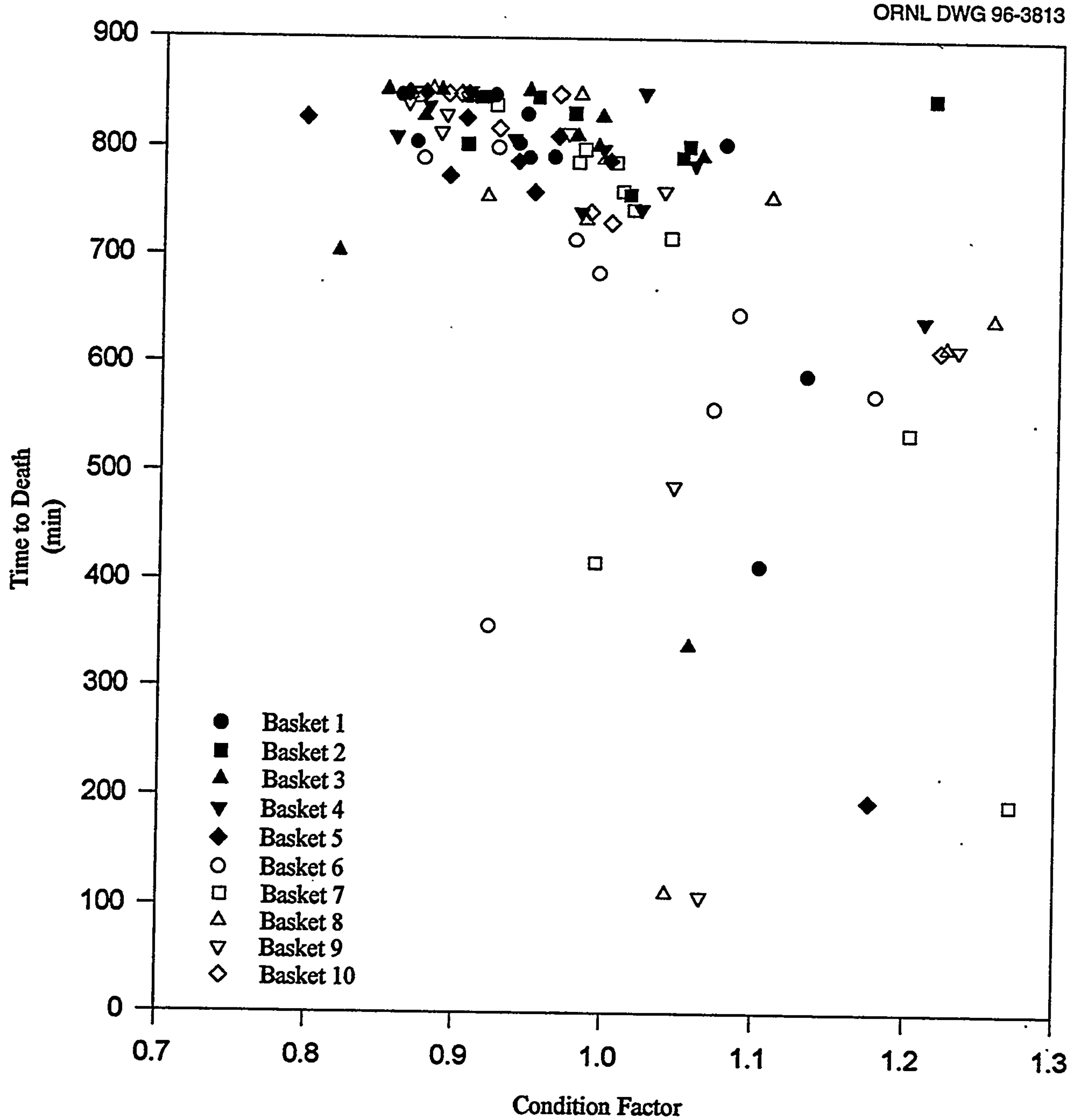

Fig. D.2. Plot of condition factor vs time to death for central stonerollers in Massac Creek water. Plot contains hidden observations

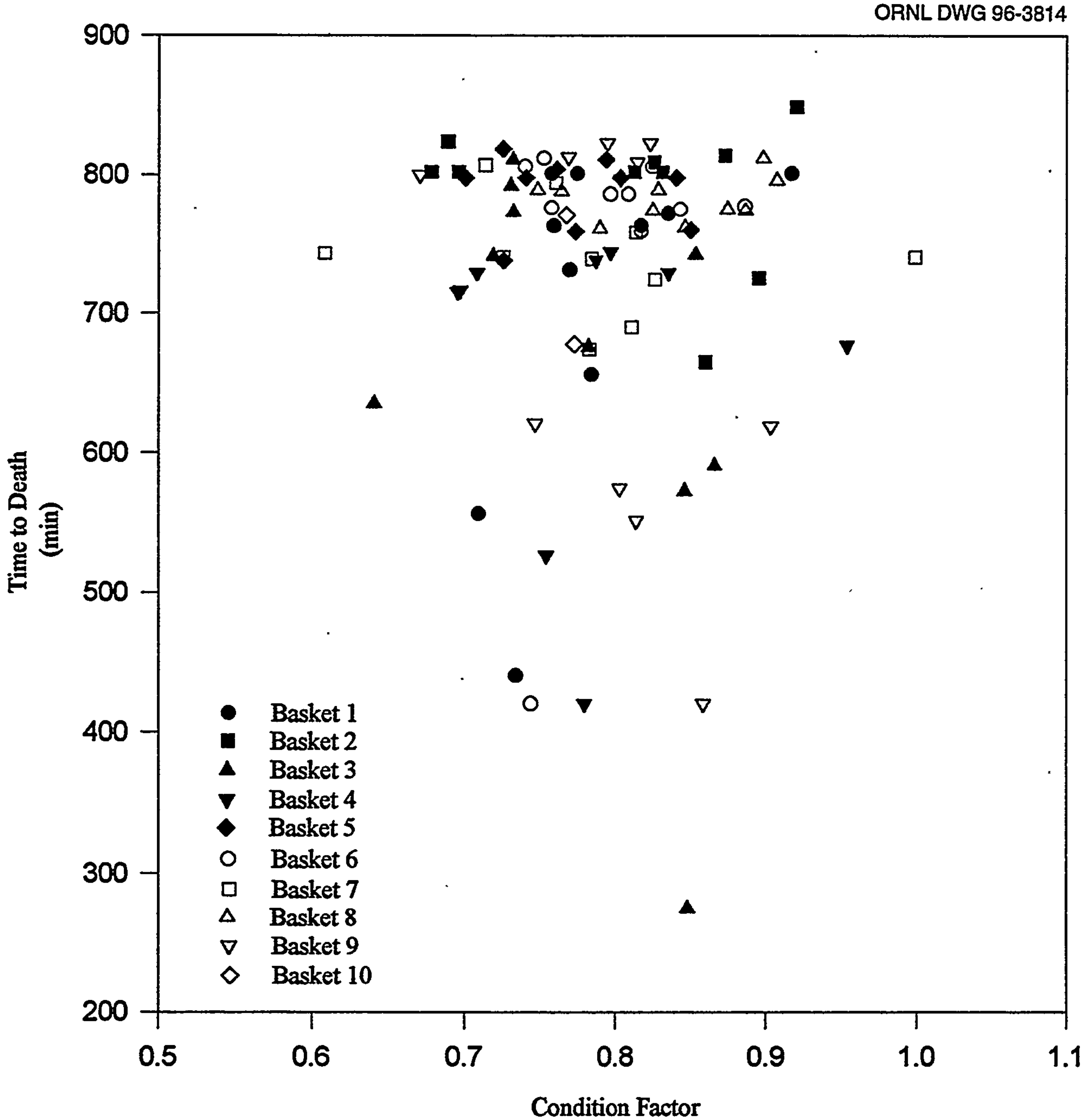

Fig. D.3. Plot of condition factor vs time to death for redfin shiners in Outfall K001 water. Plot contains hidden observations.

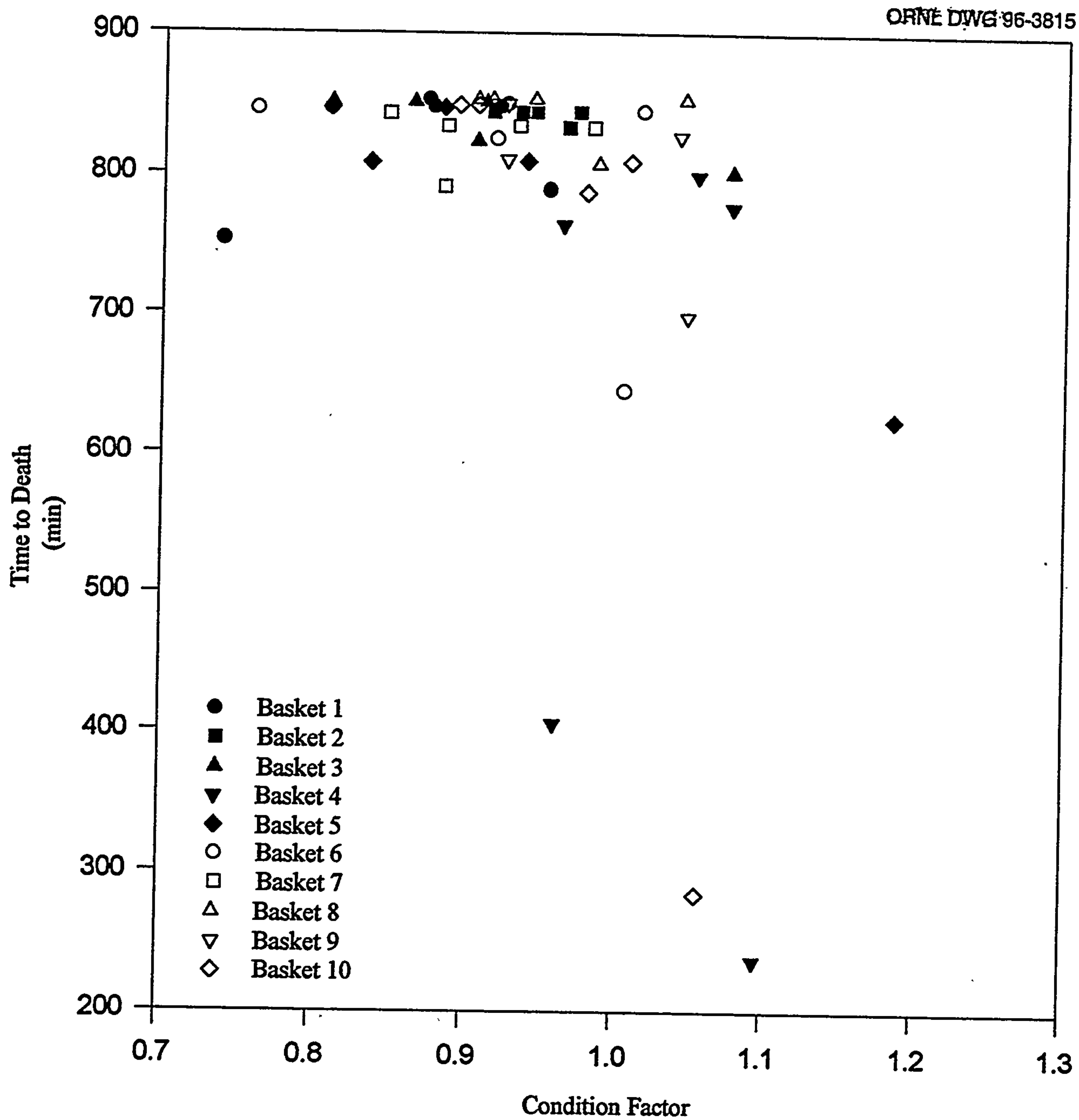

Fig. D.4. Plot of condition factor vs time to death for central stonerollers in Outfall K001 water. Plot contains hidden observations.

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